Conference Proceedings



15th Australian Wine Industry Technical Conference Sydney, New South Wales, 13–18 July 2013

Edited by: Kate Beames Ella Robinson Peter Godden Dan Johnson



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Introduction



Australian Wine Industry Technical Conference

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The first conference was held in 1970 in Mildura, Victoria. The conference structure and content are continually evolving to match the changing priorities of the Australian grape and wine sector. Feedback from delegates is gathered and assessed to improve subsequent conferences.

The 15th conference, held in July 2013 in Sydney, New South Wales, attracted over 1,000 attendees. The formal sessions were presented by 51 speakers, including 18 international presenters. Delegates were able to attend ten formal presentations, two 'Fresh Research' sessions and also a student forum called 'In the wine light'. There were 163 technical posters on display and an expansive trade exhibition which attracted around 1,000 additional visitors to the event. The 15th conference also included 44 workshops. Notes from the presentations at the workshops are not reproduced in these proceedings.

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Proceedings of the 15th Australian Wine Industry Technical Conference

Sydney, New South Wales 13–18 July 2013



edited by K.S. Beames, E.M.C. Robinson, P.W. Godden and D.L. Johnson

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A global macroeconomic perspective on the Australian wine industry

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Abstract

Australia's wine industry is coming out of the bottom of its latest cycle – its fifth since 1850. A key question is: how, and when, might producers be able to earn sustainable profits again? This paper briefly examines the anatomy of the latest cycle, which began in the late 1980s. It points to differences as well as similarities with previous cycles. A key feature is the strong export focus of the latest expansion – at a time of rapid globalisation of many industries – and then its emulation by other New World wine-producing countries. For nearly two decades the stars were favourably aligned for Australian producers. However, they suddenly became badly misaligned. One major element of the boom and then the crisis was the pattern of movements in real exchange rates. It helps explain the differing phases of the Australian industry's competitiveness relative to competitor countries. A model of the world's wine markets is used to show empirically the strength of this influence over recent years. The model also explores prospects for the next five years, focusing in particular on the roles not only of further changes in bilateral exchange rates but also of a return by consumers to higher-quality wine purchases and of continuing rapid growth in wine demand in emerging economies, especially China. The model results reveal how much the recent devaluation of the Australian dollar, if sustained, could benefit Australian winemakers and hence grapegrowers by 2018, and how quickly China could become a major destination for Australian wine exports. Both could boost substantially the profitability of those in the industry that adapt most successfully to those prospective market developments.

Introduction

Two major shocks to the world economy have impacted non-trivially on the wine industry in all major wine-producing countries in recent years. One is the global financial crisis, which brought substantial changes to bilateral exchange rates and - due to the fall in income and wealth - a temporary decline in the quantity and quality of wine demanded in traditional markets. The other development is the rapid economic growth in China and other emerging Asian economies, which slowed only slightly when high-income economies went into recession after 2007. Since Asia's emerging economies are natural resource-poor, their rapid industrialisation and economic growth has strengthened primary product prices and hence the real exchange rates (RERs) of natural resource-rich countries such as Australia. And since their income growth has led to a burgeoning middle class and enriched their elite, the demand for wine in Asia and especially China has surged. The latter in turn has stimulated vineyard expansion and rapid growth in wine production in China, although not (yet) quite enough to match domestic demand growth. Australia's wine industry has been hurt by the appreciating Australian dollar (AUD) but is being helped by the growth in Asian import demand.

Grapegrowers and winemakers in both the Old World and the New World are far more exposed to such shocks to the world economy now than they were in the 20th century. This is partly because of the move by most countries to flexible exchange rates since the 1980s, and also because the wine industry has become more globalised in the past two decades than ever before in its long history. The share of global wine production exported more than doubled between 1989 and 2009, rising from 15% (which was already above its peak in the first globalisation wave a century before) to 32% (Anderson and Nelgen 2011); it reached 41% in 2012 (OIV 2013). For the four biggest European wine-exporting countries, their export propensity rose over the two decades to 2009 from 20% to 35%, while for New World exporters it rose from just 4% to 37% (Anderson and Nelgen 2011). By 2012, those shares had reached 49% and 42%, respectively, according to OIV (2013).

The extent of exposure to global shocks varies across countries according to not only the share of their production that is exported,

but also the extent to which their domestic wine markets are open to imports. Figure 1 shows just how pervasive the growth in two-way trade in wine has been over the 25 years to 2007, and it has risen even more since then. In 2012, the share of Australian wine production volume that was exported was 64%, and 16% of its domestic sales volume was supplied by imports (up from just 2% and 3%, respectively, in 1980–84). In value terms the share of imports in domestic sales in Australia is even higher, at around one-quarter. Moreover, it



Figure 1. Trade volumes as per cent of production and consumption volumes, 1980–84 and 2007. For 2007 the Australian number refers to 2006–08, because 2007 was a severe drought year. ECA is the group of countries in Eastern Europe and the former Soviet Union. Source: Anderson and Nelgen (2011, Tables 51, 52, 120 and 121)

is not only winemakers who are vulnerable to exchange rate and other shocks to the market: even though wine-grapes themselves are not often traded internationally, their prices soon adjust when wine price prospects alter.

The dramatic growth in Australia's wine exports since the mid-1980s was stimulated by a low AUD. In US dollar (USD) terms, the AUD hovered between 0.60 and 0.80 from 1983 to 1999, and then it fell to slightly below 0.50 in 2001 before returning to 0.80 by the beginning of 2007. Since then, however, it rose to a peak of USD1.10 in 2011, and it remained in the 0.98 to 1.08 range for the 18 months to early May 2013. Similar paths have been traced by the UK pound (GBP) since 1985 and the Euro (EUR) since 2007 (Figure 2). As a consequence of those and other bilateral exchange rate movements, Australia has lost global market share to other wine exporters. Since 2007, the gap between the USD value of Australia's wine exports and that of the smaller New World exporters has halved (Figure 3), while the share of the country's domestic consumption supplied by imports has more than doubled.

In light of these developments, the purpose of this paper is twofold: to assess the extent to which bilateral RER movements globally (not just the nominal USD, EUR and GBP rates for the AUD) have reduced Australia's competitiveness in the world's wine markets since 2007; and to examine how Australia's competitiveness might evolve over the next five years. Two alternative changes from 2011 RERs are considered over those next five years: no change, and a movement of all RERs by 2018 equal to reversing half-way back from 2011 to 2009 RERs. The latter seems the more likely scenario, given recent prognoses by Garnaut (2013) and Sheehan and Gregory (2013) and the sudden fall in the value of the AUD in May-July 2013. Nevertheless, a comparison with the no-change scenario gives a sense of the importance of future RER movements.

Exchange rates are not the only pertinent things that will change between now and 2018 of course. There will be changes in national



Figure 2. Nominal value of the Australian dollar, January 1970 to May 2013 (USD, EUR and GBP per AUD). Source: Reserve Bank of Australia (www.rba.gov.au, accessed 11 June 2013)



Figure 3. Value of wine exports from New World countries, 1995 to 2012 (USD million). Source: Updated from Anderson and Nelgen (2011, Table 63)

consumption as populations and incomes grow, and also in national preferences, technologies and capital investments in grape and wine production. Two trends in particular that are expected over the next half-decade are the growth in China's import demand, and the expected preference swing toward higher-quality wine consumption in many markets. A formal model of economic behaviour in the world's wine markets is used to analyse the market responses to such anticipated changes.

The next section of the paper outlines briefly a revised model of the world's wine markets and the way in which RER changes and shocks to other variables are applied. The model's results of the effects of RER changes between 2007 and 2011 on Australia's wine industry are then summarised. Prospective changes to grape and wine markets by 2018 are then reported for two alternative paths for RERs over the next five years (no change, and a movement of all RERs by 2018 equal to reversing half-way back from 2011 to 2009 RERs) and, starting with the second of those, an alternative scenario for China involving slower wine import demand growth than in our baseline cases. The paper concludes by drawing out implications for Australia's wine industry in the years ahead.

Outline of a model of the world's wine markets

We have revised and updated a model of the world's wine markets that was first published by Wittwer et al. (2003) to examine wine's globalisation (Anderson 2004, Ch. 2), details of which are in Anderson and Wittwer (2013). Several significant enhancements have been made to that original model. Wine has been disaggregated into five types, namely non-premium (including bulk), commercial-premium, super-premium and iconic still wines, and sparkling wine.¹ There are two types of grapes, premium and non-premium. Non-premium wine uses non-premium grapes exclusively, super-premium and iconic wines use premium grapes exclusively, and commercial-premium and sparkling wines use both types of grapes.

The world is divided into 44 individual nations and 7 composite regions. The model's database is calibrated initially to 2009, based on the data provided in Anderson and Nelgen (2011). For the first part of the report, the model is shocked by the changes in RERs between 2007 and 2011, assuming no other changes occur (so as to isolate the effects of movements in just this one variable). Those RER changes, shown in Appendix Table 1(a), are calculated for each country as the ratio of the percentage change in national production costs to the percentage change in US production costs times that country's nominal exchange rate. For the second part of the report, the model is projected forward in two steps. The first step involves using actual aggregate national consumption growth between 2009 and 2011 (Appendix Table 2(a)), together with actual changes in RERs between just 2009 and 2011 (Appendix Table 1(b)). This second step assumes aggregate national consumption and population growth from 2011 to 2018 at the rates shown in Appendix Table 2(b), and that RERs over that period either (a) remain at their 2011 levels (the Base scenario) or (b) change by 2018 to RERs at the midpoint between the 2009 and 2011 RERs (the more-realistic scenario given the changes in RERs during May-July 2013). In the latter scenario (call it Alternative 1) Southern Hemisphere RERs devalue relative to both the USD and the EUR; but for China and India we assume in this alternative case that their RERs continue to slightly appreciate (by an aggregate of 15% between 2011 and

¹Commercial-premium still wines are defined by Anderson and Nelgen (2011) to be those between USD2.50 and 7.50 per litre pre-tax at a country's border or wholesale. Non-premium wines are defined as those below USD2.50 per litre and super-premium wines are defined as those greater than 7.50 per litre. Iconic still wines are a small subset of super-premium wines. They are assumed to have an average wholesale pre-tax price of USD80 per litre and to account for just 0.45% of the volume of global wine production in 2009. The sparkling wine category in the model includes sparkling wines at all price points.

2018). In each of those two steps, a number of additional assumptions are made concerning preferences, technologies and capital stocks.

As for preferences, there is assumed to be a considerable demand swing in China towards all wine types as more Chinese earn middleclass incomes; aggregate increased wine consumption is set in the more-likely scenario of RER reversals at the level projected by the major commodity forecasters (a 70% rise between 2011 and 2018). That implies a rise in per capita consumption from 1.0 to 1.6 litres per year in that scenario. This may be too conservative. Per capita wine consumption grew faster than that in several Western European wineimporting countries in recent decades, and Vinexpo estimates China's 2012 consumption was already 1.4 litres. With the number of middle class people in China currently around 250 million and growing at 10 million per year (Kharas 2010; Barton et al. 2013), and with grape wine still accounting for only 4% of Chinese alcohol consumption, large increases in volumes of wine demanded are not unreasonable to expect. However, if China's income growth were to grow more slowly than the rate we assume, and if that meant the Chinese renminbi (RMB) did not continue to appreciate slightly, wine import growth would be slower. For the rest of the world, the long trend preference swing away from non-premium wines is assumed to continue.

Both grape and wine industry total factor productivity is assumed to grow at 1% per year everywhere, while grape and wine industry capital is assumed to grow net of depreciation at 1.5% per year in China but zero elsewhere. This means that China's production rises by about one-sixth, one-quarter and one-third for non-premium, commercial-premium and super-premium+ wines respectively between 2011 and 2018 – which in aggregate is less than half that needed to keep up with the modelled growth in China's consumption. If China's wine production from domestic grapes were to grow faster than the rate we assume, wine imports would increase less.

Given the uncertainty associated with several dimensions of developments in China's wine markets, we also compare the more likely of our two main scenarios from 2013 to 2018 (in which RERs for all but China and India change by 2018 to RERs at the midpoint between the 2009 and 2011 RERs, called Alternative 1) with a third scenario (called Alternative 2) in which three dimensions are altered: China's total expenditure growth during 2011–18 is reduced by one-quarter (from 7.5% to 5.6% per year), its RER does not change from 2011 instead of appreciating 15% over that period, and its grape and wine industry capital is assumed to grow at 3% instead of 1.5% per year. All three changes lead to a much smaller increase in China's wine imports by 2018. It should, however, be considered very much a lower-bound projection. Even if China's growth in GDP, industrialisation and infrastructure spending were to slow down even more than assumed in our Base scenario, and there was less conspicuous extravagance and iconic gift-giving by business and government, Chinese households are being encouraged to lower their extraordinarily high savings rates and consume more of their income.

The model has supply and demand equations and hence quantities and prices for each of the grape and wine products and for a single composite of all other products (so that total expenditure in all countries is exhausted). Grapes are assumed to be not traded internationally, but other products are both exported and imported. Each market is assumed to clear before any shock, and to find a new marketclearing outcome following any exogenously introduced shock.

Impacts of exchange rate movements on competitiveness, 2007 to 2011

The first column of Table 1, and Figure 4, summarise the actual changes between 2007 and 2011 in RERs in key wine-exporting and wine-importing nations. It is clear that, during the 2007 to 2011 period, Japan and China (like other rapidly emerging East Asian economies) and natural resource-rich Australia experienced heavy appreciation in their RERs against the US dollar (by 29–35%). Other Southern Hemisphere wine exporters (Chile, New Zealand, South Africa) also saw their RERs appreciate, albeit more moderately (by 9–23%). By contrast, the GBP depreciated heavily against the USD (by 18%), while for other Western European countries – both wine-exporting and wine-importing – their RERs remained close to the USD during that period.

If there were no other shocks to the world's wine markets over this 2007–11 period, what would those RER changes lead one to expect? Since Australia has experienced one of the largest real appreciations among the wine exporters, its wineries are likely to have been seriously affected, receiving less AUD for their exports and facing more foreign competition in their home market. As for wine-importing countries, those whose RERs appreciated most (notably China and Japan) would be expected to import more wine, if all other things were equal, while for those experiencing a real depreciation, most notably the United Kingdom, wine imports would be expected to fall.

(a) Main exporters (per cent)	Real exchange rate	Non-prem. grape price	Prem. grape price	Comm. prem. wine ^b producer price	Super prem. wine ^b producer price	Comm. prem. wine [⊾] prod'n volume	Super prem. wine ^b prod'n volume	Domestic wine consum. volume (model)	Domestic wine consum. volume (actual)
W. Europe 6ª	0	6	5	5	5	2	2	0	-10
United States	0	3	4	2	4	1	2	-1	2
New Zealand	9	-1	-1	-1	-1	0	0	2	0
Chile	16	-8	-6	-8	-8	-2	-1	-2	-5
South Africa	23	-9	-8	-10	-12	-2	-2	1	-1
Australia	33	-12	-13	-13	-19	-2	-3	4	3

Table 1. Estimated impact of 2007–2011 changes in real exchange rates on domestic prices (in real local currency) and guantities of wine, main exporters and importers

Australia	55	-12	-15	-15	-17	-2	-5	-	5
(b) Main importers (per cent)		Real exchange rate	Comn con	n. prem. wine ^ь sumer price	Super prem. wi consumer prie	ine ^b Doi ce	mestic wine consum. volume (model)	Domestic wi volume	ine consum. (actual)
United Kingdom		-18	·	8	8	·	-4	-7	7
Other Western Europe	c	4		-2	-3		1	n	а
Japan		29		-9	-8		10	-2	2
China		35		1	2		0	2	2

^aFrance, Italy, Spain, Portugal, Germany and Austria. ^bCommercial-premium still wines are defined by Anderson and Nelgen (2011) to be those between USD2.50 and 7.50 per litre pre-tax at a country's border or wholesale. Non-premium wines are defined as those below USD2.50 per litre and super-premium wines are defined as those greater than 7.50 per litre. The sparkling wine category in the model includes sparkling wines at all price points. ^cOther Western Europe = Belgium, Denmark, Finland, Ireland, the Netherlands, Sweden and Switzerland. Source: Authors' model results

That is indeed what is shown in the other columns of Table 1; and the impacts on bilateral wine trade volumes are summarised in Table 2. Specifically, the RER changes are associated with declines in grape and wine production in the Southern Hemisphere where RERs appreciated, and for slight production increases in the United States and Europe where RERs changed relatively little.

Since Australia has had the largest appreciation of the wineexporting countries shown in Table 1, its winemakers and hence grapegrowers are estimated to suffer the largest reduction in domestic prices in real local currency terms from this shock: wine-grape and commercial-premium wine producer prices are reduced by almost one-eighth, and super premium wine prices by one-fifth. Associated with that is a decline in the volume of Australia's wine production, but given the resistance of producers to downsize in the short term, the actual change is small. Real prices in domestic currency terms decline in the other Southern Hemisphere countries shown in Table 1 as well, but by less than two-thirds as much as in Australia. Furthermore, real grape and wine prices (again in domestic currency terms) rise in the United States and Western Europe, by between 3% and 6%, so output is estimated not to have been reduced at all in those regions as a consequence of recent RER movements. In short, exchange rate shocks have been a major contributor to the decline in the international competitiveness of Australian wine producers since 2007.

The trade consequences of that set of exchange rate shocks also depend on its impact on wine consumption. With lowered prices for both domestic and imported wines, Australian consumption is estimated to have been boosted by 4% because of these RER changes – which is very close to the proportional change in actual consumption during that period (see final two columns of Table 1). This suggests the net effect on domestic consumption of all other influences over the period 2007–11 was close to zero.

In Europe's key wine-exporting countries and in the United States, by contrast, the rise in wine prices would have reduced domestic wine consumption in the absence of other influences. Other influences evidently were not absent, however. In the United States, wine consumption actually rose by 2% over that period, perhaps as the economy there began recovering from the global financial crisis by 2011. In Western Europe's wine-exporting countries, by contrast, it fell by 10%, perhaps because those economies were still recovering from the financial crisis in 2011.

Estimated changes in consumption in wine-importing countries are shown in Table 1(b). The 18% real depreciation of the GBP against the US dollar on its own caused the consumer price of wine in that market to rise such that estimated wine consumption fell 4%, which is a little less than the actual decrease over that period of 7%. Discrepancies arise when there is a non-trivial net effect of economic changes other than in RERs. For example, China's rapid income growth and increasing absorption of Western tastes meant that there was a substantial increase in wine demand there between 2007 and 2011, so that observed wine consumption grew by 22% over that period despite almost no contribution from RER changes. In the case of nations that went into recession, income deterioration between 2007 and 2011 affected actual consumption markedly. For example, Japan's actual wine consumption declined 2% even though RER changes on their own are estimated to have induced a 10% increase.

The negative impact on consumption of the real depreciation in the United Kingdom is bad news for all wine-exporting countries, but the impact is particularly serious for Australia, which was the 2^{nd} most important supplier in volume terms of wine to the UK market after Italy, and 3^{rd} in value terms after France and Italy. The first set of rows of Table 2 shows the impact on the UK's import volumes by country of origin. Australia and other Southern Hemisphere countries (most notably South Africa) are the standout losers in this scenario, with annual demand for their wine falling by 64 ML – half of which is borne by Australia. By contrast, the annual sales by the Old World and the US each fall by only 2 ML as a consequence of RER movements between 2007 and 2011.



Figure 4. Real exchange rate changes, 2007 to 2011 (per cent appreciation relative to USD). Source: Authors' calculations

Table 2. I	Impact of real	exchange rate cl	nanges on	export volume of	Australia and	other wine-exp	porting c	ountries,	2007 1	to 2011	in ML
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Exporter: Importer:	Australia	Other Southern Hemisphere	United States	Western European exporters	Other
United Kingdom	-33	-31	2	2	1
United States	-23	-38	0	6	0
Canada	-3	-10	4	6	0
New Zealand	0	0	0	0	0
Germany	-2	-13	1	7	-6
Other W. Europe ^a	-7	-24	2	32	9
China	5	8	2	7	2
Other Asia	-1	1	5	30	-1
Other countries	0	-3	3	75	1
TOTAL WORLD	-64	-110	19	167	6

^aOther W. Europe = Belgium, Denmark, Finland, Ireland, the Netherlands, Sweden and Switzerland. Source: Authors' model results

The modelled reduction in wine consumption in the United States is borne almost entirely by Australian and other Southern Hemisphere producers (Row 2 of Table 2), whose wines become more expensive than domestically produced or Old World wines in the US market. That set of RER shocks reduces the Southern Hemisphere's share of US total wine consumption from 21% to 19%. The pattern of impact on bilateral wine trades with Canada, Germany and other Western European wine-importing countries is not quite as severe, but in all those cases Australian and other Southern Hemisphere producers lose out to US and Old World suppliers.

China remains the market in which wine exporters anticipate the highest rate of import growth in the future. China's RMB appreciated in real terms more than most major currencies between 2007 and 2011, the effect of which in isolation would be for China to increase its share of global wine consumption. Table 1(b) shows that real local currency prices of wine in China were barely affected by observed RER movements. Thus income rises ensured increased imports of wine from all sources, with more from the New World (15 ML including the US) than the Old World (7 ML). Those imports substituted for domestic wine, whose consumption is discouraged by the real appreciation: estimated consumption of domestic wine is 24 ML less than it would have been without RER changes, and imports 24 ML greater. As for other Asian markets and the rest of the world, Australia again loses slightly while the US and Old World wine exporters gain.

In aggregate, RER movements over the 2007–2011 period are estimated to have reduced Australia's annual wine exports by 64 ML (Table 3). This is more than half the aggregate loss to all other Southern Hemisphere exporters of 110 ML, and it contrasts with estimated export gains of 193 ML to the United States and 167 ML to Western Europe's key wine-exporting countries. This reversed somewhat the massive gains of the Southern Hemisphere exporters at the expense of the Old World over the past two decades. It also strengthened the competitiveness of the US wine industry relative to other New World wine producers in both the US and European markets.

Australia is the country whose wine trade has been most adversely affected by real currency changes since 2007. In addition to losing export sales, however, it has also seen a considerable increase in imports. One-sixth of the estimated extra imports due to currency changes are from New Zealand, because of the greater real appreciation of the AUD compared with the NZD. The bracketed numbers in Table 3 show that New Zealand's extra penetration of the Australian market is especially strong in the super-premium+ category (predominately Sauvignon Blanc and Pinot Noir), while France's is predominantly in sparkling wine and Italy's in commercial-premium wines.

How do the modelled outcomes compare with observed export changes in Australia? Historic data indicate that between 2006-07

Table 3. Impact of real exchange rate changes on Australia's wine export and import volumes and values, by wine category, 2007 to 2011 $\,$

1							
	Volum	ne (ML)	Value (AUDm)				
	Exports	Imports (and % from NZ)	Exports	Imports			
Non-premium wine	-17	0.4ª (43)	-94	-2			
Commercial-premium ^c	-35	1.7 (20)	-531	-11			
Super-premium+ wine	-7	0.8 (90)	-89	5			
Sparkling wine	-4	1.5 ^b (1)	-35	-9			
Total	-64	4.4 (18)	-748	-17			

^a33% of the increase in commercial-premium wine is from Italy. ^b37% of the increase in sparkling wine is from France. ^cCommercial-premium still wines are defined by Anderson and Nelgen (2011) to be those between USD2.50 and 7.50 per litre pre-tax at a country's border or wholesale. Non-premium wines are defined as those below USD2.50 per litre and super-premium wines are defined as those greater than 7.50 per litre. The sparkling wine category in the model includes sparkling wines at all price points. Source: Authors' model results and 2010–11, the volume of Australia's wine exports fell only slightly, from 798 ML to 727 ML; but, in domestic currency terms, exports dropped from almost AUD2.9 billion to just under AUD2.0 billion over that period (www.wineaustralia.com). Therefore, the modelled effects of RER changes shown in Table 3 suggest those RER changes explain all but one-tenth of the actual drop in the volume of wine exports of 71 ML, and all but one-sixth of the actual drop in value.

Thus these results go a long way towards explaining why market shares and producer prices have changed so much for some New World wine-exporting countries in recent years. In particular, they explain most of the improvement in competitiveness of the US and EU and the decline for Australian and other Southern Hemisphere exporters between 2007 and 2011. This only slightly reverses the upward trend in the Southern Hemisphere's share of global wine exports over the previous 15 years though, and does not necessarily mean that previous trend won't return. After all, RER changes can easily reverse. We turn now to consider the period to 2018, and in particular to examine how much a reversal of RER trends would affect Australian and other wine exporters.

Projections of the world's wine markets to 2018

To project global wine markets forward, it is important to first update the model's 2009 baseline with known data. Sufficient data were available globally to calibrate the model to 2011, so we project the model to that year first using actual aggregate national consumption and population growth together with actual changes in RERs between 2009 and 2011 and assumed changes in preferences, technologies and capital stocks as described. Once this new baseline is in place, the second step is to assume aggregate national consumption and population growth from 2011 to 2018 at the rates shown in Appendix Table 2(b) and that preferences, technologies and capital stocks continue to change as described above, plus that RERs over that period either (a) remain at their 2011 levels or (b) change by 2018 to RERs at the midpoint between the 2009 and 2011 RERs, effective as of 2013 (except for China and India) as reported in Appendix Table 1(b)². The latter may well happen long before 2018, according to both Garnaut (2013) and Sheehan and Gregory (2013) and given the rapid changes in exchange rates during May-July 2013 when the AUD fell more than 10% against the USD, the EUR and the GBP (which is more than half the change in those bilateral rates being modelled in this Alternative 1 scenario). A third scenario, Alternative 2, presents a lower-bound projection of what might happen to Chinese wine import demand if China's economy slows and simultaneously domestic grape and wine production grows twice as fast.

The impacts of those changes on real producer prices in the sector, in local currency units, are reported in Table 4 for the world's main wine-producing countries. For the period to 2018, Australia's non-premium grape and wine prices are projected to fall further if RERs don't change from their 2011 levels, while super-premium and iconic still wine prices rise by more than 40% (Table 4(a)). If, on the other hand, RERs were to return half-way toward what they were in 2009, real prices in Australia in local currency terms would rise above 2011 levels for most grape and wine types, especially for super-premium+ wines (Table 4(b)). The extent of those rises would be somewhat but not substantially less if China's import growth were slower as in the Alternative 2 scenario (Table 4(c)). Consumer prices tend to move in the same direction as producer prices, but the changes are more muted because of the presence of trade and transport margins.

²Except for China and India, whose currencies are assumed to appreciate a further 2.15% per year over this projection period from 2011 because of their assumed strong economic growth.

Even if there were no changes in exchange rates, Australia is projected to expand its output by 2018 for all wine types except non-premium (Table 5). For commercial-premium and superpremium, the increases are 8% and 15%; but, with the reversal in RER trends, those output increases would be 13% and 18%, respectively, unless China's import growth was much slower in which case they would be one percentage point less. Note that production grows in both hemispheres, thanks to the assumed growth in grape and wine productivity of 1% per year. Were there also to be a devaluation of Southern Hemisphere exchange rates, Table 5(b) suggests that output in that region would expand even more while output expansion in the Northern Hemisphere would be slightly less, although less so if Chinese market growth slows – consistent with the producer price changes shown in Table 4.

The income, population and preference changes together mean that consumption volumes grow over the period to 2018 for all but non-premium wine, but least so for commercial-premium. The percentage increases are very similar in the three scenarios for the Old World and Japan, but are somewhat more in the United Kingdom, China and especially the United States in the altered currencies scenarios versus the scenario with no changes in RERs. This is consistent with the differences in local currency consumer price changes. What is more striking is the concentration of consumption growth and declines, as shown in Figure 5. In all scenarios the growth is concentrated in the US, Brazil and especially China, while there are substantial declines in consumption in the Old World (mostly of non-premium wines).

When combined with the changes projected in production, it is possible to get a picture of what is projected to happen to wine trade. Table 6 provides projections for the main wine-trading regions. In

Table 4. Projected real producer price changes, in local currency, 2011 to 2018

(a) 2011 to 2018: Base scenario (assuming no RER changes from 2011)

terms of volumes, world trade grows 6% in the base scenario and 7% in the Alternative 1 scenario in which RERs change. Virtually all of that increase in those two scenarios is due to China's import growth. In the Alternative 2 scenario, in which China imports less, global trade also expands less (by only 4%). In terms of the real value of global trade, however, the upgrading of demand elsewhere means that China accounts for only a fraction of the global import growth, namely 36%, 43%, and 30% in the Base, Alternative 1 and Alternative 2 scenarios, respectively. In all three scenarios the value of global wine trade rises by about one-sixth (last row of Table 6).

China has already become by far the most important wineconsuming country in Asia (Figure 6) and, with a projected extra 620–940 ML to be added by 2018 to its consumption of 1630 ML in 2011, that dominance is becoming even greater. Since China's domestic production is projected to increase by 'only' about 210–290 ML by 2018, its net imports are projected to rise by between 330 and



Figure 5. Changes in consumption of all wines, 2011 to 2018. (ML). Source: Authors model results

	FRA ITA POR SPN AUT GER AUS NZL USA ARG CHILE SAF CHIN													
Non-premium wine	-24.9	-26.9	-26.0	-26.0	-26.3	-26.6	-15.3	-19 1	-23.4	-18.8	-17.7	-17 1	29.2	
Commercial-premium	-2.0	-5.0	-4.3	-5.2	-8.3	-3.4	2.7	-1.3	-2.1	3.9	3.1	-0.2	93.2	
Super-premium	37.9	37.4	41.8	35.5	30.0	35.1	49.7	42.9	40.7	46.4	45.8	54.0	164.4	
Iconic still wine	41.2	41.8	42.3	41.9	39.9	40.9	44.8	45.2	46.4	85.3	61.6	84.3	119.5	
Sparkling wine	4.2	4.8	5.0	5.1	3.3	3.0	8.3	7.7	7.7	34.9	9.9	7.8	8.9	
Premium grapes	21.5	10.8	14.4	7.1	24.4	9.6	20.1	34.6	29.8	7.0	13.9	13.5	60.2	
Non-premium grapes	-7.5	-18.6	-19.4	-15.9	-18.3	-12.8	-6.1	-10.6	-10.6	-3.8	-7.5	-11.9	28.8	
(b) 2011 to 2018: Alternative	e 1 (assuming o	hange by	2018 to I	RERs at th	e midpoi	nt betwee	n the 200	9 and 20	11 RERs)					

	FRA	ITA	POR	SPN	AUT	GER	AUS	NZL	USA	ARG	CHILE	SAF	CHINA
Non-premium wine	-25.5	-27.5	-26.4	-27.0	-26.7	-27.4	-5.9	-14.2	-24.1	-17.2	-12.4	-12.1	20.8
Commercial-premium	-3.9	-7.2	-6.5	-7.3	-9.4	-5.8	19.0	6.4	-3.7	7.3	11.4	8.3	75.9
Super-premium	36.0	35.2	38.9	33.7	29.7	33.5	67.9	56.0	40.2	52.5	56.5	63.6	144.4
Iconic still wine	38.5	39.0	39.5	39.5	39.2	38.9	49.6	55.4	44.6	84.9	64.3	85.7	102.7
Sparkling wine	3.0	3.0	3.4	3.2	2.3	2.0	19.0	15.0	6.7	35.9	18.1	20.2	-0.2
Premium grapes	19.7	8.4	11.9	4.9	23.8	7.9	34.6	45.9	29.0	10.5	23.5	24.9	52.4
Non-premium grapes	-9.2	-20.1	-20.7	-17.9	-19.5	-14.5	12.2	-1.2	-12.2	-0.9	1.3	-2.3	24.3

(c) 2011 to 2018: Alternative 2 (assuming also slower Chinese import growth)

	FRA	ITA	POR	SPN	AUT	GER	AUS	NZL	USA	ARG	CHILE	SAF	CHINA
Non-premium wine	-26.9	-28.0	-26.8	-28.0	-27.1	-28.1	-11.7	-17.2	-26.0	-18.0	-16.3	-13.3	-16.0
Commercial-premium	-7.6	-9.7	-8.8	-9.8	-10.7	-8.8	12.2	2.7	-6.5	5.2	5.8	5.6	47.4
Super-premium	33.8	33.6	37.2	32.4	29.5	32.2	59.0	53.2	39.8	51.0	53.5	62.2	97.4
Iconic still wine	38.5	38.9	39.4	39.4	39.1	38.8	49.5	55.3	44.6	84.9	64.3	85.6	67.2
Sparkling wine	2.6	2.7	3.1	2.9	2.1	1.7	18.5	14.5	6.5	35.8	17.6	19.8	1.3
Premium grapes	17.7	6.1	9.7	2.5	23.1	6.3	29.8	42.8	27.8	8.4	17.7	21.7	36.8
Non-premium grapes	-11.7	-21.6	-22.1	-19.9	-20.7	-16.0	4.4	-6.0	-15.2	-2.5	-5.0	-4.9	6.1

Source: Authors' model results

740 ML. The Southern Hemisphere supplies a little more than half of those extra imports in the base scenario, and a little less than half in the alternative scenarios. The United States reduces its imports by 24 ML and expands its exports to China by 50 ML in the base scenario, but in the alternative scenarios it increases its imports of premium wines (Table 7).

Implications for Australia's wine industry over the next five years

The above results suggest that RER changes over the period 2007 to 2011 altered substantially the global wine export shares of the Old World and USA versus the Southern Hemisphere's New World exporters and especially Australia. This development reversed somewhat the massive gains of the latter group at the expense of the Old World over the past two decades. The exchange rate changes also



Figure 6. China's increasing dominance in Asian wine consumption, 2000 to 2012. (ML per year). Source: Anderson and Nelgen (2011, Table 16), updated for China from OIV (2013) and for other countries from Euromonitor International

Table 5. Projected grape and wine output volume changes, 2011 to 2018 (per cent)

(a)	Base	scenario	(assuming	no	RER	changes	from	2011
۱a	Duse	scenario	lassannia			Changes		2011

strengthened the competitiveness of the US wine industry, relative
to other New World wine producers, in both the US and European
markets. Given those results, it is not surprising that the comparison
between scenarios involving no RER changes from 2011 versus a
half-way return to 2009 rates suggests there would be a reversal in

Table 6. Projected change in global wine import and export volumes and values, 2011 to 2018

(a)	Imports	
(4)	mports	

(,									
	١	/olume (M	L)	Va	Value (USD m)				
	Base	Alt. 1	Alt. 2	Base	Alt. 1	Alt. 2			
United Kingdom	-54	-36	-29	98	174	93			
North America	-23	11	37	961	1097	1015			
Other Europe	-122	-162	-140	1012	646	552			
China	627	739	334	1948	2305	1178			
Other Asia	20	14	16	877	788	769			
Other developing	152	133	141	498	311	318			
WORLD	600	696	359	5394	5321	3925			

(b) Exports

	١	/olume (M	L)	Value (USD m)				
	Base	Alt. 1	Alt. 2	Base	Alt. 1	Alt. 2		
Australia	0	90	59	336	933	675		
Other New World	78	219	75	469	954	597		
Old World	538	412	263	4370	3489	2653		
WORLD	600 (6%)	698 (7%)	359 (4%)	5394 (17%)	5321 (17%)	3925 (15%)		

Source: Authors' model results

	FRA	ITA	POR	SPN	AUT	GFR	AUS	NZI	USA	ARG	BRA	CHILE	SAF	CHINA
Non-premium wine	-9.0	-10.3	-11.7	-7.2	-11.7	-10.6	-8.1	-9.9	-5.0	-1.5	-7.4	-4.2	-14.0	17.9
Commercial-premium	6.4	5.9	6.0	5.7	2.6	6.5	8.1	5.5	5.9	7.2	7.9	7.3	5.1	25.9
Super-premium	15.1	15.1	15.6	15.4	14.6	15.0	15.3	18.9	15.5	15.6	17.1	15.3	18.4	29.1
Iconic still wine	15.7	15.9	16.1	16.1	15.9	15.4	15.4	19.1	15.8	12.6	14.2	15.0	18.1	34.2
Sparkling wine	8.6	9.2	9.3	9.3	8.5	8.6	11.4	10.3	9.6	12.0	10.1	11.9	9.8	0.3
Premium grapes	9.8	8.8	9.3	8.4	10.3	8.6	9.6	12.2	10.6	7.2	9.0	9.5	8.9	20.2
Non-premium grapes	6.0	2.3	1.5	3.4	2.0	4.7	6.1	3.8	4.9	5.2	3.7	5.2	0.3	17.8
(b) Alternative 1 (assum	ing chang	e by 2018	to RERs	at the mic	dpoint bet	tween the	2009 and	d 2011 RE	Rs)					
	FRA	ITA	POR	SPN	AUT	GER	AUS	NZL	USA	ARG	BRA	CHILE	SAF	CHINA
Non-premium wine	-9.7	-11.0	-12.2	-8.3	-12.2	-11.6	1.4	-3.7	-5.6	-0.9	-2.2	-3.5	-6.2	17.2
Commercial-premium	5.6	5.0	5.1	4.9	2.0	5.6	13.4	9.6	5.2	8.3	11.6	9.1	10.1	24.6
Super-premium	14.9	14.9	15.3	15.2	14.6	14.8	18.0	20.4	15.4	16.7	18.1	15.4	19.2	28.4
Iconic still wine	15.3	15.6	15.8	15.9	15.8	15.2	16.3	20.1	15.6	12.8	14.2	15.1	18.1	32.9
Sparkling wine	8.2	8.7	8.8	8.8	8.1	8.3	15.1	12.6	9.3	12.2	12.6	13.5	15.2	-15.9
Premium grapes	9.6	8.5	9.0	8.1	10.3	8.4	11.4	13.0	10.5	7.7	10.1	9.7	10.5	19.7
Non-premium grapes	5.6	1.8	1.0	2.8	1.6	4.3	9.6	7.0	4.5	5.7	6.6	6.2	5.1	17.3
(c) Alternative 2 (assum	ing also sl	ower Chin	iese impo	rt growth)									
	FRA	ITA	POR	SPN	AUT	GER	AUS	NZL	USA	ARG	BRA	CHILE	SAF	CHINA
Non-premium wine	-11.6	-11.6	-12.6	-9.4	-12.6	-12.6	-4.4	-7.3	-7.6	-1.3	-5.9	-3.9	-7.7	23.5

															-
Non-premium grapes	5.0	1.2	0.4	2.1	1.1	3.9	8.2	5.6	3.6	5.4	4.7	5.9	4.0	27.4	
Premium grapes	9.5	8.2	8.7	7.8	10.2	8.2	11.0	12.8	10.4	7.4	9.4	9.7	10.1	30.9	
Sparkling wine	8.2	8.7	8.8	8.8	8.1	8.3	15.3	12.6	9.3	12.2	12.8	13.5	15.2	15.2	
Iconic still wine	15.4	15.7	15.9	15.9	15.8	15.3	16.4	20.2	15.6	12.8	14.3	15.1	18.1	43.6	
Super-premium	14.6	14.7	15.1	15.1	14.5	14.6	17.3	20.1	15.4	16.5	17.9	15.4	19.2	39.3	
Commercial-premium	3.7	3.7	3.9	3.6	1.0	4.1	11.7	7.8	3.8	7.6	9.2	8.7	8.7	35.3	
Non-premium wine	-11.6	-11.6	-12.6	-9.4	-12.6	-12.6	-4.4	-/.3	-/.6	-1.3	-5.9	-3.9	-/./	23.5	

Source: Authors' model results

international competitiveness of the various exporting countries.³

The projections to 2018 reveal an even more striking prospect, however. It has to do with the continuing growth of China's net imports. Australia is projected to supply between 65 and 150 ML of China's extra imports (Table 8), amounting to between USD350m and 650m per year. That represents about one-fifth of China's total import volume increase and, more importantly, between 22% and 30% of the value of China's extra imports.

What about Australia's exports to other countries? Again it depends very much on the scenario. If RERs did not change from 2011 to 2018, Australia's exports to all destinations other than Asia would decline, and in aggregate volume would be no more than in 2011. By

Table 7. Projected changes in wine consumption in major importers by source of imports, 2011 to 2018 (ML) $\,$

(a) Base scenario (assuming no RER changes from 2011)

USA	Old World	USA	All Sthn. Hemisph	All imports	Home sourced	Total cons'm
Non-premium wine	0	0	-34	-37	-38	-75
Commercial-premium	22	0	-30	-9	22	13
Super-premium+	12	0	2	15	71	86
Sparkling wine	7	0	0	7	8	15
Total	41	0	-61	-24	62	38
China						
Non-premium wine	82	21	121	224	116	340
Commercial-premium	179	29	169	383	97	480
Super-premium+	11	0	4	18	6	24
Sparkling wine	2	0	0	2	0	2
Total	274	50	293	627	218	845

(b) Alternative 1 (assuming change by 2018 to RERs at the midpoint between the 2009 and 2011 RERs)

USA	Old World	USA	All Sthn. Hemisph.	All imports	Home sourced	Total cons'm
Non-premium wine	-2	0	-17	-23	-40	-63
Commercial-premium	19	0	-9	9	19	28
Super-premium+	13	0	6	19	71	90
Sparkling wine	7	0	1	8	8	16
Total	37	0	-19	14	58	72
China						
Non-premium wine	86	23	181	290	111	401
Commercial-premium	187	30	202	425	93	518
Super-premium+	12	0	6	20	6	26
Sparkling wine	2	0	0	2	0	2
Total	287	53	389	739	209	948

(c) Alternative 2 (assuming also slower Chinese import growth)

USA	Old World	USA	All Sthn. Hemisph.	All imports	Home sourced	Total cons'm
Non-premium wine	-4	0	-11	-17	-38	-55
Commercial-premium	18	0	6	23	21	44
Super-premium+	14	0	8	22	71	93
Sparkling wine	7	0	1	8	8	16
Total	35	0	5	37	62	99
China						
Non-premium wine	21	5	48	74	152	226
Commercial-premium	107	16	121	248	133	381
Super-premium+	6	0	3	10	8	18
Sparkling wine	1	0	0	2	0	2
Total	134	22	172	334	292	626

Source: Authors' model results

contrast, if exchange rates were to settle at half-way back to those of 2009 (Alternative 1), Australian total annual exports would increase by 90 ML to become about one-eighth more than in 2011; while in Alternative 2 (slower import growth by China) that increase is only two-thirds as large. The impact of the scenario on the USD value of total exports from Australia is much greater though, ranging from 20% to 50% over 2011 values (Table 8).

There is little joy for Australian producers of non-premium wines (and thus grapes) in these projections; however, their exports are expected to fall in all but the most optimistic (Alternative 1) scenario (Table 9). This is partly because only a small fraction (between one- and two-fifths) of the increased volume of imports by China is projected to be non-premium wines (Table 7). For Australia those fractions are similar: between 25% and 42% of the projected increase in volume of its exports to China – and much less of the value of those sales – is non-premium.

 Table 8. Projected change in Australian wine export volumes and values, 2011 to 2018

	١	/olume (MI	_)	Va	alue (USD i	m)
	Base	Alt. 1	Alt. 2	Base	Alt. 1	Alt. 2
United Kingdom	-40	-25	-11	-59	42	48
Other Europe	-20	-13	-5	-26	28	36
United States	-36	-14	4	-22	115	130
China	108	147	65	428	649	356
Other	-12	0	56	15	99	105
WORLD	0 (0%)	90 (13%)	59 (8%)	336 (18%)	933 (49%)	675 (36%)

Source: Authors' model results

 $\ensuremath{\text{Table 9}}$. Projected change in Australia's wine export and import volumes and values, 2011 to 2018

(a) Base scenario (assuming no RER changes from 2011)

	Volum	e (ML)	Value (A	AUD m)
	Exports	Imports	Exports	Imports
Non-premium wine	-22	0	-38	-5
Commercial-premium	20	4	213	18
Super-premium	2	2	130	19
Iconic still wine	0	0	25	34
Sparkling wine	1	3	6	33
Total	0	8	336	97

(b) Alternative 1 (change by 2018 to RERs at the midpoint between the 2009 and 2011 RERs)

	Volum	e (ML)	Value (A	AUD m)
	Exports	Imports	Exports	Imports
Non-premium wine	26	-1	44	-1
Commercial-premium	55	3	944	58
Super-premium	6	1	268	23
Iconic still wine	0	0	71	37
Sparkling wine	3	1	34	50
Total	90	4	1361	166

(c) Alternative 2 (assuming also slower Chinese import growth)

	Volum	ie (ML)	Value (A	AUD m)
	Exports	Imports	Exports	Imports
Non-premium wine	-3	-1	10	-3
Commercial-premium	52	2	754	45
Super-premium	7	1	214	20
Iconic still wine	0	0	71	37
Sparkling wine	3	1	33	49
Total	59	3	1081	148

Source: Authors' model results

³Had we analysed the effect of changes in real exchange rates over the dozen years to 2000, we would have predicted a dramatic growth in Australian wine exports because over that period Australia's currency depreciated in real terms by almost 30 per cent. In fact the volume and USD value of Australia's wine exports grew 16 and 18 per cent per year, respectively, over that period. An analysis of the effects of US dollar appreciation at the turn of the century is provided by Anderson and Wittwer (2001).

China's share of Australia's total value of wine exports is projected to grow from 6% in 2009 to between 20% and 28% by 2018, depending on how rapidly China's aggregate wine imports grow. The UK share, by contrast, is projected to stay flat or fall by two percentage points so as to be well below China's by 2018 in the Base and Alternative 1 scenarios and to be barely above it even in the Alternative 2 scenario. Even the US share barely recovers from its low 2012 level and falls below China's if China keeps growing rapidly (Figure 7).

In terms of competition in Australia's domestic market, the share of sales supplied from abroad is projected not to change if there is no change to RERs, but to fall by two percentage points in both value and volume terms in the two Alternative scenarios in which exchange rates change to an RER at the midpoint between the 2009 and 2011 RERs, effective as of 2013.

Conclusion

This modelling exercise suggests RER changes go a long way towards explaining why market shares and producer prices have changed so much for New World wine-exporting countries in recent years - especially the decline in competitiveness for Australia and the improvement for the US. They also suggest exchange rates are capable of playing a major role in the years ahead. But on top of that, the above projections point to the enormous speed with which China may become a dominant market for Australian wine producers. While the recent and projected rates of increase in per capita wine consumption in China are no faster than what occurred in several Western European wine-importing countries in earlier decades, it is the sheer size of China's population - and the fact that grape wine still accounts for only 4% of Chinese alcohol consumption - that makes this import growth opportunity unprecedented. It would be somewhat less if China's own wine-grape production increases faster, as in the Alternative 2 scenario, but certainly in as short a period as the next five years that is not able to reduce the growth in China's wine imports very much, especially at the premium end of the spectrum.

Of course these projections are not predictions. Actual exchange rate changes, and the ability of Australian wine producers (as compared with their competitors abroad) to capture the projected market growth opportunities in Asia will determine the changes in market shares over the coming years. Not all segments of the industry are projected to benefit, with non-premium producers facing falling prices if demand for their product continues to dwindle as projected above. Nor will all exporting firms benefit. In particular, those firms that fail to invest sufficiently in building relationships with their Chinese importer/distributor may find they do not get repeat orders, for example. But at least the above results can alert producers to possibilities, given the range of assumptions built into our model of global wine markets.

Acknowledgements

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(a) Alternative 1 (assuming RERs return half-way from 2011 to 2009 rates)





Figure 7. Shares of value of Australian wine exports to US, UK and China, 2009 to 2018 (per cent). Source: Historical data from www.wineaustralia.com and projections from authors' model results

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Appendix Table 1. Cumulative changes in exchange rates and prices relative to the US dollar, 2007-11 (per cent)

2007 to 2011

	$\phi_{_d}$	P_d^g	P_d^c	${\pmb{\phi}_d^{\scriptscriptstyle R}}$		$\phi_{_d}$	P_d^g	P_d^c	${\pmb{\phi}_d^{\scriptscriptstyle R}}$
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
FRA	-1.5	5.8	6.7	0.1	UKR	57.8	91.4	71.4	13.0
ITA	-1.5	6.5	8.6	0.7	TURK	28.5	35.4	35.7	-1.9
POR	-1.5	4.3	6.9	-1.3	AUS	-18.9	16.2	13.0	33.4
SPN	-1.5	4.3	9.0	-1.3	NZL	-7.0	8.8	13.4	9.0
AUT	-1.5	6.9	9.1	1.1	CAN	-7.9	8.5	7.5	9.7
BEL	-3.9	7.3	10.5	4.0	USA	0.0	7.3	8.5	0.0
DEN	-1.4	10.3	10.1	4.1	ARG	32.8	77.2	100.0	24.3
FIN	-1.5	7.3	7.2	1.5	BRA	-14.1	34.4	24.1	45.8
GER	-1.5	3.4	6.5	-2.2	CHILE	-7.4	15.7	5.3	16.4
GRE	-1.5	11.3	14.1	5.3	MEX	13.7	26.0	23.3	3.3
IRL	-1.5	-7.7	1.0	-12.7	URU	-17.7	30.0	33.2	47.1
NLD	-1.5	4.2	7.5	-1.4	SAFR	3.1	35.8	30.8	22.8
SWE	-3.9	7.3	7.2	4.0	OAFR	5.3	52.7	61.9	35.2
SWI	-26.0	3.3	2.9	30.1	CHINA	-15.1	23.2	14.5	35.1
UK	24.9	10.4	14.2	-17.7	НК	-0.2	4.8	13.0	-2.2
BUL	-1.6	22.0	23.3	15.5	INDIA	12.9	34.9	46.5	11.3
CRO	-0.4	13.0	12.2	5.7	JAP	-32.2	-5.8	-1.0	29.4
GEO	1.0	27.4	30.1	17.6	KOR	19.3	12.2	15.2	-12.4
HUN	9.5	16.3	20.5	-1.0	MAL	-11.0	14.3	11.3	19.6
MOLD	-3.3	33.2	30.3	28.4	SING	-16.5	0.7	15.9	12.5
ROM	25.0	31.9	27.8	-1.7	TAIW	-15.1	23.2	14.5	35.1
RUS	14.9	55.6	47.6	26.2	THAI	-11.7	14.5	12.1	20.7
2009 to 2011									
	ϕ_{d}	P_{d}^{g}	P_{l}^{c}	ϕ_{I}^{R}		ϕ_{i}	P_{d}^{g}	p_d^c	ϕ_{d}^{R}
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
FRA	-0.1	2.4	3.7	-1.4	UKR	2.3	31.6	18.1	23.9
ITA	-0.1	1.7	4.3	-2.1	TURK	8.1	14.8	15.6	2.2
POR	-0.1	1.7	5.1	-2.1	AUS	-24.4	6.4	6.3	35.5
SPN	-0.1	1.8	5.1	-2.0	NZL	-20.9	3.5	6.8	25.9
AUT	-0.1	3.9	5.1	0.0	CAN	-13.4	6.3	4.7	18.1
BEL	-0.1	3.7	5.8	-0.2	USA	0.0	3.9	4.8	0.0
DEN	0.2	4.7	5.1	0.6	ARG	10.8	35.3	45.0	17.5
FIN	-0.1	4.1	4.2	0.2	BRA	-16.3	15.8	12.0	33.1
GER	-0.1	1.4	3.5	-2.4	CHILE	-13.8	10.5	4.8	23.3
GRE	-0.1	3.4	8.2	-0.4	MEX	-8.1	9.8	8.2	14.9
IRL						0.1			
NLD	-0.1	-1.5	1.6	-5.2	URU	-14.4	13.9	15.3	28.0
014/5	-0.1 -0.1	-1.5 2.5	1.6	-5.2	URU SAFR	-14.4 -14.3	13.9 16.5	15.3 9.5	28.0
SWE	-0.1 -0.1 -15.2	-1.5 2.5 1.9	1.6 3.7 4.2	-5.2 -1.3 15.6	URU SAFR OAFR	-14.4 -14.3 7.0	13.9 16.5 22.4	15.3 9.5 22.5	28.0 30.8 10.1
SWE	-0.1 -0.1 -15.2 -18.4	-1.5 2.5 1.9 0.7	1.6 3.7 4.2	-5.2 -1.3 15.6 18.7	URU SAFR OAFR CHINA	-14.4 -14.3 7.0	13.9 16.5 22.4 15.0	15.3 9.5 22.5 8.9	28.0 30.8 10.1 17.0
SWE SWI UK	-0.1 -0.1 -15.2 -18.4 -2.8	-1.5 2.5 1.9 0.7 5.3	1.6 3.7 4.2 0.9 7.9	-5.2 -1.3 15.6 18.7 4.2	URU SAFR OAFR CHINA HK	-14.4 -14.3 7.0 -5.4 0.4	13.9 16.5 22.4 15.0 3.9	15.3 9.5 22.5 8.9 7.7	28.0 30.8 10.1 17.0 -0.4
SWE SWI UK BUL	-0.1 -0.1 -15.2 -18.4 -2.8 0.0	-1.5 2.5 1.9 0.7 5.3 7.9	1.6 3.7 4.2 0.9 7.9 6.8	-5.2 -1.3 15.6 18.7 4.2 3.8	URU SAFR OAFR CHINA HK	-14.4 -14.3 7.0 -5.4 0.4 -3.6	13.9 16.5 22.4 15.0 3.9	15.3 9.5 22.5 8.9 7.7 21.9	28.0 30.8 10.1 17.0 -0.4 16.9
SWE SWI UK BUL CRO	-0.1 -0.1 -15.2 -18.4 -2.8 0.0	-1.5 2.5 1.9 0.7 5.3 7.9 3.1	1.6 3.7 4.2 0.9 7.9 6.8 3.3	-5.2 -1.3 15.6 18.7 4.2 3.8 -1 9	URU SAFR OAFR CHINA HK INDIA	-14.4 -14.3 7.0 -5.4 0.4 -3.6	13.9 16.5 22.4 15.0 3.9 17.1	15.3 9.5 22.5 8.9 7.7 21.9	28.0 30.8 10.1 17.0 -0.4 16.9 8.1
SWE SWI UK BUL CRO	-0.1 -0.1 -15.2 -18.4 -2.8 0.0 1.1	-1.5 2.5 1.9 0.7 5.3 7.9 3.1 18 5	1.6 3.7 4.2 0.9 7.9 6.8 3.3 16.2	-5.2 -1.3 15.6 18.7 4.2 3.8 -1.9	URU SAFR OAFR CHINA HK INDIA JAP	-14.4 -14.3 7.0 -5.4 0.4 -3.6 -14.7	13.9 16.5 22.4 15.0 3.9 17.1 -4.2	15.3 9.5 22.5 8.9 7.7 21.9 -1.0 7.1	28.0 30.8 10.1 17.0 -0.4 16.9 8.1
SWE SWI UK BUL CRO GEO HUN	-0.1 -0.1 -15.2 -18.4 -2.8 0.0 1.1 1.0	-1.5 2.5 1.9 0.7 5.3 7.9 3.1 18.5 6.7	1.6 3.7 4.2 0.9 7.9 6.8 3.3 16.2 8.0	-5.2 -1.3 15.6 18.7 4.2 3.8 -1.9 13.0 3.3	URU SAFR OAFR CHINA HK INDIA JAP KOR	-14.4 -14.3 7.0 -5.4 0.4 -3.6 -14.7 -13.2	13.9 16.5 22.4 15.0 3.9 17.1 -4.2 5.4	15.3 9.5 22.5 8.9 7.7 21.9 -1.0 7.1	28.0 30.8 10.1 17.0 -0.4 16.9 8.1 16.9 23.3
SWE SWI UK BUL CRO GEO HUN	-0.1 -0.1 -15.2 -18.4 -2.8 0.0 1.1 1.0 -0.6	-1.5 2.5 1.9 0.7 5.3 7.9 3.1 18.5 6.7	1.6 3.7 4.2 0.9 7.9 6.8 3.3 16.2 9.0	-5.2 -1.3 15.6 18.7 4.2 3.8 -1.9 13.0 3.3 8 7	URU SAFR OAFR CHINA HK INDIA JAP KOR MAL	-14.4 -14.3 7.0 -5.4 0.4 -3.6 -14.7 -13.2 -13.2 12.5	13.9 16.5 22.4 15.0 3.9 17.1 -4.2 5.4 11.3 8 1	15.3 9.5 22.5 8.9 7.7 21.9 -1.0 7.1 4.9	28.0 30.8 10.1 17.0 -0.4 16.9 8.1 16.9 23.3 21.4
SWE SWI UK BUL CRO GEO HUN MOLD ROM	-0.1 -0.1 -15.2 -18.4 -2.8 0.0 1.1 1.0 -0.6 5.7 0.0	-1.5 2.5 1.9 0.7 5.3 7.9 3.1 18.5 6.7 19.3 10.9	1.6 3.7 4.2 0.9 7.9 6.8 3.3 16.2 9.0 15.6 12.2	-5.2 -1.3 15.6 18.7 4.2 3.8 -1.9 13.0 3.3 8.7 6.8	URU SAFR OAFR CHINA HK INDIA JAP KOR MAL SING	-14.4 -14.3 7.0 -5.4 0.4 -3.6 -14.7 -13.2 -13.2 -13.5 -5.4	13.9 16.5 22.4 15.0 3.9 17.1 -4.2 5.4 11.3 9.1	15.3 9.5 22.5 8.9 7.7 21.9 -1.0 7.1 4.9 8.2 8.8	28.0 30.8 10.1 17.0 -0.4 16.9 8.1 16.9 23.3 21.4 17.0
SWE SWI UK BUL CRO GEO HUN MOLD ROM RUIS	-0.1 -0.1 -15.2 -18.4 -2.8 0.0 1.1 1.0 -0.6 5.7 0.0 -7.4	-1.5 2.5 1.9 0.7 5.3 7.9 3.1 18.5 6.7 19.3 10.9 29.3	1.6 3.7 4.2 0.9 7.9 6.8 3.3 16.2 9.0 15.6 12.2 15.9	-5.2 -1.3 15.6 18.7 4.2 3.8 -1.9 13.0 3.3 8.7 6.8 34.4	URU SAFR OAFR CHINA HK INDIA JAP KOR MAL SING TAIW	-14.4 -14.3 7.0 -5.4 0.4 -3.6 -14.7 -13.2 -13.2 -13.5 -5.4 -11.1	13.9 16.5 22.4 15.0 3.9 17.1 -4.2 5.4 11.3 9.1 15.0 8.1	15.3 9.5 22.5 8.9 7.7 21.9 -1.0 7.1 4.9 8.2 8.9 8.9 7.3	28.0 30.8 10.1 17.0 -0.4 16.9 8.1 16.9 23.3 21.4 17.0 16.9

Key: ϕ_d = nominal exchange rate change; p_d^s = change in GDP deflator; p_d^c = change in the consumer price index; ϕ_d^R = calculated change in real exchange rate. Source: Authors' compilation based on data downloaded from data.worldbank.org, and on estimated inflation rates for Argentina from Cavallo (2013)

Appendix Table 2. Cumulative consumption and population growth, 2009-11 and 2011-18 (per cent)

Observed, 2009 to 2011

	Aggregate consumption	Population		Aggregate consumption	Population
FRA	2.0	1.1	AUS	5.9	3.0
ITA	0.6	1.0	NZL	3.0	2.1
POR	-2.1	0.0	CAN	5.7	2.2
SPN	0.2	0.7	USA	3.7	1.6
AUT	1.6	0.6	ARG	18.5	1.8
BEL	2.4	2.0	BRA	12.8	1.8
DEN	0.4	0.9	CHILE	19.7	1.9
FIN	3.2	0.9	MEX	8.8	2.5
GER	2.5	-0.2	URU	20.5	0.7
GRE	-13.6	0.2	OLAC	12.9	2.2
IRL	-4.3	0.6	SAF	8.3	2.6
NLD	-0.2	1.0	TURK	13.8	2.5
SWE	5.4	1.7	NAFR	9.4	3.5
SWISS	2.9	2.1	OAFR	9.4	3.5
UK	0.4	1.3	MEST	0.0	0.0
OWEN	-1.4	0.2	CHINA	5.6	1.0
BUL	-0.9	-1.4	НК	14.5	1.0
CRO	-0.6	-0.5	INDIA	14.8	2.8
GEO	0.0	1.7	JAP	2.8	0.2
HUN	-2.6	-0.5	KOR	6.9	1.2
MOLD	6.5	-0.2	MALAY	5.3	3.3
ROM	15.0	-0.4	PHILI	9.3	3.4
RUS	22.9	0.0	SINGA	8.6	3.9
UKR	17.6	-0.8	TAIW	5.6	1.0
OCEF	22.9	0.0	THAI	6.1	1.2
			OAPA	0.0	4.6

Assumed, 2011 to 2018

	Aggregate consumption	Population		Aggregate consumption	Population
FRA	10.0	0.7	AUS	17.8	7.3
ITA	10.0	0.7	NZL	15.4	5.9
POR	10.0	0.7	CAN	14.2	5.6
SPN	10.0	0.7	USA	15.5	5.2
AUT	10.0	0.7	ARG	30.0	4.9
BEL	10.0	0.7	BRA	27.3	3.8
DEN	10.0	0.7	CHILE	23.4	5.0
FIN	10.0	0.7	MEX	22.0	4.6
GER	10.0	0.7	URU	25.6	7.3
GRE	10.0	0.7	OLAC	25.6	7.3
IRL	10.0	0.7	SAF	23.1	3.0
NLD	10.0	0.7	TURK	31.8	9.1
SWE	10.0	0.7	NAFR	31.8	9.1
SWISS	10.0	0.7	OAFR	55.8	15.1
UK	10.0	0.7	MEST	31.8	9.1
OWEN	10.0	0.7	CHINA	69.0	2.7
BUL	23.1	1.9	НК	23.7	4.7
CRO	23.1	1.9	INDIA	63.1	7.0
GEO	23.1	1.9	JAP	7.1	-1.3
HUN	23.1	1.9	KOR	22.0	0.7
MOLD	23.1	1.9	MALAY	34.4	8.2
ROM	23.1	1.9	PHILI	34.4	9.8
RUS	20.6	-1.7	SINGA	18.6	5.6
UKR	23.1	1.9	TAIW	34.6	2.3
OCEF	23.1	1.9	THAI	36.0	2.6
			ΟΔΡΔ	32.2	11.2

Source: Projections from global economy-wide modeling by Anderson and Strutt (2014)

An overview of the Australian wine sector

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Abstract

This presentation will outline what the Winemakers' Federation of Australia (WFA) sees as the two clear priorities for the wine industry, the strategies it is adopting, and why it takes a 'glass half full' view of wine's future prospects. The first priority is to better understand the drivers behind the lack of profitability within the sector and what can be done about them at the industry and regulatory level. Wine businesses need to know more about future demand opportunities, where supply/demand mismatches are occurring and the impact of market distortions such as exchange rates, wine tax arrangements and retail consolidation. The second priority is a suite of initiatives around the broad issues of health, alcohol and social responsibility. WFA is particularly concerned about regulatory creep, with public health advocates pushing for increased taxes on wine products and greater restrictions on how our products can be marketed. WFA has developed a detailed action plan that acknowledges the wine industry's responsibilities as an alcohol producer, while highlighting its commitment to a moderate drinking culture. WFA will vehemently defend wine's social licence and legitimate role in balanced Australian lifestyles. The positive and significant regional and national socio-economic footprint of the wine industry must be a key consideration in any assessment of the public interest when considering policy reform to issues that affect wine and the community.

Introduction

Although I do have a more conservative outlook on the industry than the previous speaker, Kym Anderson, I do believe there are good reasons to take the 'glass half full' perspective of the industry. Our brands continue to attract international attention and Australian companies of all sizes continue to compete with the best of them globally. We've been blessed with high quality vintages in the last three out of four years. And there are signs of strengthening grape grades, up 9% this vintage over last. There of course is optimism around the recent depreciation of the Australian dollar – provided Ben Bernanke keeps his mouth shut! There are some signs that the global supply is coming into better balance, and potentially an emerging undersupply in the northern hemisphere that may increase demand for our commodity grape wine at least.

However, the 2013 vintage crush estimate of 1.83 million tonnes that WFA announced a couple of weeks ago should remind us all that our industry still faces a number of significant structural and profitability challenges and is likely to do so for some time yet. I say this not to talk the industry down. Far from it. But to highlight the fact that the issues we face are complex and that no silver bullet exists, including a fall in the Australian dollar, as helpful as it is. We should and can retain a 'glass half full' approach but we must also acknowledge the ongoing structural mismatch between the supply and the demand for Australian wine. And today I would like to provide some context around those comments.

I will use some of the analysis that is being produced by the WFA expert review of the industry which is due to be released in the second half of this year and I'll come back to this at the end of my presentation. But today you will get an early insight, a bit of a sneak peek into some of the outcomes of that work. And I'd like to take this opportunity again to thank Stuart Thomson and his team at the Grape and Wine Research and Development Corporation, Andrew Cheesman and the team at Wine Australia and the Wolf Blass Foundation for their support for that industry review over the last six months. The session chair has also asked me to spend a little time specifically on the US market to complement the other presentations during this opening session.

The first point to note at least in volume terms is that the Australian industry has shown considerable resilience in the face of a number of significant challenges in local and export markets, particularly since 2007. Figure 1 shows export volume which is the red part of the graph against domestic volume which is in blue and the squiggly line going across is the US dollar per Australian dollar over a monthly average for the years 1991 to 2007. What it shows is the enormous importance of exports to the industry's success. From 1991 to 2007 the Australian wine industry tripled in size, almost 100% of that was due to export growth. This period saw robust and sustained support from distributors and consumers for our commercial grade wine, particularly in the key US and UK markets and a rise of the small but formidable Australian fine wine segment on to the international stage. The production base expanded and investments soared. In 2007 exports peaked, volume had grown by some 720 million litres, more than 12 times the level of 1991. Since then export volume has slightly declined but the mix has shifted dramatically and as we will see value has significantly declined as a consequence. Domestic demand has remained relatively flat, growing at around 2% annually.

But if we look in value terms the picture is far, far more challenging. Figure 2 shows the value of Australian wine sales, both domestic and export, in real terms. Again export is the top line in the reddish colour and domestic sales the bottom line in blue. The dotted lines are those adjusted for inflation. And what we see is that in 2012 export values were down by \$1.2 billion in real terms from peak value in 2005. The US and UK markets alone account for some 91% of these losses. In 2012 the domestic value had also declined in real terms. The consequence for the industry has been a significant decline in profit levels. The expert review analysis estimates that aggregate gross margin



Figure 1. Australian wine volume, export and domestic. Source: ABS; Wine Australia; xe.com; US Treasury

across the industry is some \$680 million or 38% lower in 2012 than it was in 2007. In exports gross margin has declined by approximately three quarters of a billion dollars and of this some \$448 million can be directly contributed to exchange rates with a further \$220 million lost from export volume due to increased competition from other wine-exporting countries and a deteriorating mix. Domestically a significant volume of C and D grade wine that was previously being exported now competes in a highly consolidated domestic retail market and for limited shelf space, along with an increasing volume of imports and private labels.

Now if we take a deep dive into the decline of our export performance it seems to me that the problem we confront is far more complex than just exchange rates. Let's have a look at the US market as a case study. Figure 3 shows the demand curve for our wine in the US market at local currency price points to remove the impact of the Australian dollar's appreciation. What we see is a shift to the left in the demand curve at price points in US dollar terms. The analysis shows that in 2007 US consumers purchased some 77 million litres of Australian wine at USD3.75 and above. However in 2012 they only purchased 16 million litres for the same price range - a decline of some 61 million litres. We have found similar shifts in the demand curve in destination currencies in our other key markets such as the UK. What it suggests is that while a rising Australian dollar may have been a catalyst or trigger for the decline in Australia's export performances, recovering lost share at profitable price points is not going to be a given even with a structural adjustment in the value of the Australian dollar. Our challenge in our traditional markets is more than just price - it is also about the health of the Australian brand. When we go into the detail of this shift we see a decrease in demand for our wine across all price segments. For example in 2007, 1.5 million litres was purchased at USD15 and above; in 2012 it was only 0.5 million litres - a decrease of some 200%. In 2007 approxi-



Figure 2. Australian wine value, export and domestic. Source: ABS; Wine Australia; xe.com; US Treasury



Figure 3. US market demand for Australian wine. Source: Wine Australia; xe.com for foreign exchange rates; analysis

mately 80 million litres was purchased at between USD4 and USD6 while only 10 million litres was purchased in the same price range in 2012, a 700% decrease.

A snapshot of Australian exports to the US market in 2012 suggests that we are underrepresented in all price points and that Australian sales continue to decrease in most price points (Figure 4). Last year both volume and value for Australian wine continued to decline by 5% and 6% respectively. This is counter to the overall market trend where total volume increased by 2% while total value increased by 5%. For the year ended December 2012 Australian sales are down in all price segments except for the USD15-19.99 price point. The decline in Australian wine sales runs counter to the total market sales increase for most price segments. And the main takeaway messages for me seem to be that we will need to reengage consumers and we will need to reengage distributors and other market gatekeepers in key markets such as the US where many do not currently feel compelled to put their resources behind the Australian category. A declining Australian dollar will help, but will it present just a volume opportunity for commercial and commodity priced wine or will we be able to convert this into a genuine and sustained uplift in demand across the entire Australian portfolio at profitable price points? That is the key question and not just for the US but for all of our traditional markets. This is why initiatives such as the upcoming Savour event by Wine Australia are so important and why I believe Savour's aim of influencing the key influencers is spot on and very timely. If you are not already signed on and supporting this event I would encourage you to do so.

On the supply side of the equation the story emerging from our expert review is equally challenging (Figure 5)¹. We analysed the production profitability of 13 sample regions which represent approximately 80% of total grape supply in the 2012 vintage. We used cost per hectare, a seven year average yield and price dispersion data. The pie chart on the left is the outcome and it tells us that up to 81% of 2012 production may be unprofitable, while only 7% was considered profitable. There is an excellent article in this month's edition

¹Grade definitions are as follows. In terms of domestic retail prices: A is \$30 per bottle or above, B is \$15-\$30, C is \$10.\$15, D is \$7-\$10 and E and F is below \$7. In terms of export FOB (free on board) prices: A is greater than \$10 per litre, B is \$7.50-\$9.99, C is \$5-\$7.49, D is \$2.50.\$4.99, and E and F below \$2.50.

		Austral	ia	Total	Market
	Total sales	Change (%)	Market share	Total sales	Change (%)
Volume (million cases)	9.0	-5%	6.9%	130.9	2%
Value (million USD)	665	-6%	6.3%	10,564	5%





Figure 4. Australian wine sales in the US

of Australian & New Zealand Grapegrower & Winemaker by Gary Baldwin and Paul van der Lee that reaches a similar conclusion that at least 50% of grapes were purchased at a price below the cost of production. When we break down our analysis, as shown in the chart on the right of Figure 5, we see that the vast majority of A and B grade grapes were profitable. But 50% of C, 84% of D and almost unbelievably 100% of E and F grade grape production were unprofitable. What we have found is that very large volumes of D, E and F grade grapes in warm inland regions are being sold just below average growing costs. Significant volumes are being sold from cooler and more temperate regions at hundreds of dollars per tonne below typical growing costs. These figures are based on last year's vintage. This vintage, as you know, WFA recently announced an unexpectedly high crush number of 1.83 million tonnes. Yes, it is true that average grape prices have strengthened again this year, but the long-term downward trend is set to return next vintage in response to this year's larger crush number and in response to the anticipated increases in inventory levels that will accompany it. As I said when releasing these figures a couple of weeks ago, regardless of some positive seasonal developments the industry must acknowledge that a structural mismatch between supply and demand of Australian wine remains, and that profitability levels throughout the supply chain will be difficult to shift and sustain until a better balance is struck.

Figure 6 tries to reinforce this point. It maps current production by grape grade against projected demand out to 2013 to demonstrate where our supply/demand mismatches are and are likely to be. We have a blue bar by grape grade at the bottom which represents 2012 demand for each wine grade. The red bar is a conservative scenario for projected demand out to 2013 in which exchange rates remain at current levels, global economic conditions improve only marginally and growth rates for the Australian category are reasonably similar to

2012 Production Profitability



Figure 5. Profitability of Australian wine grape production



what has been achieved in recent years. The green bar (scenario two) is more optimistic and assumes that the Australian dollar depreciates significantly to less than US 90 cents, global economic conditions improve significantly and growth rates for the Australian category are similar to pre GFC levels. The dashed line above each set of bars represents 2012 supply for the corresponding grape grade. Looking at the detail, the analysis indicates a significant oversupply in C and D grade grapes and wine. It also shows the distorting impact of this oversupply. The oversupply of fruit in C grade (5 million cases), and D grade (26 million cases) is more than filling an undersupply of A and B and E and F grade grapes respectively. Much of this excess demand for E and F grade fruit is being created by the sale of wine at low and unprofitable prices. Figure 6 also highlights that projected demand, even under our most optimistic assumptions, is unlikely to deal with oversupply at C and D grade for the foreseeable future. This will mean ongoing pricing distortions for grapes at all grades and sustained downward pressure on supply margins particularly in the commercial and commodity segments. Again the conclusion is clear: oversupply is likely to remain a feature of the Australian commercial wine segment for some time until either export demand is significantly increased or long-term economic forces rationalise the supply base to bring it to a better balance.

Now I hear you all saying to yourselves "Well Paul, thanks for all of that. What's WFA going to do about it all?". Well the truth is that there is only so much we can do. Individual participants and companies will continue to react to these issues and make their own commercial decisions along the way. For some it will mean a change in their business model or their portfolios, for others consolidation or joint ventures, and for others it will mean exiting the industry altogether. Over time economic forces will prevail. That said, we as a Federation have plenty to do to support you during this period of transition and

> to help you to rise to the challenges and the opportunities. The first thing is to get you a data set to help you make better decisions. The expert review analysis is a good first step. The second thing we can do is to work with the other national wine bodies and the government on putting in place industry support and a favourable regulatory setting that encourages profitability rather than getting in its way. That is why, when the expert review analysis is released later this year, it will be accompanied with a set of WFA actions and recommendations to the industry. They will cover such issues as how we can grow the demand opportunity, what steps can be taken to further support the corrections to supply, the future of wine tax arrangements, and the issue of retail power here in our domestic market.

> The information presented today is just a very small glimpse of a much larger body of analysis that is being done. That work is now before the WFA Board and is being finalised. Our aim is to release both the analysis and our recommendations following our next Board meeting in August. You will be invited at that time to tell us whether you think we have it right or not. This is important and expensive work. If you are not members of the two national industry associations, the Winemakers' Federation or the Wine Grape Growers Australia, you really should be to support these endeavours. But I trust today has given you some understanding of where we are heading and I look forward to hearing your views once the expert review's findings and our suggested next steps have been released.

Taming the Chinese market – preparing for the second wave

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Introduction

The topic today is taming the China market – preparing for the second wave. Maybe it's the third or fourth wave by now. I'll explain a little background of ASC and then talk about the history of the imported wine market development in China, the current challenges that we're facing and some of the key issues for the future.

My father and I started ASC in 1996. We certainly followed the first speaker's advice of "failing early and failing often". Today we have 1,200 staff and 26 offices throughout China, are the exclusive importer for around 100 different internationally known brands, and the largest importer by value in China. Suntory, a Japanese company, became my partner and controlling shareholder in 2010, and in 2012 I moved from CEO to Executive Chairman.

ASC's sales are 30% on-premise, 30% off-premise, 20% direct and 20% through distribution partners. One of the unique things about our model is that 80% of our sales go through our sales staff, our own sales network – that's why we have so many people.

Growth of our business has been rapid (as most things have been in China); last year we generated about 1.2 billion renminbi (RMB), equivalent to 200 million US dollars (USD), in sales.

From an operational standpoint our philosophies really are to be more than just a seller of wine; we are a solution provider. This is very important in China. We do a lot of education, training and promotional initiatives, working closely with our brand owners, and we try to maintain very strong relationships with our customers throughout the country.

On the supply side I think the most important thing we do is transparently engage with our supply partners, emphasising quality, professionalism and service, and really focus on building the wine appreciation culture in China.

Imported wine market in China

Last year 29.6 million 9 litre cases of bottled wine were imported into China; that was up from 27.3 million in 2011 and 16.6 million in 2010, so recent times have seen an average compound annual growth rate (CAGR) of 61% (Figure 1). This information is sourced from China Customs – the volume figures in China Customs are quite accurate, although the value figures are questionable because of the nature of the tax structures. China taxes on value as opposed to volume, so some companies are under-declaring value figures. On the import



Figure 1. The imported wine market in China 1996–2012. Source: China Customs – imported still bottled wine – not including bulk imports

side, in 2012 France was 48% of the volume, Australia 13%, Spain 10%, Italy 7%, Chile 8%, US 5% and other countries 9%. If we look over the last 15 years France has been around 50% for that period of time. Australia's market share has fallen over the last two and a half years – I think it was as high as 20% two or three years ago.

Looking at 2008 in more detail, in that year 57.6 million litres of wine were imported into China equating to USD276 million in value; Australia's portion of that was 11.6 million litres or 54 million Australian dollars (AUD) (Table 1). In 2010 these figures increased significantly but 2010 to 2011 saw a massive increase from 146 million litres in total volume imported to China to 241 million litres, with value increasing from USD657 million to USD1.2 billion. During the 2010–2011 period, Australia's volume increased from 23 million litres to 32 million litres and value increased from AUD116 million to AUD193 million.

The number of importers has skyrocketed in China; this is one of the challenges that the professional side of the business is facing. In 2008 there were approximately 500 registered importers; in 2010 there were 2,300; and in 2012 there were 4,200. The top 500 importers make up an important portion of the volume and an even more important portion of the value. In 2012, 50 of the 4,200 importers imported more than1 million litres and 50 of the 4,200 importers imported more than USD4 million worth of wine. ASC's rank by value was number one; by volume it was number three. You can see from these figures there's a massive number of importers that have come onto the market over the last two or three years, largely due to the domestic wine scene and opportunities that premiumisation has given to wine importers in China.

In terms of major importers Nanpu, a company based in Shanghai, is the largest by volume, importing 6.4 million litres with an average per litre price of USD2.72. The companies C & D and ASC are second and third in volume terms respectively (Table 2). However, on the value side the ranking changes, with the ASC average price per litre highest at USD10.20 and Nanpu ranked at number five with USD2.72. The top ten importers make up 13% of the volume and 17% of the value.

Key factors behind this growth

The photograph on the left of Figure 2 is of a government official being toasted by some friends, probably trying to find a way to do some business. In the late 1980s and early 1990s the Chinese Government decided that wine consumption was something it wanted to push in place of Bijou or white spirits and that really began the domestic wine industry and planting of grapes.

Table 1.	China	import	figures	2008-	-201	12
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Year	2008	2010	2011	2012
Total Volume	57,600,000	146,369,675	241,391,884	266,121,502
Total Value	\$276,000,000	\$657,000,000	\$1,274,000,000	\$1,375,000,000
Australian Volume	11,600,000	23,767,710	32,616,636	33,883,070
Australian Value	\$54,000,000	\$116,400,000	\$193,830,000	\$207,825,000
Total Registered Importers	500	2,300	3,900	4,200
Top 500 importers Volume		117,971,322	187,280,273	193,811,480
Top 500 importers Value		na	na	\$929,871,000
#Importers Volume > 1m ltr.		20	41	50
#Importers Value > 4m USD		na	na	50
ASC Rank by Volume		6	3	3
ASC Rank by Value		3	2	1

ASC started in 1996 when the imported wine business began; the Chinese government was largely responsible for that by pushing all government related functions to use wine. In the beginning that was domestic wine but then the economy started to grow quickly, per capita income started to grow, China entered the World Trade Organisation (WTO) in 2005, wine import duties came down and the government became very wealthy. And people became very wealthy. With that increased wealth came the desire to live a healthier, more sophisticated lifestyle and wine very much epitomised that.

Then about five years ago you really saw a dramatic increase in wine imports. One of the critical reasons was domestic wine premiumisation. The average price for what was referred to as premium domestic wine went up from around 40 RMB (4 Euros (EUR)) per bottle, to 200 RMB (20 EUR) per bottle. All of a sudden imported wine was not so expensive. Imported wine became a lot more attractive to individual consumers and to government officials who were being both entertained with wine and purchasing wine for their own personal enjoyment. The number one challenge for imported wine was no longer price – from 1996 to 2005 ASC's number one challenge was encouraging Chinese consumers to buy a bottle of imported wine. While China's entry to WTO brought duties down and made wine more affordable, it was domestic premiumisation that made imported wine comparatively more affordable.

The number one challenge ASC now faces is no longer price – it's brand awareness and getting Chinese consumers to be interested in drinking a wine that they've never heard of. Chinese consumers are now realising that the domestic premium and super premium wines are really not very good in terms of value. More and more local consumers are shifting to imported wine because they just assume the quality must be better than domestic wine.

The domestic Chinese wine industry has effectively premiumised price and packaging without premiumising quality. There's been



Figure 2. Factors behind the growth in the China wine market

Tab	le 2	2. To	р	ten	importe	rs by v	olume	and	value	into	China	in	2012
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very little improvement in the quality of domestic wine. You'll read stories from time to time about smaller producers that are making better wines, and that's true - but the big boys, the dominant domestic Chinese players, have really not improved the quality of what they make relative to the price they are seeking.

However, the recent explosion of importers relative to the maturity of the market has led consumers to conclude that importers are taking advantage of the fact that consumers don't know wine. Unscrupulous importers are importing wine for USD5–6 per litre and by the time it reaches the end consumer it will cost USD30 per litre. So one of the real challenges we are facing now is the explosion of importers combined with a lack of consumer understanding; it's created an unprofessional and messy market in which the Chinese consumers are very confused.

The Chengdu Candy and Liquor Fair, the largest wine fair in China, happens in March every year. ASC had a stand there in March and I was talking with one of our Australian suppliers – a winemaker who's quite well known – and he noted that there were more Australian brands at the fair than there are in all of Australia. It demonstrates that a large number of products, many client-branded, are being produced for the China market. This is not just happening with Australian wine, it is happening for all wine-producing countries that export to China. Importers that don't know very much about wine secure a special channel that they can sell into, and purchase five, six, ten containers a year. They're not interested in buying a wine that is well known; they'd rather buy a wine that looks okay and doesn't have any brand identity so people can't go on the web and find out what it is selling for in the home market. This has just led to an explosion of wine brands that no-one has ever heard of, with prices that, frankly, are ridiculous.

Economic restructuring

Another challenge that ASC is facing is economic restructuring; midto long-term this is a good thing for China, and probably a good thing for the Australian wine industry because of the effect it will have on the Australian dollar versus the renminbi. The economy is changing; the new leaders of China, Xi Jinping and Li Keqiang, are determined to drive future growth through domestic consumer consumption rather than cheap exports and infrastructure investment (Figure 3). That's bad for the mining industry but it should be good for the wine industry over time. In the short term however, it is creating some real challenges; consumer confidence is being eroded. We're not sure how long this trend is going to last; it's difficult to quickly transition an economy the size of China, but Chinese leaders have surprised the

	F	Rank by Volum	e		R	ank by Value	
	Volume(Litre)	Sum(USD)	Avg per litre		Volume(Litre)	Sum(USD)	Avg per litre
Total Imports	266,371,035	1,376,200,938	5.17	Total Imports	266,371,035	1,376,200,938	5.1
Importers				Importers_			
Shanghai Nanpu Food	6,472,285	17,578,211	2.72	ASC Fine Wine	5,140,882	52,442,947	10.20
Shanghai C & D Wines Co., Ltd.	5,968,294	49,083,193	8.22	Shanghai C & D Wines Co., Ltd.	5,968,294	49,083,193	8.22
ASC Fine Wine	5,140,882	52,442,947	10.20	Chen Yi Logistics	3,524,136	32,279,323	9.16
Chen Yi Logistics	3,524,136	32,279,323	9.16	Pernod Ricard	2,687,357	17,612,525	6.55
Local Logistics company	3,485,099	17,609,107	5.05	Local Logistics company	3,485,099	17,609,107	5.05
Tianjin Port Free Trade Zone Xingheng Int'l Trade Co., Ltd.	2,903,293	14,131,681	4.87	Shanghai Nanpu Food	6,472,285	17,578,211	2.72
Pernod Ricard	2,687,357	17,612,525	6.55	Tianjin Port Free Trade Zone Xingheng Int'l Trade Co., Ltd.	2,903,293	14,131,681	4.87
Charter Base	2,468,266	9,521,619	3.86	Aussino World Wines	1,486,347	13,487,712	9.07
Guangzhou Joyin	2,187,572	9,239,003	4.22	Waigaochao duty free zone	2,018,321	13,132,289	6.51
Local Trading Company	2,034,073	5,195,544	2.55	Shanghai Torres	1,671,555	10,880,551	6.51
Total of Top 10	36,871,257	224,693,153	6.09	Total of Top 10	35,357,569	238,237,539	6.74
% of total	14%	16%		% of total	13%	17%	

rest of the world by being able to achieve things others thought they couldn't.

Austerity campaign

A further challenge we're facing is the austerity campaign – Xi Jinping refers to it as the 'Clean Your Plate Campaign' – a reduction in government and government-related company spending on banquets and entertainment, events at which wine has played a very important role. Most government agencies/government companies are not entertaining, creating a massive challenge for Chinese restaurant,



Source: Thomson Reuters Datastream, ABN AMRO Group Economics



Figure 3. China's economic restructuring plans

banqueting and hotel businesses. The austerity campaign seeks to increase confidence in the government, which I think is a good thing, but it's affecting domestic and international wine and spirit sales and the luxury goods business. The impact is much more dramatic than anticipated and, frankly, we didn't have a lot of warning that this was going to happen.

Anti-corruption campaign

The anti-corruption campaign, tied to the austerity campaign is highlighted in Figure 4. The photograph is of a local city mayor being caught having an expensive dinner and him pleading with the people not to take him out and beat the hell out of him. Government officials are now afraid to go to dinners and the effect on sales of wine, on Bijou, on all products that were consumed in that type of environment has been dramatic. This is positive change for the long term, but in the short term it's creating some unexpected challenges to the industry as a whole.

Thoughts regarding the future

If we look towards the future, Figure 5 shows still wine totals (local and imported). In 2007, 64 million 9 litre cases of wine were consumed in China. In 2012 it was 182 million 9 litre cases of which 36 million cases were imported. Now the difference between that figure of 36 million cases and the figure of 29.6 million cases outlined earlier is



王敏山:巡視要发現问题形成震慑 温制腐效现象通道势头 2013年0月1日的: 中: 年基·國家特別的問題。 年代各部间 17世 午編 和國 出版 日世 相同 《A·Rath 云 大中国 平相国 王林山区2013年中央18月1日和丹國建築時後上編集 2018年2月20日和美術人工作中共同的工作時月期時下半地山17日出

after an expensive baroust

Figure 4. The impact of the Chinese government anti-corruption campaign



Figure 5. Global wine market by volume. Source: IWSR, Internal estimation in part. Imports include bottle, bulk and sparkling wine. *Probably, No. 2 or No. 3 by value

that the 29.6 million cases imported were 9 litre cases of bottled wine, while the 36 million case figure includes bulk and bottled wine – in other words approximately 6.4 million 9 litre cases worth of bulk wine were imported to China in 2012. China was the world's number five wine market by volume in 2012 and from 2007 to 2011 it experienced 25% CAGR. If you just look at the imported wine market, the CAGR was 55%. If the market for domestic and imported wine grows at 7% it will reach 258 million 9 litre cases by 2017. If you combine Hong Kong with that, it's 263 million cases – on our projections, China goes from the world's number five market to the world's number three market. In terms of imports, China would go from 36 million cases to 73 million cases, or 78 million cases if Hong Kong is included. That would put it at the world's fourth largest wine importer behind Germany, the UK and the US by volume – but by value I estimate it would be number two or at worst number three.

In terms of important thoughts or questions for the future I've identified five. Firstly, what will happen to per capita wine consumption growth? In the late 1990s per capita consumption in China was 0.4 litres. Vinexpo now estimates per capita consumption at 1.4 litres, so the question is 'how quickly will that grow?'. How much will the recent economic slowdown negatively impact the historical growth trends? I think it is safe to assume that it's going to continue to grow at a significant pace. It's always difficult to look at per capita consumption of anything in China because you've got so many people but if you take the 250 million people considered as middle class you're definitely going to see a reasonable growth rate on that 1.4 litre figure, I don't know what it will be but it will grow.

Secondly, will government seek to regulate the wine industry and institute minimum standards? We feel this is important; we're biased because we tend to think of ourselves as professional versus a lot of the others, but there are two important ways in which government must regulate the industry. One is to implement minimum standards for importers and distributors, and the other is to regulate the domestic wine industry. We're not very hopeful that this regulation will occur in the next five years and the danger is that without regulation consumer confidence will erode and inhibit growth. That 1.4 litre per capita consumption figure could be significantly higher if the government steps in and regulates or sets minimum standards for the industry.

Thirdly, will the Ministry of Commerce and the Ministry of Finance agree to change import taxes from value to volume? Wine imported into China is taxed on value; if this were to change to a tax on volume it would dramatically reduce smuggling and, in parallel, go a long way towards professionalising the industry. As an aside, it would also change Hong Kong's role in the world of wine, with as much as a 50% decline in the import value into Hong Kong as the significant volumes currently smuggled from Hong Kong into mainland China are reduced.

Fourthly, will the domestic wine industry be forced to increase quality for its current premium wine price points or will it maintain quality and reduce prices? One of these two things must happen; in fact a reduction in prices is currently happening across the board. The domestic wine industry is really struggling because its premium price points are dependent upon government-related demand; the austerity measures and the anti-corruption drive have affected sales and their profitability is under tremendous pressure. And as I've explained, the government really plays an important role on the imported wine side as well. If prices for domestic wines are reduced my guess would be that the top four or five wineries will become more progressive in acquiring wines and wineries outside of China, which they would then import and sell at higher price points.

Finally, as consumer understanding of wine increases, will consumers move towards brands that are more globally recognisable? A lot of Chinese importer-owned brands would struggle in this environment. We think that Chinese consumers will shift towards globally recognisable brands, and if that does happen the brands that have done all the hard work up to now will really benefit.

SESSION 2: Trends and new opportunities in the global market



Defending wine's role in modern society J. Breach

Expanding export markets for Australian wines D. Hughes, X. Wang

Capturing Gen Y's interest in wine – how to ride the millennial wave for fun and profit L. Hennessy

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Defending wine's role in modern society

J. Breach

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Abstract

The historical foundations of the role of wine in society are well documented and often quoted, however in our present age we are increasingly facing a social and political environment where the legitimacy of wine is under serious challenge. What differentiates this current debate from the recent prohibitionist past is the globally coordinated scale being undertaken by 'teetotalitarian' advocacy groups who seek to restrict where wine is accessed, at what price it is offered, in what volumes it is purchased, what level of public promotion and discourse is permitted, which channels of communication are deemed acceptable, and potentially, even who can consume it. The response by the wine industry to these challenges does need to take into account the natural affinities that exist with allied alcohol industries, but also recognise that there is a unique narrative for wine that differentiates itself from other beverages. This should form the basis of our industry in establishing our own social licence to produce and promote amongst the wine drinking populace. In the context of a global wine industry, the ability to react to legitimate concerns and changes in consumer preferences can be assisted by innovation and technology, but similarly impeded by tradition and convention of what is recognised as wine in international law. Where the free movement in export markets is impeded by regulation, or where the ability to communicate amongst a digitally savy consumer is restricted, this in turn directly impacts the ability of the wine industry to provide a global response to these present challenges and substantiate its bona fide position.

Introduction

Many would find it surprising that there is a growing need to assert that drinking wine is a normal activity. As for any other alcohol, consuming wine is not an entirely risk free activity, but between the consumption patterns of a reasonable consumer of wine and the existing controls currently placed upon access, affordability and promotion, it is still an acceptable activity within a responsible society.

Furthermore, the inherent acceptability is directly implied within the numerous governing institutions of Australia that underpin the legitimacy of our industry. The roles of the Wine Australia Corporation and the Grape and Wine Research and Development Corporation, entities soon to be united as a single statutory authority, make it clear that the responsible consumption of wine is not only a socially desirable activity, but an economically important one. The critical role of international trade in this positioning is demonstrated by Australia's participation in vital bilateral and multilateral agreements (Department of Agriculture, Forestry and Fisheries (2008) and World Wine Trade Group (2001)).

The National Health and Medical Research Council (NHMRC) (2009) is clear that Australians do not have a straightforward relationship with alcohol, and that problems do exist, a point not under any dispute. But it also acknowledges that most Australians drink at levels that constitute a low risk to health and wellbeing, to the individual and wider society. The provision of evidence-based guidelines to educate and facilitate consumers making informed individual decisions is an indicator of a mature society that does not deny that there are certain benefits for wine consumption. The most recent Australian Dietary Guidelines (2013), published by the NHMRC, acknowledges the role of alcohol in a balanced diet, and the probable association between limited responsible intake and reduced risk in cardiovascular disease morbidity and mortality. While this same intake has potential associations with increased risk in other health conditions, this is a riskbased decision for the individual to make, with guidance from health professionals where appropriate.

Changing narrative

It is becoming clear, however, that a different narrative is emerging that seeks to challenge moderate wine intake as part of a balanced lifestyle. This new narrative is deliberately and directly taking its cues from the techniques of the anti-tobacco lobby, using an inappropriate argument of equivalency to blur and reframe 'normality' as a negative and thereby suggest any alcohol consumption is in fact 'abnormal'.

In the consultation paper issued by the Australian National Preventative Health Agency (ANPHA) (2012) *Alcohol Advertising: The Effectiveness of Current Regulatory Codes in Addressing Community Concerns*, a critique is specifically cited that existing regulation allows social media marketing to embed brand awareness and encourage normalisation of drinking as part of everyday life, without violating regulatory codes. Quite aside from the fact social media is covered by existing alcohol advertising controls and complaints processes, the implication from such an assertion is that the NHMRC guidelines giving guidance on appropriate daily consumption are wrong, and that moderate alcohol consumption as part of everyday life is not a normal activity. This is a stark contrast to previous understandings that inappropriate consumption was what was 'abnormal', and consumption patterns in line with evidence-based guidance for low risk drinking could be considered 'normal'.

Public health advocacy groups are taking quite definitive positions on alcohol that are not dissimilar to temperance movements of previous centuries. In their position statement *Alcohol and Cancer*, Winstanley et al. (2011) of the Cancer Council of Australia convey the message that any level of alcohol consumption increases the risk of developing an alcohol related cancer, and that to reduce the risk people should limit their consumption "or better still avoid alcohol altogether". That abstinence is the preferred option runs counter to the frequent assertions of many public health advocates that they are not anti-alcohol and to their fundraising activities that have historically solicited sponsorship from winemakers and other alcohol producers (Tippet 2011).

The NHMRC Guidelines (2009) state that "every drinking occasion contributes to the lifetime risk of harm from alcohol". This is true in the context that lifetime risk is associated with patterns of drinking, the number of standard drinks consumed on each occasion and further influenced by factors such as gender, age and body size. Using this statement out of context as a standalone by-line in consumer public health promotion, the responsible drinker is provided neither the context nor conditions to determine personal risk; rather the message is reduced to an equivalent of the anti-tobacco tagline "Every Cigarette Is Doing You Damage". This is undoubtedly quite a deliberate strategy from sections of the public health advocacy movement who do see alcohol and tobacco as equivalent and have engaged in reapplication of previously successful tactics used on tobacco control. This has extended to public health advocates dismissing publicly any genuine efforts to independently research the scientific basis for health benefits of alcohol in moderation, a confrontational position which is arguably ideologically-driven as opposed to evidence-based (Stark 2013).

Challenges to industry

The wine industry has been actively investigating market category development in the area of lower alcohol wines. This category represents significant opportunities in major export markets such as the United Kingdom. 'Light wine' has experienced 20% growth in the year up to 2012, representing GBP38 million in total retail sales (Wine and Spirits Trade Association 2012). Market commentators have suggested there may be opportunity for this category to represent up to 10% of the UK market. It thus remains a significant opportunity for Australian producers with access to alcohol reduction technology, or adopting viticultural practices such as early harvesting. However, barriers do exist to developing products that not only have a degree of market demand, but clear public health benefits.

The first is that European regulations (2009) specifically preclude the naming of some types of reduced-alcohol products as 'wine', a barrier that does not exist in Australia, the United States and other New World producing nations. Significant dealcoholisation of greater than 2% is not permitted nor is labelling the product as wine below 8.5%; the typical alternative nomenclature is 'reduced-alcohol winebased beverage'. This in itself is not an insurmountable barrier, however additional restrictions such as prevention of the use of varietal terms akin to wine means that products lose the ability to access a range of established consumer recognition and purchasing cues.

The second barrier is the elements of the public health advocacy movement that generally reject the possibility that marketing innovation and public health benefit can co-exist in the same narrative. Some in particular see alcohol-reduced products as a potential public health risk in their own right. Commentary in the Medical Journal of Australia (McKenzie et al. 2011) ventured that "If they are consumed instead of soft drinks or water in the belief that they are healthier than regular wines, or consumed in larger quantities than regular wine in the belief that they are healthier, they could represent a community threat." This proposition is quite notional given it assumes wine is a readily substitutable product to water and soft drinks in terms of access and availability.

Maintaining our social licence

From the frequent calls for increased legislative intervention over labelling, advertising and pricing, it is evident that the public health advocacy movement in Australia has overlooked the formal process adopted by government for industry regulation and guidelines for self-regulatory and co-regulatory arrangements.

Under the Council of Australian Governments (COAG) Principles of Best Practice Regulation (2007), a set of guidelines agreed and endorsed by State, Territory and Federal governments, regulatory processes need to be consistent with the following:

- the establishment of a need for regulatory intervention
- due consideration of a range of regulatory options inclusive of self-regulatory, co-regulatory and non-regulatory approaches, and their cost/benefit
- regulatory impact assessment
- that any legislation not be anticompetitive unless the benefits of the restrictions to the community outweigh the costs and that the objectives of the regulations can only be achieved by restricting competition

- guidance to ensure the policy intent and expected compliance requirements are clear
- ensuring the regulation remains relevant and effective over time
- effective consultation with key stakeholders occurs at all stages
- any government actions should be effective and proportional to the issue bring addressed.

The wine industry has repeatedly demonstrated good selfregulation in a number of areas of public health. The Winemakers' Federation of Australia – Cask Initiative saw manufacturers of bag-inbox format wines introduce a wine glass silhouette on the tap side of the packaging advising drinkers that "Your pour could be more than you think". This is supplemented with clear information as to how many standard drinks may be in the glass of wine, and the NHMRC recommended daily intake of alcohol.

Further self-regulatory initiatives have been manifest in the efforts by the combined alcohol industry to implement DrinkWise health messaging and drinking-in-pregnancy warning logos/messaging, with the Winemakers' Federation of Australia (WFA) formalising an arrangement with DrinkWise to allow the proprietary labelling designs to be utilised by all wine producers without requiring formal membership of DrinkWise Australia (WFA 2012).

Such efforts have regularly come under criticism by the public health advocacy movement on the basis that only their professional intervention can produce labelling suitable for communication to consumers. In contrast to this assertion, previous research cited in the government report Labelling Logic - Review of Food Labelling Law and Policy has indicated that warning labels in isolation are unlikely to be effective in modifying behaviour and require a range of additional educational strategies to be effective (Australia New Zealand Food Regulation Ministerial Council 2011). With a significant number of major alcohol producers financially supporting DrinkWise, this has enabled implementation of responsible drinking campaigns in the media to complement self-regulatory labelling initiatives, focusing not only on the health risks to the individual but also undue parental influence in terms of drinking behaviour in front of children. These efforts have been recognised by independent market and social research organisation, the Research Industry Council of Australia, with the Kids Absorb Your Drinking campaign receiving an award for excellence in research that makes a difference to business and social policy planning performance (DrinkWise 2010). It is clear therefore that an industry self-regulatory funded initiative can, and does, meet the criteria under the COAG guidelines.

The opposition to industry self-regulation and co-regulation initiatives are on a scale transcending the national scale of debate. Dr Margaret Chan, Director-General of the World Health Organisation (WHO) was quoted in the British Medical Journal (BMJ) (2013) as stating "The development of alcohol policies is the sole prerogative of national authorities. In the view of the WHO, the alcohol industry has no role in the formulation of alcohol policies." This position, which runs counter to COAG principles recognising industry as a potential partner, was noted as being at odds with issues of national policy development by Mark Leverton, Director General of the Global Alcohol Producer Group when he responded in the same publication (2013), "It is our experience that many governments do not agree with the WHO's view that the private sector has no role in policy formulation, as private sector companies from a range of sectors are often invited by governments to contribute their views and expertise to the policy development process".

The public health advocacy movement in Australia and overseas is increasingly resorting to the use of linguistic tropes and slogans rather than evidence-based dialogue in order to push their messaging into a space of media repetition. "Cheaper than Bottled Water" is one such assertion frequently repeated when it comes to discussing the relative price of lower tier wine, using a dishonest implication that the two drinks are easily interchangeable to the majority of the population. In addition it conveniently ignores reports from consumer-based organisations with public health concerns that the pricing of bottled water is perhaps two thousand times what Australians should be paying for it (Dalley 2013), which suggests the comparison is fanciful and that the bottled water industry engages in profit driven pricing strategies in a manner not matched by the wine industry.

The public health lobby advocacy movement has also been instrumental in creating a rival advertising watchdog – the Alcohol Advertising Review Board (ARRB). The Alcohol Beverages Advertising Code (ABAC), a quasi-self-regulatory scheme that is accepted by government, is the only legitimate alcohol advertising review scheme in Australia. It is funded by industry but functions with a complaint review panel which is totally independent of industry. Alcohol advertising which is legal and legitimate under the criteria of ABAC is routinely found in breach of somewhat arbitrary and socially conservative criteria under the AARB.

Under ABAC, the criteria for advertising takes into account the legal drinking age (18) in addition to a preventive prohibition on using images of individuals aged from 18 to 25 to minimise the risk of mistaking them as being below legal drinking age. The AARB criteria however is that advertising should not occur to anyone considered a 'young person', that being anyone up to 25 years of age, on the basis that brain development is not complete until 25 and at ongoing risk of injury from alcohol. The validity of physiological criteria to guide an advertising framework when it is counter to the national legal basis for access and consumption of alcohol must be seriously questioned.

On this inequitable basis, legitimate advertising is frequently held to be 'in breach' of AARB advertising conventions because it may appeal to or be readily exposed to someone up to 25 years of age, as a consequence of the use of the following in advertising executions: social media, YouTube, bus stops, the colour pink, popular music, surfboards and beaches or mixed doubles tennis. Producer associations in Australia have recommended to their members that they do not engage with or respond to any complaint from the AARB and instead request referral to the ABAC scheme.

Industry strategies

Companies do need to be proactive in risk management of their businesses and the degree of exposure they have to the opponents of the industry. This means establishing formal internal review processes for product design, packaging, advertising and social media strategy and in-trade promotions.

There are some excellent resources now available to industry to help better manage the risks. Customer interface at cellar door, through product labelling and engagement on social media are critical spaces in terms of maintaining the practices of social responsibility. WFA has launched a Responsible Winery Initiative (2013) to assist producers in this endeavour.

It is only through thorough and comprehensive voluntary adoption of these sorts of initiatives by wine producers of all sizes that the industry will demonstrate a common commitment to the principles of social responsibility, and in so doing maintain the status of wine as a normal and integrated part of a balanced lifestyle.

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Expanding export markets for Australian wines

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Abstract

Wine consumption in ageing, recession-bound Europe and slow growth North America has stalled or is even in decline, whilst competition for Australian wine exporters is relentlessly more intense in concentrated retail and food service markets. Food and drink exporters look to fast-growing emerging markets in Asia for financial solace, although wine consumption is still at an early stage of development and routes to the consumer are under-developed. Developing new markets for wine does not just mean planting a flag in a new country! Emerging consumers, rather than emerging markets, are hyper-connected. Information on all products and services they are considering buying is literally at their fingertips. Smart phones are an extension of their arms and virtual shopping is the norm. Online grocery shopping may be 20% of the total in the UK and South Korea by 2020 and the proportion of wine sales in these markets will exceed this figure. The marketing of wine is no different than any other product area. The challenge is to work out what prospective consumers value and are willing to pay more for. Demystifying the wine purchase will be well rewarded. Great taste and bouquet is a starting point to provide a complement to a great story that meets the aspirations of new wine consumers.

Difficult conditions in developed country wine markets

Wine markets in Western developed economies have served Australia well over the past 20 years or more but demographic trends, and slow economic growth compounded by a severe recession have raised the profile of emerging markets as growth avenues for the future. Over the next 40 years, the world population will increase from 7 to 9 billion with, essentially, 1 billion extra people in Africa and 1 billion more in Asia. Overall, population will decline in many European countries, Russia and in Japan. Whether it be wine, beer or cars for that matter, consumption growth will be substantially higher in emerging markets than in the 'Old Economic World'. The UK is a case in point:

- Red, white and rosé wine consumption is in long-term decline.
- Cafés are replacing pubs as social hubs for the young.
- 16–24 year olds have reduced alcohol consumption by 12% over the past 10 years.
- Retail wine sales are dominated by powerful, margin-hungry supermarkets. Price promotions are pervasive and destructive.
- Across the Atlantic in the US, 'Two-Buck Chuck' (Trader Joe's) and 'The Big Kahuna' (Tesco's lapsed 'Fresh & Easy') set everyday bargain basement prices for wine at \$2–3 per bottle.

So, should we abandon the Old World and focus on emerging Asia? Do so at one's peril! Western economies have a taste for wine and the income to afford it. Rabobank lists North America, Japan, Switzerland, the Scandinavian countries, Germany, Holland and the UK as, still, the most attractive markets for branded wine. Top emerging markets are identified as China, Hong Kong and Korea, with four 'hidden gems' (Mexico, Brazil, Poland and Nigeria) but these will require time and substantial market development resources to emerge as significant volume purchasers.

Understanding the Chinese wine consumer and shopper

What's the best way to maximise the potential of, in prospect, a huge market in China? First, learn from previous faltering steps in developing the Japanese market – listen, learn and understand what Chinese consumers value about wine. For the 15th Australian Wine Industry Technical Conference (AWITC), we undertook a qualitative survey of young male and female Chinese professionals in their mid-to late-20s to find out their interest in buying/drinking wine and what they knew about wine. Principal findings included:

- The majority of respondents rarely drink wine now, but believe they likely will in the future whether for business purposes or for pleasure.
- Wine is viewed as a 'challenging', albeit aspirational drink most wine is not in their taste repertoire so they have little basis to assess whether it is good or bad. They seek help in the choice and even the manner of drinking wine.
- Wine quality was the most influential factor driving choice but, interestingly, quality was a composite attribute that included the safety and integrity of 'ingredients' in the wine. Food and drink safety is of huge concern in China and periodic problems/ scandals reinforce this (e.g. most recently, concerns about milk powder from New Zealand). Brand name is an important element as consumers with little product knowledge seek the security of a known and trusted brand.
- Wine taste is key, too and this requires active research to identify what appeals to the taste buds of young Chinese consumers because it may be very different from that which holds sway in more mature markets. Mondelez/Kraft launched the iconic Oreo cookie in China under the mistaken belief that the Oreo suited world tastes. Not so, the launch was a sales failure. Late-in-the-day research showed that the Chinese love cookies but have specific taste preferences. The re-launch featured a green tea-flavoured Oreo and proved a huge commercial success. What is the unique flavour of wine that would appeal to young Chinese consumers? Best find out!
- Our sample had high expectations of wine from Australia and assumed it would be of good quality and taste. However, French wine was perceived to be 'the best' and few interviewees had any knowledge of Australian wine brands, with Yellowtail being the most likely known.
- Young, well-educated Chinese professionals offer strong prospects for Australian wine exporters but the exporters and the consumers need help! This group wants guidance and help in wine selection and they seek trusted sources of information that can tell the story of wine and how/where it fits in their emerging social and business lives.
- This market segment is wildly and widely digitally educated! They seek information online, exchange information and opinions with friends online, purchase online and complain vociferously online if they are disappointed with the products they purchase. For a

very special occasion, they might visit a specialist outlet to have a face-to-face discussion with a recognised wine expert. Clearly, social media is a particularly important means of communication for this aspirational segment.

- In many developed markets, wine and food are inextricably linked. Will this be the case in China? If yes, then, a prerequisite for success for wine exporters will be understanding the dynamics of the very sophisticated Chinese food culture, traditions and heritage which is a long way from our 'meat and three veggies', and/or white wine with fish and red with beef! What wine goes with lip-numbing Szechuan dishes or subtle, mild Guangdong (Cantonese) fare? You better know!
- The predominant interest is in red wines red colour is associated with joyous and happy occasions such as weddings, birthdays, and romantic festivals such as Valentine's Day.
- Remember, there is no silver bullet geographic market. For entry level, aspirational wine consumers (our sample in China), we have to educate, communicate and promote all in one go! They

are 'fast track' professionals with high income prospects – but there are a lot of calls on their income ("I want to buy an apartment/car, fashionable clothes and accessories to show my friends how successful I am!"). Explaining why they should add wine to their shopping list is really important.

Conclusion

Irrespective of whether the target wine market is in developed or emerging countries, the future of wine marketing is in getter closer to the purchaser using emerging technology and shopper data. Business life is much more complicated, now, than simply getting an order from a bottle shop. The wine consumer journey is an odyssey which embraces apps, shops, social media sites, online sources and using fixed and mobile communication devices. The winning wineexporting company will be the one that can provide a consistent brand experience across all connection points with customers – whether these be bricks and mortar wine stores, virtual cellar doors, online purchasing, or website interactions with the winemakers.
Capturing Gen Y's interest in wine – how to ride the millennial wave for fun and profit

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Abstract

Millennials, also known as Gen Y, have been called the Great White Hope of the wine industry. Poised to be the wealthiest generation the world has ever seen, this group has demonstrated a unique fascination with wine and a culture all their own. So why does the wine industry find it almost impossible to connect with this generation? To achieve this, companies must educate themselves not only on millennial consumption habits, but their communication preferences, relationship with media, and self-image. Led by a 32-year-old millennial, these foundational topics will be discussed, as well as strategies for marketing to millennials across different media platforms.

Introduction

Hi there! I'm really excited to be here speaking, and I'm very excited to be speaking after David Hughes. Today we are going to be talking about how to capture Gen Y's interest in wine, and specifically how you can position yourself to ride the wave for fun and profit.

First I want to thank the AWITC, specifically Dan Johnson, Kate Beames, George Wahby and the entire team for having me here. It's my first time in Australia and I'm very much enjoying myself and I love the opportunity to talk about something I'm so passionate about. Because we may not have a tonne of time, everybody take your phones out! If you've heard the term 'digital native' you know that it means somebody that was born into the technology that we have today, that is myself - I will not be offended if your phones are out. If you have questions for me that we don't get to cover feel free to tweet them out to me @_LeahHennessy. Please use the hashtag #AWITCgenY so that everybody can listen in. If you want you can also follow me on Instagram - I'm @hennessie with an 'ie'. So I have one thing to ask everybody first, could you please just smile and wave for me? OK, keep going ... INSTAGRAM! [takes photo of audience]. So, if you want to see it you can follow me @hennessie, tag yourselves, have a good time. We'll talk a little more about that later.

I'm Leah Hennessy, I have been called an expert on millennials and wine. In 2009 I started a business that focused specifically on marketing wine to US millennial consumers. Obviously you can tell from the accent and from my introduction that I really specialise in the US market. I have been speaking on this topic for the last three years or so. I am a millennial, I am 32 years old and I'm a marketing vice president. I wanted to give you guys a little bit of insight into millennials or Gen Y – the terms are interchangeable, I prefer the term millennial as do most folks in my cohort. In the US we've got between 70 and 77 million millennials; it depends on who you're listening to – Nielsen, Deloitte, Pew Research – but the generation starts anywhere between 1978 and 1982.

Capturing

So today's focus is going to be that key word 'capturing'. It's not about working, it's not about manufacturing, it's about capturing. How do we position these brands to ride this wave? Millennials are going to be buying wine, especially US millennials. We're buying wine already. How do you get out in front of that? How do you become a part of it? And I also want everybody in this room to understand the investment that it's going to take to get there.

Today, I'm really going to be focusing on qualities over quantities. There's one Venn diagram, no graphs – I really want you to feel like you can get your hands dirty after I speak today. I'm trying to focus on universal truths, they're true in the US market which is obviously a huge market for everybody here, but I've tried to focus on things that can be extrapolated into other markets as well. My main goal today is to empower every person in this room as an individual to go through and do one, two, three of these things. I'm going to give you guys all actionable items through marketing and we're going to be taking a holistic approach.

If you walk away with three things, let it be these – education, aspiration and authenticity. In marketing to millennials it is these three things that you will absolutely need and you will have to understand them front to back.

Education: empower yourself to make the best decisions possible

So let's start with education: again, empower yourself to make the best decisions possible. This really comes in on the research and analysis end of things, so we're starting at the very beginning. Step 1: you get your relevant and specific data – and I've been seeing amazing data here today. We're going to focus on Step 2 which is understanding the behaviour behind the data. So don't just look at something and say "Ok, this exists, I'm going to create product X so that I can get in front of this wave". You need to be able to ask yourself "Why?". Don't assume you know the reason why Moscato is selling really well in the US right now. Ask yourself "Why is that?".

I'll give you a quick example. There was a very, very large parent company that wanted to put out a wine that would target millennials. They did their research and one of the questions was "Do you like dry wines?". So the answers they got back were "No" from their millennials, "No, we do not like dry wines". So what they did was they put out two sweet wines, a sweet red and a sweet white. They did all the rest of their research perfectly, they had a gorgeous label, it was very indie looking, and the sweet red tanked. They had to come out two years later with a dry red. Why is that? That's what I want you to ask. Millennials at that time in the US did not know wine-speak. They did not understand when they were asked by this huge company what 'dry' was. They assumed that dry was the drying feeling that they get from a wine that's over tannic, they did not understand that dry means there's no residual sugar. So that's what happened. Rather than this huge company asking "Do you understand what dry means?", "Do you like wines that are sugary?" or "Do you like wines that are sweet and have fruit flavour?". If somebody had asked "Do you know what dry is?" and had a field for them to answer, they would have saved so much money. The red's still around today and the dry wines are doing quite well.

Data does not exist in a vacuum. Just try and remember to always, always, always analyse in context. Analyse in the context of the real world. Your products are not going to be in a vacuum. Decisions by your consumers will not be made in a vacuum. Try and keep everything in context. And here's the deal, with millennials they're new consumers, you might need a new context. Whether it's a market that's buying online, whether it's people that are buying more wine at a younger age - which is the fact with the US millennials - you'll need to understand what that context is. We've got, you know, 22, 23, 24, 25 year olds that have no extra income to speak of, but they're putting wine in between the milk and eggs on their grocery lists. So how do you appeal to those people that are spending lots more money on wine than the baby boomer generation was while still giving them what they need and what they can afford and what they want? So again, know your consumers' "Why?". Why are consumers buying this wine? It's a social thing. We're going to get into branding in a second. But why do consumers want it? Why are people picking one label over another? It's going to be a little scary when you're looking at your competition. But it's going to be worth it. The last piece of advice I can give to you is if you don't have these experts in-house, if you don't have somebody that can automatically contextualise your research for you, go out and find one. But please, choose your experts very, very wisely. It could be an expert who's been around for 30 years and they just get it. Or it could be somebody that's new. Or it could be another set of research where you try and get these people to contextualise for you. Be smart about it though.

Aspiration: wine is luxury – luxury is something to which we aspire

OK, aspiration, this is the second word we're really going to focus on today. So I hate using the word luxury when dealing with wine, especially with wine branding, but at the end of the day wine is a luxury and luxury is something to which we aspire. So, let's talk about branding and within branding we'll talk about positioning. It's wine - treat it like wine! Please don't treat it like beer, don't treat it like a sneaker when you're branding or positioning it. There's always going to be an aspirational element to wine. In the US it's really intense: we developed in the 70s a market where our parents decided that wine was really cool. We needed to be competing with the French so it was all about knowing the wine words, being fancy, wearing ascots, blazers, boat shoes - it's not what we want. We're not our parents. And in the US especially, we have US brands that are marketing to us in that way. Then we have people that are trying to say "Oh well you know what, they're not their parents, let's do something cool for the kids, let's do, yeah, we'll treat it like beer, we'll make this label look really cool and really approachable." I mean I'm sure there are people in this room that work for this company but there's one company that literally in their motto it's "Don't sip this", it's like a chugging wine and that's not what we want from wine. Wine is something very specific. Even though I don't want to have to wear ascots and boat shoes and blazers unless I'm being ironic about it, I still want wine to be special. It's something I aspire to, this is so important, when you're positioning it let it be that. Please.

So, the other part of this, especially with US millennials, is we want to bring wine into our lifestyle, we want the fact that we drink wine to say something about us. Right? We don't want to leave our lifestyle every time we grab a bottle and put on the blazer, put on the ascot, put on the boat shoes, speak with specific words – we don't want to lose who we are. We want it to be a part of who we are.

Here's the biggest thing with branding: wine for millennials is a social accessory. You can think of it like a tattoo if you want to. It's something that expresses who we are. I'll get back to this in a second. But I'm sure if you've been paying attention to Gen Y/millennials at all, you'll know we're experts at personal branding. All you need to do is go onto Facebook and take a look. Take a look! If you are a millennial you get what I'm talking about, if you're not, go to your nearest

millennial on Facebook and their life looks amazing, oh my gosh! They just had the coolest vacation ever, they got a promotion, they bought this really cool thing, they got this amazing gift from their boyfriend for their birthday, they look like superstars. They know that you're looking. We understand what Facebook is; it used to be just friends, now it's everybody. We want you to know that - that's the point. We're branding ourselves every day. So with wine, wine is so social. Obviously, everybody in this room knows this. So when I buy a bottle of wine, and take it to my friend's house for a dinner party and I put it on the table it says something about me. Everything I do says something about me. My tattoos say something about me, my jacket, my shoes, my hair, my lip colour, everything says something about me including this bottle of wine. And if it looks cheap, if it looks old school, all those things say something about me. If it looks unique, if it has a name that can't be pronounced, if it's anything it says something about me. That's something that's so important to remember, especially when we talk about labels, which unfortunately we don't have the time for today.

Everything with a social accessory is an extension of ourselves and a reflection of who we are. If your wine reflects who I am in some way, shape or form I will buy it, I will tell my friends to buy it for ever. Period. So when we're branding or when we're repositioning it's all about: How can you help? How can you help me feel better in front of my friends? Period. So remember that dinner party.

Authenticity: reaching a generation notorious for corporate cynicism

All right, now we're getting into the actual marketing and there's a lot to get through so I'm going to go through pretty quickly but remember if you have a question tweet it out at me.

All right, first off find your voice. We've done our research; we've applied that into the branding and the positioning of it. It's aspirational, it's actually wine! Now find your voice. Who are you? When you're out there whether it's an advertisement, an event, or on social media, behave like a person – the voice has to come from a person, not from a salesman. And this is so important. When you're figuring out this voice you want to identify the relevant overlap in your interests versus your demographic's interests. And that's where you start to build organically. So I've drawn a little something for you...(Figure 1).

Figure out - ok are you really interested in sustainability? Guess what - millennials are too. Are you interested in having fun, being social, this or that? Figure out what you and your target audience both care about and start and build organically from there.

All right, now for strategy and planning, my personal favourite part of everything. Here is where you have the opportunity to step outside of wine. Now you can market it a little more like beer – don't position



Figure 1. Identify the relevant overlap in your interests versus your target audience's interests

it like beer **please** – but you can market it like other products, you can market it like shoes, you can market it in these ways. Try and step outside of wine because that's where you're going to do better than your competitors and I **guarantee** you that's where you will do better than the US markets for the millennial market.

Make sure that you know about integrated and native content - if you don't, please look it up. Find me, ask me about it. This is such a huge opportunity for wine, especially Australian wine. This is where you can actually go talk to a publisher, talk to somebody and say "Ok, I want my wine to be seen in context in somebody's life" whether it's product placement, anything. Think about it. Spend the money. Again, place products in context. Stop it with the vineyards and the sunsets and the wonderful things, that's great - keep your boomers happy with that, don't do that for me. Put it in my life. Put it in context and actually amuse me with it. Here's the deal: this is different. Take the time to plan and budget from zero. Don't just assume that all of those magazine and traditional ads are going to pay off - start from zero. So in that vein, figure out what your strategic return is, it might be a little different! What you might need is street cred, what you might need is more people actually knowing about you. What you might need is people knowing that you actually have amazing wine. And of course you need people to buy it. Think about that before you put your plan together. And again question your current plan and please start from zero and remember marketing is not a place for tradition or for sacred cows. Be a revolutionary.

All right, social media – this is where a lot of people have the most questions. Just like we talked about social accessories with the actual wine, we're talking about this with social. Everything you do, let's talk about Facebook for example. When you're on Facebook it's a place for 'friends', everything I do on Facebook my friends know about. And just like we talked about earlier, it's about me branding myself. So everything that you do on Facebook should be a social accessory. Do you make me look good? Is it cool? Is it an interesting fact? Is it a really cool video? What is it? Is it something I can win? Make me look good. And what are you providing as a reward? This reward doesn't have to be money, it doesn't have to be a giveaway, it doesn't have to be anything. The reward can be just making me look good. So, remember: social is not advertising. No matter what the legal folks have to say about it, it is not advertising, it is 'communicating'. It is back and forth.

New platforms, questions I get a lot. What do you do when a new platform pops up because they are popping up all the time? First off you use it personally. You learn the community and you learn the etiquette. You don't just go barging in there. Once you know that, that's when you launch your brand profile and always, again like the voice, you function as a user not as a commercial.

All right, the last bit for marketing and authenticity: let's talk about events. Events are incredibly important - it kills me when somebody does an event and it's the same event they have been doing for the last 15 years. It doesn't work anymore if you want to reach millennials, we're not our parents, do something different. The second thing that kills me about events: when you have an event and you haven't hired a photographer, you haven't hired a videographer, and you're not leveraging that event out. Because, sure, I might do an event for 50 people but if I take that and I pin it on Facebook I could reach thousands, hundreds of thousands of people more. Make sure that your event is an authentic experience - that is the social currency for the millennial generation. It is why I Instagrammed you. Because this is crazy... my face is up on this giant screen. This is an experience I may never have again and a lot of other people don't have this. This is a huge thing for me. That's what your events should be. It should be unique. Is it something that you care about? It doesn't matter. Is it something that they care about? Absolutely. Have something at harvest time. Organise a giveaway and don't just put the winners up in a hotel. Make them work during vintage. That's incredible. Who gets to do that?

So think about what you can bring to the table when it comes to authentic experiences. It might not be the fanciest, slickest thing in the world. Again, with millennials, it's probably not what you think.

Summary

So again, the three things I want you to take away:

- Education ask why, always, always, always ask why. What's the behaviour driving the data?
- Aspiration the concept of a social accessory. If you need to think tattoo, do it.
- Authenticity step outside wine. Here is when you get creative. It's worth it.

So remember if you have any other questions you can tweet me @_LeahHennessy and I will be answering over the next couple of days, and if you see me grab me and let's chat. Please use this hashtag (#AWITCgenY) and Instagram if you want to see your smiling faces, remember you can find me @hennessie.

Wine online – insights into the opportunities of online channels

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Abstract

When things move so fast in the online world, it's a dangerous presumption to pitch yourself as an 'expert'. But we've learned a lot through our adventures with Qwoff and now Vinomofo, and I'm happy to share my stories, learnings, mistakes and direction. It's easy to think that our journey has been an exploration of social media, video and blog content, consumer reviews, deals, wineclubs and online retail. But really, it's been about listening to consumers – REALLY listening, and identifying what they want, how they want it, and then if that's in line with what excites us, and we can identify with it... do it. It's been about awareness of a changing environment, a changing audience, and adapting to that environment early. That sounds boring when I re-read it, so maybe I'll say that the world and the way we consume and communicate has changed dramatically and continues to change. We've been at the pointy end of the change, and it's exciting as hell, and there's a lot I'd like to share. But the end goal – sitting down with a nice glass of wine – has not changed. Only the path we took to get there. Thank God! So let's talk about that path...

Introduction – my journey

Things move so fast in the online world, I'm wary of anyone who pitches themselves as an 'expert'. I'm no expert, but I'm out there doing it, and I've learned a lot through my adventures with Qwoff and now Vinomofo, and I'm happy to share some of those learnings, and opinions, with you.

So here's a super-quick background, for those of you thinking 'who is this guy and does he know that Vinomofo means Wine Mother &#%!@?' I know, and I'm not proud. That's a long story that I'm happy to share over a beer at the bar later!

In 2007 I started an online wine community site called Qwoff with my brother-in-law, Justin Dry. We saw the potential of both consumer reviews and social media, and we brought those things together. We really embraced Facebook and Twitter to build a good tribe of wine geeks like us, following in the footsteps of Dave Brookes and his amazing work at Teusner, we built the largest wine following on Twitter in the country.

Two years ago Justin and I had the honour of being inaugural winners of the Digital Wine Communicators of the Year Award. For us, we just wanted to get into the wine industry, we saw that we might actually be able to help the industry embrace all the new possibilities that social media presented. We knew we could reach a younger audience, and that's what we did. We did a lot of video stuff, as that technology grew, to get ourselves out there – even bought a kombi and started filming a show called *Road to Vino*. It was a lot of fun, I really miss it actually. With the emergence of mobile technology, we launched a location-based check-in campaign called 'The Great Australian Wine Adventure'. Swing and a miss. Great idea, but it didn't really get the traction it needed. But we tried.

And then finally in 2011, stone broke and sick of it, we launched our online retail site Vinomofo with a Barossa mate of ours, Leigh Morgan. Our members had been telling us for years that it was all good and well for us to crap on about wine, but when were we actually going to start selling it? So we did, and we've spent the last two years growing Vinomofo. Last year we sold a large stake of the company to the Catch of the Day group – Australia's largest online retail company, and two weeks ago with the help of a group of private investors, we bought it back. And we're super-excited!

So that's it, that's been my online journey in the wine industry for the last six years. I don't know if that makes you more or less inclined to listen to what I have to say, I'll let you be the judge of that. But before I launch further into it, in the interest of transparency – because I do want to be open with you – it's hard for me to take my Vinomofo hat off. I live and breathe it, and let's be honest, I want all of you to sell your wines to us, so we can sell them to our members and get filthy rich and then retire and plant a vineyard so we can lose it all again. But I'll try to be objective, because I can't stand it when people sell their own businesses to you when they're in a situation like this and they're meant to be sharing knowledge.

So if you feel I say something that's a sales pitch, or if I lapse into a bit of competitors' Tourette's – '&#%! Dans' which was going to be the title of my speech, but I thought with Woollies owning half the industry, that might get half the room booing at me – if I do any of that, then you have my permission to throw something at me. Not a bottle of wine, maybe a crumpled up piece of paper, unless the bottle is a sample of 94pt Shiraz and you've got 20 pallets you're looking to clear, in which case – chuck it over...

Changing environment

It's easy to think that my journey has been an exploration of social media, video technology, mobile technology and online retail, because that's what we've done. But really, it's always been about being where the people are. I'm going to go into that sentence a bit more, because it's the theme of my talk, it's the only slide I've got, and it helps to keep things simple.

The world and the way we communicate and consume has changed. It's changed a lot, and it's changed for the better. Because consumers have a voice again.

Think back a hundred years when both production and communication were confined to a village. If there were only two bakers, for instance, then Jim the Baker had to be very nice to Aunt Martha, and he had to stock what she was after, or she'd go next door for her lamingtons and she'd tell all her friends that Jim the Baker was a very rude man, and Jim the Baker would find himself with no customers, and Jim the Baker would go out of business.

Then along comes the industrial revolution, and Jim the Baker's son has upped his operations, and he's now selling Jim's lamingtons to all the villages nearby, and pretty soon he's selling them across the whole country. Suddenly it's not so important what Aunt Martha says. She can complain to all the friends she knows, and Jim can still tell her to go away, because he's selling plenty of bread anyway. And that's the way it was until very recently, when along came social media, and suddenly now if Aunt Martha (or her great-greatgranddaughter) complains about Jim the Baker's lamingtons or his service, millions of people are going to know about it. And Jim the Mighty Baker might still find himself with no customers, and Jim the Baker might go out of business. So Jim the Baker starts looking after Aunt Martha again, and he starts listening to her.

The power is back in the hands of the consumer, more than ever, which is really how it should be. We should be listening to them. Not necessarily everyone, but we should listen to those consumers we're producing for or selling to.

I've watched this change unfold, and it excites me.

So let's have a look into this sentence here with my moustachioed little friend...



Be where the people are

Five years ago I would have been standing here preaching to all of you about the enormous potential of social media. And whether you admit it or not, many of you would have rolled your eyes and tuned out, convinced that Facebook and Twitter were little more than a passing fad for teenagers, and Twitter was the domain of self-obsessed C-grade celebrities.

And although you would be partly right, time has proven that that is far from the full picture. Social media is an integral part of most peoples' lives, and it's been very rewarding to see the wine industry drag itself into the world of possibilities that it offers. It took a bit of work with some, but it seems to be headed in the right direction.

But I find I'm encountering the same level of fear, negativity, and scepticism, and no small amount of confusion over online retail. And look, I felt the same way, to be honest. When Justin came to me in 2011 and said he thought we should start a wine deals site, I thought, "That's not for us, that's for 2006 Sauvignon Blanc wines that have been rotting in the sun in a warehouse for the last five years". I only thought that because a lot of the early online retailers – not all, but enough to set the tone – were about just that: cheap, distressed inventory, and that gave the whole channel a reputation.

But that's not right, and it's certainly not what the online retail landscape looks like today. Like Facebook, online retail is neither good nor evil. If you think about it from a consumer's perspective – for them it's simply an alternative to driving down to Dan Murphy's to get their wine. More and more people are buying wine online all the time, just as more and more people started using social media. And it's here to stay, and it'll keep growing.

And if online is where people want to buy wine, or talk about wine, then as a wine producer, it's a simple choice. You're either there where the people are, or you're not. There's no big mystery, you don't need to over-strategise it. If you want to grow your brand and sell your wine, you want to be where the people are. The people YOU want to reach.

Online opportunities

Let's stay with the consumer for a moment, because generally that's the right way to approach things, I've always found. There are basically four things that people do online that as a wine producer, you need to concern yourself with. They're either interacting (basically social media), consuming content (YouTube, blogs, articles, etc.), they're investigating (Google searching, comparing prices, researching products), or they're shopping (Amazon, eBay, Jim's Lamingtons. com, and everything in between). People go online to do these things, and they're comfortable doing those things in that environment. It's fruitless to try to stem that, or subvert it.

Take Facebook. If someone is happy talking to their friends on Facebook and they're open to discoveries in that environment, you can be one of those discoveries. If someone is open to forming new relationships, then you might be able to build a relationship with them. There, on Facebook, where they're happy being. You don't need them to go to your site, necessarily, if you can give them a brand experience right there, and have a conversation with them. I think the key to getting your online presence right is to understand what people are doing there. What do they want to do on Twitter? Talk. Interact. Share information. What do they want to do on Instagram? Share pictures. Pinterest? Get inspired. Share thoughts and ideas.

So you want to be there, you create a Facebook page, and you're lucky enough that a few people 'like' you. Do they want to hear from you? Yep. And they want to talk. They want to have conversations. Do they want to be force-fed a constant stream of news and updates about ONLY your brand? Not particularly. Do they want to be sold to? That's the magic question. The answer is YES, but in the right context, and only once the relationship is established.

Imagine a friend of yours is a car salesman. If he's always pushing a new car on you, he's not going to be your favourite friend. But maybe he likes talking about cars, and engines, and F1 racing, and maybe so do you. And then maybe when the time comes and you DO want to buy a car, you're going to think of him, and there's a relationship there. There's trust. Because he's your car friend. That's how you should treat social media. Be the wine friend. It's a chance to build relationships with new and existing customers, let them get to know the people behind the brand, and give them a more personal brand experience.

Use it for that. Share your passion for wine, don't just talk about your own wines. Interact with your audience; share stuff with them – interesting stories you've read online, photos, anything. Create a place that reflects not just your brand, but what you and your brand stands for – that's the place that potential new customers are going to want to like, or follow.

You can still sell things. We do Facebook-only and Twitter-only sales, and they do really well, because the customers we have who interact with us on those platforms are happy to be there, and we don't ONLY sell to them. And we don't just offer them what they could get on our site anyway, we make it special just for them. Build relationships. Be human. That's my mantra this year. Be human. Share your knowledge, your passion, your discoveries.

That's all I'm going to say about social media, because they're the basics, and it's important to get the basics right. Let's move on to online retail.

Online retail

What do people want to do on Google? Find things. What do they want to do on Amazon? Buy things. When you look for a book on Amazon, are you looking for a book that maybe you've read a review of, maybe it's a *New York Times* Best Seller, maybe a friend told you about it? Of course you are. Imagine if Amazon only stocked books that they commissioned themselves? Maybe it's not even their choice

- perhaps publishers didn't want Amazon selling their books too cheaply - so they published new titles just for the online channel.

So as an avid reader of science fiction and fantasy novels, you're browsing, and can't find *Game of Thrones*. Sorry, how about the *Lord of Dragons* – it's a very similar story...? What? You don't want *Lord of Dragons*, you want *Game of Thrones*. Well, sorry, you're going to have to drive down to Dymocks to get that. But you don't want to drive to Dymocks, you want to order it online. It's rubbish.

So why then, are so many wine producers, big and small, approaching online retail like this? Creating new, online-only brands? I understand why. It's the same approach that was taken with on- and off-premise channels, and supplying the majors. It's an obvious way around pricing discrepancies with the same product. I get that. But if someone is going online to look for a wine, they're also looking for the wines they're familiar with, the wines they've grown up with, or tasted the other day, or read about, or a wine friend told them about. Maybe they heard about it on your Facebook page. They're looking for the same wines that producers have put all this effort into building a market for.

But what about the price? There's too much discounting going on in online retail. The fact is that online retail involves a different cost structure to most traditional bricks-and-mortar retail. It rarely involves distributors, so there's a chunk of margin the customer can and SHOULD save. You're not paying high retail space rent as an online wine store, so again, there's a saving that either goes to the customer, the retailer, or the producer. Personally, as long as the producer and retailer are making enough money to thrive, I think it should go to the consumer. And consumers know this, and they EXPECT to get something at a sharper price online than they would in a store – whether it's a bicycle, ski gear, a pair of Converses, or a bottle of St Henri.

And not only do they EXPECT it – with one Google search, they can compare pricing on that pair of Converses and shop from the cheapest website. Service is important, it'll come into consideration, but people are rarely willing to pay more for it, sadly. If they can get a case of Vat 1 Semillon \$10 cheaper by clicking here instead of there, chances are they're going to do it. Trust is important, thankfully more important than ever online, but as a producer, you've got very little to do with where someone shops, except to be selective about who gets to sell your product. And the most selective you can be is to just sell it yourself, on your own website.

I strongly advise every producer, big or small, to put every effort into their own direct-to-consumer channels, be it your own wine club or mailing list, or online store on your website. But that's not necessarily going to get you where the people are. That's like having a cellar door, but you probably want your wines in a few restaurants and a couple of wine stores too. Because that's where the people go to taste and buy wines. Similarly, if I've got 200,000 customers at Vinomofo, or Dan's have half a million people visiting their website each month, then that's where the people are – Dan's don't have half a million. And if they did, they'd just be comparing prices. But I'm not bitter!

Before I go into how to choose the right online channels, let's just look at the channel as a whole.

Choosing the right online channel

Hopefully I was loud and clear on my objections to producers relying on creating 'online only' products or brands. I UNDERSTAND the incentive to do that, but quite frankly it's rude and inconsiderate to the consumer – they want to buy the same wine online as they want to buy in a store. "Too bad for them", you might say. But what happens when online retail grows to 30% of national sales. What about when it grows to 50%, or 70%? Suddenly these brands and products you've made up just for online have a bigger market than the brands you've put your heart and soul into, and so for the bigger part of your audience, your brand has lost its soul.

So let's say you agree with me, and you have the courage to put your babies, your heart and soul brands, online. Where does that leave you, as a producer? Well, it leaves you in no different a situation as you've already got when deciding whether or not to give a brand to the majors, who as is turns out LIKE having bespoke products for themselves, so customers can't compare prices. Which is also rude and inconsiderate for the consumer, by the way, and it's not a longterm, sustainable play. It might be for the retailers, with their own wines, but it's just shrinking the market for the REAL wines that you as producers have created, again, with heart and soul.

It drives me mad. But I digress. What to do as a producer? You're trying to decide the right channels to sell your product. How do you choose? Well, forget online vs bricks-and-mortar. That's not where the distinction should lie. As a producer, when looking at online retailers, you shouldn't be looking for any different factors than you would with a bricks-and-mortar retailer. Do they have the right audience? Are they going to represent my product well? Will I get paid on time? All of the same things you bring into consideration in deciding whether to get your wine in Dan Murphy's or the Prince Wine Store.

The pricing issue

It IS a changing environment, but the good thing is there's more choice in the online channel than ever – for consumers and also for producers. But the issue of pricing discrepancies, and recommended retail pricing (RRP), it's a real issue. The idea of a consistent recommended retail price for wine across different channels – it's not realistic, and it's not particularly fair on the consumer, and it's going to be a tricky one for the industry to navigate.

I hate the idea of RRP. I hate the concept of a discount. And I'm well aware of the hypocrisy of me saying that. We use RRP, or normal retail pricing references, we even reference competitor pricing, because it helps give consumers a measure of the value they're getting on that product. 'Hey, it's 50% off recommended retail. That's good value. And \$5 cheaper than anywhere else. Better grab it.' I'll be honest, without stating discounts, we'd sell far fewer wines on Vinomofo. And I hate that. But ultimately, we're there to sell wines for producers, and as long as you're being honest and transparent and not making up inflated discounts, then it's an important selling point for consumers. It reassures them they're making a wise choice.

This next bit is dangerously close to self-promotion, or at least selfserving, but I'll share it anyway, because I genuinely believe it. I think that sustained discounted pricing can re-set the price expectation on a product. A genuine sale that's up and gone, that doesn't. It just helps get your wines in peoples' hands fast. But that's your call to make, with your brands. Ultimately we're all here for the people who drink our wines.

And if the customers you want are shopping at the little wine store around the corner, then that's where you want your wines to be. And if the customers you want are eating at their favourite Italian joint, then that's where you want your wines to be. And if the customers you want are buying wine online, be it at Vinomofo, or Cracka Wines, or Get Wines Direct, or East End Cellars, or Dan Murphy's... then that's where you want your wines to be.

What are consumers drinking on-premise?

J. Kosmina

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Abstract

Enjoyment of wine in the on-premise environment is intrinsic to most diners as part of the overall experience. On-premise is also the place where a great number of consumers first make a connection with a particular wine brand, style, variety and wine price points. Yet how much do we actually know about the on-premise environment from a wine perspective? Furthermore, are on-premise venues harnessing all the insights that are available to fully maximise and optimise the return and profitability from their wine list? Visibility of wine in venue is crucial to capturing the hearts and minds of consumers to get the most from wine operations. But how much space is actually devoted to wine in most venues? The majority of wine in venue is consumed by the glass, is this the starting point or an afterthought when constructing a wine list? Which varieties and how many of each and at what price points should be placed on a wine list for success? Far too many venues have the approach of buying on price and applying the maximum return they can squeeze out of their consumers. A more holistic approach to constructing a wine list, putting consumer behaviour and insights at the heart of selection, will result in better returns for on-premise venues and wine producers.

Introduction

Hello and thank you. Firstly thanks to everyone that's here today and especially the AWITC team for organising this great event.

I'm currently on-premise account manager for Treasury Wine Estates (TWE) here in NSW and have been a key part in rolling out this on-premise strategy. So what I'm here to talk to you about today is what Treasury can do to help you make more money from wine in the on-premise channel. Keep it in mind that I'm the last person presenting to you today and the only one standing between you and a drink. From this presentation over the next 20 minutes if you can walk away from here with two or three key points, one that's handy for your business or general information that you find interesting, then happy days and I'll join you at the bar for that drink later.

So, making money from wine on-premise. The first question I have for you is: why is wine so important to the on-premise occasion? If you have a look at what makes up a consumer's experience when they are in your venue you would have great food, stylish decor, cold beers, branded spirits, good coffee, friendly staff, value for money offerings, and nice wines. All of this equals a great experience. As a general rule, consumers don't remember all these aspects of their experience, however it only takes one bad experience to disappoint a consumer and generally a disappointed consumer is unlikely to return to your venue and also will tell their family about the experience they have just had. Many venues are currently spending a lot of money on renovating, training and improving staff capabilities, and a key branded product selection throughout their bars. For example, a venue will use Coca-Cola, a leading brand, Red Bull, a leading brand, branded beers and branded spirits throughout their first pour and back bar selections. However what we have then found is they serve a 60 to 80 cent by the glass LUC unknown house wine as their priority wine. So what does this mean? Venues are effectively giving away the cheapest house offering that doesn't match their quality of food and their style of venue. This is like sacking your barista and serving Nescafé Blend 43 as your first priority coffee! This does not enhance the consumption occasion!

As consumers drink more they expect more, the opportunity to trade consumers up a dollar per glass is a better focus than driving as much house wine as you can.

Four key reasons that you need to get your wine offering right:

- Wine consumption in Australia has been growing steadily for more than 10 years
- Australia is an ageing population and people drink more wine as they get older

- As people get older they have more disposable income
- Older people are looking for experiences more than material possessions.

Why will these insights be any different to what I have heard before? It's simple – they are based on the largest comprehensive wine list study ever undertaken in this country:

- TWE has spent two years collating more than 10,000+ wine lists
- Across all channels and postcodes
- · From premium dining and drinking to mainstream pubs and cafés
- Across all price points and varietals
- Across all brands not just TWE brands.

As a result of this survey we have come across some key challenges that venues will be consistently facing in all channels; these challenges are as follows:

- Currently we have 20,000+ licensed venues in NSW
- Wine is complementary to the experience
- · Creating differentiation between categories
- Inconsistent wine experiences for consumers are leading to poor confidence in purchasing wine
- Visibility issues.

However all challenges lead to great opportunity for growth. There will be an estimated \$450 million growth in the Australian wine market over the next three years. 80% of that growth will be driven by Australian and New Zealand brands.

Visibility is crucial in on-premise but currently wine is almost invisible in the channel, which is further restricting our consumers' choice. Let's put ourselves in our consumers' shoes for a second and have a think: you walk into a your local corner pub, you see a great back bar display, the beer taps are looking icy cool and very appealing, and food is dominating all visuals. You sit down and have a look at the food menu on the table and decide to have a rump steak. Then further thinking a nice Shiraz would go well with that, but where is the wine list? Looking around, hard to find a list or see a wine rack, you walk to the bar to order your steak and when it comes time and the staff member asks you "Would you like something to drink?". You look at what's in your direct sight and go with a schooner of beer! This schooner will return to your venue half the dollar margin that a \$9.50 glass of Pepperjack Shiraz would have got you.

From a venue's point of view wine arguably would be the second most profitable, or possibly the highest profit-returning category of beverage, yet so many times it is left unloved in venues. Our challenge: other than menu boards and wine lists, how does a venue make wine more visible in a venue? After collating and working through all the research found from all surveys and wine list collection, Treasury has put together an eight step program of how to simply develop an effective and profitable wine list.

1. Wine purchases on-premise are dominated by 'by the glass' sales. 80% of wine in mainstream is purchased by the glass, 60% in premium venues. While there is less wine sold on-premise versus retail, there are just as many consumption and purchase occasions. Both of these are an opportunity to make an impact on a customer - be it negatively or positively. All house wine currently sells for about \$1.50 less than other higher quality product on the list and there is currently no consistency or minimum standards on how a wine list is laid out which is confusing our consumers. A key note from all of this: focusing on existing behaviour by making the 'by the glass' offer simpler, clearer and more engaging will increase wine sales.

Figure 1 is a very busy figure so I'll break it down for you. On the Y axis there is the number of wine lists that were surveyed throughout the 24 month period. The X axis is the varietals and blends that were most commonly surveyed and the colour-coded legend is the price points that these varietals and blends were surveyed in. So, breaking this down even further: of the wine lists we collated, 10,872 had Chardonnay and a total of five wine types delivered a total of 85% of listed products. These are: Shiraz, Cabernet, Sauvignon Blanc, Chardonnay and sparkling.

And what does this mean? When it comes to structuring a wine list and where the opportunities may lie to drive a higher price point, it would make sense to use one of these five varietals. A key note: give your consumers premium options and they will spend more in your venues!

2. Sauvignon Blanc. Love or hate New Zealand Sauvignon Blancs they sell and they have become a brand in themselves in the market. This leads to a great area with the ability to upsell! As consumers feel comfortable with Marlborough as a region, they have confidence in the product without tasting. This all helps in driving them to the next level. There is an average 35% uplift in value sales when New Zealand Sauvignon Blanc is listed by the glass, which averages 2.85 sales by the glass (BTG) compared to by the bottle (BTB), which is well above the next closest varietals. Ensure the wine list has a number of BTG options around Sauvignon Blanc and across different price points. A key note: give your consumers a greater choice to spend more money in your venues!

3. Sparkling wine. Sparkling wine on average has a 10% share of all BTG listings but represents approximately 20% of all wine consumed in the on-premise channel. This currently averages out to about one BTG being listed in mainstream venues and two BTG listed in premium. This all leads to the question: why not build a sparkling offer that provides a more premium listing with multiple options BTG across a number of different regions? Again, give your consumers premium options and they will spend more money in your venues!



4. Income loss - don't let it be you! Venues that use subjective methods to set their pricing BTG risk around a minimum of 10% loss of income. This loss could be 70 cents a glass or \$3.50 by the bottle - gone! As venues don't want to be seen as too expensive and it is difficult to get good data to make informed decisions, TWE has developed a benchmarking tool that allows a venue to test their wine list versus best practice to then get a greater understanding of effective pricing in the marketplace for their wines. We have techniques for getting immediate growth on a wine list: small glass and big glass options for all BTG listings. By using the TWE wine list database, venues can benchmark their current list by varietal to gauge what pricing opportunities they have. Give consumers the opportunity to trade up to a larger glass offering. The small glass/big glass technique has been quite successful in the UK for a number of years now. It ticks a lot of boxes when it comes to the on-premise channel. As a lot of venues don't currently use Plimsoll Lines and are having 150 mL as their standard pour, it alleviates wastage when you bring the Plimsoll Line as the small glass option. And then it's about blending your margins. It's about getting that consumer that comes into your venue and buys the one glass of 150 mL at \$7.50 to trade up to the one glass of 250 mL at \$10.50, and getting them to spend an extra \$3 at your venue. A key challenge from this: how can a venue use real data and knowledge to develop a wine list and be confident about varietals and prices?

5. Review wine lists thoroughly when making changes. 63% of venues change their wine list every six months with minimal changes occurring between November and January. When a venue is going through a wine list change ensure that wine list changes go through a review of actions one to four before signing off. This will provide your venue with the most comprehensive review and ensure maximum profits are realised. Remember:

- the majority of wine is sold by BTG
- Sauvignon Blanc has the greatest uplift when poured by the glass compared to any other varietal
- sparkling wine represents only 10% of your wine list yet delivers 20% of total wine consumed in the channel
- venues that use personal opinion to set their pricing in wines BTG risk lost income as a result.

How do I develop a good wine list? The evidence is clear, breaking this down into three clear points:

- a) Quality cues: regional appellation drives a higher dollar return for premium wines. Consumers like to feel comfortable and not embarrassed when purchasing wine. The following regions play a key part when making these purchases easier, more approachable and will also command a higher dollar return for your venues:
 - Marlborough, New Zealand
 - Margaret River, WA
 - Barossa, SA
 - McLaren Vale, SA.
- b) Trust in brands: the top 10 brands out of 2,500+ in the market deliver one-third of total value sales in Australia. This all says that consumers use well-known brands as reassurance when purchasing wine.
- c) Key source of familiarity: people will buy what they've heard of. Many shoppers can't describe the taste of Sauvignon Blanc or Chardonnay, but they've heard of it and so have their friends and family.

So, bringing all this together: a regional appellation is a short cut to quality; leading brands build trust and reassurance; and familiarity is important – 70% of value sales come from four varietals plus domestic sparkling. A balance of these three factors will equal an effective and profitable wine list!

6. How can you be different? Driving differentiation from commercial retail brands has resulted in a fragmented on-premise offering. To avoid retail price comparisons, the on-premise channel has effectively fragmented the product selection so significantly that often we are confusing our consumers with products they have never heard of. We are asking the consumer to take a risk on too many occasions. From our research we've found:

- branded on-premise exclusive products achieve the best result in the channel
- these products mixed with regional appellation ultimately command a greater price and represent better value and quality
- house wine sells for at least \$1.50 less than any other higher quality product on the lists.

TWE's challenge is to then further provide recognised products that don't suffer from retail price comparisons. Overall, an effective wine list will have recognised brands that are supported by exclusive and focused brands. This then differentiates the consumption occasion from commercial retail products.

Don't lead with house wine. Ensure it is embedded in your list and let your consumers trade up – give them the choice.

The question I have for you is: are you sacrificing a minimum of 70 cents by the glass?

7. The ideal layout. Formatting a wine list should be done in such a way that it is easily read and drives the perception of quality that matches the style of the venue. Keep wine list layouts and standards consistent so as not to confuse your consumers. On average 60% of people over 50 years old drink wine and are probably wearing glasses – so put it in a font that is easy to read and understand. An approach that has three consistent first pour offerings clearly demonstrates a cheap house wine, so don't let house wine drive the layout, as this will trade your consumers down. Our challenge: provide a value for money wine list that enhances the consumption occasions and increases cash gross profits.

8. Knowledge is power. Staff interaction with consumers will either upsell or downsell according to their skills and capabilities. Wine is a relatively complex category and often staff are completely overwhelmed when talking about wine selections with their consumers. A challenge to this: how do we upskill staff quickly to sell better wines with better cash margins without adding more complexity and cost when it comes to training? As I mentioned before, all challenges lead to great opportunities. These opportunities are:

- recommend a wine based on a higher price point to drive trade up
- · let consumers make the choice to trade up: small glass/big glass

- emphasis should be placed on regionality and winemaking credentials – build the quality cues
- a confident consumer spends more money!
- confident staff sell more wine at a greater price.

So how can TWE help you in making more money in the on-premise channel? To summarise what I have just gone through:

- TWE has developed a benchmarking tool that allows venues to test their wine list versus best practice, to get a greater understanding of effective pricing in the marketplace for their wines
- We have developed a guide for how wines should be laid out on the list
- We can provide a guide for what price wines should be by the glass to ensure we drive consumers to higher quality products that they will enjoy more and venues will maximise their profits
- We are currently researching ways to make wine more visible in your venues
- We offer to help coach your staff to help your staff influence the consumers' wine choice
- We have techniques for getting immediate growth on the wine list, e.g. small glass/big glass options for all BTG listings.

The outcome we want and expect is to become the on-premise experts and consultants for our customers, as we know that our products merely complement your consumption occasion and we don't believe any wine company is taking this approach. To date we have seen an average 10% lift in profits when we implement this strategy. It is also building confidence in staff that we now have science to back up our decisions. Many venues spend a lot of money on renovations, staff and product selection. However we have found that they still want to serve Nescafé Blend 43 as their leading wine. This does not enhance the consumption occasion!

Let consumers have what they want. Don't confuse them. Don't pretend that house wine is of great quality. Don't be concerned about letting them make better choices. Don't restrict what they want. Don't make it hard for your staff to sell wine. A confident consumer drinks more and spends more and then tells their friends about the great occasion they've had at your venue. They drive the foot traffic and we want to focus on helping you drive consumption occasions as a priority.

So to finish up, a couple of final questions: do you know how competitive your wine list is? And do you know what successful wine lists are doing to differentiate?

TWE does! And we want to help you improve your wine consumption offer and profits!

SESSION 3: Rein in the sugar and spur on the flavour



"Tell me about your childhood" – the role of the vineyard in determining wine flavour chemistry

G.L. Sacks, T.E. Acree, M.T. Kwasniewski, J.E. Vanden Heuvel, W.F. Wilcox

Physiological indicators to predict harvest date and wine style

A. Deloire

Understanding and managing the timing of berry ripening and the flavour-ripe/ sugar-ripe nexus

C. Davies, C. Böttcher, P.K. Boss

Targeting wine style: alcohol adjustment in white wine A. Blank, O. Schmidt, D. Blankenhorn, R. Amann, J. Sigler



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"Tell me about your childhood" - the role of the vineyard in determining wine flavour chemistry

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Abstract

Assuming that wines produced from the same grape variety but produced under different growing conditions have consistent sensory differences, the growing conditions must have affected grape chemistry in some consistent manner. In many varieties, these differences in chemistry are not readily detectable by sensory evaluation because compounds important to wine aroma are derived from non-volatile grape precursors. Understanding the link between environment, flavour precursors, wine chemistry and eventual wine flavour is of importance to winemakers interested in either mitigating or enhancing differences among grapes. Riesling wines make for a particularly interesting case study because i) Riesling often has several compound classes at or near sensory threshold, and thus sensory perception should be susceptible to differences in growing conditions, and ii) many grape-derived odorants potentially important to Riesling including monoterpenes, volatile polyfunctional thiols, and C_{13} -norisoprenoids, are derived from non-volatile precursors. For some cultural practices and aroma compounds, such as leaf removal around veraison and the concentration of 1,1,6-trimethyldihydonaphthalene (TDN, 'petrol' aroma) in wine, there is a solid body of evidence to correlate vineyard practices to grape and wine chemistry. For other compound classes like monoterpene glycosides or S-conjugate precursors of thiols, the correlation of growing conditions and wine chemistry is more ambiguous, either because the effects of cultural practices seem to be relatively small, or else precursor concentrations are poorly correlated with wine concentrations. Studies are further complicated by the fact that changes in cultural practices do not generally affect single flavour compounds. Finally, grapes can also contribute less desirable flavour precursors, for example pesticide residues, particularly elemental sulfur (S^0), which is well known to increase hydrogen sulfide (H_2S , 'rotten egg') production during winemaking. Specific recommendations regarding late season sprays have been lacking, in part due to absence of simple analytical methods. Our laboratory has recently developed an inexpensive and convenient method for measurement of S-residues appropriate for a minimally equipped lab, based on conversion of S to H_2S and subsequent quantification of H_2S . In our field trials, we observe that safe windows for harvest can be up to eight weeks after final spraying, but will vary considerably depending on weather, spray formulation, application rate, and vinification practices.

Introduction

Depending on the reference cited and the criteria used for 'identification', approximately 700 volatile compounds have been characterised in wine (Fischer 2007), of which a subset of about 50 explain the major features of most wine aromas (Ferreira and Cacho 2009). It is doubtful that any of these volatile compounds is truly unique to a particular varietal wine (or, for that matter, to wine as opposed to other foods). Rather, concentrations of volatiles in wines differ from each other quantitatively instead of qualitatively, since at least a few molecules are likely to be detectable following sufficient analytical struggles.

As an example of this phenomenon, important odorants representing the major compound classes found in three varietal aromatic white wines are listed in Table 1, along with sensory characteristics and typical ranges of odour activity values (OAV), compiled from several sources (Benkwitz et al. 2012; Chatonnet et al. 1993; Lacey et al. 1991; Ribereau-Gayon et al. 2006; Sacks et al. 2012; Tominaga et al. 2000). Representative structures of three of the compounds are shown in Figure 1. An OAV is calculated as the ratio of compound's concentration to its odour detection threshold. OAVs are a crude measurement of the contribution of a compound to the aroma of a wine (or any other foodstuff), since they ignore masking and additive effects

Representative	Compound sloss	Aroma Sensory threshold in model wine Riesling Musc	Sensory	Odour activity value (OAV) range in young wines			- Precursor in grape?
Odorant(s)	Compound class		Muscat	Sauv. Blanc			
TDN (1,1,6-trimethyl-dihydronaphthalene)	C ₁₃ -norisoprenoids	Petrol, kerosene	2 µg/L	0.5-10	low	low	Glycosides
Linalool Geraniol	Monoterpenes	floral	50 µg/L 130 µg/L	0.1-5	20-40	<1	Glycosides or monoterpene polyols
3-mercaptohexanol	Polyfunctional thiols	Citrus, passion-fruit	60 ng/L	2-15	2-15	15-300	S-conjugates
IBMP (3-isobutyl-2-methoxypyrazine)	Methoxypyrazines	Bell pepper	2 ng/L	low	low	1-28	None (primary)
4-vinylguaiacol 4-vinylphenol	Volatile phenols	Medicinal, smoky	180 µg/L 130 µg/L	<0.5-10		Hydroxycinnamic acids o glycosides*	
<i>cis</i> -3-hexenol	C ₆ alcohols	Grassy	400 µg/L	0.5-1	n/a	0.5-2	Unsaturated fatty acids
Other grape-produced odorants that co Sugar degradation products, e.g. Fura	ould contribute to aromas of t neol and homofuraneol ('coc	these wines include ked sugar' odour), p	articularly in botryt	tised wines			

Table 1. Grape-derived aroma compounds in three aromatic white varieties. References are listed in text

o-aminoacetophenone ('UTA' note) from indole acetic acid precursors

1.8-cineole ('eucalyptus taint')

Fungal metabolites or degradation products of pesticide residues Dimethylsulfide ('canned corn') from S-methylmethionine

* Concentrations in smoke-tainted grapes could be much higher

(Grosch 2001). Allowing for this caveat, three observations can be made from Table 1.

First, while a compound or compound class may be higher on average in one varietal wine vs another (TDN in Riesling, 3-MH in Sauvignon Blanc, linalool in Muscat), there are no unique compounds.

Second, Riesling has a number of grape-derived aroma compounds at or just above their sensory thresholds (OAV between 0.5–10), at least in comparison to other aromatic white wines. For example, Muscat wines typically have one compound class (monoterpenes) well in excess of odour threshold. The flavour of Riesling is thought to be more dependent on site or region than many other varietals (Robinson 2006), and speculatively (that is, **very** speculatively), this balance of peri-threshold odorants may explain this phenomenon.

Third, the majority of important grape-derived odour compounds in Riesling are absent from the fruit, but are instead released from non-odorous precursors during fermentation and storage. Of particular importance are:

- Glycosides, in which the precursor includes a sugar molecule
- S-conjugates, in which the precursor contains the amino acid cysteine, the tripeptide glutathione, or related cysteine containing dipeptides.

These two compound classes are also well known to plant toxicologists as common products of Phase II metabolism of herbicides (Figure 2). Although harmless at concentrations found in wine, odorant compounds can cause acute toxicity at sufficiently high concentrations, e.g. the LD₅₀ (lethal dose, 50%) for β-damascenone in mice is 300 mg/kg, comparable to caffeine. Post-emergence herbicides have low polarity (mean log P = 2.7) and molecular weight (85–610 g/mol) (Tice 2002) ranges that overlap with the properties of the many odorants. The fruity smelling odorant β-damascenone is reported to inhibit growth of grape cell cultures at concentrations > 1 mg/L (Shure 1994). Smoke-exposed vines are also reported to have decreased yield and to develop lesions (Kennison et al. 2009), which may be due to the cytotoxic nature of guaiacol and other smoke volatiles. Formation of glutathionylated and glycosylated adducts are



3-mercaptohexanol

Figure 1. Structures of three of the compounds discussed: linalool and TDN, which derive primarily from glycoside precursors, and 3-mercaptohexanol, which derives primarily from S-conjugates



Figure 2. Glycosides and S-conjugates, the two major classes of flavour precursors in Riesling and many other wine grapes, are well known products in both human and plant toxicology. Although this figure may look like it came from a wine flavour textbook, it was in fact adapted from an edited book on plant toxicology (Hatzios 1997). Similar detoxification pathways exist in humans, particularly in the liver. Winemakers have the good fortune that grapes have vacuoles instead of kidneys, which means that they can accumulate potential flavour compounds.

common strategies for decreasing the toxicity and improving the transport properties of toxic compounds in both plants and animals, with the major difference being that the former will usually store the metabolites within the plant vacuoles rather than excreting them (see Figure 2).

The remainder of this section will consider how vineyard practices can affect some of these flavour precursors common to wines. Much of the data will consider results generated by our groups on Riesling, since it has suprathreshold concentrations of several of these precursor classes.

Glycosides, Part 1: TDN and C₁₃ norisoprenoids

Over a dozen C_{13} -norisoprenoids have been identified in wines, including the vitispiranes, the actindiols, β -ionone, (*E*)-1-(2,3,6trimethylphenyl)-buta-1,3-diene (TPB), Riesling acetal, and others (Baumes 2009). Many of these species, such as the vitispiranes, appear to be at concentrations well below their sensory thresholds. β -damascenone ('cooked apple' aroma) is often present at concentrations above its odour threshold of 50 pg/mL in model wine, but its role in wine seems to be to enhance 'fruity' aromas rather than behave as an 'impact' or characteristic odorant (Escudero et al. 2007; Pineau et al. 2007). Cultivar selection and viticultural factors often appear to have negligible or contradictory effects on β -damascenone in wine. For a detailed review on the chemistry of β -damascenone, readers can consult a recent publication by Sefton et al. (2011).

The other well characterised C_{13} -norisoprenoid is 1,1,6-trimethyldihydronaphthalene (TDN), which has an aroma of 'petrol' or 'kerosene'. Unlike β -damascenone, TDN does act as an impact odorant in some wines. Cultivar selection and viticultural practices have known effects on TDN, which will be discussed in more detail below.

TDN and many other C₁₃ norisoprenoids are at (near)-undetectable concentrations in unheated juice, and instead exist predominantly as non-odorous glycosides (Mendes-Pinto 2009). Several glycosylated precursors have been identified for both TDN and β-damascenone; these can be enzymatically and/or acid hydrolysed to produce intermediary (generally non-odorous) C₁₃ norisoprenoids during fermentation, which can subsequently rearrange under acidic conditions to form odorous compounds (Lloyd et al. 2011; Sefton et al. 2011; Winterhalter 1991; Winterhalter et al. 1990). The amount of C13-norisoprenoids released during fermentation will depend on winemaking conditions (Lloyd et al. 2011). In our own work, we observed that only 10% of TDN precursors were converted to free TDN during fermentation (Kwasniewski et al. 2010). Acid hydrolysis of TDN glycoside precursors can continue during storage, and TDN concentrations are reported to increase with wine age (Simpson 1979). It is possible to estimate the potential TDN pool by heating a must sample in the presence of acid to force hydrolysis (Kwasniewski et al. 2010; Marais et al. 1992a), but this approach may be less appropriate for predicting β-damascenone concentrations following storage because several precursors that degrade under forcing conditions appear to be stable under normal wine conditions (Sefton et al. 2011).

The precursors of C_{13} -norisoprenoids and their glycosides are larger 40-carbon molecules called carotenoids (Baumes et al. 2002; Mathieu et al. 2005; Mendes-Pinto 2009). Carotenoids are widely distributed naturally occurring pigments, and include β -carotene, lycopene, and astaxanthin, responsible for the colour of orange carrots, red tomatoes, and pink flamingoes. Carotenoids (primarily lutein and β -carotene) are present in mature grape berries at total concentrations around 0.5–3 mg/kg (Oliveira et al. 2006; Razungles et al. 1998), with 2 to 3-fold higher concentrations pre-veraison. Carotenoids are found in photosynthetically active tissue, including immature grape berries, and will begin to degrade approximately one week pre-veraison. This degradation is believed to be primarily enzymatic,

as several carotenoid cleavage dioxygenases (CCD) have been identified in grapes (Young et al. 2012), and at least one (VvCCD1) can produce C₁₃-norisoprenoids from carotenoids (Mathieu et al. 2005). Additional contribution of non-enzymatic degradation cannot be completely ruled out. C13-norisoprenoid precursors begin to accumulate 1-2 weeks after veraison (Mathieu et al. 2005). The pathway for formation of C₁₃-norisoprenoids from carotenoids is summarised in Figure 3.

TDN is well known to contribute to the characteristics aroma of bottle-aged Riesling, where it can reach concentrations over 50 ng/mL (Simpson 1978). Our group has recently re-evaluated the odour threshold of TDN in a white wine and determined it to be 2 ng/mL - a factor of 10 below the previous reported threshold (Sacks et al. 2012). We also determined that TDN was in excess of this threshold in 31 of 32 young Riesling wines, while it was below threshold in most non-Riesling red and white wines (Figure 4). The median TDN concentration was nearly 5-fold higher in Riesling as compared to other wines (5.7 vs 1.2 ng/mL). Thus, TDN may contribute to varietal character of young Riesling wines, along with other compound classes shown in Table 1. The recognition threshold of TDN (the point where wine takes on a 'petrol' aroma) is still not determined.

Beyond cultivar selection, several viticultural factors have been related to higher concentrations of TDN precursors (potential TDN) in grapes or higher TDN in finished wines:

- · Greater exposure of clusters to sunlight, e.g. through leaf removal or artificial shading (Gerdes et al. 2001; Kwasniewski et al. 2010; Lee et al. 2007; Marais et al. 1992b; Meyers et al. 2012; Ristic et al. 2007; Robinson et al. 2011)
- Warmer climate (Marais et al. 1992c)
- Less nitrogen fertilisation (Linsenmeier and Lohnertz 2007)
- Less irrigation and lower water potential (Bindon et al. 2007).

Of these cultural factors, the best established is the effect of cluster light exposure, which typically results a 2-fold increase in potential TDN. Greater cluster exposure should result in higher berry temperatures, but light exclusion treatments that avoid temperature changes still increase TDN in wine (Ristic et al. 2007), further indicating that





Figure 4. Concentrations of TDN in Riesling (left) vs non-Riesling wines (right). Data is adapted from Sacks et al. 2012, and includes results for interspecific hybrids (Vidal Blanc, Seyval Blanc, Vignoles, etc.) that were not included in the original publication.

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light exposure has a direct effect. The effects of the other factors could potentially be confounded with light exposure by reducing canopy growth, but could be mediated through other mechanisms. For example, lower N availability can directly affect carotenoid accumulation and inter-conversion (Chen and Cheng 2003), which may have a role in C₁₃-norisoprenoid production.

To determine if there is a critical time during the season in which leaf removal affects TDN precursors, a 75% leaf removal treatment was applied to the fruit zone of Riesling grown in NY State at one of three timings (berry set, ~2.5 weeks prior to veraison, ~2.5 weeks after veraison) (Kwasniewski et al. 2010). As compared to the control, the late and early season leaf removal had no effect, but leaf removal just prior to veraison resulted in an increase in about a 2 to 3-fold higher concentration of potential TDN in grapes and free TDN concentrations in wines (Figure 5).

Although pre-veraison light exposure is correlated with increased TDN potential, a mechanistic explanation for this phenomenon is still lacking. Since carotenoids degrade just before veraison, one possible explanation is that light exposure and/or berry temperature increases carotenoid substrate and eventual C13-norisoprenoid precursor concentrations (Marais et al. 1999). However, no consistent trend has been observed regarding the effects of sunlight exposure on total carotenoid concentrations in grape berries (Kwasniewski et al. 2010; Oliveira et al. 2004). Increased photodegradation of carotenoids has also been proposed to explain differences in C13-norisoprenoid precursors (Baumes et al. 2002), but this would not explain why post-veraison leaf removal has no effect on TDN. Concentrations of some specific carotenoids like zeaxanthin are increased by 2-fold or more with sun exposure (Kwasniewski et al. 2010), although it is not clear that this compound can serve as a precursor to TDN precursors (Stingl et al. 2002). Similarly, there is no proposed explanation for why Riesling wines have higher concentrations of TDN (Sacks et al. 2012) as well as vitispirane (another C113-norisoprenoid) than other varietal wines (Eggers et al. 2006).

Glycosides, Part 2: Monoterpenes

Over 50 monoterpenes or their glycosides have been detected in grapes. However, many of these are not effectively extracted into wine or else are at concentrations well below their sensory thresholds. The two monoterpenes that are most often reported to contribute to the aroma of wine are linalool and geraniol ('floral', 'citrus'), which can cumulatively exist at 20-fold over their sensory thresholds in wines produced from Muscat-type grapes. A third grape-produced monoterpene, cis-rose oxide ('lychee') is well known to contribute to the aroma of Gewurztraminer. A mutation in a key enzyme



Figure 5. Effects of timing of leaf removal treatment (at berry set, pre-veraison, and post-veraison) on formation of TDN precursors. Error bars reflect standard deviations for field replicates (n=4). Adapted from Kwasniewski et al. 2010

in monoterpene synthesis (*VvDXS*) has been linked to increased accumulation of monoterpenes post-veraison in Muscat varieties. Following initial synthesis, monoterpenes may undergo further transformations (hydration, oxidation, reduction, cyclisation, etc.) (Luan et al. 2005). Presumably, differences in the relative activity of these steps result in observed differences in monoterpene profiles among cultivars (Rapp 1998).

The majority (50–90%) of linalool and geraniol exist as glycoside precursors in grapes, and both free and glycosylated forms begin to accumulate after veraison (Gunata et al. 1985; Park et al. 1991). These glycosylated precursors can be hydrolysed enzymatically during fermentation to release free monoterpenes (Ugliano et al. 2006). Monoterpene glycosides will also be hydrolysed non-enzymatically under acidic wine conditions; however, acid hydrolysis products may undergo further rearrangement, either immediately or after prolonged storage. For example, both geraniol and linalool can rearrange in acidic conditions to form the less odour-active α -terpineol (Ribereau-Gayon et al. 2006). Thus, aged Muscat-type wines are expected to have lower concentrations of linalool and geraniol following prolonged storage.

Studies on the effects of vineyard practices on monoterpene accumulation have generally shown less dramatic results than what has been observed for TDN. For example, full cluster exposure is reported to increase both free and bound monoterpenes in several studies as compared to shaded clusters (Belancic et al. 1997; Macaulay and Morris 1993; Reynolds et al. 1986, 2007; Reynolds and Wardle 1989; Skinkis et al. 2010). However, the reported increases in monoterpenes in these studies are usually in the order of 20–30%. This is far less than the effect of sun exposure on TDN, and is also small compared to the 2 to 4-fold variation that can be observed in monoterpenes across vintages at the same site (Reynolds et al. 2007). Thinning treatments and trellising systems appear to have similar effects (Reynolds 2010) - often resulting in significant differences, but small in comparison to variation across vintages. One exception to this may be nitrogen fertilisation, which at 224 kg/ha reportedly doubled concentrations of linalool in Riesling wines (Webster et al. 1993).

Harvest timing may have a greater impact on monoterpenes, and in particular on the relative ratios of monoterpene and C_{13} -norisoprenoid precursors. In two years of our study (2009 and 2010) we observed that accumulation of C_{13} norisoprenoids reached a plateau around 4–5 weeks after veraison, as observed by another group (Mathieu et al. 2005). By comparison, monoterpene precursors were still accumulating at harvest (eight weeks post-veraison) and had not clearly reached a plateau, as reported by others (Park et al. 1991). Representative data from 2010 is shown in Figure 6. This phenom-

enon may be because norisoprenoid precursors are determined by the extent and type of carotenoid degradation, which occurs at veraison, while monoterpene biosynthesis can continue during maturation. Regardless of explanation, this result indicates that harvest timing should affect the relative contributions of monoterpenes and C_{13} -norisoprenoids.

S-conjugates and volatile polyfunctional thiols

Historically, thiols have been associated with 'reduced' off-aromas in wines, especially those with molecular weight <100 g/mol (H_2 S, CH_3 SH). However, since the mid-1990s, a wide range of potent odorous thiols with higher molecular weights and multiple functional groups ('polyfunctional') have been identified. These thiols include 3-mercaptohexanol (3-MH, 'citrus', 'passionfruit', 60 ng/L threshold) and 4-methyl-4-mercapto-pentan-2-one (4-MMP, 'cat pee', 0.8 ng/L threshold). While most closely associated with the aroma of Sauvignon Blanc,

the polyfunctional thiols (particularly 3-MH) have been detected at suprathreshold concentrations in a wide range of white and rosé wines, including Riesling (Tominaga et al. 2000).

3-MH and many related thiols are undetectable in grapes, but instead appear to be formed by enzymatic degradation of S-conjugate precursors during fermentation. The two best-characterised of these S-conjugate precursors are those covalently linked to glutathione and cysteine. Glutathione is a tripeptide, and is present at concentrations around 50 mg/kg in grapes (Kritzinger et al. 2012). Glutathione is widely distributed in the plant kingdom, where it has roles as an antioxidant and in detoxification pathways. In the case of the 3-MH precursor, glutathione is believed to react with *trans*-2hexenal (formed by enzymatic oxidation of grape fatty acids) which is subsequently reduced to form the S-glutathione precursor. This S-glutathione precursor can then be enzymatically hydrolysed to form an S-cysteine conjugate (Figure 7). Currently, there is still debate as to several points regarding thiol formation (Capone et al. 2012; Pinu et al. 2012):

- The degree to which S-conjugates are formed in the grape berry vs formed following harvesting or crushing
- The importance of minor alternative pathways involving more direct formation of thiols, including reaction of H₂S with other grape-derived compounds during fermentation
- The possibility that other unidentified or poorly characterised precursors exist, as the conversion efficiencies of known precursors may be too low to account for thiol production during fermentations.



Figure 6. Relative concentrations of monoterpene and C_{13} -norisoprenoid precursors in NY State Riesling during the 2010 growing season. Error bars represent field replicates (n=4).



Figure 7. Diagram of 3-MH formation from glutathione and *trans*-2-hexenal. Several intermediate transformation steps are omitted for clarity.

Environmentally stressful conditions will result in very large changes in S-conjugate precursors. *Botrytis* infection, for example, can result in 50-fold increases in precursor concentrations and eventual thiol concentrations in wines (Sarrazin et al. 2007). UV light exposure and water deficit are also reported to increase formation of S-conjugate precursors in greenhouse conditions (Kobayashi et al. 2011). These stresses (abiotic, biological) may result in increased precursor formation either by producing more *trans*-2-hexenal or related substrates, or by upregulating the activity of enzymes associated with formation of S-conjugates (Kobayashi et al. 2011).

However, under less extreme conditions,understanding factors that affect eventual thiol concentrations in wines is hindered because there is a very poor correlation ($r^2 < 0.1$) between the known S-conjugate precursors and eventual thiol concentrations, even with similar winemaking practices (Pinu et al. 2012). Potential explanations for this phenomenon may be that other unknown precursors are more important; that must nutrient status (such as high yeast assimilable nitrogen, YAN) can suppress release of thiols; and/ or that S-conjugate precursors can form post-harvest as a result of berry damage. Furthermore, yeasts vary considerably in their ability to metabolise S-conjugate precursors, and unlike with TDN there is little evidence for hydrolysis of these precursors to form thiols during storage. Thus, for volatile thiols, post-harvest practices may obscure vineyard effects.

Future directions for linking vineyard conditions with flavour precursors and wine flavour chemistry

The previous discussion considered flavour precursors and their related odorants in isolation. However, a consumer's 'flavour' experience will be determined by the emergent properties of these odorants in mixtures with other odorants, tastants, and tactile compounds, not to mention non-flavour cues like prior expectations. Vineyard may also have less direct effects on odour, for example i) low must YAN status will decrease production of esters, and increase formation of H₂S and fusel alcohols, or ii) lower pH during storage should increase formation of TDN from precursors but result in more rapid loss of linalool. Finally, many of the differences arising from a grape's experiences in the vineyard can be obfuscated by decisions made in the winery. For example, wine yeasts can differ in their ability to release 3-MH and other thiols from precursors, and in their ability to synthesise esters during fermentation acetyltransferase activity and their ability to produce acetate esters ('banana', 'fruity'). In recent years, multiple studies have reported on using more holistic, multivariate approaches to correlate differences in Sauvignon Blanc flavour chemistry with differences in sensory characteristics, site, and/or region (Benkwitz et al. 2012; Green et al. 2011; Jouanneau et al. 2012; Lund et al. 2009). While Riesling sensory characteristics can vary among sites (Douglas et al. 2001), similar multivariate approaches to correlating chemistry with sensory data across sites or regions are not as widely reported in the literature. Considering the wide range of compound classes important to Riesling flavour, multivariate approaches should be useful, and recent reports indicate that these should be emerging soon (Bauer and Fischer 2009; Nelson et al. 2010; Reynolds 2010).

Changes to cultural practices rarely operate selectively. For example, basal leaf removal will increase TDN precursors, but also increases spray efficacy and UV light exposure, resulting in a reduction in the incidence of powdery mildew (Austin et al. 2011). Light exposure typically also results in a reduction in titratable acidity. A grower interested in avoiding Riesling wines with excess 'petrol' character while simultaneously trying to minimise disease pressure or acidity will need to balance these competing objectives. By generating response curves for different attributes, e.g. TDN or disease incidence versus light exposure metrics like cluster exposure flux availability (CEFA) (Meyers and Heuvel 2008), we have demonstrated that it is possible to optimise these decisions computationally (Meyers et al. 2012). Also, current methods for measuring flavour precursors are rather laborious and inappropriate for field settings. The development of field-appropriate sensors that can provide direct or indirect information about flavour potential in aromatic whites would build on existing precision viticulture work based on vegetative indices (Bramley 2010).

Finally, the majority of reports on the effects of growing conditions on flavour chemistry have been empirical in nature, which has made extrapolation of results challenging. Since many of the enzymes and substrates involved in formation of key aroma compounds are now characterised, there should be a better molecular-level understanding of vineyard phenomena in coming years. For example, it was recently demonstrated that decreased 'vegetal'-smelling methoxypyrazines (MP) as a result of cluster light exposure could be at least in part related to decreased expression of a key enzyme involved in the last step of MP biosynthesis (Dunlevy et al. 2013). Analogously, the higher monoterpene concentrations in Muscat varieties can be explained at the genetic level (Battilana et al. 2009), but it is not yet possible to provide a genetic explanation for why TDN is typically higher in Riesling, or volatile thiols in Sauvignon Blanc.

Pesticide residues as precursors

There exists another class of much less desirable flavour precursors that can arise from the vineyard – pesticide residues, some of which can degrade during fermentation or storage to yield off-flavour compounds. The most problematic of these pesticides often contain sulfur (S) atoms, since the resulting S-containing degradation products (e.g. thiols, disulfides) often have very low sensory thresholds. Examples of this unwelcome type of flavour precursor are reviewed elsewhere (Bertrand and Beloqui 2009), and include acephate (which can form methanethiol), methomyl (methanethiol and ethanethiol), and thirame (several compounds, including carbon disulfide).

Perhaps the best known pesticide/flavour-precursor is elemental sulfur (S⁰). S⁰ is widely used throughout the grape industry as an effective and inexpensive control for grapevine powdery mildew (PM) (Gadoury et al. 2012). However, S⁰ residues are also well known to yield increased formation of H₂S during fermentation (Acree et al. 1972; Rankine 1963), likely through non-enzymatic reduction of S⁰ by yeast-produced glutathione (Sluiter 1930).

$S^0 + 2$ glutathione \rightarrow H₂S + oxidised glutathione

 $\rm H_2S$ has a 'rotten-egg' like aroma and an odour threshold of around 1 µg/L, and is reported to be in excess of sensory threshold in most wines with so-called 'reductive' off-aromas (Siebert et al. 2010). $\rm H_2S$ is formed as part of normal yeast metabolism as a by-product of amino acid biosynthesis, particularly in musts with low yeast assimilable nitrogen content (Bell and Henschke 2005). While the total amount of H₂S formed throughout fermentation can be in the order of mg/L, the majority will be lost due to entrainment in CO₂ (Acree et al. 1972; Thoukis and Stern 1962). In contrast, H₂S formed from S⁰ is particularly problematic not only because it increases total H₂S production, but also because it continues to be formed late in fermentation after CO₂ production has nearly ceased (Acree et al. 1972), which increases the possibility that the H₂S can react with other off-odours that are more challenging to remove.

Based on spiking experiments, there is reasonable agreement that S^0 concentrations ≥ 10 mg/kg in must will result in both increased H_2S formation during fermentation and higher concentrations of H_2S in the finished wine (Acree et al. 1972; Thoukis and Stern 1962).

The effects of lower spike additions are more variable, with some groups reporting that $1-2 \text{ mg/kg S}^0$ will increase H_2S (Wenzel et al. 1980), and others reporting that additions of 3 mg/kg S⁰ had no effect (Thomas et al. 1993a). This variability could arise from differences in background formation of H_2S by yeast resulting from yeast strain, must nutritional status, fermentation temperature, etc.; differences in glutathione production by yeast; or, differences in the reactivity of different S⁰ formulations (Acree et al. 1972; Schutz and Kunkee 1977).

Most grapegrowers avoid late season S^0 application, although the definition of 'late season' is not well agreed upon. Based on data mentioned above, the maximum residue limit for S^0 on grapes should be no more

than 10 mg/kg, and perhaps as low as 1 mg/kg, to avoid excess H_2S production. The point at which S⁰ sprays should be ceased to avoid these limits is unclear, as one study showed that residues decline to <4 mg/kg within two weeks of spraying (Thomas et al. 1993b), and another claimed that residues as high as 8 mg/kg from a sprayable S⁰ formulation ceased seven weeks before harvest (Wenzel et al. 1980). Comparison of these studies and extrapolation of results to other regions is complicated because S-residue persistence is expected to vary with weather, canopy architecture, formulation type, application rate, sprayer design, and other factors.

We postulated that a major handicap in understanding the persistence of S⁰ following spray applications was the absence of an inexpensive, rapid, and valid method for quantifying sulfur residues on grapes or in musts. Existing approaches for quantification of S^o on grapes required expensive instrumentation, HPLC-UV/VIS or ICP-MS (Thomas et al. 1993b; Wenzel et al. 1980). Additionally, these S⁰ quantification methods required an initial extraction step with organic solvent (e.g. benzene), which will be infeasible in most modestly equipped wineries, or with aqueous detergent, which may not effectively extract the water-insoluble Sº-residues. We recently reported on a rapid, inexpensive method for quantifying S⁰ residues (Kwasniewski et al. 2011). A cartoon is shown in Figure 8. Briefly, a grape or juice sample is dispersed in polyethylene glycol in a small flask. The S⁰ residues are then converted to H₂S by a benign reducing agent (dithiothreitol), and the H₂S is quantified by colorimetric gas detection tubes. Antacid tablets are used as a convenient source of gas to sweep the H₂S into the tubes. The amount of H₂S evolved is proportional to the initial concentration of S⁰. The reagents and consumables are safe, inexpensive (<\$5 USD per analysis), and individual analyses require <15 min. The methodological limit of detection was 0.01 mg/L in juice, well below the concentration associated with increased formation of H₂S during fermentation. A demonstration of the technique can be found at http://www.youtube.com/ watch?v=yH83vDX8ORQ.

We utilised our new methodology to follow S^0 persistence in the vineyard over three vintages (2009–2011) in a New York State vineyard (Kwasniewski, Sacks and Wilcox; unpublished results). Variables included:

- Pre-harvest spray interval
- Formulation (wettable vs micronised sulfur)
- Application rates.

Samples were taken for each treatment at roughly 1-2 week intervals. We observed considerable variation in the persistence of S⁰ residues across years, even for similar treatments. For example, in 2010 and 2011, trials were performed in which a micronised sulfur



Figure 8. Recently described methodology for quantifying S⁰ residues in winery settings. Adapted from Kwasniewski et al. 2011



Figure 9. Representative data from sulfur residue trials, showing elemental sulfur residue vs time for 5.4 and 4.5 kg/ha micronised sulfur (Microthiol) sprays in 2010 and 2011. The final spray dates were 35 and 38 days, respectively. Error bars represent standard deviations for field replicates (n=4).

preparation (Microthiol, ~5 kg/ha) was sprayed regularly up until five weeks before harvest (Figure 9). In 2010, S⁰ residues were still above 10 mg/kg within one week of harvest before decaying to a harvest value of 4.6 mg/kg. In 2011, concentrations were <10 mg/kg at four weeks before harvest, and slowly decayed to a final concentration of 3.7 mg/kg. Importantly, the residues in both experiments were above the 1 mg/kg threshold reported to lead to increased H₂S production by at least one group (Wenzel et al. 1980). In fact, ceasing sprays as far as eight weeks pre-harvest still led to residues in excess of 1 mg/kg in some circumstances.

Measurements of S⁰ residues on berry macerates, as was performed here, are valid for grapes which are fermented on, or cold macerated with skins. However, S⁰ residues will be greatly decreased by must clarification and to a lesser extent by crushing and pressing, as reported by other authors (Wenzel et al. 1980). We observed that S⁰ concentrations in juice immediately following pressing were about 50% of concentrations in grapes, although the concentrations were well correlated (r^2 =0.85, n=9). Cold settling of musts for 14 hours resulted in a 95% decrease in S⁰ residues, such that < 1 mg/kg S⁰ was detectable in juice even for grapes sprayed two weeks before harvest.

In summary, because of the wide variability in S⁰ persistence observed among vintages even within the same site and using the same formulations, we believe that the safest strategy for winemakers and growers concerned about S⁰ residues is to make measurements using our newly described approach. Strategies for dealing with sites with excess spray residue could include delaying harvest; segregating the fruit to prevent contamination of clean fruit; or vinifying the wine with minimal skin contact (i.e. producing a rosé from red grapes).

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Physiological indicators to predict harvest date and wine style

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Abstract

Optimal maturity of grapes depends on multi-faceted criteria. Several important classes of compounds are biosynthesised during the berry growth period, before and/or after veraison (e.g. aromatic precursors, phenolics, hormones, organic acids, amino acids), while others are provided by roots and/or leaves (e.g. water, minerals, sugar, nitrogen). Several of these compounds change during the ripening stage of the grape berry. These changes do not occur in a highly coordinated fashion, and instead, suggest a series of independently regulated pathways of synthesis. Each pathway is influenced by seasonal climatic factors, vineyard practices, and cultivar. Optimal grape ripeness is defined according to the wine style goal, which in turn is dictated by market demand or by the objective of producing a wine that respects the expression of a typical terroir-related character. Professionals working within the sector are therefore obliged to accurately characterise the grapes in order to make an informed decision about optimum harvest date, and to adapt the winemaking process to obtain a target wine style. One of the most important and difficult parts of a viticulturist and winemaker's job is to predict the wine style from the berries and the oenological process. The evolution of sugar loading in grape berries, for red cultivars, and the evolution of skin berry colour, for white cultivars, give an indication of the ripening process from a new perspective and are novel approaches to identifying practical indicators for obtaining particular styles of grapes and wines. These indicators aim to help vignerons and winemakers predict grape harvest dates which will deliver optimum results according to wine style. Depending on the variety, harvest can be planned 10 to 40 days before it's due to start, allowing producers to plan ahead for harvest and wine production.

Introduction

Optimal maturity of grapes depends on multi-faceted criteria. Several important classes of compounds are biosynthesised during the berry growth period, before and/or after veraison (e.g. aromatic precursors, phenolics, hormones, organic acids), while others are provided by roots and/or leaves (e.g. water, minerals, sugar). Several of these compounds change during the ripening stage of the grape berry. These changes do not occur in a highly coordinated fashion, and instead, suggest a series of independently regulated pathways of synthesis. Each pathway is influenced by seasonal climatic factors, vineyard practices, and cultivar (Terrier et al. 2005; Kalua and Boss 2010).

Recent results, from research on molecular biology aspects of *Vitis vinifera* at the transcriptional level, and gene expression data obtained from berries sampled before and after veraison for three growing seasons, were analysed to identify genes specifically involved in fruit ripening and to investigate seasonal influences on this process (Boss et al. 1996; Davies and Robinson 1996; Vivier and Pretorius 2002; Pilati et al. 2007; Lund et al. 2008). From these results, a core set of 1,477 genes were found which was similarly modulated in all seasons. To add to this complexity, each berry within a bunch has its own dynamic of growth and maturation. A recent study showed the impact of cultural practices and climate (including extreme climatic events) on the plasticity of the grapevine berry transcriptome (Dal Santo et al. 2013).

The question, therefore, is how to capture this complexity and to decide on and predict the appropriate harvest date in relation to wine styles and categories?

How are harvesting decisions made today by viticulturists and winemakers? Several methods could be listed:

- 1. To harvest according to the knowledge of a specific cultivar and vineyard, even without any analysis but through visual observations (building up personal experience as a vigneron).
- 2. To harvest according to one criterion which requires simple, routine analysis, such as Brix (the most commonly used indicator in the wine industry today).

- 3. To harvest according to berry tasting, which can be very subjective. The decision is mainly related to the personal experience and training of the taster.
- 4. To harvest using a series of indicators and appropriate analysis methods. This implies that the necessary apparatus is available at the estate, or an appropriate laboratory nearby. Knowledge in interpreting analytical results to take the appropriate decision is therefore required. The cost per hectare has to be considered.
- 5. To harvest using new decision-making tools and take into consideration new scientific results. This implies the ability to access the information, understand, assimilate it and then implement it successfully (extension and adoption process). In addition, the ability to afford this new technology, which may be expensive, has to be considered.

This list is not complete. In addition, it is important that skills and information be transferred to the people who are using these methods to decide the harvest date. Such skills include, for example, being able to interpret the analytical data, to properly use the analytical tools with a standard protocol, and to sample properly in the first place.

Geographical origin is important for products which lay claim to a terroir-linked typicality. Measuring the terroir effect on an agrifood product remains difficult for both trained experts and for the consumer, for whom the appreciation of the product or lack thereof remains the principal criterion in their evaluation. This does not exclude the ability to recognise the product's properties, but it should be remembered that the perceived taste and aromas will be transformed by the individual's experience into a unique overall sensory impression (Deloire et al. 2008).

Optimal grape ripeness is defined according to the wine style goal, which in turn is dictated by market demand or by the objective of producing a wine that respects the expression of a typical terroirrelated character. Professionals working within the sector are therefore obliged to accurately characterise the grapes in order to make an informed decision about optimum harvest date, and to adapt fermentation practices to obtain a target wine style. The quality of the grapes is a determining factor in the quality of the finished wine. But how is grape quality itself determined? What are the relevant parameters of the berry that enable the dynamics of ripening to be monitored?

One of the most important and difficult parts of a viticulturist and winemaker's job is to predict the wine style from the berries and the oenological process. The classical indicators like Brix, malic and tartaric acids, titratable acidity, tannins, anthocyanins, etc. are strongly related to the perception of the **taste** of the wine (mouthfeel). Therefore, it is also highly useful to be able to predict or predetermine the future wine style in terms of aroma, from the fruit itself.

At the National Wine and Grape Industry Centre (NWGIC), we aim to develop an ambitious but realistic integrated program on grapevine berry ripening. We will study the berry aromatic sequence (i.e. the evolution of the potential berry aromatic profile with respect to possible wine styles) during fruit maturation in relation to the wine composition and flavour profiles. The scientific aim is to better understand fruit growth and composition (fruit quality) and to develop practical tools and methods to predict or predetermine the future wine style in terms of aromatic characteristics.

Berry ripening, wine flavours, and the elaboration of low alcohol wines are, today, among the priorities of the worldwide wine industry, mainly in the context of climate change (i.e. increase of temperature and evapotranspiration) and scarcity of water.

Proposed methods for red cultivars

The method, which will be calibrated for the Australian wine industry for red cultivars, uses the concept of berry sugar loading (Wang et al. 2003a, b; Deloire 2011) and the method for the white cultivars uses the berry colour evolution (Deloire 2013). Both methods are based on relationships which are established between the use of fruit physiological indicators and the possible wine styles determined by sensory analyses. Both methods are based on sequential harvest to understand the relation between harvest time and wine composition and profile (Bindon et al. 2013, 2014), (Figure 1, Deloire et al. 2011). The berry aromatic sequence could be explained as follows (this is a one example of a possible sensory description for red cultivar):

Red cultivars. When sugar per berry reaches a plateau (or slows down), there are four stages which progress in the same sequence (Figure 2):

- stage 1) 'fresh fruit'/'green plant-like' aroma/'unripe plum'
- stage 2) 'neutral'/'spicy-like' aroma or 'pre-ripe' ('mature' berry aromas)
- stage 3) 'mature' berry aromas such as 'blackcurrant', 'raspberry', 'cherry'
- stage 4) overripe aromas such as 'dried fruit', 'prune'



Figure 1. The berry aromatic sequence for red cultivars

Stage 1 always occurs from 12 to 20 days onwards after sugar per berry has reached a plateau (cessation of berry sugar loading or slowdown of berry sugar accumulation), respectively for Syrah and Cabernet Sauvignon (Figure 1). Stage 3 always occurs from 24 to 40 days onwards after sugar per berry has reached a plateau, respectively for Syrah and Cabernet Sauvignon. Between 'fresh' and 'mature' fruit stages, the stage 2 is called 'neutral'/spicy' (or 'premature') and may vary according to the sites (climate and soil) and cultural practices. Stage 2 has to be avoided when it is considered 'neutral' as the related wines will show a deficiency of fruitiness and will be judged as onedimensional wines, and could be determined/predicted using the sugar loading method.

There is no direct relationship between fruit Brix or titrable acidity levels and the berry aromatic sequence stages, meaning that 'fresh', 'neutral', and 'mature' stages can be reached at the same Brix value. In that regard, the berry aromatic sequence model shows that harvest using only Brix value can't help in predicting harvest date and wine style.

Proposed method for white cultivars

Berry colour development for white cultivars. Berry colour is a new and important indicator, notably to assess the ripening of white varieties, because a possible relationship exists between berry skin colour evolution and the possible wine aromatic profile. Carotenoids, phytoprotective pigments produced by photosynthesis, are localised in the skin and are considered as biogenetic precursors of C₁₃-norisoprenoid glycosides. Certain aromas are derived from the degradation of such skin pigments (Kalua and Boss 2010; Baumes et al. 2002; Tominaga et al. 2000; Darriet et al. 1995; Razungles et al. 1988).

The technology to measure berry skin colour has been developed by Vivelys Society, France (http://vivelysusa.com/the-vivelys-group) and is currently being used in the Northern and Southern Hemisphere. The method uses the development of the berry tint angle (berry

Red cultivars: berry aromatic sequence (B.A.S.)

Ripening levels and sugar loading



Tempo of berry ripening according to a physiological clock and to possible style of wine. Not directly linked to Brix/Baume

Figure 2. Example of Syrah berry aromatic sequence. Source: Vivelys, Deloire 2008



Figure 3. The Hue, Saturation and Luminescence (HSL) model of colour representation which gives hue values in degree from 0 to 360°

colour evolution), which is determined using optical technologies, as an indicator of berry ripening versus wine aromatic profile. This method is based on an indirect relationship between the evolution of the berry tint angle (according to the HSL model – Hue, Saturation, Luminescence; Figure 3) and the wine sensorial analysis (Table 1) and as can be seen has potential to be very useful for profiling berry maturation, harvest potential, and selection of the most appropriate harvest dates for white cultivars.

No direct relationship has yet been established between berry colour development from veraison to harvest, and Brix and titrable acidity. Although berry colour monitoring will give a far better understanding of berry aromatic sequence evolution during ripening, it is therefore still recommended that at least two or more of the other classical indicators are used to monitor sugar and acidity in order to achieve the correct wine style.

No doubt climate change will influence berry ripening and this may have repercussions for time of harvest and style of wine produced. The concept of grape quality at harvest should be considered in terms of the required wine composition and winemaking process, resulting in wine with particular sensorial properties. Several important works have recently studied the relationship between grape, wine composition and its aromatic profile (Ristic et al. 2007; Kalua and Boss 2009, 2010; Sweetman et al. 2012; Capone et al. 2012) whereas others emphasised some wine markers potentially linked to wine aromatic maturity (Pineau et al. 2009; Lytra et al. 2012; Dubourdieu et al. 2012; Pons et al. 2013). Despite all these new important insights, the topic is so complex that the relationship between the grape, wine composition and its sensory profile associated with the different stages of fruit maturity remains poorly understood.

As the world becomes more technologically advanced, more advanced technology is being developed to monitor berry ripening. These decision-making tools have rapidly been adopted by large estates and corporations to enhance their marketing edge. The NWGIC, in collaboration with other partners, aims to calibrate those tools for the Australian wine industry and improve their efficiency. The methods presented in this article are not exclusive; other new methods or decision-making tools could be developed in parallel.

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 Table 1. Thresholds of berry hue (in degree) according to the HSL model of colour representation and expected style of wine for most of the white cultivars.

 Simplified thresholds (berry colour evolution occurs irrespectively of Brix and titrable acidity)

- > 80 = 'green'/'asparagus'/'citrus'/'unripe'
- < 80 and > 70 = 'tropical'/'grapefruit'/'citrus'/'boxtree'
- < 70 = 'fermentative'/'neutral'/'terpene'

Berry hue thresholds (in degree)	Expected wine aromatic profiles
>90	Green/unripe
90–85	Green/asparagus
85-80	Asparagus/citrus
80-75	Asparagus/tropical fruit/grapefruit/citrus
75–70	Tropical fruit
70–65	Fermentative/terpene
65–60	Phenolic/neutral/terpene

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Understanding and managing the timing of berry ripening and the flavour-ripe/sugar-ripe nexus

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Abstract

Fruit ripening is a complex process which seems to be regulated by plant growth regulators (PGRs). In contrast to climacteric fruit, the ripening of non-climacteric grape berries is less dependent on ethylene and appears to be controlled by several other PGRs. Some endogenous PGRs, e.g. abscisic acid and castasterone appear to promote the onset of grape berry ripening. Others, for example auxins, appear to be inhibitors of ripening and delay its onset and hence delay harvest. PGRs are therefore important at two levels. First, endogenous PGRs play important roles in the control of berry development and a greater knowledge of their action is crucial to understanding processes such as ripening. Second, this knowledge can be used to develop methods to alter berry development in useful ways. For example, exogenous PGRs provide potential tools with which to manipulate the timing of harvest and could be used to overcome a variety of problems associated with the increased season compression and higher temperatures during ripening caused by changing climatic conditions. We are investigating the role that endogenous PGRs play in the control of berry ripening at both macro and molecular levels, and how this knowledge can be applied. Examples discussed will include treatments that can delay or promote the timing of ripening, and therefore harvest, and their effects on sugar accumulation, skin colouration, organic acid metabolism, ripening synchronicity and wine flavour and aroma.

Introduction

Grape berry development is a rapid process. In the examples given in this paper the time from flowering to commercial ripeness was approximately 16 weeks with the onset of ripening (veraison) occurring roughly in the middle of this period (approximately eight weeks post-flowering). Despite the relatively short amount of time taken for fruit to develop from flowers to ripe berries, there are considerable morphological and biochemical changes that occur (Ollat et al. 2002; Conde et al. 2007). Grape berry development can be seen as consisting of three distinct phases. During the first phase, cell division and expansion occur along with berry expansion. This is followed, in many cases, by a phase of little or no growth often referred to as the lag phase. Ripening begins at the end of the lag phase and during ripening the berries accumulate hexoses, expand considerably and accumulate many of the secondary metabolites that are involved in berry and wine colour, flavour and aroma. This is an oversimplification of the many changes involved, particularly the myriad changes in metabolite levels that occur during development but it reminds us of the level of control and coordination of the various processes that together constitute berry development.

The changes in shape, size and composition that occur during fruit development are fundamentally the result of changes in the expression of grape genes. Transcripts are RNA (ribonucleic acid) copies of the genes that serve as the templates for making proteins such as enzymes which are the real drivers of plant metabolism. Changes in the pool of transcripts (the transcriptome) that are expressed at any time reflect the state of the cell and play a large role in controlling cellular and therefore, organ and whole plant development and metabolism. A number of studies have detailed the large changes in the profile of gene transcripts that occur during berry development (for example, Zenoni et al. 2010; Fortes et al. 2011). There are many genes whose transcripts appear at veraison and many transcripts that are removed from the pool at this time. This coordination indicates that there are active 'organisers' that control which genes are expressed and when, where, and to what level they are expressed. Plant growth regulators (PGRs) are considered to be these controllers and have long been known to affect fruit development and, in particular, the ripening process. There are historical examples where man has altered fruit ripening through manipulating PGRs while being ignorant of their existence. These include the hastening of fig ripening through wounding, as practiced by the ancient Egyptians, and the burning of incense in closed pear store rooms to advance ripening by the ancient Chinese. Both of these examples involve the gas ethylene. Fruit have classically been divided into two groups. Climacteric fruit, for example apples, tomatoes, figs and pears, exhibit a peak in respiration and ethylene evolution at around the time of ripening and their ripening is promoted by ethylene. Non-climacteric fruit, for example, grapes, olives and strawberries, either do not undergo these events, or experience them to a much lesser degree and are not so dramatically affected by exogenous ethylene.

Understanding ripening is important for practical reasons as more knowledge of this pivotal process will provide opportunities for its useful manipulation. Grape development appears to be quite sensitive to changes in temperature and recent studies show that increases in temperature due to climate change are posing new problems for the grape and wine industries. Higher temperatures during fruit development can reduce the perceived quality of the resultant wine and therefore its sale price. In addition, harvest seasons are compressed, putting strain on the ability of wineries to process fruit in a timely manner without substantial further investment in infrastructure. Warmer temperatures also have the effect of ripening the fruit earlier and more rapidly than usual which can lead to increased sugar and therefore, increased wine alcohol levels. Apart from causing 'hotness' in the wines the increased alcohol levels have implications for health and may have regulatory and taxation repercussions. Understanding the control of berry development and in particular ripening will be important in combating the effects of a changing environment. The reason for the susceptibility of grapes to higher temperatures may lie in their small mass compared to many fruit which means that their internal temperatures follow air temperature very closely and so berries have to endure very high temperatures when exposed to incident light (Figure 1).

This paper describes our recent attempts to better understand the role of PGRs in controlling berry development and in particular in controlling the initiation and progression of ripening. The role of several PGRs in berry development is discussed briefly and there is a particular focus on the metabolism and role of the auxin group of PGRs during grape berry ripening.

The role of ethylene during grape berry ripening

The traditional division of fruit into climacteric and non-climacteric types has been helpful in the past in defining ripening. However, like many processes in biology such broad definitions are less clearcut when examined more closely. The role that ethylene plays in the ripening of different fruits is still the subject of considerable debate. Ethylene has a range of functions in plants apart from a role in ripening, which include the plant response to stress, control of root and flower development and tissue senescence. It is incorrect to state that ethylene does not play a role in grape ripening (and development) but it is probably true that it does not play the same potent role that it does in the ripening of climacteric fruit. The literature is somewhat divided on whether ethylene, or the ethylene releasing compound 2-chloroethylphosphonic acid (CEPA), consistently advance both sugar and colour accumulation in grapes and the evidence for significant changes in endogenous ethylene levels at ripening is variable (reviewed by Böttcher and Davies 2012). Some studies have found small increases in ethylene levels at veraison, others have not. Interestingly, the response to ethylene during berry development is biphasic (Hale et al. 1970; Coombe 1973; Böttcher et al. 2013). In our study the treatment of grape berries with CEPA close to the time of veraison (seven days pre-veraison) advanced anthocyanin accumulation (Figure 2A). In contrast, treatments earlier in development (17 days pre-veraison) delayed ripening, as measured by changes in total soluble solids (TSS) and anthocyanins (Figure 2B,C).



Figure 1. Graph showing Shiraz berry and air temperatures throughout a summer's day, McLaren Vale, South Australia. Green line = air temperature measured in shade of the canopy. Blue line = internal temperature of shaded berry. Red line = internal temperatures of berry exposed to sunlight. Temperatures were measured by inserting fine thermocouple wires into the berry flesh.



Figure 2. Effect of CEPA application on Shiraz berry ripening. CEPA = blue dashed line, Control (wetting agent alone) = solid black line. (A) Advancement of anthocyanin accumulation (OD 520 nm/g fresh weight) resulting from treatment with CEPA seven days before veraison. (B) Delay of anthocyanin accumulation (OD 520 nm/g fresh weight) resulting from treatment with CEPA 17 days before veraison. (C) Delay of total soluble solids (Brix) increased by CEPA treatment 17 days before veraison

If exposing berries to ethylene through the application of CEPA 17 days before veraison can delay ripening then reducing the endogenous levels at this time should advance it. Aminoethoxyvinylglycine (AVG) is a naturally occurring amino acid that is made by soil bacteria and is produced by fermentation. It has the ability to reduce ethylene production by inhibiting the activity of 1-amino-cyclopropane-1-carboxylate synthase which is a key enzyme in ethylene biosynthesis (Boller et al. 1979). When applied to berries at a developmental stage when ethylene delayed ripening (17 days pre-veraison) AVG advanced it (Böttcher et al. 2013). These experiments allow some important conclusions to be made in regard to the PGR control of berry development. They show that the PGR perception and signalling pathways change rapidly during berry development and that these changes must have profound effects on cellular metabolism. They also demonstrate that the polarity of the response to endogenous and exogenous PGRs can change during development. This tells us that the developmental stage of the fruit defines the status of PGR metabolism and signalling and the response to exogenous PGRs. As with many things timing is important. Both CEPA and AVG are used in a range of horticultural crops to control various aspects of plant and fruit development. These experiments indicate that PGRs may be one approach to manipulating ripening to improve harvesting logistics or wine style. Given the changing climate, it would seem that retarding veraison and therefore delaying harvest date could be useful in reversing some of the effects of climate change.

Other PGRs that can advance ripening are involved in the control of berry development

Another PGR involved in the control of grape berry ripening is abscisic acid (ABA). Like ethylene it is often associated with stress responses but is also involved in processes such as seed development and stomatal conductance. ABA also seems to play a positive role in fruit ripening (reviewed by Böttcher and Davies 2012). Its levels exhibit a biphasic pattern of accumulation being high in young berries, low just before veraison and increasing again at veraison peaking approximately two weeks later (Wheeler et al. 2009). This pattern suggests ABA is a possible promoter of ripening or at least has some involvement in the process. Indeed, ABA application to berries prior to veraison can advance ripening as demonstrated by the earlier onset of colour and sugar accumulation and the increase in berry weight (Wheeler et al. 2009). Another PGR, which has a similar pattern of accumulation in berries to ABA, may also act as a positive regulator of berry ripening. Castasterone is a PGR with a more complex structure than ABA that is made in the berries and accumulates during berry development with a biphasic pattern remarkably similar to ABA (Symons et al. 2006). As with ABA, the application of this class of PGR to unripe berries advanced ripening while an inhibitor of castasterone biosynthesis delayed it (Symons et al. 2006).

Auxins are crucial to berry development and can delay ripening

While ABA, castasterone and ethylene can affect ripening in a positive way, auxins have been demonstrated to be negative regulators of ripening. Auxins are involved in many important processes during plant development including cell expansion and division, the control of shoot and root architecture and vascular development. The auxin present at the highest levels in developing grape berries is indole-3-acetic acid (IAA) (Böttcher et al. 2010). Its levels are high in flowers and young berries, but decrease to be low before veraison and remain low throughout the ripening phase (Figure 3). This pattern of accumulation suggests that the reduction in levels prior to veraison might be a prerequisite for berry ripening to occur and that there may be a requirement for auxin levels to remain low throughout ripening. The application of auxins to berries during a window of opportunity of approximately 2–3 weeks prior to veraison results in a delay in berry ripening. A striking demonstration of the ripening-delaying effects of these PGRs comes from dipping the bottom half of a growing, pre-veraison bunch in a low-concentration auxin solution which results in the treated part of the bunch going through veraison much later than the upper part of the bunch which continues to ripen normally. Earlier treatments do not seem to affect berry development.

In our experiments we have made use of a range of different auxins. The application of the auxins to pre-veraison Shiraz berries delayed the ripening-related onset of berry size increase, the accumulation of sugars and anthocyanins, the decrease in organic acid content and the increase in ABA levels normally associated with ripening (Figure 4; Davies et al. 1997; Böttcher et al. 2011b, 2012). As a number of measures of ripening were affected it seems that the entire berry ripening program is significantly delayed by auxin treatment with the pre-veraison state being maintained until the inhibition is eventually released. The mechanism by which the inhibition is removed is an interesting story that reveals much about how auxin levels are controlled during grape berry development (see below).

Interestingly, the treatment of bunches with auxins before veraison can increase the synchronicity of berry ripening as judged by changes in the levels of total soluble solids and malic acid. Asynchronous ripening can be readily visualised by the unevenness of berry skin colour development at veraison and is affected by both environmental and genetic factors. By measuring Brix levels in thousands of berries, the diversity of the berry populations of variously treated fruit can be determined. Populations of berries exhibit the greatest spread of Brix and malic acid levels during the early phases of ripening but they become more synchronised as commercial ripeness approaches. Although the mechanism is unknown, populations of auxin-treated berries showed reduced standard deviations in Brix and malic acid levels during ripening compared with control fruit (Böttcher et al. 2011b, 2012) indicating that the naphthalene acetic acid (NAA)-treated fruit have become more synchronised. Although considerable delays in ripening can occur upon the application of auxins, the flavour/aroma in wines derived from these fruit can be, perhaps surprisingly, similar to that of wine made from control fruit. Small scale winemaking followed by the analysis of volatile metabolites by GC-MS was used to measure differences in the volatile components in wines produced from Control and NAA-treated fruit. In wine made from NAA-treated Shiraz, which was delayed in harvest by ten days, only 19 of the 128 volatile compounds identified were significantly different in concentration when compared with the control wine and only one of these was more than twofold different (Böttcher et al. 2011b). Ten of the 14 metabolites at higher concentration in wine from NAA-treated berries were esters, compounds associated with fruity wine aromas. Five compounds were at higher levels in the control samples, four of these were aliphatic alcohols, the other was the monoterpene linalool.



Figure 3. Graph of free indole-3-acetic acid (IAA, black columns) and the IAA aspartic acid conjugate (IAA-Asp, red columns) levels throughout Cabernet Sauvignon berry development from flowering until commercial harvest



Figure 4. Delay in Shiraz berry ripening caused by treatment of pre-veraison berries with the auxin NAA, the control was treated with a wetting agent alone. The delay in colour development caused by NAA can be seen by comparing the two photographs. The graphs show the delay in ripening processes resulting from NAA treatment. Control, black line and symbols; NAA-treated, blue line and symbols. (A) Brix levels, (B) juice pH, (C) anthocyanins (OD 520nm/g fresh weight). The red asterisk denotes veraison

NAA treatment of pre-veraison Riesling berries also delayed ripening. The increase in sugar levels was delayed as was the decrease in malic acid concentration that occurs after veraison. Interestingly, in addition to delaying the timing of veraison, the rate of sugar accumulation was also slower in the NAA-treated fruit. In wine made from NAA-treated Riesling grapes, delayed in harvest by 15 days, 35 volatile compounds out of the 105 identified were significantly different in levels compared with the control wine, but only six compounds were more than twofold different (Böttcher et al. 2012). Nineteen compounds were at higher levels in NAA-treated samples, nine of these were esters (16 compounds were at higher levels in control wine). Three acetate esters were at significantly higher levels in wine from NAA-treated berries from both Riesling and Shiraz fruit (Böttcher et al. 2012). Sensory analysis did not distinguish between the Shiraz wines, but a difference was perceived between the Riesling wines (Böttcher et al. 2011b, 2012). It is not clear from these results whether the differences observed in volatiles and sensory properties arose from direct effects of auxin application or were merely due to the fact that the treated fruit ripened during a cooler part of the year. This will require further investigation.

As higher endogenous levels of IAA may delay ripening, and because these concentrations need to decrease to allow ripening to occur, it is important to understand the processes responsible for the decrease in auxin concentration observed prior to veraison. A number of mechanisms of auxin metabolism have been proposed (reviewed by Woodward and Bartel 2005). One of these is the sequestration of free, active IAA through enzymic conjugation to amino acids. During the auxin conjugation reaction, IAA is activated by the addition of adenosine monophosphate to the carboxyl group followed by the subsequent addition of the amino acid (Chen et al. 2010). Depending on the identity of the conjugating amino acid, the conjugate can be inactive or may comprise a storage form from which free IAA can be released at a later stage (reviewed by Woodward and Bartel 2005). There is also increasing evidence that some of the conjugates themselves may have biological activity (reviewed by Korasick et al. 2013). The enzymes responsible for this reaction are IAA-amido synthetases (also known as GH3 proteins). These IAA-amido synthetases occur as enzyme families throughout the plant kingdom attesting to their importance in plant development. In Vitis vinifera, there are six genes encoding IAA-amido synthetases (Böttcher et al. 2011a). All are expressed early in berry development and as such are likely to be involved in the decrease of IAA during the first developmental stage (Böttcher et al. 2010, 2011a). However, the expression of one of these genes, GH3-1, is also upregulated during the ripening phase and may be responsible for maintaining low levels of IAA throughout ripening (Böttcher et al. 2010).

Indole-3-acetic acid-amino acid conjugates can be detected by LC-MS and quantified in tissue extracts. In grape berry extracts the only conjugate detectable is IAA-Asp, i.e. the conjugate between IAA and aspartic acid. The IAA-Asp conjugate is at high levels in flowers but is low in berries for the rest of the pre-veraison period (Figure 3). At veraison, the levels of IAA-Asp increase sharply and remain high throughout the ripening stage. This pattern is somewhat unexpected given that all six GH3 genes are expressed early in berry development. However, the pattern could be explained if the conjugate was further metabolised (modified) prior to veraison but not after. This is similar to the situation seen with ABA where only after veraison was a significant accumulation of the glucose ester of ABA observed (Owen et al. 2009). A similar developmental pattern of IAA and IAA-Asp accumulation occurs in tomato (Böttcher et al. 2010), which suggests that it may be a common feature of both climacteric and non-climacteric fruit.

Further evidence for the importance of IAA-amido synthetases during grape berry development comes from the application of IAA to pre-veraison berries. Shortly after IAA application, there was a sharp rise in IAA levels within the berries that coincided with strong induction of GH3-2 transcription (Böttcher et al. 2011a). There was also a sharp increase in the concentration of the IAA-Asp conjugate indicating that the excess applied IAA was rapidly sequestered by IAA-amido synthetase activity. This demonstrates that these enzymes are likely to be important in controlling free IAA levels in berries by the rapid inactivation of IAA through conjugation.

Our experiments have shown that different auxins have different effects on berry ripening and development. When applied to Shiraz berries at moderate levels, IAA seemed to have little, or no, effect on ripening parameters such as berry weight, colour and sugar accumulation (Böttcher et al. 2011a). In contrast, NAA caused significant delays in the timing of sugar and colour accumulation with modest effects on berry weight. Benzothiazole–2-oxyacetic acid (BTOA) was the most effective of the auxin-like compounds tested in delaying the increases in sugar, colour and berry weight associated with ripening. The reason for these differential responses may be found in the structure and kinetic properties of IAA-amido synthetase enzymes.

The enzymic activity of the grape IAA-amido synthetases has been carefully studied in vitro. These enzymes can be expressed in bacteria and purified in an active form enabling their enzyme kinetics to be determined. A study of the kinetics of the grapevine GH3 enzymes whose transcription is upregulated by auxin (GH3-1, GH3-2) provides a possible explanation for their differential response to different auxins and provides further evidence as to the importance of GH3 enzymes in auxin homeostasis. IAA is a very good substrate for both GH3-1 and GH3-2 as it is rapidly conjugated and therefore inactivated. NAA is a much poorer substrate as the catalytic efficiency values are reduced by 50-fold (GH3-1) and 21-fold (GH3-2) when IAA is replaced by NAA. Very little, or no, activity is observed with BTOA as the auxin substrate (Böttcher et al. 2011a). These data reflect the pattern of effectiveness of these auxins in delaying ripening discussed above (Böttcher et al. 2011a) and so their effectiveness as auxins is inversely proportional to their ability to be inactivated through conjugation by the IAA-amido synthetases. The reason for these differences in the ability of the IAA-amido synthetases to conjugate different auxin substrates lies in the structural differences at the molecular level. The active site of IAA-amido synthetase enzymes has evolved to work best with the auxin most commonly found in plants, IAA. Computer modelling of the docking of IAA, NAA and BTOA into the active site of GH3-1 showed that NAA and BTOA could form competitive or non-productive interactions with catalytic residues, i.e. they just do not fit very well and therefore are not readily conjugated. These flawed interactions are likely to be responsible for the dramatic reductions in catalytic efficiency (Peat et al. 2012).

Conclusions

The work described in this paper highlights some important points concerning the control of berry development by PGRs, particularly in regard to ripening. First, the PGR control/signalling pathways change rapidly during development as evidenced by the changing response of fruit to exogenous PGRs. Berry development is quite rapid and there are many significant changes to metabolism and the physical state of the berry, which require numerous changes in PGR profile, perception and signalling. Second, in agreement with the previous point, the effect of exogenous PGRs on berry development is heavily dependent on developmental stage. In practical terms this is very important as it means that, to have the desired effect, PGR application has to occur at a particular stage of development. Perhaps the most extreme example of this is the biphasic response of berries to ethylene where,

depending on the timing of application, opposite effects on the onset of berry ripening can be achieved. Third, although not specifically discussed here, there are numerous interactions between the different PGR metabolic and signalling pathways, which can change with the developmental stage of the berry. Curiously, our current knowledge of PGR levels suggests that only ABA and castasterone are elevated during the ripening phase and there is much more to learn about how they and possibly other, as yet unidentified PGRs, control and affect ripening once it has commenced.

Auxins seem critical to the timing of veraison, as IAA levels need to be low for it to occur. The reduction in auxin levels is at least in part conducted by IAA-amido synthetases. Analysis of the structure of these enzymes gives an insight into the molecular mechanisms involved in catalysis and through computer modelling offers an explanation for the biological activity of various auxins.

Although ethylene is involved in development in both climacteric and non-climacteric fruit, the responses to ethylene and ethylene metabolism do seem different. The role of auxins in delaying fruit ripening seems to be similar in the climacteric and non-climacteric fruit tested and may be a mechanism common to all fruit.

In practical terms, a better understanding of PGR action during grape berry development will enhance our ability to usefully manipulate it, to manage issues such as asynchronous ripening and problems arising from climate change. Possible benefits to the grape/wine industries include:

- Mitigation of harvest season compression resulting from climate change
- Improved winery intake scheduling reduced costs
- Fruit harvesting at the optimal time improved quality
- Manipulation of fruit composition wine style
- Increased synchronicity of berry ripening
- Reduced fruit wastage.

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Targeting wine style: alcohol adjustment in white wine

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Abstract

In recent vintages a range of viticultural and oenological techniques have been employed to lower the alcohol content in German wines. Depending on harvest date and viticultural practices, the sensory profile of white wines can be drastically modified in aroma and taste. Wine alcohol content can be controlled using must chaptalisation or partial wine dealcoholisation. Wine alcohol adjustment can be performed using distillation and membrane technologies on finished wines, but this adjustment is accompanied by a loss of aroma compounds. Nevertheless, a reduction of 2% v/v is usually not perceived in the flavour of the wines, whereas it does affect the mouth-feel attributes. Sensory analysis indicated a change in wine style due to alcohol adjustment. Wine style ranges from 'thin' for low alcohol wines, towards the positive 'elegant' or 'full-bodied' associated with moderate alcohol concentrations. Excessively alcoholic wines were described as 'burning'. Harvest date determines the fruit character of the resulting wines, therefore harvest date should be selected in accordance with desired fruit profile and the alcohol concentration can later be brought back into balance technologically according to the desired alcoholic profile of the wine. This suggests using technological methods to influence alcoholic balance, and viticultural techniques and harvest date to drive the fruit flavours and set the desired aromatic profile.

Introduction

The alcohol concentration of wines has increased in recent years (Alston et al. 2011). This can be partially explained by changes in climate (Schultz 2000); however, the adoption of new viticultural and oenological practices as well as changes in consumer demand have also influenced this increase (Hoffmann 2008; Alston et al. 2011).

In cool climates, the process of increasing ethanol content by chaptalisation with sucrose or grape juice concentrate or concentration of musts by evaporation or reverse osmosis is long established (Sigler et al. 2001, 2003). Lowering the ethanol content of wine is a fairly new technology in Europe. Partial alcohol reduction of wine has been permitted in the European Union (VO (EG) 606/2009) since 2009. Currently an alcohol reduction of up to 20% of the total is permitted. Several physical technologies can be applied to reduce alcohol content (Pickering 2000). These technologies are usually separated into distillation techniques and membrane techniques (Schmidtke et al. 2012).

Recently, membrane contactors have been introduced for the production of lower alcohol wines (Hogan et al. 1998; Diban et al. 2008). These are used in a process called osmotic distillation (OD) to reduce the ethanol content of wines. The porous, hydrophobic membrane permits wine volatiles to diffuse from the wine through the membrane into a stripping solution. The volatile aroma compounds are transferred together with the ethanol into the stripping solution (Varavuth et al. 2009) but the non-volatile wine compounds cannot pass through the membrane. Hence, the concentration of compounds such as sugars, phenolics and acids, and the wine pH, are not significantly affected by osmotic distillation (Blank and Sigler 2012; Liguori et al. 2012, 2013).

The effect of ethanol on the sensory properties of wine has been the subject of various studies. Several wine sensory attributes are influenced by ethanol content. Ethanol enhances the perception of 'bitterness' (Fischer and Noble 1994) and 'sweetness', while 'sourness' is suppressed (Zamora et al. 2006). The 'hotness', 'body' and 'length' of the wine is usually increased at higher ethanol concentrations (Gawel et al. 2007). The effect of ethanol on the aroma is described in many studies; some reports claim a decrease in aroma, others an increase in aroma perception. Ethanol has a strong influence on the partition coefficient of aroma compounds, making many of them more soluble at higher ethanol concentrations (Le Berre et al. 2007), but aroma release is facilitated in the presence of ethanol (Tsachaki et al. 2009). Thus the sensorial effect of ethanol levels on aroma cannot be easily predicted. Research (Villamor et al. 2013a, b) has shown some of these effects in a model solution analytically and in sensorial analysis.

Tasting order has a strong effect on the sensorial appreciation of a wine. This is not often taken into account (King et al. 2013). In sensory studies using descriptive analysis it is often not possible to separate wines where the alcohol has been reduced by 2% v/v alcohol via technological methods from a control. An aroma reduction is not perceived until alcohol has been reduced by about 3% v/v (Gambuti et al. 2011; Lisanti et al. 2011, 2012). An efficient and discriminative way to describe the sensorial differences due to alcohol reduction is by the temporal dominance of sensation method (Meillon et al. 2009). However, it is often reported in non-scientific articles that alcohol content can be adjusted to achieve an optimum balance – the so called 'sweet spot' – and even that multiple 'sweet spots' might be possible in the same wine. To our knowledge, however, there has been no scientific evidence of such a 'sweet spot,' and research should be directed into this field.

A novel approach in describing the changes in wine style due to an alcohol adjustment is introduced in this paper. For this approach, wines were produced that differed in ethanol content, but also in harvest date at the same ethanol content. Many studies have shown the effect of harvest timing on wine sensory attributes. It has been shown that wines show a change in aroma profile depending on harvest date (Heymann et al. 2013). Depending on harvest ripeness, the flavour descriptors for white wines range from 'green'/'unripe' to more pleasant 'citrus' characters towards intense 'tropical' and 'terpenic' aroma profiles (Deloire 2013). Usually the changes in harvest date are accompanied by a change in ethanol. Therefore the effects of ethanol and fruit ripeness are often not separated sufficiently. Only a few studies have taken the change of alcoholic content at different ripeness levels into account, showing the impact of both alcohol and harvest ripeness parameters (Pineau et al. 2011; Heymann et al. 2013).

This study aims to separate the analytical and sensory effects of grape ripeness due to harvest date from the effects of alcohol level, in a factorial design experiment on white varietal wines. A new method for describing the stylistic change due to alcohol adjustment is shown with these wines.

Materials and methods

Experimental design

In 2011, a factorial design experiment was performed on Riesling. Four treatments were produced in duplicate: two early harvested treatments and two late harvested treatments (Figure 1). One of the early harvest treatments was adjusted by chaptalisation of the must by 2% v/v. The late harvest grapes were picked when sugar ripeness was 2% v/v higher than at the early harvest. The alcohol concentration of one of the later harvest wines was reduced by 2% v/v using a membrane contactor.

In 2012, a similar experiment was performed on Kerner (Figure 2). Six treatments were produced: two treatments of the early harvest (an early harvest control and an early harvest chaptalised by 2% v/v) and four treatments of the late harvest (a late harvest control, late harvest chaptalised by 0.5% v/v, a late harvest control with alcohol reduced by 1% v/v and a late harvest control with alcohol reduced by 2% v/v).

Winemaking protocols

Riesling 2011

Riesling grapes from the vineyard 'Ranzenberg' Weinsberg in the German winegrowing region of Württemberg were harvested on 17 September 2011 with 20.0°Brix and 0% *Botrytis*. The late harvest date was 13 October 2011 at 22.8°Brix with less than 10% *Botrytis*, from the same vineyard plot.

The Riesling grapes were hand-harvested into 300 kg bins. The clusters were crushed and destemmed at 15° C, SO₂ was added at 50 mg/L on the skins, and skins were macerated for three hours, and then pressed with a pneumatic press (Vaslin Bucher XPF 8). The press juice was blanketed with CO₂ to avoid oxidation. The must was settled for 24 hours in a cold room at 3°C. The clear juice was racked off the lees and homogenised. The must was then pumped into 110 L fermentation tanks. Every treatment was fermented in duplicate. Parts of the early harvested juice were chaptalised by dissolving 3.8 kg sucrose in each 100 L of juice.

Fermentations were carried out in 110 L temperature-controlled stainless steel fermentation containers. Yeast (Uvaferm QA23) was added at 20 g/hL. Diammonium phosphate (DAP) was added at 0.3 g/L, 24 hours after inoculation. DAP additions of 0.3 g/L were made to all treatments when H₂S production was perceived in any one of the treatments. Fermentation was monitored daily using an Anton Paar DMA 35N density meter. Temperature was adjusted to between 12°C and 17°C to maintain a fermentation rate of between 1 and 2°Brix per day. At 0°Brix the fermenting tanks were racked and topped to finish fermentation in a full fermenter. One week after



Figure 1. Experimental design Riesling 2011



complete depletion of sugar was recorded, SO₂ (70 mg/L) was added and the wines were cold stored at 10°C until filtration. The wines were filtered with a tangential filter (0.2 µm) at the beginning of December. Parts of the late harvested treatments underwent alcohol reduction by osmotic distillation as described below. SO₂ was adjusted in all treatments to 40 mg/L free SO₂. The treatments were then stored in full containers at 0°C until bottling. Sterile bottling was performed in February using 500 mL bottles, closed with screwcaps. Thirty bottles of each treatment were filled. Headspace volume was kept below 5 mL per bottle, and the bottles were stored at 15°C until tasting.

Kerner 2012

In 2012, Kerner grapes from the vineyard 'Himmelreich' Gundelsheim in the German winegrowing region of Württemberg were harvested on 18 September 2012 with 20.6°Brix and 0% Botrytis. The late harvest date was 2 October 2012 at 22.4°Brix with less than 10% Botrytis from the same vineyard plot.

The Kerner grapes were vinified according to the same protocol as the 2011 Riesling, as described above.

Alcohol reduction

Alcohol adjustment was performed after filtration of the wines. The alcohol adjustment was performed using a membrane contactor equipped with a Liqui-cel X50 20m² Membrane (Membrana, USA). Twenty litres of wine was circulated in a countercurrent direction on the shell side. Forty litres of water (deoxygenated and saturated with CO_2) was circulated on the tube side of the membrane contactor, using positive displacement pumps at 800–1000 L/h. The temperature of wine and water was set to $25 \pm 3^{\circ}$ C. After approximately 30 minutes of circulation, the wine alcohol content was analysed in the alcohol-reduced wines. The wines were blended back to the desired alcoholic degree with addition of the original wine.

After blending, the wines were deoxygenated and the CO_2 content was adjusted to between 1.0 and 1.4 g/L in all treatments using a membrane contactor. Oxygen was removed in this gas adjustment step.

Analytical methods

Ethanol content was analysed using an Anton Paar Alcolyzer coupled with an Anton Paar DMA density meter. Wine analytical parameters were determined using methods specified by the OIV. Relative peak areas of ethyl acetate, isoamyl acetate, linalool, and 2-methyl butanol were determined using gas chromatography mass spectrometry (GC-MS). An Agilent GC 7890A with Mass Selective Detector 5973 C was used, following the method proposed by Ferreira et al. (1993).

Statistical analysis

Statistical analysis was performed using Excel 2010, Microsoft, Redmont, USA and XLSTAT Version 2011.3.01, Addinsoft Paris, France.

One- and two-way analysis of variance (ANOVA) was used to describe differences between the harvest timing (early or late harvest) and alcohol using Fisher's least significant difference (LSD) 5% as a post-hoc test on analytical data. Sensory data were treated using a three-way ANOVA on judge, repetition and treatment. A post-hoc test was performed using Fisher LSD 5%.

Sensory analysis

The Riesling aroma and taste attributes were evaluated in a session of sensory analysis ten months after bottling, in the sensory lab of LVWO Weinsberg equipped with FIZZ sensory software (Fizz, version 2.47 Biosystèmes, Courtenon, France). The evaluation of the wine samples was performed in isolated booths, under white lighting. All of the 23

panellists previously participated in eight weekly training sessions for the assessment of wine in descriptive sensory analysis.

Two bottles per treatment were randomly selected for assessment. A latin square design was used to randomise the sample presentation across the panel and wines were served at 12°C in clear tulip-shaped glasses.

Unstructured scales using 'low' to 'high' as anchors at the end points of the scale, were used for evaluation of aroma and flavour attributes. The panellists were required to rate the wine samples for the following aroma attributes: 'total aroma intensity', 'green apple', 'citrus' and 'tropical'. 'Sweetness', 'sourness', 'bitterness', 'alcoholic'/'burning' and 'body' were rated as taste attributes. Qualitative standards for the aroma attributes were provided. Attributes and absence of wine faults were determined by four wine experts before the wines were assessed by the main panel.

The attribute 'style' was introduced without previous training on this attribute: the panellists were asked to rate this attribute according to their own stylistic impression of the wines. The panellists were asked to rate each individual wine on a scale structured into four groups, with ticks between each groups. The groups were labelled with 'thin', 'elegant', 'full-bodied' and 'burning'/'hot'.

Sensory analysis was repeated using the replicated treatment. For the 2012 Kerner trial, aroma and taste attributes were evaluated in a similar manner in March 2013 by two different trained panels. First, the sensory properties of the late harvested treatments were subject to analysis by the main panel described above ($n=2 \times 20$). Later, the combined effects of ethanol concentration and harvest date were subject to sensorial analysis by a different panel that participated regularly in sensorial analysis (n=44). Before that sensorial analysis was conducted, fructose concentration was adjusted to 4 g/L in all treatments.

Results and discussion

Harvest data for both the 2011 Riesling trial and the 2012 Kerner trial are shown in Table. 1. As expected, the acidity is lower in the later picked treatments and the total soluble solids are higher due to the higher sugar. The total sugar content of the early harvested Riesling

Table 2. 2011 Riesling standard wine analysis

would result in about 12.0% v/v ethanol and the sugar content of the late harvest treatments would result in about 14.0% v/v ethanol at an expected ethanol yield of approximately 49%. The must acidity decreased at later harvest while the pH increased. The fermentable nitrogen of the Riesling is low for both treatments (Bisson 1999). In the 2012 Kerner trial, very low NOPA (nitrogen by o-phthaldialdehyde assay) values were observed indicating a danger for stuck or sluggish fermentation. In fact the early harvest chaptalised Kerner resulted in a sluggish fermentation that finished with 4 g/L residual sugar 44 days after inoculation.

Standard wine analysis

Riesling

Looking at the standard wine analysis using the two-way ANOVA, several effects can be observed (Table 2). Ethanol is not significantly affected by harvest date, which is due to the fact that ethanol levels were adjusted to the desired content for this trial. Residual sugars are not significantly affected by the treatment, because all fermentations of the Riesling completed to dryness. As expected from the must analysis and from other trials, the total acidity is lower in the later picked treatment and the pH is higher (Pineau et al. 2011). The two-way ANOVA does not show a significant difference in ethanol levels and the total acidity and tartaric and malic acids were also not significantly affected by the alcohol adjustment, which is also reported in other publications (Liguori et al. 2013).

Table 1. Harvest data of 2011 Riesling and 2012 Kerner

	Riesling 2011		Kerner 2012	
	early	late	early	late
Harvest date	17-Sep-11	13-Oct-11	20-Sep-12	2-Oct-12
Total soluble solids (°Brix)	20.0	22.8	20.6	22.7
Total sugar (g/L)	194	225	209	228
Potential alcohol (% v/v)	12	14	13	14.1
Juice pH	3.2	3.0	3.0	3.1
Titratable acidity (g/L)	6.9	6.0	6.9	5.7
NOPA (mg/L)	101	134	58	53

	early harvest 17 Sep 2011 late harvest 13 Oct 2011		13 Oct 2011	ANOVA significance			
	high	low	high	low	harvest date	alcohol	harvest x alcohol
alcohol g/L	95.4	111.9	108.8	96.8	ns	***	ns
	В	А	А	В			
fermentable sugar g/L	1.5	1.5	1.4	1.7	ns	ns	ns
		not sig	nificant				
sugar free extract g/L	18.3	19.0	20.1	20.6	**	ns	*
	С	В	А	А			
specific weight	0.9914	0.9893	0.9901	0.9921	**	***	ns
	В	D	С	A			
рН	3.0	3.1	3.3	3.3	***	**	ns
	D	С	А	В			
titratable acidity g/L	6.1	6.1	4.7	4.9	***	*	*
	А	А	С	В			
tartaric acid g/L	2.4	2.4	1.9	2.0	**	ns	ns
	А	А	В	В			
malic acid g/L	2.3	2.1	1.4	1.5	***	**	ns
	А	В	D	С			
volatile acidity g/L	0.3	0.3	0.3	0.3	ns	ns	ns
		not sig	nificant				
potassium mg/L	535	538	638	693	**	ns	ns
	В	В	А	A			
total phenols mg GAE/L	305	315	364	364	***	ns	ns
	В	В	А	А			

GAE = gallic acid equivalents

Post-hoc LSD 95%

level of significance: *=95% ; **=99%; ***=99.9%

No differences in the concentration of volatile acidity could be observed between treatments, although high sugar concentrations may cause a higher production of volatile acidity which was not observed in this experiment (Bely et al. 2003). No loss in the concentration of volatile acidity was observed due to the alcohol reduction by membrane contactor; it is neither concentrated nor significantly removed. This might be explained by the relatively low volatility of acetic acid at wine pH (Rayne and Forest 2011). Acetic acid is removed at the same level as the wine is concentrated.

The sugar-free extract value differs significantly among all treatments. The specific weight also differs significantly between all the treatments, which can be explained by the differences in total extract and ethanol, where total extract increases the specific weight and ethanol has the opposite effect on the specific weight.

Considering the effect of alcohol reduction by membrane contactor, it can be observed that the non-volatile matrix is slightly affected. Due to the loss of 2% v/v ethanol, the wine extract components are slightly concentrated. The total acidity, phenolics and minerals all slightly increased. However, because that increase is often within the analytical precision of the methods, it is not always statistically significant.

Kerner

Results of the 2012 Kerner trial can be seen in Table 3. It can be seen that harvest date is influencing residual sugar, pH and acids and that the alcohol concentration is influencing the specific weight and the residual sugar. In the early harvested treatments, a chaptalisation of the must did cause a sluggish fermentation, with the fermentation ceasing at 4 g/L residual sugar and the volatile acidity was slightly higher in these ferments compared to the other treatments. The sluggish fermentation together with its effects on residual sugar and volatile acidity can be attributed to the low content of assimilable nitrogen (Table 1) (Cramer et al. 2002) and the high content of fermentable sugars (Bely et al. 2003).

Both early and late harvest wines showed similar behaviour. The standard wine analysis is strongly influenced by the harvest date, while an ethanol adjustment had a slight effect on the analysis. Chaptalisation of the must might cause a prolonged fermentation which can result in some residual sugar and an increase in volatile acidity, as seen in the 2012 Kerner wine (Bisson 1999).

GC analysis of aroma compounds Riesling 2011

Relative peak area of four aroma compounds can be seen in Figure 3. None of the aroma compounds were significantly affected by the must chaptalisation or by the longer fermentation of these treatments. For the treatments where alcohol was reduced, the concentrations of the aroma compounds shown decreased between 5 and 30%. The losses for the highly volatile esters ethyl acetate and isoamyl

Table 3. ANOVA of 2012 Kerner standard wine ana	lysis
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	Harvest	Alcohol	Harvest x Alcohol
alcohol g/L	ns	***	ns
fermentable sugar g/L	**	**	*
sugar free extract g/L	*	ns	ns
specific weight	ns	**	*
рН	**	ns	ns
titratable acidity g/L	*	ns	ns
tartaric acid g/L	**	ns	ns
malic acid g/L	**	ns	ns
volatile acidity g/L	**	ns	**
total phenols mg GAE/L	ns	ns	ns

level of significance: *=95% ; **=99%; ***=99.9%, GAE = gallic acid equivalents

acetate were greater than for the less volatile alcohols linalool and 3-methyl butanol. These results are in accordance with other publications that showed ethanol reduction using a membrane contactor is accompanied by a reduction in the concentration of all volatile aroma compounds (Diban et al. 2008). In this wine the use of a membrane contactor caused losses of linalool of about 5%, quite a small loss. Two effects might be responsible for the small losses: first, the low volatility of free linalool and second, the fact that bound linalool concentration is not reduced by alcohol reduction (Lisanti et al. 2012).

The concentrations of ethyl acetate, isoamyl acetate and linalool were all observed to increase with later harvest date. The observed difference in ethyl acetate concentrations might be due to the slightly extended fermentations of the late harvest treatments. Another explanation might be in accordance with the results published by Dennis et al. (2012) which concluded that the production of various esters can be attributed to grape-derived precursors. The content of the free monoterpene linalool increased by 300% due to a later harvest, which might be due to a higher content of grape-derived precursors. This increase due to harvest date is much higher than the losses due to alcohol reduction. Therefore, it can be concluded that the concentration of this compound is only slightly affected by ethanol content. For the fruity esters ethyl acetate and isoamyl acetate, the higher concentration due to harvest date is lost during the alcohol reduction. Therefore the concentrations of these esters are highest in the late harvest control treatment, which might result in a higher perceived aroma of this treatment (Escudero et al. 2007).

Sensorial analysis of the Riesling wines

Descriptive sensory analysis of the Riesling wines shows how both factors (harvest time and alcohol content) influence the wine's aroma and taste attributes (Figure 4). In this Riesling wine the later harvested treatments have significantly higher overall aroma intensity than the early harvested treatments. This can be explained by



Figure 3. Aroma compounds across the different Riesling treatments shown by relative peak areas compared to internal standard. Error bars indicate standard deviations. Treatments labelled with different letters indicate a significant difference using Fisher's LSD at 5%.

their higher content of free monoterpenes such as linalool, which is important for the varietal character of many white wines (Campo et al. 2005). Other grape-derived aroma compounds like the norisoprenoids might react in a similar manner and contribute to this total aroma intensity; however, these were not measured in this study. The aroma attribute 'tropical' shows the same behaviour. While the early harvested treatments were rated low, the late harvested treatments had a significantly higher rating for this attribute. This is in accordance with data reported on Sauvignon Blanc (Pineau et al. 2011), although in Sauvignon Blanc, methoxypyrazines and volatile thiols are usually present in much higher concentrations than in Riesling wines (Francis and Newton 2005).

Neither chaptalisation nor alcohol reduction significantly affected the intensity of the overall aroma, though the concentration of the measured esters is significantly higher in both high alcohol treatments. This might be surprising, because the concentration of esters is known to have an enhancing effect on the fruit characteristics of wines (Escudero et al. 2007). Conversely the attribute 'green apple' is significantly more intense in the low alcohol treatments. For this attribute the higher partition coefficient for some aromatic compounds, depending on the ethanol concentration, might affect the sensory impact of the fruity aroma 'green apple'. However, at ethanol differences of 2% v/v this is rarely perceivable (Villamor et al. 2013a). In fact, a statistically significant difference is only perceived between the treatments 'early harvest high alcohol' and the 'late harvest low alcohol'. An alcohol adjustment between treatments of one harvest date did not lead to a significant change in the perception of aroma compounds.

Considering the aromatic styles of the wine, it can be concluded that the aroma profile of the wine is much more related to the harvest time than to the alcohol content. Alcohol adjustment was found to only slightly influence the aroma of the wines. The aromatic and flavour descriptor 'tropical' (a very important attribute to the aromatic composition of Riesling wines) is strongly altered by harvest date. The aroma compound losses due to alcohol reduction did not play an important role in this trial.

In this particular Riesling, significant sensorial differences can be observed comparing the taste attributes. The late harvested treatments tend to appear slightly 'sweeter' and less 'sour', which can be easily attributed to the concentration of total acidity in wine. Although ethanol is reported to influence the 'sweetness' and 'sourness' of



Figure 4. Descriptive sensory analysis for the 2011 Riesling using 22 panellists and 2 replicates. Treatments labelled with different letters indicate significant differences using Fisher's LSD at 5%. ANOVA p indicates the level of significant differences between the treatments.

wines, the ethanol content had just a slight impact on these attributes (Zamora et al. 2006). Nevertheless the lower alcohol wines tend to taste slightly more acidic. The alcohol concentration has a strong impact on the attribute 'burning'. Ratings for the attributes 'body' and 'bitterness' did not increase significantly in the more alcoholic wines, possibly because the ethanol difference was not large enough, and the content of bitter phenolic compounds is too low in the wines to show this well described effect of ethanol (Fischer and Noble 1994).

Sensory analysis of the 2012 Kerner resulted in similar observations. Figure 5 plots these sensory results on a principal component analysis. Harvest date strongly influences the aroma attributes and the attribute 'sourness', while ethanol has a strong impact on the taste attributes. Although the influence of ethanol on the perceived 'sweetness' and 'sourness' of wine is well explained, the effect on the wine matrix of harvest date seems more important for these attributes (Zamora et al. 2006). Similar to the analytical effect on aroma compounds, the influence of an alcohol adjustment is less important compared to the change due to harvest date. This change in harvest date did drastically modify the wine style in the important aroma attributes 'total intensity' and 'tropical'.

In both wines, Kerner and Riesling, the intensity of 'green apple' aroma decreased at higher ethanol concentrations. This can be explained by the lower volatility of some compounds due to ethanol concentration. Although the change in the fruit style of several commercial wines can be attributed to ethanol, that effect is increased due to secondary effects caused by fruit maturity which are accompanied by higher ethanol concentrations (King et al. 2013). In accordance with the results of Heymann et al. (2013) a chaptalisation did not move wines of the early picked treatments towards a more 'ripe' aromatic style. Furthermore, an alcohol reduction of the late harvested grapes did not change the aromatic wine style significantly towards a 'greener' early harvested wine.

Style attribute

The newly introduced attribute 'style' is plotted on a frequency diagram for all three series (Figure 6). In all series it can be observed that ethanol strongly influences this attribute. While relatively low alcohol concentrations are considered mainly 'elegant' and by some tasters as 'thin', higher ethanol concentrations are rated as 'full bodied' by more tasters, depending on the ethanol content. The Kerner wines were differentiated only by ethanol, and the wine which was reduced to an ethanol concentration of 12.5% v/v was considered as 'thin' by 45% of all panellists. That frequency was reduced to 5% for the wine chaptalised to 15% v/v. That wine was considered as 'full bodied' by more than 50% of all panellists. The wine at an ethanol level of 14.5% v/v was considered as mainly 'elegant'. The alcohol reduction of a 'full-bodied' wine resulted in a wine that was rated as more 'elegant'.

Comparing the different harvest dates at equal ethanol concentration, the 'style' attribute gives additional information on the change of the wine due to the alcohol adjustment. Considering the mean



Figure 5. PCA of the sensory attributes for the 2012 Kerner harvest and ethanol trial

rating of style, in Riesling the attributes are equal between the early and the late harvest dates at the same ethanol level. Looking at the frequency of the undesired attributes 'thin' or 'burning' it is observed that their occurrence is higher in the early harvest compared to the late harvested wines, and this effect deserves to be further studied.

In all three series of wines the 'style' attribute shows very good and reliable data to separate wines by their difference in alcohol concentration. Although the panel was not trained for this attribute, the attribute is very discriminating for differences due to alcohol adjustment. This attribute comprises several other taste attributes like 'body' and 'burning'/'alcoholic'. Nevertheless it explains how the wines adjusted in alcohol differ between each other. The discrimination between wines with an alcohol difference of 1.5% v/v and 2% v/v was excellent in all sensory analysis performed using this attribute, while sensory triangle tests or classical descriptive analysis often do not show statistically significant changes in wine sensory due to an alcohol reduction of 2% v/v (Aguera et al. 2010; Blank and Sigler 2012). Therefore, using the attribute 'style' for sensory analysis probably provides better differentiation than other sensorial tests. As a result of this study the attribute has been implemented in standard descriptive sensory analysis in our lab.

Combining all sensory data, harvest date is shown to determine the fruit character of the resulting wines. Therefore, harvest date should





be selected in accordance to the desired fruit profile. The other important factor – alcohol concentration – also has a strong influence on a wine's sensory profile; a technological adjustment of wine ethanol content changes the 'style'. Higher alcohol content wines are considered 'full-bodied', while lower alcohol wines taste more 'elegant'. When the alcohol concentration is too low, the wine is considered 'thin', and when it is too high, the wine is considered 'burning'. Alcohol adjustment allows wine to be changed towards the required 'style' without drastically modifying its aromatic character. Hence, alcohol adjustment increases the possibility of gently adjusting wine style according to consumer requirements.

Conclusion

This study provides further indication of the effect that alcohol and harvest date have on wine style. Harvest date changes the perceived aroma characteristics and perceived acidity of a wine. Ethanol has a strong influence on the perceived style of the wine. Although there is a loss in aromatic compounds due to an ethanol reduction, this loss is not perceived by trained panellists. Hence an alcohol adjustment can be used to further differentiate a wine's taste and style to a desired profile without having a strong effect on the flavour.

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SESSION 4: Flavour masterclass



From compounds to sensory perception: what affects complexity and uniqueness of wine aromas?

P. Darriet, M. Nikolantonaki, A. Schüttler, D. Rauhut, A. Pons, P. Stamatopoulos

Understanding human perception and response during aroma evaluation and tasting of wine

A. Buettner, J. Beauchamp, J. Freiherr

What role do vision and the other senses play in wine appreciation? *C. Spence*

What do consumers really value in making wine purchase decisions? L. Lockshin



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From compounds to sensory perception: what affects complexity and uniqueness of wine aromas?

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Abstract

During wine tasting, tasters assess a wine's appearance, aromatic intensity, complexity and quality. The perception of these parameters depends on the wine taster's knowledge of wine, wine tasting skills and sensitivity to aromas and flavours; all wine tasters are different in these areas. A wine taster may also consider the level of typicality, i.e. seeking unconsciously to categorise the wine, and to determine its similarity to the perceived prototype or the 'reference' wine for this category. What parameters underline the perceived aroma attributes? Wine aroma is related to numerous aspects such as: natural factors and human choices regarding varieties, vineyards and grapegrowing practices; winemaking parameters such as pre-fermentation operations; microbiological populations on the grapes and during fermentation; and the approach taken to ageing. But, initially, qualitative aroma perception is due to chemical compounds present in the wine that stimulate responses in the brain through very complex combinatorial processes. How many volatile compounds are present in the headspace of a wine glass? Do all wine components have a similar impact at low and high concentrations? Do some volatile compounds contribute to the aroma of iconic wines more than other wines? This paper presents examples of recent research into various wine volatile compounds that are associated with off-odours; contribute to varietal expression; and have synergistic effects on fruity expression of wine, and explore the relationships of these aromas with wine sensory perception.

Introduction

The quality of wine aroma is a matter of great importance. After colour, the first sensory impressions are related to the wine aroma through orthonasal, then retronasal, sensations. The taster can find in the wine a wide aromatic palette including spicy, woody, flowery and fruity components originating from the grape variety, the soil, climatic conditions under which the wine was made, and vinification and ageing processes (Peynaud 1980). Sometimes the taste is the source of great pleasure, and represents such a level of uniqueness, that it is considered a real work of art (Peynaud 1980).

The wine taster can taste using either hedonic criteria or analytical criteria, depending on their preferences and knowledge of wine tasting. In this context, they also appreciate the intensity and the complexity of the aromatic nuances, and the wine quality (Peynaud 1980). Analysis of the language used by a group of professional wine tasters showed that they seek less to describe wines than to categorise them in relation to types already memorised (Brochet and Dubourdieu 2001). Tasters unconsciously seek to associate the wine aromatic components that are related to specificity and originality, with a stored reference (an ideotype). This aspect is related to the concept of typicality (Rosch and Mervis 1975; Mervis and Rosch 1981; Loken and Ward 1990). However, not all nuances are perceived in the same manner by different tasters; all tasters have a unique personal sensitivity to aromas (Tempère et al. 2011). The context of the wine tasting may also have an impact on the perception of flavour (Peynaud 1980; Morot et al. 2001). The perception of wine aroma and typicality is a complex cognitive process involving all the senses including somatosensory perceptions.

So, on what basis are a wine's aromatic nuances perceived? The aromatic palette is initially associated with volatile compounds, which can be very numerous (from one to several hundred) in the headspace above a glass of wine. Iconic wines usually have a complex composition consisting of a higher number of compounds. These compounds are stimuli for the human olfactory system, commencing with the olfactory epithelium before being transformed into nerve impulses in the olfactory bulb and becoming conscious sensations (Lledo et al. 2004; Shepherd et al. 2006). However, volatile compounds do not equally contribute to the aroma of wine. Some, present in trace amounts (in the order of ng/L or pg/L) have a very low olfactory detection or recognition threshold, while others at higher levels (several mg/L) have a higher detection or recognition threshold (Ribéreau-Gayon et al. 2006; Ebeler and Thorngate 2009). This paradoxical situation is due to the specificity of detection by the human olfactory system. However, a higher concentration of a compound will, as a general rule, increase its perceived intensity (Grosch 2001). Also, the presence of other wine compounds (ethanol, polyphenols, wine acidity level, etc.) can impact on the composition of volatiles present in the headspace above the wine (Escudero et al. 2007; Robinson et al. 2009; Lorrain et al. 2013) and potentially on the sensory perception.

Nevertheless, the aroma perceived by the brain is not the result of an algebraic sum of all volatile compounds. It is related to a complex combinatorial process involving all volatile compounds in the unconscious stage of perception (Malnic et al. 1999; Shepherd 2006). Thus, the ultimate perception and verbalisation of aromas involve complex, unconscious combinations of volatile compounds, as well as cognitive processes and memories of past experiences (Lledo et al. 2004).

In this presentation, the relationship between volatile compounds and wine's aromatic attributes (complexity and uniqueness) will be described through recent work conducted at the Enology Research Laboratory at the Institut des Sciences de la Vigne et du Vin (ISVV) in Bordeaux. The detrimental impact of compounds responsible for off-odours, the complex interaction of some key volatile compounds in overall perception, sometimes in favour of a combinatorial perception and the aromatic attributes of wines will be discussed.

The detrimental impact of off-odours on wine aromatic expression

Many examples show us how wine tasting can be affected by volatile compounds associated with organoleptic deviations. The origin of such changes concerns both the quality of the grapes – fruit ripening conditions, bunch rot development on grapes – and changes
during winemaking or ageing in oak barrels and in bottles. Also, the characterisation of the compounds responsible for the off-odours is important for the development of control strategies and then protocols to address the problem and improve wine quality. There are many examples (Ribéreau Gayon et al. 2006): sour off-odours due to ethyl acetate, cork taints associated with the presence of 2,4,6-trichloranisole and 2,3,4,6-tetrachloroanisole formed by *Ascomycetes* fungi (*Penicillium* sp. and *Trichoderma* sp.) or 'Brett' character, from *Brettanomyces* sp. yeast (Chatonnet et al. 1992; San Juan et al. 2011). The perception of an off-odour depends on both the concentration of the responsible compound and its olfactory detection (or recognition) threshold. Overall, four points should be taken under consideration.

Firstly, the perception of an off-odour is highly dependent on individual sensitivities. The olfactory detection threshold for fungal off-flavours among students in Bordeaux revealed that 10% of the students had a 2 to 4-fold higher sensitivity (a lower threshold) in comparison to the average value of the group (n = 60) (La Guerche et al. 2006). A study of 134 wine professionals (Tempère et al. 2011) highlighted that the distribution of individual detection thresholds for a mixture of 4-ethylphenol and 4-ethylguaiacol (in a 10:1 ratio) varied by a factor of 100 between the persons with lowest and highest sensitivity.

Secondly, perception can be modulated by the presence of other volatile compounds. Taking the example of 'Brett' character, Romano et al. (2009) showed that the detection threshold of a mixture of 4-ethylphenol and 4-ethylguaiacol (in a 10:1 ratio) is increased (i.e. reduced perception) by the presence of other volatile compounds in wine related to *Brettanomyces* sp. metabolism, suggesting a type of masking phenomenon.

Thirdly, wine tasters have a variable capacity to discriminate odours in a complex mixture. For example, the ability of a wine taster to identify 'Brett' odour highly depends on their level of experience and education regarding ethylphenols (Tempère et al. 2013).

Finally, it should also be noted that some volatile compounds can have an impact on the aroma perception at concentrations that elicit a subliminal rather than conscious response. Empirical knowledge on this point was recently confirmed in relation to 2,4,6-trichloroanisole (Tempère et al. 2012).

These four aspects should be taken into account when analysing the impact of off-odours on wine aroma.

Studies concerning several off-odours have been conducted in our institute. One area of focus has been the 'mushroom', 'camphoreous' or 'earthy' off-odours that can arise from grape bunch rots in harvests with, among other things, poorly timed rain, persevering morning mists and/or hail. Analysis of these off-odours has led to the identification of several impact compounds, including 1-octen-3-one and 1-nonen-3-one (fresh mushroom odours) and (-)-geosmin (powerful 'damp earth' and 'beetroot' odour) (Pons et al. 2011, La Guerche et al. 2006). These fungal off-flavours are related to grapes with bunch rot complexes between Botrytis cinerea and secondary saprophytic invaders belonging to various species especially from Penicillium genus (La Guerche et al. 2005, 2007). Due to the potent odour of (-)-geosmin (perception threshold of 10 ng/L in water), less than one per cent infection in the plot of a vineyard is enough to contaminate the entire harvest (La Guerche et al. 2006). Particular vigilance in the prevention and control of grey mould caused by B. cinerea in the concerned vineyards, along with careful sorting of affected grapes from unaffected grapes is recommended given the strong sensory impact (La Guerche et al. 2006).

Much has been done over the last thirty years to advance the technology of dry white and rosé vinification. An emblematic example is the process of vinification of Sauvignon Blanc wines, which has been heavily revised from former practices (Dubourdieu et al. 2006). However, improving the processes to refine the aromatic component is always a hot topic. Recently, a malodourous sulfur metabolite perceived as 'baked beans' and 'Fritillaria sp. bulbs', ethyl 2-sulfanylacetate was identified, which can affect dry white and rosé wine aroma (Nikolantonaki and Darriet 2011). This compound is not associated with the sulfur metabolites that are produced during alcoholic fermentation of grape juice fermented with solids, nor excessive addition of sulfur dioxide in the must. It is produced during alcoholic fermentation, particularly in wines made from hard-pressed juices and oxygenated musts (Figure 1). Depending on the wine matrix, the level of its concentration at which dry Sauvignon Blanc aroma is affected varies in supplemented wines at between 300-500 ng/L, while the detection thresholds of ethyl 2-sulfanylacetate in water and hydroalcoholic solution are 70 ng/L and 200 ng/L respectively. Moreover, during the ageing of white wine in bottles, the concentration of this compound increases. Knowledge of this compound facilitates informed pressing and juice selection choices and a white wine vinification that preserves aroma. Particular vigilance is recommended in situations where this malodourous compound is produced, with one main strategy being grape pressing under a nitrogen atmosphere to limit grape juice oxidation (Nikolantonaki and Darriet 2011).

Oxidative changes in the aroma of white and red wines, known as prematurely oxidative evolution or 'premox' is another issue of concern considering the impact of oxidative changes on the freshness and complexity of a wine's aromatic expression. In dry white wines, premox is associated with the appearance of dominant 'waxy', 'honey' and 'nutty' aromas, while in red wines it is associated with dominant 'fig' and 'prune' aromas. The aromatic component of the wines is not directly affected in the same manner as the off-odours described elsewhere in this paper, but the wines' originality and identity are modified and the overall enjoyment is usually affected. Several odoriferous marker compounds of aromatic dry white wines affected by premox have been identified in recent years, including: sotolon which smells like nuts (and, paradoxically, contributes to the typical aromatics of some fortified wines) (Cutzach et al. 1998; Silva Ferreira et al. 2003a); phenylacetaldehyde with 'floral' and 'honey' nuances; and methional with 'boiled potato' odours (Escudero et al. 2000; Silva Ferreira et al. 2003b; Pons et al. 2008a). Fortunately, some technological strategies, such as the ageing of wines on yeast lees, help to prevent sotolon formation during ageing of bottled wine (Lavigne et al. 2008). The wine closure, and particularly its permeability to oxygen, also constitutes an important risk factor for premature oxidative evolution during wine ageing (Lopes et al. 2009).

The oxidative evolution of red wines during ageing in barrels or in bottle is related to a diminution of fresh fruity aromas, followed by the evolution of aromas reminiscent of 'prune' and 'figs'. A potent compound associated with red wine premox, 3-methyl-2,4-nonanedione (MND), was recently identified by our group (Pons et al. 2008b,



Figure 1. Quantitative assay of ethyl 2-sulfanylacetate in different young white wines (I-V) made from hard pressed juices extracted under nitrogen atmosphere (N) or in contact with oxygen (O). Source: Nikolantonaki and Darriet 2011

2011). Its very low detection threshold was determined in a model red wine solution and in red wines (16 ng/L and 64 ng/L, respectively). MND concentrations in premox red wines were always higher than the detection threshold of this compound. Also, 'prune' aroma perception in prematurely aged red wines correlated significantly with MND concentrations (Pons et al. 2011, 2013). It is surprising that MND can so significantly diminish a wine's fresh fruity flavour, since the compound itself has an 'aniseed' and 'dried parsley' smell (Pons et al. 2011, 2013).

The importance of key volatile compounds in wine's uniqueness and complexity

The uniqueness and complexity of wine aroma depends on the presence in the wine of key volatile compounds. Characterisation of these volatile compounds constitutes the heart of research on wine aroma. Indeed, the chemical characterisation of impact aroma compounds and analysis of how they contribute to wine aroma provides the opportunity to consider various aspects of oenological technology, including wine microorganisms and grape maturation conditions.

Wine aroma compounds can be associated with a varietal origin. They can be released from precursors during fermentation, originate from oak barrels or arise during wine ageing. For example monoterpene alcohols or terpenols, especially linalool, geraniol, citronellol and trans-hotrienol, are impact compounds that have been known for many years to contribute to the floral aroma of varieties such as Muscat, Gewurztraminer, Muscadelle, and Viognier. (Strauss et al. 1986; Ribéreau-Gayon et al. 2006). Also, discovery of the role of very potent varietal and ageing thiol compounds was a major breakthrough in the field of characterisation of key compounds in several wine varieties. Previously it had been assumed that such compounds could only be responsible for off-odours in wine (which remains true in some cases, e.g. the identification of ethyl 2-sulfanylacetate). It is now understood however that potent varietal thiols or sulfanyl compounds are major drivers of the typical aroma of Sauvignon Blanc wines and wines made from many other white and red grapes (Chenin Blanc, Gewurztraminer, Semillon, Petit Manseng, Arvine, Colombard, Merlot, Cabernet Sauvignon), including dessert wines (Sarrazin et al. 2007). Compounds such as 3-sulfanyl-1-hexanol ('citrus'), 4-methyl-4-sulfanyl-2-pentanone ('boxtree'), 3-sulfanylhexyl acetate ('grapefruit', 'passionfruit' and 'boxtree'), exhibit attractive aromas at concentrations in the range of ng/L (Darriet et al. 2012). Other thiols arising during fermentation and contributing to fermentative and ageing wine aroma can be related to 'cooked meat' or 'roasted coffee', such as 2-methyl-3-furanthiol (Tominaga et al. 2000; Bouchilloux et al. 1998; Tominaga and Dubourdieu 2006). Other examples of key impact compounds include rotundone (Siebert et al. 2008; Wood et al. 2008). Also, the sensory properties can vary between chiral forms of the same compound, the proportion of each enantiomer being of great importance (Tominaga et al 2006; Lytra et al. 2012).

Despite the above developments, multiple aromatic nuances have not received any molecular interpretation, and characterisation of many fragrant aroma compounds in wines is still required.

It must also be noted that excessive focus on one or two aroma compounds and practices that seek to increase these specific compounds in wines can lead to loss of aromatic complexity. For example, in the past, several examples have shown how excessive use of pectolytic enzymes with β -glucosidase activities can standardise and reduce the complexity of the aroma of white wines in a Muscat style. The impact of volatile compounds should always be evaluated by sensory analysis in order to correlate such compounds with aroma attributes. Sensory analysis tests can be categorised as discrimination tests, descriptive tests (such as quantitative descriptive analysis

[QDA]), and categorisation tests. Work over the last ten years in the fields of psychophysics and cognitive sciences has clarified empirical knowledge on the parameters of the classical approach through which tasters categorise wines (Brochet and Dubourdieu 2001; Rosch and Mervis 1975; Mervis and Rosch 1981). This methodology was introduced into oenology by Ballester et al. (2005), then Parr et al. (2007) and allows expert tasters to determine the level of uniqueness of flavour in wines. The experts develop a gradient of representation of the typicality, attributing to the most distinctive wines the best score.

This sensory approach was applied to identify compounds associated with the aromatic profile of dessert wines from Sauternes (Sarrazin et al. 2010) and Riesling wines (Schüttler et al. 2011; Schüttler 2012). Thanks to an over-ripening process in the presence of Botrytis cinerea, dessert wines can present an exceptional range of aromas, evoking 'citrus' and 'dried fruit' in young wines and 'orange peel' in older wines. By selecting a wide range of dessert wines from various sources (with and without noble rot) the existence of sensory characteristics unique to the dessert wines of Bordeaux - which were not found in a sample of dry white wines and dessert wines from other wine regions - was demonstrated. In addition, a gradient of 'representativeness' was defined for Bordeaux dessert wines. Key compounds, belonging to different chemical families, whose concentrations are significantly correlated with Sauternes dessert wines include γ -nonalactone (p< 0.01), associated with 'peach' and 'coconut' aromas, and 3-sulfanyl-1-hexanol (p< 0.01), 3-sulfanyl-1heptanol (p< 0.01) and 3-sulfanyl-1-pentanol (p< 0.01), each associated with 'citrus' aromas (Sarrazin et al. 2010). Other compounds such as furaneol and homofuraneol, which manifest as 'cooked caramel' aromas, appear to be related to the aroma of dessert wines from many countries.

Riesling wines can be identified orthonasally by key volatile compounds associated with the variety. Citrus fruit descriptors are significantly associated with young Riesling wine aroma, as determined by French and German expert sensory panels (Schüttler et al. 2011; Schüttler 2012). Young Riesling aroma was also linked with 'fruity' and 'yellow fruit' descriptors by a German sensory panel (Schüttler et al. 2011). Riesling wines' typicality in both panels was shown to be well correlated with the concentrations of the varietal thiol 3-sulfanyl-1-hexanol (23 Riesling wines; 7 non-Riesling wines). In contrast, Riesling typicality could not be correlated with linalool or TDN concentrations. Interestingly, while average linalool concentrations diminished with increasing typicality of Riesling wines, linalool concentrations were very well correlated with their floral perception (Spearman correlation, p< 0.01) (Schüttler 2012).

Phenomena of perceptual interaction, synergistic and synthetic (or configural) perceptions

Despite recent, substantial progress towards identifying unique varietal aromas, the construction of olfactory 'images' in the brain is so complex that the key compounds alone are not able to explain the nuances of the flavour characteristics of wines. Wine aromas result from combinatorial effects between volatile compounds which, due to their nature or level of concentration, contribute to the sensory perception by perceptual interaction phenomena in the brain. For example, volatile compounds can contribute to aroma attributes through additive effects or synergistic phenomena (increasing intensity, perceived complexity and/or collectively generating a new aroma not present when the compounds are considered in isolation) or masking phenomena (decreasing perceived intensity, as is the case for some off-odours). Reconstitution experiments, in which volatile compound mixtures are prepared and subjected to expert sensory panels, can generate progress. For example, in the 1970s the additive effect between monoterpenes in contributing to the aroma of Muscat were highlighted (Ribéreau-Gayon et al. 1975). More recently, Sarrazin et al. (2007) established additive effects between different volatile thiols identified in Sauternes dessert wines. Interesting synergistic effects have also been observed in recent years between some ethyl esters of fatty acids and acetates of fusel alcohols in the fresh fruity aromas of red wine. When present together, the contribution of these compounds is significant; however, when considered alone, at concentrations below their odour detection threshold, they do not contribute to red wine fruity aroma (Escudero et al. 2007; Pineau et al. 2009). By way of example, ethyl 2-hydroxy-4-methylpentanoate was recently demonstrated to be an enhancer of red wine fruity aroma (Lytra et al. 2012; Falcao et al. 2012).

Another example of perceptual interaction phenomena concerns the aroma of dessert wines (Stamatopoulos et al. 2014), as part of a study on compounds involved in the 'candied citrus' and 'orange' aromas of these wines. Emphasis was placed on the study of the phenomena of perceptual interactions and 'aromatic recovery' was an important research approach. While fractionating an extract of premium dessert wine, a fraction was recognised which contained the above mentioned characteristic aromas - a fraction which was not present in lower quality wines. Analytical chemistry coupled with sensory analysis helped to identify the compounds present in this fraction which were associated with the odour as whisky lactone ('coconut'), eugenol ('clove'), and a newly identified lactone ('minty' and 'fruity'), the latter apparently associated with noble rot. None of these compounds in isolation produced an orange aroma at concentrations close to those assayed in wines. But numerous omission and reconstitution tests have demonstrated that these compounds, particularly the two lactones (one originating from the oak wood, the other from botrytised grape), together generate a perceived 'orange' aroma. The correlation of whisky lactone with wine fruitiness has even been cited (Sarrazin et al. 2010; Spillman et al. 2004). Such a sensory phenomenon, well known in perfumery, had not previously been evidenced in wine. It appears to substantially contribute to wine uniqueness and complexity and opens new avenues for the study of the characterisation of wine aroma.

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Understanding human perception and response during aroma evaluation and tasting of wine

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Abstract

The evaluation and tasting of wine can be regarded as special skill and an act of sophisticated performance if carried out by a trained wine evaluator. It can also be an unconscious process of savouring and rating. However intense the attention that we pay to the evaluation of wine, numerous factors far beyond our consciousness or deliberate control influence and trigger our final perception. The sensations that we experience are constantly rated, ranked, integrated and modulated by diverse, poorly-understood physiological control mechanisms. These phenomena collectively trigger physiological, psychological and behavioural responses in humans that can modify our approach to assessing the wine sample including actions of swirling, swallowing or expectoration and, as a consequence, our holistic perception of the wine. This complex network of stimulation, integration and interpretation, and response is addressed in this paper.

Introduction

The aroma and flavour of wine stimulate our senses and trigger a range of physiological and psychological responses that, acting together, define our perception and appreciation of the product. These diverse sensations, and specifically their combinatory and sequential order, are complex and poorly understood. There is a growing interest in elucidating the physiological and psychological responses of humans to these sensory triggers. However, not only are the stimuli complex, the human physiological and psychological responses and their interactions are multifaceted. When aiming to understand these complex relationships, researchers need to establish a comprehensive toolbox that links analytical techniques with an array of sensory, physiological and psychological methodologies, monitoring devices and assays. Some of these will be addressed in this paper, with special focus on bridging the gaps between disciplines and research areas.

Immediate oral and nasal chemosensory effects

Perception of wine aroma compounds can be broadly divided into different stages. Initially, orthonasal sensations occur when the wine is sniffed, giving the first impression of the wine's volatile attributes (Buettner 2003; Buettner and Beauchamp 2010). But our traditional understanding of flavour and aroma compounds (for example, 'red fruit') is just one aspect of the complex sensations that trigger our senses and responses to the smell of wine. Chemosensorially active substances, including ethanol and certain volatile compounds, can further stimulate the nasal trigeminal system by activating so-called transient receptor potential (TRP) ion channels that may impart sensations such as burning, stinging or cooling (Vriens et al. 2008; Hau et al. 1999). Carbon dioxide, a characteristic feature of sparkling beverages such as champagne or sparkling wine, is another trigeminally-active substance. The nature and intensity of such trigeminal triggers influence overall perception. Moreover, trigeminal and olfactory sensations can strongly interact and modulate the perceived intensity of certain characters (Brand 2006; Hummel and Livermore 2002). At this initial stage of smelling, the interactions are already complex, with odorants potentially undergoing biotransformation or acting as modulators of biotransformation processes (Schilling et al. 2008). There is still much to learn about the perception of a complex aroma such as that of wine.

Sommeliers and experienced wine tasters are generally aware of the fact that orthonasal perception does not necessarily align with retronasal perception, itself another multi-layered phenomenon. At least three key stages of retronasal perception can be distinguished: (a) the immediate and transient aroma impression when wine is present in the oral cavity; (b) the impression of wine immediately after swallowing, sometimes referred to as 'retronasal aroma flash'; and (c) the prolonged retronasal aroma perception after swallowing, often called 'aftertaste' or more correctly 'afterodour' or 'aftersmell' – in wine degustation the term 'finish' might be a more appropriate choice.

A detailed explanation of the physiological features influencing aroma transfer from the oral cavity to the nasal cavity is outlined elsewhere (Buettner et al. 2002). Visualisation of 'normal' swallowing of liquids by real-time magnetic resonance imaging (MRI) has shown that aroma perception does not usually occur prior to swallowing since the velum (or soft palate) separates the nasal cavity from the pharyngeal and oral passages. It forms either a tight velum-tongue connection during the preparatory swallow phase or a velopharyngeal closure during the pharyngeal phase of swallowing. Immediately after swallowing, the velum opens up the nasal passage, thus allowing volatiles to be transported into the nasal cavities with the aid of a 'swallow breath'. Although this instinctive swallowing behaviour proceeds subconsciously and automatically, the manoeuvre can also be performed deliberately, as in the case of many professional wine tasters. Well-directed and well-timed opening of the velum-tongue border at the moment when wine is present in the oral cavity can lead to an enormous enhancement of retronasal aroma perception.

The volatile fraction of wine is obviously not the only stimulatory force. Taste impressions, most importantly 'sweet', 'sour' and 'bitterastringent' sensations, contribute to our overall sensory impression. In addition, trigeminal perceptions may influence taste impressions. Retronasal wine odorant perception occurs in the context of the perception of taste sensations and both orally and nasally-active trigeminal compounds.

In the taste sensation the different phases of immediate and prolonged processes can be separated in a similar manner to the phases of oral sensation. These sensations, and the order in which they occur, are processed and rated via multimodal sensory integration processes that to date are poorly understood.

Afterodour perception is the last major step in a wine taster's evaluation. Despite its importance, literature on this topic – especially relating to wine – is very rare and limited to general sensory descriptions that do not take into account the persistence of any precisely defined aroma impression after wine consumption. It is clear, however, that afterodour and aftertaste perception is influenced by a series of physiological and physicochemical parameters (Buettner and Schieberle 2000a; Buettner et al. 2001). One of these key parameters might be the adsorptive potency of odorants and tastants to the nasal and oral mucosa (Buettner et al. 2002; Buettner and Schieberle 2000b). Some chemosensory substances, for example 'bitter' compounds, can be quite persistent and even increase their sensory impact over time. In addition to physicochemical parameters such as polarity and volatility, the influence of human salivary enzymes on the differences in persistence between odorants has been proposed (Buettner 2002a, b). It is believed that odorants that are absorbed by the oral mucosa to a high extent (and that are not degraded by salivary enzymes) play a major role in a prolonged retronasal aroma perception, as long as they are released from the mucosa and not resorbed by the mucosal tissue (Buettner 2004).

Integration of sensory phenomena

Two phases can be distinguished in wine tasting - an observatory phase when examining and smelling the wine, and a tasting phase when the wine is actually introduced into the oral cavity, swirled around, 'chewed' etc., and finally expectorated or swallowed. The overall perception is considered to be the sum of the two main phases. This staged process might seem obvious and trivial, but it impacts on multisensory integration and the overall outcome. For example, taste, a sensory dimension that is at first not important when evaluating wine olfactorily, gains a kind of dominance over the other sensory perceptions that come into action during tasting. Experiments have previously shown that taste can strongly influence perceived aroma intensity (Buettner and Mestres 2005; Mestres et al. 2006). To date it is not clear whether taste perception can also override the visual impression, which is acknowledged to be dominant over all other sensory perceptions - a phenomenon termed 'visual dominance' (Spence 2009). By way of example, a white wine that was artificially coloured red was described by 54 expert wine tasters with descriptors typical for red wine (Morrot et al. 2001). It is unclear whether or not visual influences can also modify taste perception.

The propensity of our multisensory system to 'shift its attention' and place emphasis on one stimulus or another might result in a wine that is initially evaluated as having an intense and well-balanced wine aroma profile being considered a poor wine due to a weak retronasal aroma profile that reveals wine faults or coinciding offensive taste attributes such as 'bitter', 'green' or 'hard' tannins.

Monitoring analytical, sensory-perceptual, physiological and behavioural aspects

As knowledge about these complex processes and their linkages is expanded, new methodologies and techniques can be developed to achieve what was once considered impossible: to measure, understand and potentially predict how complex stimulatory systems such as foods and beverages are perceived, rated and responded to.

One significant step towards discovering the link between food volatiles and their perception was the development of online mass spectrometric (MS) techniques almost two decades ago. These systems enable volatiles from food to be monitored, including odour-active compounds released from food during mastication. Nosespace analysis – the analysis of breath exhaled via the nose, which is rich in volatiles released in the oral cavity during chewing and swallowing – was pioneered by Andrew Taylor and colleagues at the University of Nottingham, UK using atmospheric chemical ionisation mass spectrometry (APCI-MS). In the mid-1990s, the newly developed chemical ionisation MS technique of proton transfer reaction mass spectrometry (PTR-MS) equally found footing in food flavour analysis and was quickly established, with APCI-MS, as a primary research tool for characterising volatile release from food. Similar approaches were further developed to monitor the intra-oral 'release'

of tastants, which is of high relevance for solid foods (Davidson et al. 2000). Equipped with these new tools, food scientists and researchers from other disciplines were able to explore the role that the food matrix, saliva composition, chewing performance, oral and nasal anatomy, and many other factors had on volatile release and subsequent perception. A now established technique for finding relationships between volatile release and perception compares concentrations of volatiles in the nosespace with temporal dominance of sensation (TDS) or time intensity (TI) profiles recorded by panellists under investigation.

Despite the strengths of these correlation methods for characterising flavour release and linking this with perception, the volatile composition of gas exhaled via the nose does not necessarily reflect the volatile composition exposed to the receptors at the olfactory epithelium. The mode of sampling (orthonasal or retronasal), can and does have a strong influence on the aroma or odour perceived. Variations in sampling, i.e. the volume and velocity of odorant-rich gas passing through the nose, may also affect perception (Zhao 2005; Beauchamp et al. 2013, 2014).

Real-time mass spectrometry, as well as sensors with sufficiently high sensitivity and specificity, potentially hold the key to addressing these issues. PTR-MS has been used to sample gas directly at the olfactory cleft, where it could be shown that sniffing behaviour affects odorant concentrations reaching the region of the receptors (Beauchamp et al. 2013). A similar study using this method showed that *n*-butanol odour thresholds of test subjects could be corroborated by intranasal sampling of this compound at the olfactory cleft (unpublished data). Another study also used a similar technique to compare concentrations of aroma compounds introduced to the nasal cavity orthonasally versus retronasally (Heilmann and Hummel 2004).

These pilot studies have provided data on a handful of odorants and a relatively small cohort of subjects. The hugely diverse physicochemical properties of odour-active compounds, together with the widely divergent oral and nasal human anatomy necessitate further, comprehensive, research. Moreover, although tools are now available to detect odorant concentrations directly at the olfactory cleft, this information does not provide any indication of the quantitative uptake of the odorants by epithelial cells. Even an exact knowledge of the qualitative and quantitative paths and interactions of stimuli with our receptors would be unlikely to tell us anything about what we would finally perceive. Not only is there increasing evidence of the complex interactions of odorous and taste constituents acting in non-linear sensations, for example due to synergistic or suppressive effects (Dalton et al. 2000), an increasing number of studies demonstrate that the complex integration processes during multisensory perception make it close to impossible to predict what individuals might overall perceive. Besides sensory processes, higher-cognitive processes like evaluation and integration of different sensory perceptions must also be taken into account. Those processes interact with our memory of a previously experienced situation of perceiving that specific wine. In order to better understand those complex neural processes, the application of non-invasive brain imaging techniques like electroencephalography (EEG) or functional magnetic resonance imaging (fMRI) in combination with real-life stimulation scenarios should be applied in the future.

Post-inhalation and post-ingestion effects

The sensations involved in savouring and tasting outlined above might not be solely responsible for our subsequent rating and appreciation of a wine. Other effects potentially elicited by the diverse wine constituents are far less understood. There is an increasing number of reports on the action of aroma and taste substances on further targets, such as common receptor structures, specifically G-protein coupled receptors and ion channels (Kessler at al. 2013; Vriens et al. 2008; Hossain et al. 2002). Activation of these is commonly related to physiological effects that might well contribute to the commonly-reported feeling of relaxation, well-being, stimulation and arousal when drinking wine. A prominent example for such an effect is ethanol, which acts on a variety of physiological targets. The ultimate physiological effect is influenced by, among other things, the concentration of the active compound or mixture.

Many odour-active compounds can act via diverse physiological pathways, potentially further enhancing each other or acting synergistically to create a unique effect. Diverse compounds act not only on the same target, for example the gamma-aminobutyric acid A $(GABA_A)$ receptor, but potentially on several physiological targets. As a consequence, additional post-inhalation or post-ingestion effects might very well be further integrated by our physiology into a multimodal sensory concept that, whilst not fully revealed to our conscious awareness, modulates our rating and responses. For example, it is a well-described phenomenon that $GABA_A$ activation is important in learning, and may influence hedonic rating and behavioural response (D'Hulst et al. 2009).

When considering post-ingestion or post-inhalation effects one also needs to bear in mind that compounds typically undergo substantial changes in the human body; in the course of digestion and uptake molecules may be metabolised into more or less active forms. Volatiles and odorants are in any case exceptionally interesting candidates as they are small and lipophilic and, accordingly, quite likely to be mobile and able to easily access even remote parts of the body, including the brain (Neuhaus et al. 2008; Menini et al. 2004). The crucial parameters in such effects are the same as those in common pharmacokinetics: the original composition and its concentration need to be considered alongside biotransformation products of the organism (Heinlein and Buettner 2012; Schilling et al. 2008; Buettner and Beauchamp 2010), their bioavailability, their distribution, and the mechanisms and kinetics of their clearance from the body. By way of example of these effects, odorants can appear quite rapidly in systemic circulation, but their elimination via urine and breath can likewise occur at a fast rate (Beauchamp et al. 2010; Wagenstaller and Buettner 2013); potential intermediate deposition effects of such substances, for example in lipophilic tissues and bodily compartments, can lead to extended delivery to the blood circulation system and therefore longer-lasting effects. The potential locations of resorption of such molecules in the gastro-intestinal tract (stomach, small and large intestine) have not been fully resolved to date.

Conclusion

The diverse aspects that play a role in food consumption clearly demonstrate that we are still far from understanding the fundamental mechanisms of post-ingestion or post-inhalation effects of odorants, tastants or other chemosensory substances with regard to their influence on what we experience and feel – not only in the immediate act of savouring wine but possibly later as a result of interaction of its constituents and/or metabolites with the body.

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What role do vision and the other senses play in wine appreciation?

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Abstract

In this article, I want to take a broad look at the various ways in which the senses contribute to our experience of wine. I will go all the way from the use of sensory cues at the point of purchase (an area known as sensory marketing) through to demonstrating the impact of the multisensory atmosphere at the point of consumption. In the middle, I will take a look at what is currently known about the way in which the senses are combined to give rise to a drinker's perception of the flavour of the wine itself. I will demonstrate how flavour results from a complex interplay of gustatory, olfactory, oral-somatosensory, visual and auditory cues. In conclusion, I hope to convince you just how multisensory the wine drinking experience really is, be that in the glass, in the mouth, and/or in terms of the environments in which we choose to imbibe or purchase wine.

Introduction

When thinking about the senses and wine, it is tempting to focus solely on the sensory properties of the drink itself, and how they are integrated in the mind of the consumer (Spence 2013) or, for that matter, the wine expert, when tasting a wine. However, as we will see below, the senses can also influence which wine we end up drinking in the first place. What is more, once we are happily supping on whichever wine we (or someone else) has chosen, it is important to note that the multisensory attributes of the atmosphere in which we drink can also impact on the overall experience. In what follows, I will take a brief look at some of the intriguing ways in which the senses contribute to determining both what wine we choose to drink and what we end up thinking about it, once we have tasted it.

Sensory marketing at the point of sale

First, let's look at the role of the senses at the point of sale. Perhaps most research has been conducted on the impact of environmental music on our drink-related behaviours (see Spence 2012b, for a review). It has, for example, been reported that the type of music playing in the background can exert a surprisingly large effect on our shopping behaviours in both the wine store and in the supermarket (Areni and Kim 1993; North et al. 1997, 1999). So, for example, Areni and Kim found that people purchased more expensive wine from (or at the very least spent significantly more at) a wine store when classical music was playing in the background than when 'Top 40' tunes were played instead.

Meanwhile, North et al. (1997, 1999) observed that consumers in the alcohol section of a British supermarket were far more likely to purchase French (than German) wine when French accordion music was played over the sound system. The pattern of sales was, however, reversed when German music was played instead (see Figure 1). Given such a pattern of results, it is surprising how many wine stores are still seemingly happy to let their store manager blast their own iPod selection out across the wine aisles. I would argue that the decision about what music to play in-store is simply far too important to be left to chance.

One other key point to stress here is that shoppers typically do not realise what a profound effect the background music has on their wine selection (or, for that matter, on their choice of any other food or beverage product). If you don't believe me, just consider the following: when the shoppers came away from the tills in North et al.'s (1997) supermarket study, an experimenter asked them whether they thought that the background music had had any influence on their purchasing decisions. Of those shoppers who agreed to be interviewed, only 6 out of 44 acknowledged that the music **might** have exerted any influence over their choice of wine. This was despite the fact that the evidence clearly demonstrated that the background music was having a profound effect on their purchasing behaviour (see Figure 1). In other words, if you want to know what the key drivers underlying a shopper's wine purchasing behaviours are, probably the last person you should ask is the shopper him or herself.¹

Although less extensively studied, there is also some evidence to suggest that the visual attributes of the store atmosphere can influence a consumer's behaviour, be that in a wine cave or when tasting at a winery (Areni and Kim 1994; Oberfeld et al. 2009). Indeed, it certainly wouldn't surprise me if the liberal sprinkling of a nation's flags in the wine section of a supermarket or wine store (assuming it is a reasonably well-known flag) were not found to bias sales in a manner similar to that demonstrated by North et al. (1997, 1999) following the presentation of French or German music (Bell et al. 1994). And, finally, given how many writers have been known to describe specific wines in terms of particular styles of music (Spence 2011a), who knows whether there might not be much more that could be done here in terms of using background music to bias the consumer toward one kind of wine selection versus another (see also Knöferle and Spence 2013).

Although less studied to date, it has been suggested that wine marketers may also be able to influence a wine consumer's purchasing behaviour by means of haptic (i.e. active touch) cues. You may, for example, have observed how undecided wine shoppers with time

¹Putting two and two together, the astute Australian wine marketer will have realised that the thing to do is to start sending out free CDs of classical Australian music if they want to promote the sale of Australian wine.

French accordian German Bierkeller music music Bottles of 12 40 French wine (77%)(23%)sold Bottles of 22 8 German wine (27%) (73%) sold

Figure 1. Number (and % in brackets) of bottles of French vs. German wine sold as a function of the type of background music played. Source: North et al. (1997)

Background Music

on their hands will occasionally pick a couple of bottles up off the shelf and weigh them up in their hands, as if unsure of which one to take. Now while weighing up the bottles obviously cannot provide the shopper with any direct information about the quality of the wine contained within, the weight of the bottle may nevertheless provide a subtle cue that the shopper (or, more importantly, the shopper's brain) may use when trying to decide which of the two bottles represents better value for money. As Goldstein and Herschkowitsch (2010) put it when describing the wines from one producer: "These Bogle bottles are hefty, and their weight is a nice feature – one that often tricks people into thinking the wine is more expensive than it really is."

Of course, using the weight of the bottle as a cue to product quality (or value for money) only works if there happens to be a correlation between wine quality and bottle weight out there in the marketplace. Now, while any attempt to look for such a correlation is going to be fraught with difficulty, given the problems associated with trying to provide an objective measure of wine quality (see my other article in these proceedings for details), what can be objectively determined is whether there is a correlation between the price of the wine and the weight of the bottle that it comes in. This is precisely what Piqueras-Fiszman and Spence (2012) did when they weighed the more than 600 bottles for sale at the Oxford Wine Company store on Oxford's Botley Road. Their results highlighted the existence of a significant correlation between weight and price. Put simply, for every pound sterling extra that the shopper paid, they were rewarded with an extra 8 g of wine bottle!

Knowing this, the New World wine producer can therefore obviously think about increasing the perceived value of their product offerings simply by packaging it in a bottle that is noticeably heavier than that of the competition (see also Faraday Packaging Partnership & Glass Technology Services 2006).² Now while many Chilean producers have already jumped on this bandwagon (just try lifting a bottle of Caetana Zapata, for example – it comes in at a whopping 1.53 kg empty, when many a budget wine weights just under 1 kg full), I have seen far less evidence of weight being used as a strategic marketing cue by Australian producers of premium wines!

More often than not, I have come across producers (e.g. in the Adelaide Hills) who have started using heavier bottles for one of their premium wines but are not sure of quite what difference it will make (psychologically) to their customers. Obviously, putting one's wine in a heavier bottle does not come without a consequence in terms of price. However, my suggestion here would have to be that the added weight may be something that turns out to be well worth the investment in terms of increased costs, at least for one's premium product offerings (the move toward light-weighting notwithstanding; http://www.wrap. org.uk/retail_supply_chain/grocery/drink/wine/lightweighting. html).³ More generally, playing with the weight, and possibly feel of one's wine bottles (textured wine labels anyone?) can be seen within the context of trying to engage with all of the customers' senses – an area known as sensory marketing (see Lindstrom 2005; Spence and Gallace 2011, for reviews).

Currently, I am not aware of any studies having been conducted on the influence of fragrance in a wine store on wine sales. However, such a study cannot be far off, given that many other retailers are already thinking about how to boost their sales through the intelligent use of scent (Leenders et al. 1999; Mitchell et al. 1995; Spence 2002). To give you an idea of what might be done in the context of boosting sales at the cellar door, just think about the results of a study by Hirsch (1990). He reported that shoppers were (or at least reported being) willing to pay more than US\$10 extra for a pair of trainers, and, what is more, their purchase intent increased by more than 80%, when in the presence of the fragrance of flowers. Given results such as these, it should be no surprise that many big retailers are currently experimenting with scenting their point-of-sale environments. Now, to the extent that the eucalypt note is a distinctive (and sought after) attribute of certain Australian wines, one might even wonder whether introducing such a fragrance in a wine store could once again bias the consumer's wine choices, regardless of whether the shopper says that the fragrance is having any influence on their wine purchasing decisions or not.

Taken together, then, the results reviewed in this section have hopefully demonstrated just how important the senses are when it comes to the selection of wine in store. In fact, we are currently trying to set up a study in order to investigate whether a similar influence of the atmospherics can also be demonstrated when it comes to a consumer's wine choice in the restaurant setting. Elsewhere, clear evidence that the multisensory atmospherics of the environment can influence people's choice behaviour has been reported in an intriguing set of studies conducted in the context of a bar (Sester et al. 2013). Once again, these French researchers demonstrated that if you change the music and change the visual attributes of the environment then you can change what the consumer (or some proportion of consumers) will order.

One final point to note here is that while the majority of studies of atmospherics published to date have tended to look at the effect on wine sales of changing just one factor at a time (i.e. changing just the lighting, or just the music...), the most dramatic effects of changing the atmosphere on people's purchasing behaviours are likely to be observed when several of these factors are manipulated at the same time, especially if they are coordinated to give a congruent multisensory message (Sester et al. 2013; Spence 2002; Spence et al. in press).

Multisensory flavour perception

Over the last few years, researchers have learnt far more about the multisensory nature of flavour perception than was ever known before (see Spence 2013; Stevenson 2009, for reviews). Crucially, it turns out that all the senses (that is taste, smell, vision, touch, and even hearing) can contribute to what a consumer experiences, and reports, as the taste of a food or beverage. This is despite the fact that the official International Standards Organization definition of flavour (see ISO 5492, 1992, 2008) involves a much more restricted range of senses. According to their definition, flavour can be defined as a "Complex combination of the olfactory, gustatory and trigeminal sensations perceived during tasting. The flavour may be influenced by tactile, thermal, painful and/or kinaesthetic effects."

When it comes to wine, perhaps one of the first clues/cues that the consumer gets comes from the colour of the wine (see Spence 2010a, b, for reviews). Intriguing evidence concerning just how important visual cues can be to determining what a taster reports as the taste or flavour of a wine comes from a classic study reported by Morrot et al. (2001). The participants in this rightly-famous experiment consisted of 54 students enrolled in a university oenology course at the University of Bordeaux. In the first session, the students were given two glasses of wine (AOC "Bordeaux", 1996 vintage), one Semillon/Sauvignon Blanc white, the other a red made from Cabernet Sauvignon and Merlot grapes. They then had to make a list of odour descriptors for the two wines (a list of descriptors was also provided). For each of the descriptors that was chosen, the students had to indicate which of the two wines presented that characteristic most

²Many Old World producers are, of course, stymied by the need to sell their wine in the standard recognisable bottle shape. Though, that said, many a super-Tuscan red comes in a significantly/dramatically heavier bottle (Williams 1999).

³Of course, should you decide to increase the weight of your wine bottles, then you'll need to be ready for the occasional criticism. As an example take the following from McIntyre (2011): "...how heavy is that bottle in your hand? Some wineries use ridiculously thick, heavy ones to impress you with their seriousness. Wouldn't you rather the winery put more effort into the wine you'll drink than the bottle you'll recycle?"

intensely. The students used one set of terms (such as honey, lemon, lychee, and straw) to describe the odour characteristics of the white wine and another set of terms (e.g. chicory, coal, prune, chocolate, tobacco) to describe the red wine.

In the second part of the study, conducted a week later, the students were given two further glasses of wine, one white, the other red, and an alphabetical list of the odour descriptors they had chosen during their previous session. They then had to say for each odour descriptor, which of the two wines presented that characteristic more intensely. This time, however, what looked like the red wine was in fact the same white wine that they had been given originally, but now coloured so as to make it look indistinguishable from the red wine. The key result to emerge from this study was that the budding oenologists now used the red wine odour descriptors for the inappropriately-coloured white wine.

These results have been taken by many to demonstrate (at least in oenology students) vision's dominance over judgments of a wine's aroma. It would seem as though people smell what they see! That, at least, is how Morrot et al.'s results have often been described. Subsequent results collected in New Zealand with a group of wine experts suggest that they are just as gullible when it comes to being misled by the inappropriate colouring of a wine (Parr et al. 2003). The one study that no one has yet done is to see whether if the wine expert knows that the colour of the wine before them may be misleading they can ignore the evidence before their eyes or not.

Hearing is probably the last sense that anyone considers when thinking about the factors contributing to the consumer's experience of a wine. However, I suspect that auditory cues may play a bigger role than any of us realise. Just take the following quote from Harry Lawless (2000 p. 93): "I often think I can tell something about the quality of a fine champagne by listening to the fizz. Many small bubbles give off a higher pitched fizz than the gross clumpy fat bubbles of a club soda". Elsewhere, Barry Smith (2007) has suggested that expensive wines make a distinctive gentle glugging sound when poured from the bottle (see also Vickers 1991). Now, while we haven't been able to put such speculative claims to the empirical just test yet, our latest findings in this area have already demonstrated that people are surprisingly good at telling the temperature of a drink from the sound it makes when it is poured out into a glass (see Velasco et al. 2013a). What is more, in some of our earlier research, we have been able to demonstrate that people's perception of the carbonation of a drink can be altered simply by changing the sounds of the popping bubbles that they hear (Zampini and Spence 2005). It is important to note here that the subtle auditory cues that a consumer hears when a wine is poured out into a glass will set up expectations in their mind about the likely temperature of the drink and its level of carbonation. Although consumers normally do not pay any attention to such subtle auditory cues, they will nevertheless still set up expectations in the consumer's mind concerning what they are about to taste.

Having looked at the visual and auditory cues and their contribution to the perception of wine it is now time to take a look at smell and taste. Together with the oral-somatosensory (or mouth-feel) qualities, these are perhaps the most important senses when it comes to wine appreciation. However, it is important to note that these senses can interact in surprising ways when it comes to the delivery of taste and flavour experiences. While gustatory cues can only tell us about the sweetness, sourness, bitterness, and occasionally saltiness of a wine, the majority of the more interesting wine characteristics come from the nose (as when we sniff – what is known as orthonasal olfaction), or from the joint contribution of taste and retronasal olfaction.⁴ Intriguingly, Pam Dalton and her colleagues at the Monell Chemical Senses Laboratory in Philadelphia have reported that odourless tastants on the tongue can serve to enhance a taster's experience of the aroma/flavour of a liquid. Dalton and her colleagues focused on the selective enhancement of the almond aroma of benzaldehyde when a drop of sugar was placed on a person's tongue (see Figure 2). In the years since Dalton first published the study, a number of other research groups have demonstrated very similar results for a variety of other flavour attributes and beverage types (see Spence 2012b, for a review).

Interestingly, however, it turns out that which gustatory and olfactory cues combine to give rise to a superadditive (see Figure 2) or subadditive⁵ multisensory flavour interaction depends on where in the world one grew up. So, for example, while sweetness and almond aroma go together for the Western palate, salt and almond do not. By contrast, in Japan, the reverse is true. There, salt can enhance the perception of almond aroma/flavour, whereas sugar just doesn't do the trick (see Spence 2008). So, in other words, everyone's brain uses the same rules to integrate the inputs from their various senses, but what differs from one region to the next, is precisely which combination of gustatory and olfactory qualities go well together (and give rise to superadditive neural responses). The implications of such crosscultural differences for the world of wine (especially given the recent growth of the Asian wine market) have yet to be fully worked out. Who knows, though, whether such cross-cultural differences can help to explain why some affluent Chinese consumers apparently prefer to drink their Châteaux Pétrus and Margaux mixed with a dash of Coke!

The oral-somatosensory attributes of our experience of food and drink are known to be very important, if often understudied (Spence et al. 2013). These attributes include everything from temperature through to astringency (think of the 'grippiness' of young tannins or the viscosity of a higher alcohol wine). And this would seem to be equally true when it comes to the case of wine. Indeed, it is particularly noticeable nowadays how many red wines are advertised in magazines in terms of their tactile properties – silky, smooth, satiny, etc. However, as we have seen already, it is important to note that our perception of the texture of a food or beverage product can be influenced by its smell (or aroma). It wouldn't surprise me at all if it were

⁵Subadditive interactions occur when the inputs to two or more of the consumer's senses do not match (e.g. as when combining a salty taste with the smell of strawberries). Such interactions between incongruent elements give rise to a neural/behavioural response that can be worse, or lower, than the best of the constituent signals (Spence 2012a).



Figure 2. Figure highlighting the results of a series of experiments conducted by Pam Dalton and her colleagues, showing the integration of orthonasal olfactory (i.e. sniffing) and gustatory cues (Dalton et al. 2000). When a sub-threshold solution of saccharin was placed on the tongue, a significant increase in participant's olfactory sensitivity was observed, despite the fact that the tastant had no odour. These results provide a dramatic demonstration of the multisensory interactions that can take place between smell and taste. Note that holding a small amount of water, or monosodium glutamate (MSG), in the mouth has no effect on olfactory thresholds (at least in the Western participants tested in this study). These latter results highlight the stimulus dependency (both olfactory and gustatory) of multisensory integration in human flavour perception, a result that has now been demonstrated in many other studies. Figure courtesy of Charles Spence

⁴Retronasal olfaction refers to the detection of the olfactory stimuli that emanate from a wine that we are drinking as odours are periodically forced through the nasal cavity when we swallow. Intriguingly, orthonasal and retronasal olfaction, while relying on the same receptors in the nasal cavity, appear to be processed by somewhat different areas in the human brain (see Spence 2012b).

to be found that something like viscosity (e.g. in an aged Riesling) is a multisensory concept involving a contribution of both oralsomatosensory cues in the mouth, together with some contribution from olfactory cues (Bult et al. 2007). Note here also that one of the roles of oral-somatosensory cues in multisensory flavour perception may be to help localise the flavour gestalt firmly to the oral cavity (e.g. rather than to the nose where the majority of the relevant information is transduced; see Spence 2012b).⁶

Finally, here, is it worth noting that we all live in somewhat different taste worlds. In fact, some wine drinkers may have as many as 16 times more taste buds on their tongue than others (Miller and Reedy 1990). It has been known for years that differences in one's taster status (ability to taste 6-*n*-propylthiouracil [PROP]) can influence how one perceives the taste and astringency of a red wine (Pickering et al. 2004). Intriguingly, Gary Pickering and his colleagues have recently demonstrated that one's taster status can also impact on the perceived nose of a wine (Bajec et al. 2012; Hayes and Pickering 2012). Given that taster status varies by region, there may be some interesting questions to be addressed here for the international wine marketer.

⁶Some researchers say as much as 80% of flavour (or what is commonly referred to as taste) comes from the nose, though it is not altogether clear where this statistic comes from.



Figure 3. Results of Oberfeld et al.'s (2009) study conducted in a winery on the Rhine illustrating the impact of ambient illumination on hedonic ratings of a Riesling wine given by wine buyers (ratings expressed on a 10-point scale; upper panel). The lower panel highlights the maximum buying price that the participants reported that they would be willing to pay for a 750 mL bottle of wine (in Euros) as a function of the hue of the ambient lighting. n = the number of participants taking part in each condition (note that a between-participants experimental design was used). Error bars show 1 standard error of the mean. Asterisks and crosses indicate significant pair-wise differences (*: P < 0.05, f: P < 0.1). Source: Oberfeld et al. (2009)

Atmospherics at the point of consumption

Particularly interesting, are those studies demonstrating that people may be willing to pay as much as 50% more for exactly the same bottle of Riesling under one kind of ambient lighting versus another (Oberfeld et al. 2009)! In a study conducted at the Allendorf winery in Oestrich-Winkel on the Rhine, wine buyers reported that they would have paid significantly more for the wine that they were tasting (a dry Riesling from the Rheingau region) when the normally white lightbulbs were replaced by fluorescent red ones (blue and green lighting were also tried). The wine was rated as tasting significantly better under red or blue lighting than under green or white lighting (see Figure 3). Given that the wines were served in black tasting glasses, such results must reflect the generalised impact of ambient illumination, rather than any effects that the lighting might have had on the colour of the wine itself. Oberfeld and his colleagues followedup this field study with further experiments conducted under bettercontrolled laboratory conditions, and obtained a similar pattern of results. Furthermore, the latter studies revealed that the ambient lighting appeared to be affecting the taste of the wine rather than its aroma.

That said, it is important to note that not everyone has reported effects of changing the ambient lighting that are as quite as dramatic (e.g. Sauvageot and Struillou 1997). Nevertheless, I would argue that the German group's findings hint at just how important the visual aspects of the environment can be in terms of potentially influencing a consumer's wine purchasing behaviours, especially at the cellar door.

But what about the sound of the environment in which a person drinks wine? Can that also impact what we think about the wine that we happen to be tasting? The answer, once again, is that indeed it can. At least if the latest results to have been reported by Prof. Adrian North are anything to go by. North (2012) published an article in which he showed that the kind of music playing in the background can exert a significant influence when it comes to a taster's rating of a wine. Two hundred and fifty undergraduates were offered a glass of either Chilean red (a Cabernet Sauvignon) or white wine (a Chardonnay). While they drank their wine, one of four different pre-selected pieces of music was played in the background at 70 dB. There was also a control condition in which no music was played. The music samples had been chosen because they scored highly (in a pilot study) on one of several emotional dimensions: 'powerful and heavy' (Carmina Burana by Orff), 'zingy and refreshing' (Just can't get Enough by Nouvelle Vague), 'subtle and refined' (Waltz of the Flowers from Tchaikovsky's 'Nutcracker'), and 'mellow and soft' (Slow Breakdown by Michael Brook).

After having finished their wine, the students had to rate it by giving a score from 0 to 10 on four scales anchored with the labels 'powerful and heavy', 'zingy and refreshing', 'subtle and refined', and 'mellow and soft'. A value of 0 indicated that the wine definitely didn't have the named quality, while a score of 10 indicated that it definitely did. The students were also asked to rate how much they liked the wine. The results demonstrated that the wines were rated as significantly more powerful and heavy when Carl Orff was played in the background than with any of the other musical selections. Meanwhile, the wines were rated as significantly more 'zingy and refreshing' by those students who had been forced to listen to the track from Nouvelle Vague. Equivalent effects were reported for the other two musical pieces. Would wine experts be similarly influenced by the background music? Only further research will tell.

Interestingly, however, there was no significant effect of the music on the students' ratings of how much they liked the wine. According to Spence and Deroy (2013), the latter result can be taken to show that the music influenced the descriptive, rather than the evaluative, aspects of the students' tasting experience. Perhaps one can think of North's (2012) results in terms of contextual priming. In other words, however you get a particular thought, or concept, into a taster's brain, be it by means of the sensory descriptors on the wine label, be it by the associations primed by a particular style of music, or even by means of the posters than happen to be hanging on the wall, then that can influence the judgments that a wine drinker will subsequently make.

The sense of hearing can interfere with the other senses during tasting and quiet has always been considered necessary for a taster's concentration. Without insisting on absolute silence, difficult to obtain within a group in any case, one should avoid too high a level of background noise as well as occasional noises which can divert the taster's attention. (Emile Peynaud 1987, p. 104)

Maybe, then, the famous French oenologist Emile Peynaud was right after all when he suggested that tasting should occur under conditions with as little background noise as possible. Indeed, the latest research from Stafford et al. (2012) has also demonstrated that playing loud background music can certainly impair a social drinker's ability to discriminate the alcohol content in a drink. It can also apparently make an alcoholic drink taste sweeter. Finally, it is important to note that the loudness of the background music, the speed of the music (e.g. the number of beats per minute), and even the type of music, have all been shown to influence the rate at which people drink (see Spence 2012a, for a review).

Now, I have yet to conduct the study, but from everything that I have read about the influence of the glass you drink or taste from, on the perception of wine, I feel sure that the weight of the glassware will impact on the taster's experience (see Spence 2011b). In fact, I have just been sent a pair of new wine glasses made from a material that it is apparently pretty difficult to break. Great, you think. Until, that is, you pick one of them up to pour yourself a glass of wine. Then you suddenly realise that the glass is surprisingly light (which is rarely a good thing when it comes to crockery or cutlery; see Spence and Piqueras-Fiszman, in press, for a review). It appears as though consumers normally believe that heavier is better (Lindstrom 2005; Spence and Gallace 2011), and that across a range of food products, eating from a heavier bowl, or with the aid of heavier cutlery, makes whatever it is that they happen to be eating or drinking taste significantly better (not to mention more expensive). Given the above observations, one cannot help but be surprised when those merchants trying to shift their wares at the airport (or supermarket) so often choose to serve their premium product from cheap (and very light, often plastic) glasses when offering shoppers a sample.

Multisensory atmospherics

Now, as mentioned already, the most dramatic effects of changing the atmospherics on a wine drinker's experience of a glass of wine are likely to come when several attributes of the multisensory environment are changed at the same time (Spence 2002). Although not from the world of wine, the results of one of our latest real-world experiments gives an idea of just what is possible here (see Velasco et al. 2013, 2013b). We took over three rooms in a building in London's Soho and changed the multisensory atmosphere in each room. And by changing the atmosphere I mean we changed everything from the colour of the lighting through to the soundscape playing in the background, and from the feel and textures used in each room, through to each room having a different fragrance. Well over 400 members of the general public came to the event which ran over three consecutive nights. Each person was given a glass of whisky and a scorecard, and was then taken on a tour through the three rooms, filling in a part of their scorecard in each room.

The results of this study revealed that people's rating of what they knew to be exactly the same whisky (since everyone carried one and the same glass through all of the rooms) could be changed by as much as 15–20% simply by changing the atmosphere in the environment in which they tasted that drink. We focused on people's rating of the nose, the taste/flavour (sweetness), and the aftertaste (or texture) of the whisky. Ratings of all three of these attributes were significantly altered as a function of the atmosphere people were tasting in. I see no reason why a very similar effect of the atmosphere could not be achieved should the drink being tasted be switched from whisky to wine, since both offer complex flavour profiles. Other researchers, meanwhile, have also recently started to investigate the effect of changing the audiovisual environment on people's eating behaviours in the setting of a fast food restaurant (Wansink and van Ittersum 2012). Once again, significant effects were obtained.

Conclusions

Taken together, the results reviewed here demonstrate some of the various ways in which a person's experience of wine can be influenced by the senses. Early on, we saw how the sensory attributes of the environments in which we decide what to buy/order can be used to nudge people toward paying more for their wine, or to choose the wine from one region versus another. When it comes to the interaction between the senses in the act of tasting, things get very much more complicated. That said, the research that has been conducted over the last decade or so has now started to demonstrate some of the key rules governing the integration of the senses in the case of multisensory flavour perception – rules such as sensory dominance, super-additivity, and subadditivity. One of the key things to note here is that expectations play a powerful role in determining what we ultimately think that we are tasting.

Given that we normally see a wine before tasting it, and given the large proportion of cortical real estate given over to processing visual information, it should come as little surprise to find that the visual attributes of a wine can play a very important role in setting a drinker's expectations, and hence their subsequent experience when tasting a wine. That said, the interaction between gustatory (taste) and olfactory (smell) cues cannot be ignored. Here, researchers have demonstrated how these two senses can interact in ways that are non-linear, meaning that their integration can sometimes give rise to flavour percepts that are very much greater than the sum of their parts (this is known as superadditivity).

Finally, we saw how the sensory attributes of the atmosphere in the place where we happen to be drinking can also impact not only what we think about the tasting but also how quickly we end up drinking. All told, the senses exert a profound impact on all aspects of our interaction with wine, from purchase through to consumption. Understanding the nature of these interactions, and moving away from an approach that relies too heavily on what the consumer says (to a closer observation of what they actually do) will hopefully allow for a more scientific approach to wine in the years to come.

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What do consumers really value in making wine purchase decisions?

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Abstract

Wine and sensory scientists are focused mainly on the perceived flavour in a wine and often measure this in blind tastings. Consumers purchase wine in busy environments without the benefit (usually) of tasting the wine beforehand. The context surrounding the wine purchase at the retail outlet, restaurant, or cellar door, as well as the consumer's own state of mind must be taken into account when trying to measure 'value'. This presentation reports first on the influence the buying context has on consumer purchase decision-making. Studies of shopping behaviour show a narrow range of attention to actual purchasing with low levels of noticing displays and packaging. Second, the presentation provides a summary of the author's research on the effects of on-shelf and on-package information and graphics on wine choice.

I'm not a chemist and I'm not a brain scientist, I'm just a humble marketing person who tries to observe consumers in their native habitat. Today I'm going to talk to you about what happens when consumers are actually buying wine. We've heard presentations about consumers appreciating wine and I think that we are starting to make some progress in understanding what happens when they are appreciating wine, not in a little sensory booth, but at a wine event, or in the home. It's hard to measure, and expensive to measure, but I think that is the frontier.

I want to talk to you about what happens in the real world. We know that there are two kinds of wine consumers - high involvement and low involvement. The high involvement consumers spend more money on wine, they really think about wine, they read books and articles, they tend to read advertisements, they like learning, they have what we call a larger repertoire, which means they buy more different types of wine and they buy some of the cheapest wine and some of the most expensive wine because they are more experimental. The low involvement consumer is the person who just likes wine, they think it tastes good, they like what happens when you drink wine: the relaxing, the fun, the people, all that. We call this 'peripheral processing' because they don't really think about it that much, it's more of a subconscious process, they are not concerned with the detail when they are reading advertisements and they choose from a smaller repertoire of wines they often consider safe. But I want to emphasise that you can't identify these people walking down the supermarket aisles or in the wine shop, but both groups like and drink wine, and both buy wine.

So to look at low involvement people from our research, they focus (especially in Western countries like Australia, the United States and United Kingdom) on brand name, grape variety, country and region. If we were turning this around and looking in France, Italy or Spain, the country/region would move up towards the top and the grape variety would move down but this is typically what people are looking at. They prefer simple labels, they are looking at the colours, they are looking at the variety, the big brand name, the proprietary stripe that tells you what that brand is. We've done research to show that's what people focus on. If you look at high involvement branding, the kind of wines that people buy at the higher price range, it's a lot harder to pick out what the brand name is. Is it the negociant, is it the region, is it some special bottling? The grape variety is often not listed, maybe vintage is more important and certainly if you ask people that's what they'll tell you, and of course price tends to be higher. Labels are not as revealing about what's in the bottle, you have to know a bit more about it before you can even process the information.

I want to emphasise that when your bottle is sitting on a shelf or in a wine list, you don't know who is looking at it and you have to be able to deal with the situation that occurs with either type of buyer shopping. Now it may seem strange to you to say that shoppers are people but what I mean is that shopping is just an activity and for most people it's important enough because we need our food, our drink, pharmaceuticals, whatever we are out there trying to buy, but we don't really focus much on it. Research shows that if you even put cat food in the aisle with the beer or you put cornflakes in the cat food aisle and then people walk by and they choose their brands and then you ask them, "Did you see anything different today?" they will respond "No, nothing". People don't even notice because they aren't looking.

Herb Sorensen has focused on the time that people spend in the store and found that people go more to a store with a time budget rather than a dollar budget. And so if you can increase the speed in which they can find the products they'll actually buy more. It has much less to do with lingering and eye focus than engaging attention, as people are busy. Even high involvement people are thinking about other things than just the wines they are seeing, and their main goal is to is 'get in and get out'. People are interested in their family, their life, where they have to go next after shopping, what they are doing later, worrying about an exam, worrying about their boyfriend/ girlfriend etc. They are not really thinking much when they are in the store. So what happens when people are shopping? It's brief, there is little cognition. A number of studies have shown that the average time someone spends looking at a category is 12 seconds. That is not a lot of time to do in-depth reading and understanding and most people, close to half of people, spend even less time. Occasionally people do weigh options but for the majority of people, if they touch it, they take it.

This is revealed in our own research. We did some observational work in wine stores, different types of stores, big stores, small stores, different cities in Australia, and we found that 82% of wine shoppers spent less than six minutes in the store, not just shopping, in the store. About 45 seconds was spent per category, so about four times as much time as a dog food, tooth paste or laundry detergent shopper spends but still not a lot of time. And the average time among these 1500 consumers was about four minutes, and that's in the store. These consumers move really fast until they get to the checkout – from when they walk in until they are waiting in line. So there's not a lot of thinking going on to process all the things that we know people are seeing. Things are happening in the shopper's mind, but not in a cognitive sense; it is almost stimulus response based on learned behaviours.

We also looked at what people bought, after they came out of the store, and said "Have you ever bought this brand before? Is it something that you buy regularly? Is this something brand new?" We found that whether or not they were highly involved, 80% of items purchased were things that they had bought before. This means that the door is only open for new brands or new choices about 20% of the time. And so engaging someone's attention and getting them to at least try your product is a difficult thing. There is no simple solution; but certainly if someone has heard of your brand or seen your brand, there is a much higher probability they will purchase it. Having previously seen your brand is particularly powerful, because visual acuity in humans - except for maybe supertasters - exceeds our use of other senses. When we asked people directly after they had been shopping to "just name some wine brands", the majority of people could only name three brands. High involvement shoppers had higher recall, they could recall and name more brands, because they have a more complex memory structure for the names of wines. We also asked people to recall wine regions and they named on average about 2.5 regions.

So we call this 'screening out' – when someone is shopping they really don't notice most things. It's not because they don't like it, or reject it, they just don't notice it. They're looking to speed their way through the store to find something they will appreciate and there's a lot more work that needs to be done with cues in the store – does a heavier looking bottle or a round label get chosen more often? We have some idea about what people perceive when they're drinking a wine with a round or square label, but what are they doing when they're passing by the shelf at quite a clip looking to their next appointment or to pick the kids up after school?

We have found that consumers with the highest involvement use a broader range of cues to make a choice. These cues might be grape variety or region, or perhaps they may know that they like cool climate Shiraz and that will be part of their choice criteria. It might be a brand they've never heard of but those cues to the region are very important in their mind if they're paying attention. If they're not paying attention they are just looking for something they recognise. As an example, two years ago 'Tropicana', one of the largest orange juice brands in the US, went through a complete redesign of their packaging. What happened? They spent \$35 million on the design and launch and then within a month they gave up and went back to the old packaging because people couldn't find the brand. It's silly but it's true, and the data we collect from some of our corporate sponsors shows that almost any time they launch new or changed packaging there is a decrease in sales at least temporarily. You can get an increase over time if you improve something but you have to communicate that and get through the wall when people can't find the product. So, packaging matters.

But what else matters? I'm going to talk quickly about information that can be presented on the wine shelf. We've done some online experiments in conjunction with Leigh Francis and Patricia Williamson at The Australian Wine Research Institute (AWRI). People are shown a small selection of wines on a shelf, with some information under the bottles, such as wine ratings from three sources and taste descriptions. We used two different kinds of wine ratings – ones where the three scores shown were fairly similar, and ones where they were quite variable. Including a taste description under the bottle increased the likelihood that someone would choose that wine by about 7% and for wines that were well known it increased even more. When wine ratings are provided, if there is at least one score of 95 and no really low scores it increases the probability of that wine being chosen but even with one score of 75, one 95 score still increases the probability of someone buying that wine by 6%. If we put a gold medal on that bottle, you could increase it by about 7% as well.

So what about the taste of the wine? In another experiment with the AWRI, we did some research putting bottles in front of 420 consumers online and asking them to choose the wine they would buy, and then they came to a central location and tasted those same wines. Now they tasted those wines with a picture and a price, so it was not a blind tasting. They tasted five of those 21 wines, they had a picture, they knew what the wine was, and they had a price in front of them. And then we also had as part of the research analysis by a trained descriptive panel so we knew what flavours and attributes were in the wine. But what did we find? Well, when the consumers looked at a shelf of wines, and they saw multiple shelves, overall 21 different wines in different combinations, they tended to buy less expensive wines. In this experiment there were wines between about \$10 and about \$30. When they tasted the wines of course they liked the wines at a higher price. This is well known - if the price is higher, of course I like that wine better. But then when they were asked to choose wines after the tasting, they actually chose to buy, in simulated buying, the cheaper wines. So, what people bought online and what they chose after tasting was pretty similar, they were predictive of each other, but not highly correlated to the wines they 'liked' during the tasting. We found that some tastes did matter in that experiment: fruitiness, sweetness, a bit of oak but not much oak, were all things that helped predict the choice of wines regardless of the price. Some tastes were not liked by most of the consumers: for example aged wines and wines with faults - and yes consumers did taste and notice wine faults!

So, what can we conclude? People shop very quickly – if you're going to do something with labelling you've got to create recognition that's going to help people and aid their choice. If you change your package, especially drastically, you are going to lose sales because people won't be able to find your product. You need to work on making your wine easy to find and easy to buy. It's the same with online purchasing, it's a convoluted process but if consumers can't find a product quickly they'll find something else that they recognise. Graphics and colour are the key elements in visual acuity that drive people's recognition of wine, so keeping a colour scheme is really important. Price and quality are related but consumers have taste preferences and budgets and that's what they tend to stick to when they're shopping. High involvement consumers have repertoires of a wider range of wines but they act the same way, they are people just like everyone else.

FRESH RESEARCH SESSION A



Wine phenolic and aroma outcomes from the application of Controlled Phenolic Release to Pinot Noir must A.L. Carew, N.D.R. Lloyd, D.C. Close, R.G. Dambergs

Proctase – a viable alternative to bentonite for protein stabilisation of white wines M. Marangon, S.C. Van Sluyter, E.M.C. Robinson, N. Scrimgeour, R.A. Muhlack, H.E. Holt, E.J. Waters, P.W. Godden, P.A. Smith



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Wine phenolic and aroma outcomes from the application of Controlled Phenolic Release to Pinot Noir must

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Abstract

Approximately 40% of Pinot Noir grape must is grape solids which are pressed off as marc, post-fermentation. Rapid phenolic extraction by Controlled Phenolic Release (CPR) offers an alternative to alcoholic fermentation of Pinot Noir on pomace. In this independently replicated trial, 1kg lots of Pinot Noir grape must were subjected to CPR and pressed off after approximately three hours' total skin contact time. CPR juice was inoculated for alcoholic fermentation and compared with control wine that was fermented on pomace for seven days. Analysis of wines by UV-Visible Spectrophotometry at 210 days post-harvest (six months' bottle age) showed that CPR wines were equivalent to control wines for mean concentration of: total phenolics, total pigment, anthocyanin, total tannin, colour density and pigmented tannin. Non-targeted profiling analysis of volatile aroma compounds was carried out by Gas Chromatography–Mass Spectrometry (GC-MS) at 320 days post-harvest (ten months' bottle age). Control and CPR wines were distinct from each other for 12 out of 16 aroma compounds identified, with CPR wines generally four to sixfold higher for the acetates, and twofold higher for most of the ethyl esters. We showed that microwave maceration may reduce constraints on winery capacity by eliminating pomace during fermentation, provide greater control over red wine phenolics, and that CPR may generate wines with distinct aroma qualities.

Introduction

Phenolic concentration and composition are central to red wine quality. Phenolic compounds contribute visual appeal in the form of colour (e.g. anthocyanins, non-bleachable pigments), mouth-feel qualities like astringency (e.g. tannins) and red wine aroma in the form of volatile phenols. The concentration of phenolic compounds in red wine has been correlated with subjective measures of wine quality (Cozzolino et al. 2008; Mercurio et al. 2010). For example, analysis of 1,643 Cabernet Sauvignon and Shiraz wines showed that concentration of total phenolics and total tannin in wines was positively correlated with wine grade (Mercurio et al. 2010).

Pinot Noir grapes are generally low in anthocyanin concentration (Cliff et al. 2007) and Pinot Noir anthocyanins are of the non-acylated form (Heazlewood 2006), unstable at normal wine pH. Pinot Noir grapes have an unusual tannin distribution, with a disproportionate amount of the total grape tannin bound up in the seed (Kennedy 2008). Seed tannin can be difficult to extract and this may explain why Pinot Noir wines are often tannin poor. Analysis by protein precipitation of tannin concentration in 1,325 red wines showed Pinot Noir and Shiraz wines were the lowest in tannin of the red varietals examined which included Cabernet Sauvignon, Zinfandel and Merlot (Harbertson et al. 2008). Tannin is important for stable long-term colour in red wine. Stable colour results from polymerisation between anthocyanins and tannins (Hayasaka and Kennedy 2003). Routine red winemaking processes extract approximately 40% of available grape phenolics (Boulton 2001; Stockley and Høj 2005). So for varieties with a challenging phenolics profile, like Pinot Noir, winemakers need maceration options which allow them to achieve optimal phenolic extraction.

Thermal maceration has been identified as effective for optimising phenolic extraction in red winemaking (Sacchi et al. 2005). For example, thermal maceration of Merlot, Cabernet Sauvignon and Pinot Noir musts under two different regimes (60°C for 1 hour; 80°C for 3 minutes) was associated with significantly higher concentration of total phenolics compared with control in wines from all varieties trialled except Merlot under the 80°C for 3 minutes treatment (Atanackovic et al. 2012). The Atanackovic study confounded two variables (two peak temperatures; two hold times) and so it was not possible to discern if the observed phenolic effects were attributable to peak temperature, duration of hold time, or the combination of both variables. Flash Détente (also called Flash Release) is a thermal treatment that has proven effective for extraction of phenolic compounds. This process involves heating must to approximately 95°C, applying vacuum to simultaneously rupture grape cell walls and vacuolar membranes, then cooling the must (Doco et al. 2007; Morel-Salmi et al. 2006). Flash Détente was applied to Grenache, Mourvedre and Carignan musts over two vintages and Total Polyphenolic Index (TPI) in wines was shown to be higher in Flash Détente treatment wines for all varieties over both vintages, compared with control wines (Morel-Salmi et al. 2006). TPI does not distinguish between anthocyanins and tannins, however, and anthocyanins tend to extract readily so it is possible the high TPI result was dominated by anthocyanin extraction.

A newly developed thermal maceration process called Controlled Phenolic Release (CPR) also has the capacity to optimise phenolic extraction in red winemaking. CPR involves microwave heating of must to 70°C, followed by a managed hold time at that temperature to allow for diffusion of phenolic compounds from grape solids into juice (Carew et al. 2013, submitted). Application of CPR to Pinot Noir must generated significant differences in wine phenolic concentration when compared with control wines fermented on skins, for example, mean total tannin at 18 months' bottle age was 0.60 mg/L for CPR wines and 0.14 mg/L for control wines (Carew et al. 2013).

Both Flash Détente and CPR have been trialled for rapid phenolic extraction as a precursor to fermenting extracted red grape juice in the liquid phase (i.e. pressed off pomace prior to alcoholic fermentation). Flash Détente with early press-off generated wines with significantly lower Total Polyphenolic Index than control wines (Morel-Salmi et al. 2006). In contrast, CPR with early press-off generated Pinot Noir wines with concentrations equivalent to, or greater than, the control wine for total pigment, anthocyanin, total tannin and non-bleachable pigment (Carew et al. 2013, submitted). Direct comparison of Flash Détente and CPR has not been undertaken, and hold times differed in the early press-off studies described above – Flash Détente hold time was six minutes (Morel-Salmi et al. 2006), CPR hold time was one hour (Carew et al. submitted) – which may account for the differences in phenolic outcome between the two trials. Red winemaking processes involving thermal phenolic extraction and press-off prior

to alcoholic fermentation are worthy of further research as they offer potential efficiencies in red wine production. Pomace occupies approximately 40% of tank space and requires active management over the life of a red wine alcoholic fermentation. The impact of thermal treatments like CPR on red wine aroma, however, requires further research.

The aroma of wine perceived by a consumer is due to the presence of a complex mixture of volatile odour-active compounds. Many important odour-active compounds in wine are metabolic by-products of yeast fermentation, like acetate esters, ethyl esters and higher alcohols (Swiegers et al. 2005; Varela et al. 2009). The concentration of aroma compounds in finished wines is influenced both by the chemical, and physical conditions in fermenting must. Yeast metabolism can be influenced by chemical conditions like variation in glucose concentration, availability of aroma compound precursors and must nutrient status (Swiegers et al. 2009; Ugliano et al. 2009; Vilanova et al. 2012). Physical conditions which can influence yeast metabolism, and hence aroma compound concentration, include fermentation temperature, degree of must oxygenation and the rate of CO₂ evolution from must (Albanese et al. 2013; Girard et al. 1997; Morakul et al. 2013; Zhang et al. 2007). Few researchers have related the chemical and physical impact of thermal maceration processes on red grape must to red wine aroma outcomes (Chai et al. 2011; Fischer et al. 2000). A pilot-scale study compared aroma outcomes in wines from standard winemaking, with those from thermovinification of must at 75°C for 20 minutes followed by press-off immediately after hold time and alcohol fermentation without pomace. Control and thermovinification winemaking processes were applied to Dornfelder, Pinot Noir and Portugieser musts, and resulting thermovinified wines were significantly higher in ester compounds, and displayed 'fruity' character (Fischer et al. 2000). Given the role of esters in Pinot Noir wine aroma (Fang and Qian 2005), investigating the impact of novel thermal winemaking processes on aroma compounds like esters is important for this variety.

Our study compared the phenolic and aroma outcomes in Pinot Noir wines made using a control microvinification process, with Pinot Noir wines made by CPR with early press-off. The CPR treatment involved approximately three hours' total skin contact time before must was pressed off and enriched juice fermented in the liquid phase. We report on the impact of these winemaking treatments on wine phenolics concentration at six months' bottle age (220 days postharvest), and 16 wine aroma compounds at 10 months' bottle age (320 days post-harvest).

Materials and methods

Fruit, maceration and microvinification

Pinot Noir fruit at 13°Baume and pH 3.3 was harvested from a vineyard in Northern Tasmania, Australia during April 2012. Fruit was randomly allocated to eight 1.1 kg replicates and each was crushed and destemmed using a custom-made crusher. Each must replicate was treated with 50 mg/L sulfur dioxide in the form of a potassium metabisulfite solution, and four replicates allocated to the control treatment were transferred to a 1.5 L Bodum[™] coffee plunger and moved to a 28±3 °C constant temperature room for vinification according to the 'French Press' method (Carew et al. 2013; Dambergs and Sparrow 2011).

Four replicates were subjected to the CPR process which entailed heating must to 70°C in a domestic 1150W Sharp[™] 'Carousel' R-480E microwave oven followed by a one hour hold time in a 70°C waterbath. Replicates were pressed off immediately after the one hour hold time at 70°C, enriched juice was transferred to 500 mL Schott bottles and cooled to 28°C by immersion in an icebath. CPR replicates were then loosely lidded with a Schott bottle cap and moved to a 28±3°C constant temperature room for yeast inoculation and fermentation.

All replicates were inoculated with the yeast strain Saccharomyces cerevisiae EC1118 (Lallemand) which had been rehydrated according to the manufacturer's instructions. Fermentation kinetics were monitored by daily weighing of fermentation vessels to calculate evolution of CO₂. At day three of the ferment, 60 mg/L of yeast assimilable nitrogen was added to each replicate in the form of diammonium phosphate solution. Alcoholic fermentation was complete by day seven and wine was tested for residual sugar using Clinitest™ tablets (Bayer) and all wines were found to be dry with ≤2.5g/L residual sugar. Control wines which were fermented on skins were pressed off, racked into 375 mL bottles and cold settled for two weeks at 4°C. CPR wines were racked directly to 375 mL bottles and cold settled for two weeks at 4°C. All wines were then racked under CO, cover to 250 mL Schott bottles and stabilised by the addition of 80 mg/L sulfur dioxide in the form of potassium metabisulfite solution, and settled for an additional two weeks. Wines were bottled under CO₂ cover into 100 mL and 28 mL amber glassware with wadded polypropylene capping. A new 28 mL bottle of each wine was opened for each analysis - phenolics at six months' bottle age and volatile aroma compounds at eight months' bottle age.

Phenolics by UV-Visible Spectrophotometry

Wines were analysed for the concentration of seven red wine phenolic measures at six months' bottle age. Analysis was undertaken using a modified Somers method and chemometric calculator, both of which have been validated and are described in full elsewhere (Dambergs et al. 2011, 2012; Mercurio et al. 2007). In brief, wine samples were diluted in each of three solutions (1M hydrochloric acid, metabisulfite solution and acetaldehyde solution), and scanned in 10 mm quartz cuvettes at 2 nm intervals for the wavelength range 200–600 nm using a Thermo Genesys[™] 10S UV-Vis Spectrophotometer. Resulting absorbance data for each sample were exported to Excel 2007 spreadsheets and selected absorbance data were entered into the chemometric calculator to quantify wine tannin, total phenolics, total pigment, free anthocyanin, non-bleachable pigment, colour density and hue.

Aroma by GC-MS

The analysis of wine volatiles was performed on an Agilent 7890 gas chromatograph equipped with Gerstel MPS2 multi-purpose autosampler and coupled to an Agilent 5975C XL mass selective detector. The gas chromatograph was fitted with a 30 m \times 0.18 mm Restek Stabilwax - DA (crossbond carbowax polyethyleneglycol) 0.18 mm film thickness that has a 5 m \times 0.18 mm retention gap. Helium was used as the carrier gas with flow rate 0.8 mL/min in constant flow mode. The oven temperature started at 33°C, held at this temperature for four minutes, then heated to 60°C at 4°C/min, further heated to 100°C at 16°C/min, then heated to 240°C at 25°C/min and held at this temperature for two minutes. The volatile compounds were isolated using large volume headspace sampling and injected into a Gerstel PVT (CIS 4) inlet fitted with a Tenax TA liner. The injector was heated to 330°C at 12°C/min. Positive ion electron impact spectra at 70eV were recorded in scan mode. Wine samples (in triplicate) were diluted (2:5) in buffer solution (10% (w/v) potassium hydrogen tartrate, pH adjusted with tartaric acid to 3.4). A total of 16 authentic volatile compounds were analysed concurrently with the wine samples and each sample was spiked with deuterated internal standard.

Statistical analysis

Means and standard deviations for phenolic measures and aroma compound response ratios were calculated in Excel 2007. The independent samples T-test was used to establish where there were significant differences between treatments ($P \le 0.05$).

Results and discussion

Wine phenolics

Statistical examination for differences between the control and CPR treatments in mean concentration of the seven phenolic indicators examined at six months' bottle age showed no significant difference for total phenolics, total pigment, free anthocyanin, tannin, non-bleachable pigment or colour density (Table 1). This demonstrates that control and CPR wines could be termed 'phenolically equivalent' according to six out of the seven measures used in this study. Wines from the CPR treatment were significantly different from control wines for hue, however, with CPR wines showing a more garnet hue, compared with control wines which were more blue-purple at six months' bottle age.

The phenolic results presented here concur with our previous findings that CPR treatment involving microwave maceration to 70°C and one hour hold time, followed by alcoholic fermentation off pomace delivers Pinot Noir wine which is similar in phenolic concentration to wine fermented on pomace for seven days (Carew et al. 2013, submitted). Similar results were recorded in a small-scale comparison in Shiraz must of control and CPR with early press-off, however, that variety required a three hour hold time to produce CPR wine equivalent in phenolic profile to the control treatment (Carew et al. 2014). The difference between treatments in hue value that was observed in this trial (Table 1) suggests that the CPR wines may have matured at a faster rate than control wines, although if this were the

Table 1. Mean concentration of phenolics (\pm SD) in Pinot Noir wine from control (CTL) and controlled phenolic release (CPR) maceration treatments at six months' bottle age (220 days post-harvest). Results in bold typeface are significantly different to each other according to the independent samples T-test (P \leq 0.05).

	CTL	CPR	P-value
Total phenolics (AU)	20.2±2.0	21.2±3.2	0.25
Total pigment (AU)	10.0±0.7	9.1±0.3	0.32
Anthocyanin (mg/L)	163±12	147±4	0.07
Non-bleachable pigment (AU)	1.08±0.07	1.07±0.11	0.69
Tannin (g/L)	0.09±0.08	0.16±0.16	0.15
Colour density (AU)	5.07±0.37	4.95±0.41	0.35
Hue	0.68±0.01	0.74±0.03	0.04

case, a significant difference in non-bleachable pigment value might have been expected. Alternatively, the CPR wines may have suffered greater oxidation (oxidative browning) due to the lack of protective pomace layer during alcoholic fermentation, or poor management of the final days of alcoholic fermentation; CPR wines were largely dry by day five, whereas control wines did not finish fermentation until day seven.

Wine volatiles

There were significant differences between the control and CPR treatment wines for 12 of the 16 aroma compounds analysed, with CPR wines generally higher in these compounds than control wines (Table 2). Differences in aroma profile varied between the three classes of aroma compounds identified. The level of butanol was significantly different between treatments, with CPR slightly higher than control for this compound. Butanol can be perceived as fruity at low concentrations in wine, and as fusel or spiritous at higher concentrations. In contrast to the results for higher alcohols, differences between treatments for the three acetate compounds examined were four to six times higher in CPR wines than control wines. For example, 2- and 3-methylbutyl acetate, which are known for their fruity and banana characters, were six times higher in CPR wines compared to control wines. The ethyl esters examined were also consistently higher in CPR wines than control wines, with the exception of ethyl 3-methylbutanoate. Ethyl octanoate and ethyl decanoate have been identified as key odorants in the varietal aroma of Pinot Noir wine (Fang and Qian 2005) and these compounds were twofold higher in the CPR wines than the control wines.

The aroma compound differences observed between control and CPR wines may have resulted from chemical, biological or physical differences in musts due to the different maceration regimes applied in this study. The treatments applied may have differentially influenced the availability of volatile aroma precursors, the viability of enzymes and transferases which act on aroma compounds, or must parameters which impact on yeast metabolism. Such changes to the must environment would likely influence the production of aroma compounds by yeast. For example, previous research has shown that CPR liberates around 16% greater yeast assimilable nitrogen than is

Table 2. Mean aroma compound response ratio (±SD) in Pinot Noir wine from control (CTL) and controlled phenolic release (CPR) maceration treatments at ten months' bottle age (320 days post-harvest). Results in bold typeface are significantly different from each other according to the independent samples T-test (P≤0.05). Aroma descriptors are drawn from several references (Fang and Qian 2005; Siebert et al. 2005) and several descriptors are offered because the perception of an aroma compound may vary depending on compound concentration and human perception threshold.

	CTL	CPR	P-value	Aroma Descriptor
Ethyl Esters				
ethyl acetate	1.37±0.03	2.30±0.21	<0.01	sweet, tart, volatile acid, nail polish
ethyl propanoate	3.56±0.12	3.90±0.08	<0.01	fruity
ethyl 2-methylpropanoate	3.19±0.22	4.19±0.15	<0.01	fruity, sweet, apple
ethyl butanoate	1.06±0.04	1.47±0.08	<0.01	fruity, peach
ethyl 2-methylbutanoate	0.34±0.02	0.42±0.01	<0.01	sweet, fruit, honey
ethyl 3-methylbutanoate	0.25±0.04	0.26±0.02	0.47	berry, fruity
ethyl hexanoate	1.94±0.06	2.85±0.09	<0.01	green apple, fruity, wine
ethyl octanoate	1.67±0.05	3.67±0.15	<0.01	red cherry, raspberry, cooked fruit
ethyl decanoate	0.29±0.04	0.65±0.10	<0.01	fruity, black cherry, chocolate, barnyard
Acetates				
2-methylpropyl acetate	0.012±0.001	0.046±0.006	<0.01	banana, fruity, floral
2- and 3-methylbutyl acetate	0.053±0.006	0.297±0.16	<0.01	banana, fruity
hexyl acetate	0.009±0.000	0.039±0.003	<0.01	sweet, perfume, floral
Alcohols				
2-methylpropanol	30.6±1.3	32.3±1.2	0.09	fusel, spirituous, nail polish
butanol	0.55±0.04	0.66±0.05	0.02	fruity, fusel, spirituous
2- and 3-methylbutanol	48.1±2.2	51.3±1.8	0.06	nail polish
hexanol	0.058±0.007	0.050±0.004	0.10	grape juice, green grass

liberated in control musts (Carew et al. 2013), and yeast metabolism has been shown to be directly affected by not only must nutrient status but also by the type of nitrogen available (i.e. ammonia nitrogen, primary amino acid nitrogen) (Bell and Henschke 2005; Ugliano et al. 2008; Vilanova et al. 2007).

Pinot Noir wine has at least 37 known aroma active compounds (Fang and Qian 2005) and the sensory threshold for each of these compounds may differ. Pinot Noir aroma is also influenced by aroma compound synergies, where different proportions of various aroma compounds generate perceived odour differences (Fang and Qian 2005). This means the aroma data reported here do not provide a clear indication of how the human sensory response may differ between wines from the treatments applied in this study. The data presented here do, however, provide a clear conclusion that the concentration of aroma active compounds differed by treatment. Formal sensory appraisal of these wines would be required to establish if the differences revealed by GC-MS translate into different aroma experiences for consumers of CPR wines.

Winemaking differences

In this study, we compared two different winemaking processes and reported their impact on wine phenolics and aroma compounds. Three variables were confounded in this experiment. The CPR process differed from control winemaking in that: must was microwave macerated, enriched juice was fermented in the absence of pomace, and CPR juice was fermented in a 'semi-closed' fermentation system (loosely lidded 500 mL Schott bottles). Each of these factors may have contributed to the results observed. Preliminary research (data not shown) informed the design of the CPR treatment process and the parameters of peak temperature and hold time were managed to ensure CPR and control wines would be approximately equivalent for phenolics (Table 1). This ensured that microwave maceration did not contribute significant differences for phenolics, and the trial demonstrated the capacity of CPR to deliver production efficiencies (alcoholic fermentation without pomace, no cap management required).

The distinct differences in aroma compounds between CPR and control treatments in this study (Table 2) and similar aromatic differences observed in an earlier comparison of control and thermovinification wines (Fischer et al. 2000), need to be interpreted with the confounded variables in mind. Seven hypotheses can be advanced to explain why aroma differences have been observed between thermovinified and standard wines:

- Liberation of grape aromas and aroma precursors aroma compounds may have been heat-mediated products from precursors in grape juice, or heat may have liberated aroma precursor compounds which were subsequently available as yeast metabolites.
- 2. Fermentation temperature differences Fischer and others (2000) employed a lower fermentation temperature with thermovinified must because high fermentation temperature, which is often used to enhance phenolic extraction in red winemaking (Haeger 2008; Peynaud 1984), has been imputed in volatilisation of red wine aroma compounds during fermentation. Our CPR replicates were fermented at the same temperature as control replicates and still showed significantly higher levels of most of the aroma compounds examined, however there were marked differences in the scale of difference between our trial and that of Fischer et al. (2000). Their trial reported 20–50 times greater hexyl acetate in thermovinified Pinot Noir compared with control, whereas we recorded only four times greater hexyl acetate for CPR, compared with control wines.
- Slower CO₂ evolution rate Fischer et al. (2000) suggest a slower CO₂ evolution rate may account for greater preservation of volatiles in wine, however model system research examining gas-liquid partitioning in wine fermentation suggested must composition

and fermentation temperature, not CO_2 evolution rate, were key drivers of aroma loss (Morakul et al. 2011). We have previously reported faster fermentation kinetics for CPR with early press-off than for control fermentation (Carew et al. submitted), and the aroma results reported in this paper support the conclusions of Morakul and others'.

- 4. Volatilisation of aroma compounds during cap management (Fischer et al. 2000).
- 5. Heat inactivation of aroma degrading enzymes and transferases (Fischer et al. 2000).
- 6. The presence of pomace pomace may contribute aroma precursors as it degrades and as chemical conditions in the fermenting must change (i.e. hydrophobic aroma precursors may liberate more readily as ethanol concentration increases). Visual observation of fermenting must also suggests that pomace can act as a trap which slows CO₂ release. CO₂ has been identified as an 'aroma scrubber' with differential effects on various wine aroma species. Recent research demonstrated that around 50% of ethyl hexanoate produced in a model red wine fermentation was stripped away with CO₂ gas emissions (Morakul et al. 2013). An earlier study identified ethyl decanoate as particularly susceptible to CO₂ scrubbing (Ferriera et al. 1996). Coincidentally, control wines fermented in the semi-open fermentation system in our study were approximately 50% lower in ethyl hexanoate and ethyl decanoate than wines from the semi-closed fermentation system (CPR) (Table 2). These two compounds are key odorants for Pinot Noir wine (Fang and Qian 2005). This hypothesis may account for variation between aroma compound differences as the volatility and hydrophobicity of individual wine aroma compounds influences their capacity to be stripped out in CO₂ emissions (Morakul et al. 2010).
- 7. Use of semi-open and semi-closed fermentation systems wine aroma differences may have resulted from differences in transfer dynamics between the two fermentation systems. In the semiopen system, gas-phase or volatilised aroma compounds could readily exit the system, whereas those compounds may well have remained trapped in the semi-closed system. Boulton (2001) has highlighted the diffusion equilibrium between solid and liquid phases in grapes as potentially influencing phenolics extraction; we propose similar diffusion equilibrium conditions may govern exchanges between the gas (headspace) and liquid (fermenting juice) phases in the semi-closed CPR fermentation system.

Conclusion

CPR treatment for making Pinot Noir wine was demonstrated as efficient, with pomace pressed off after three hours skin contact time, and resulting wines equivalent to control wines for phenolics. The CPR treatment wines were, however, quite different from the control wines for 12 out of 16 aroma compounds analysed. CPR wines showed particularly high levels of ethyl esters and acetate compounds which have been associated with fruity and floral aromas in wine. The study was not able to identify which of the three variables distinguishing CPR from control vinification was responsible for the marked differences observed for aroma profile, but seven hypotheses were offered which warrant further investigation. The CPR process may offer efficient production of wines with highly fruity or floral bouquet, and further research on the mechanisms driving aroma differences may offer insights of more general value to winemaking.

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Proctase – a viable alternative to bentonite for protein stabilisation of white wines

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Abstract

White wines must be treated to remove proteins that could otherwise aggregate into light dispersing particles and cause unsightly haze. Bentonite is commonly used to remove the grape proteins responsible for haze formation, but is associated with significant processing and environmental costs. Proteases potentially represent an alternative to bentonite, but until now none has shown satisfactory activity under winemaking conditions. Proctase, a mixture of Aspergillopepsins I and II, is proposed as a viable bentonite alternative. It is food grade, well characterised and inexpensive, active at wine pH and at high temperatures (60–80°C). When added to clarified grape juice and combined with short-term heating (75°C for one minute), Proctase has shown excellent results in removing haze-causing proteins (80–90% total protein reduction). Experiments have been conducted at laboratory, pilot and commercial-scale across a range of juices. Sensory and chemical characteristics of wines made from Proctase-treated juice have not shown any significant differences when compared with bentonite-treated controls. In addition, the cost of Proctase treatment has been shown to compare favourably with traditional batch bentonite treatments.

Background

Securing wine stability is an essential step of the winemaking process. Protein instability is one of the major possible instabilities that winemakers face, particularly for white, rosé and sparkling wine production (Waters et al. 2005). Wine-grapes contain proteins that, when not removed during winemaking, can make their way into the bottled wines in a soluble state, in which case the wine is seen as clear (Figure 1, on the left). With time, and particularly when the wines are exposed to high temperatures or after a long time in storage, the proteins can slowly denature and subsequently aggregate. As these aggregates become larger they scatter more light and we see these particles as haze (Figure 1, on the right).

Prevention of haze formation

Not all proteins found in wine are involved in haze formation. The proteins responsible for wine haze are the grape pathogenesis-related (PR) proteins, namely thaumatin-like proteins (TLPs) and chitinases (Waters et al. 1996).

The most effective tool to prevent protein haze is treatment with bentonite, a clay cation exchanger negatively charged at wine pH so that it can bind the positively charged wine proteins, and then be removed by racking or centrifugation. Bentonite fining is a relatively low cost and effective method for removing proteins from wine or grape juice. However, bentonite fining has some negative attributes including dilution of the wine by the bentonite slurry, removal of



Figure 1. Life cycle of protein in wine: from soluble after bottling (clear wine), to insoluble aggregate formation over time (hazy wine)

positive flavour attributes, high labour costs, handling and disposal problems associated with spent bentonite, and quality loss of wine recovered from lees (Waters et al. 2005). A recent study estimated the hidden cost of bentonite fining to be around \$1 billion dollars worldwide (Majewski et al. 2011). For these reasons, alternative methods for white wine stabilisation have been extensively investigated, including the use of other adsorbents (Cabello-Pasini et al. 2005; Marangon et al. 2012a; Lucchetta et al. 2013), flash pasteurisation (Pocock et al. 2003) and proteases (Waters et al. 1992; Benucci et al. 2011; Van Sluyter et al. 2013), but none has proven sufficiently effective to replace bentonite.

New techniques, new understanding

Several recent breakthroughs in the study of protein instability have allowed the development of an alternative strategy to bentonite for the stabilisation of wines. The first breakthrough came with the development of a method based on two laboratory techniques - Strong Cation Exchange (SCX) and Hydrophobic Interaction Chromatography (HIC) - for the isolation of large quantities of purified haze-causing proteins (Van Sluyter et al. 2009), to be used for characterisation studies. In one of these studies the purified proteins were analysed by Differential Scanning Calorimetry (DSC) to assess, for the first time, their unfolding temperatures and behaviour (Falconer et al. 2010). In this study it was also discovered that the unfolding temperature of chitinases is approximately 55°C and approximately 62°C for TLPs. Moreover, the unfolding behaviour of the two proteins is different; once heated, chitinases stay unfolded upon cooling (irreversible unfolding), while TLPs refold (reversible unfolding). This was a critical finding because unfolding is a key step in the process of haze formation.

The link between protein unfolding and protein aggregation was also investigated using a technique called Dynamic Light Scattering (DLS) (Marangon et al. 2011a). During these studies it was found that sulfate concentration and the overall ionic strength of wines played a part in haze formation, as the presence of sulfates and other ions in sufficient quantities can favour protein aggregation. As a result of these breakthroughs a much deeper understanding has been reached about wine proteins and why they unfold and aggregate – findings that were used to develop a strategy to break proteins down, which could eliminate the need for bentonite (Marangon et al. 2012b). The strategy consisted of adding an enzyme and putting it to work on the proteins after they have unfolded, which is a time when they are much more susceptible to enzyme attack (Figure 2).

Finding the right enzyme

It has commonly been thought that the ideal way to deal with this issue would be to use proteolytic enzymes able to degrade the heat unstable proteins at normal winemaking temperatures. That is why a great deal of research has been focused in investigating the effects of different proteases, in particular of microbial origin such as those from *Aspergillus niger* (Bakalinsky and Boulton 1985), *Saccharomyces cerevisiae* (Dizy et al. 2000; Younes et al. 2013; Younes et al. 2011), and *Botrytis cinerea* (Cilindre et al. 2007; Van Sluyter et al. 2013). In each study, however, the enzymes were not able to effectively degrade all grape PR proteins because of their high proteolytic resistance and because winemaking temperatures are unfavourable for enzyme activity.

An alternative approach has been adopted – putting an enzyme to work on the proteins in their unfolded state, when they are much more susceptible to attack. To achieve this an enzyme mixture named Proctase, which is food grade and active at wine pH and high temperatures, was identified as a lead enzyme candidate. Proctase is most effective when samples are heated to the temperatures at which the target proteins unfold (around 70–75°C), leaving them susceptible to enzyme attack. For this reason, Proctase was used to treat juice prior to fermentation, rather than wine, because short-term heating of juice has been shown to have no negative sensory impact (Francis et al. 1994).

Scaling up

The next step was laboratory testing using different concentrations of Proctase and juice at different temperatures. Several exploratory experiments were undertaken to identify the most appropriate conditions for a larger pilot-scale experiment. An assessment of the effects of temperature and enzyme dosage on the residual protein content of a 2009 Chardonnay juice found that Proctase began degrading proteins in juice heated at 65°C, with increased protein degradation up to 75°C. However, at 80°C the protein reduction was lower (Marangon et al. 2012b). It is likely that the temperature needs to be high enough to allow the substrate proteins to unfold (Falconer et al. 2010) and be susceptible to proteolysis (i.e. 65°C) but not so high as to slow down the enzyme activity (i.e. 80°C). The more heat stable grape proteins, such as invertases and lipid-transfer proteins, were not affected by the treatments and therefore accounted for the remaining 10% of protein still in solution after the treatment (determined by



Figure 2. Strategy for unfolding and subsequent degradation of haze forming proteins

electrophoresis analysis, data not shown). The optimal combination was identified to be 15 mg/L Proctase concentration in juice heated to a nominal temperature of 70–75°C for about one minute. This combination was then tested in a pilot-scale experiment during the 2011 vintage (Marangon et al. 2012b).

The pilot-scale experiment used two juices (one Chardonnay and one Sauvignon Blanc, both from the Barossa Valley) and applied four initial treatments to each juice:

- 1. An unheated control
- 2. Unheated juice + Proctase
- 3. Heated juice + Proctase
- 4. Heated without Proctase

Reverse Phase High Performance Liquid Chromatography (RP-HPLC) protein profiling was used to qualitatively detect the changes in protein caused by the treatments in the two juices in presence or absence of Proctase and before and after heating (Figure 3).

Heating without Proctase caused a reduction in the total protein content (measured by total HPLC peak area) of 14% for the Chardonnay and 49% for the Sauvignon Blanc. These reductions were mainly attributable to the decrease of the chitinase peaks as chitinases are more heat sensitive than TLPs (Marangon et al. 2011b). Although heat unfolds both chitinases and TLPs, the unfolding of chitinases is irreversible and they precipitate, while for TLPs which refold, precipitation is lower.

For the juices treated with Proctase and subjected to heating, the protein reduction measured by HPLC was 27% for Chardonnay and 60% for Sauvignon Blanc. However, close inspection of the chromatogram of the heated samples showed the appearance of new peaks at the beginning of the chromatogram (between 6 and 9 minutes) that are likely to be degradation products from the TLPs and chitinases peaks that were strongly reduced in size. These early eluting peaks were accounted for in the sum of the total peak area and so the estimated total protein content based on the total peak area may be inaccurate. Protein quantification immediately after treatment confirmed, for both varieties, that heating without Proctase reduced the total protein content by about 40%, and it also showed that when Proctase was used, protein was reduced by 85% in the Sauvignon Blanc and 91% in the Chardonnay juice (Figure 4).

The three different juice treatments and the control (untreated) juice were then fermented in triplicate 80 L volumes. The wines made from the control juice were divided into two after fermentation, with one half left untreated and the other half fined with bentonite to represent normal industry practice. This resulted in five different treatments for each variety. Protein content results for the wines echoed the juice results closely, with the Proctase + heat treatment leading to a 84% and 81% reduction in total protein content in Sauvignon Blanc and Chardonnay respectively (Figure 5)



Figure 3. Protein profiles by RP-HPLC of Chardonnay and Sauvignon Blanc juices before and after flash pasteurisation at 75°C for one minute in absence (Chardonnay and Sauvignon Blanc) and presence (Chardonnay + Proctase and Sauvignon Blanc + Proctase) of 15 mg/L Proctase

Further analysis showed that the majority of proteins removed by the Proctase treatment are those known to contribute most significantly to haze formation (chitinases in particular, data not shown).

From the lab to the tank farm

With the positive results from the 2011 pilot-scale trial, the project was scaled-up in 2012 to assess the behaviour of the new stabilisation method in a commercial winery using existing, rather than specialised, equipment (Robinson et al. 2012). For this purpose two industry partners were recruited to try out the new treatment for protein removal. A total of three juice varieties (Riesling, Sauvignon Blanc and Chardonnay) were treated across the two wineries at a 5,000 L scale, and this time the experimental plan was simplified. For each juice variety, the Proctase + heat treatment was compared against the industry standard bentonite treatment. Each juice was split into two parcels, with one parcel being heat treated with Proctase, while the other parcel acted as the control. The two parcels were then fermented under identical conditions, with the control subsequently fined with bentonite post-fermentation as per typical industry procedures.

After cold stabilisation, sub-samples of each wine were bottled under typical commercial conditions (filtered 0.45 μ m and bottled under Saran tin laminate screw caps in 750 mL bottles). Juices (preand post-Proctase treatment) and wines (treated and bentonite fined) were analysed for protein content. The total protein content of the samples (analysed in triplicate) is summarised in Figure 6.

In all three juices, Proctase treatment caused a reduction in protein content from over 80 mg/L to below 16 mg/L, similar to the results achieved following bentonite fining. HPLC analysis was conducted to



Figure 4. Total protein content of Chardonnay and Sauvignon Blanc juice samples: Unheated juice (control); Heated, 75°C for 1 min; Heated + Proctase (15 mg/L), 75°C for 1 min. Unheated juice + Proctase not shown



Figure 5. Average protein content of wines from the 2011 vintage pilot-scale trial

provide more information about the types of proteins that remained in the juice and wine samples.

The HPLC results show that while chitinases were present in all of the control (untreated) juices, the Proctase treatment successfully removed them and also reduced the concentration of TLPs dramatically. In two out of three cases, Proctase treatment resulted in lower levels of TLPs than bentonite in the finished wines, suggesting that Proctase is as effective as bentonite in removing PR proteins.

Effect on other wine parameters and overall Proctase performance

The composition of the finished wines produced in the pilot-scale and commercial-scale trials was analysed in great detail. Generally the treatments did not affect the main wine characteristics, such as alcohol content, pH, total acidity, organic acids content, and colour (Marangon et al. 2012b; Robinson et al. 2012).

To date, juice flash pasteurisation in combination with Proctase has been trialled on several juices across three vintages. A snapshot of the overall performance on the residual protein content of treated juices and wines is given in Figure 8.

For all of the 7 juices and 5 wines analysed there was a large reduction in protein content upon treatment with heat and Proctase. The reduction was similar to those observed in Figures 4, 5 and 6, and generally was above 80%, with variation in reductions being due to differences in the initial protein content of different samples.

Sensory impact

A key factor for the commercial success of an alternative stabilisation procedure is the impact that it might have on the sensory characteristics of wines. For this purpose, a triangle test was performed to assess sensory differences among treatments, using 47



Figure 6. Average protein content of treated Riesling, Sauvignon Blanc and Chardonnay juice and wine samples. Error bars indicate standard deviation across three replicates.



Figure 7. Average levels of chitinases and thaumatin-like proteins in treated Riesling (RIE), Sauvignon Blanc (SAB) and Chardonnay (CHA) juice and wine samples. Error bars indicate standard deviation across three replicates.

experienced panellists. Wines made from the Proctase-treated juices in 2011, with and without heating, were not found to be significantly different from the bentonite-fined control wine (Marangon et al. 2012b). This suggests that Proctase treatment does not produce a sensory effect when compared to bentonite treatment.

Qualitative sensory analysis of the 2012 wines was carried out using the AWRI's Quality Panel. Wines were presented in pairs of the same variety. The differences in average quality scores between the treated and control wines were not significant, with no taints or faults identified.

The heat test puzzle

To check for protein stability, winemakers currently use a heat test, in which a sample of filtered wine is heated at 80°C for two to six hours and its turbidity is compared with an unheated sample (Pocock and Waters 2006). Several wines made from Proctase-treated juice passed the two-hour heat test, however others (such as the Chardonnay wine from the pilot experiment) gave results of a borderline fail, although they did show a significant reduction of the bentonite required to reach full stability. However, some caution in interpreting the stability test results is needed, as the nature of the test may result in false positives. The heat test is conducted at a temperature (80°C) that leads to the precipitation of all wine proteins, even those (such as invertase) that are known to be heat stable and would not precipitate during flash pasteurisation or in bottle (Esteruelas et al. 2009; Falconer et al. 2010). Therefore the residual haze in Proctase-treated wines after the 80°C heat test seems most likely due to the precipitation of proteins that do not form wine hazes in bottle.

In light of these results, the method for measuring wine heat stability needs to be adjusted and work is currently being carried out to develop a new method in order to solve this issue. The new test will likely involve a lower test temperature, to preserve proteins that do not contribute readily to haze formation. It is hoped that this could become the new industry 'standard' test and provide a more rapid analysis of protein stability in all white wines, irrespective of the method used for protein stabilisation.

Long-term performance

Protein analyses were conducted on the wines after 12 months' storage in order to assess the long-term performance of wines treated with Proctase. For example, the 2011 trial Sauvignon Blanc wines were revisited after one year in bottle, to see if any changes in protein content or composition had occurred during storage. Turbidity tests showed that the wine produced from the Proctase-treated juice was still haze-free after one year of storage, whereas the unfined control had a light haze. Protein content measurement and heat stability tests produced very similar results to those obtained a year earlier,



Figure 8. Average protein content of juices and wines (three replicates) before (control) and after Proctase treatment

with the only exception being the unheated + Proctase treatment which showed a slight decrease in protein concentration over the year period. This was not entirely surprising given that this is the treatment most likely to have residual enzyme activity (Marangon et al. 2012b). The results to date suggest that Proctase is an effective long-term treatment for achieving protein stability in white wines and might ultimately prove to be a viable alternative to bentonite.

Cost comparison

To be economically viable, any alternative to bentonite must deliver cost savings. Therefore, economic analysis was conducted to compare operating costs between Proctase and bentonite treatments. For completeness, in-line bentonite addition was also included – this method is used by several large Australian wineries.

The study took processing conditions into account (flow rates, temperatures, heat exchanger specifications, etc.). It also analysed heating and refrigeration energy, heat exchanger losses, pumping requirements and Proctase purchase costs. To compare batch and in-line bentonite addition, wine volume and downgrade losses were included, together with filtration and centrifuge performance, as well as energy and labour requirements. Results are shown in Figure 9.

Further analysis revealed that operating costs are more sensitive to bentonite requirements and heat exchanger performance than to fluctuations in operating temperature and process flow rate. Increasing the cost of the Proctase enzyme by a full 100% resulted in an operating cost increase of approximately 12–25% under commercial conditions, suggesting that the process is relatively insensitive to Proctase cost variability. The analysis also highlights that juices with high protein levels benefit most from Proctase treatment in terms of process efficiency and cost. This makes sense, considering that juices or wines with higher protein levels require higher bentonite doses, which carry higher associated costs. This means that the cost differential is more pronounced in high protein juices than it is for low protein juices where a smaller bentonite dose is needed.

In-line bentonite treatment costs were lower when compared with the combination of heat and Proctase treatment. This suggests that if suitable equipment is available for in-line bentonite dosing, this option offers some advantages when processing juices or wines with lower protein concentrations. Considerable capital investment is associated with in-line bentonite dosing, however. Consequently, this method is cost prohibitive for all but the largest commercial wineries.

What is the regulatory status of Proctase?

A review of the regulatory environment indicates that enzymes of the same origin (*Aspergillus niger var. macrosporus*) and in the same class as those present in Proctase are already approved as winemaking



Figure 9. Economic analysis of heating + Proctase addition, compared with batch and in-line bentonite addition for Sauvignon Blanc, Chardonnay and Riesling juices treated during the 2012 commercial-scale trial (treatment cost in cents per L) additives in Australia (Carboxyl proteinase is listed as a permitted class of enzymes under clause 17 of the Food Standards Code 1.3.3). However, in order for Proctase to be used legally for winemaking purposes, a change to the Food Standards Code is required to update the nomenclature used for this class of enzymes. The AWRI has recently submitted an application to Food Standards Australia New Zealand (FSANZ) and it will be assessed in March 2014. Wines treated with Proctase are not currently permitted for export to the EU, so the AWRI will be working with the OIV (International Organisation of Vine and Wine) to overcome this and gain approval for wines destined for the European market. A dossier is tabled for submission at the March 2014 meeting of the OIV Scientific & Technical Committee.

Summary

Proctase treatment has been identified as a viable alternative to bentonite fining in reducing haze in white wines. The novelty of the treatment is that it targets only those specific proteins responsible for haze formation, leaving behind in the wine the other proteins that could have a positive impact on wine attributes such as texture and foam in the case of sparkling wines. This project builds on recent breakthroughs in fundamental research on the mechanism of haze formation that have revealed new information about how hazecausing proteins behave when exposed to heat.

Other key findings, beside the stabilisation ability of this treatment, are the fact that wines produced with this method were judged as being not different compared to wines stabilised with bentonite. In addition, from an economic point of view, in-line bentonite dosing may be more cost-effective, but Proctase treatment may be less costly for smaller wineries that cannot afford to invest in the infrastructure required for in-line bentonite dosing. The economic benefit of Proctase, in relation to batch dosing of bentonite, is significant. While Proctase cannot currently be used in commercial winemaking, the AWRI is working with regulatory bodies to gain approval for its use and to ensure that Proctase-treated wines do not encounter regulatory hurdles in Australia and overseas.

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FRESH RESEARCH SESSION B



From grape to consumer: relationships between grape maturity, wine composition and wine sensory properties in Cabernet Sauvignon K.A. Bindon, C.A. Varela, H.E. Holt, P.O. Williamson, I.L. Francis, J.A. Kennedy, M.J. Herderich

Can non-conventional yeast be used for the production of wines with lower alcohol concentration?

A. Contreras, C. Hidalgo, P.A. Henschke, P.J. Chambers, C.D. Curtin, C.A. Varela

Effects of metals on the evolution of volatile sulfur compounds during wine maturation

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From grape to consumer: relationships between grape maturity, wine composition and wine sensory properties in Cabernet Sauvignon

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Abstract

Vitis vinifera L. cv. Cabernet Sauvignon wines are notably distinguished by the presence of both 'green' and 'fruity' characters. Some evidence exists that a loss of 'green' characters is associated with wines made from riper grapes, together with an increase in fruitiness of the wines. A suite of chemical and sensory analyses was employed to assess the relationships between grape maturity, wine chemistry, wine sensory attributes and consumer preference. Five wines were produced in triplicate from sequentially harvested Cabernet Sauvignon grape parcels, giving a range of alcohol contents between 12% and 15%. Wine compositional measures such as dimethyl sulfide, glycerol, isobutyl methoxypyrazine, hexanol, Z-3-hexen-1-ol, tannin, ethyl- and acetate esters, higher alcohols and polysaccharides were strongly influenced by grape ripeness. The sensory attributes 'dark fruit', 'hotness' and 'viscosity' increased in wines produced from riper grapes, while 'red berry' and 'fresh green' characters decreased. Using partial least squares regression, many sensory attributes were strongly associated with the chemical data, which indicates scope for understanding the components of wine which are important to wine style and consumer preference.

Introduction

The grape ripening process in Cabernet Sauvignon can produce a systematic transition in the sensory profile of the resulting wines (Heymann et al. 2013) whereby an earlier harvest results in more 'acidic' and 'vegetative' attributes, and later harvest results in 'hotter' wines with 'dark fruit' attributes. As such, wines produced from this variety are frequently described as presenting a 'dichotomy of sensory attributes' since wines can simultaneously have both 'vegetative' (also described as 'green') and 'fruity' characteristics (Heymann and Noble 1987; Preston et al. 2008). 'Green' flavour and aroma is thought to arise from the presence of isobutyl methoxypyrazine (IBMP), a compound which is also known to decline during grape ripening (de Boubee et al. 2000; Ryona et al. 2009; Sala et al. 2005). Nevertheless, some studies have shown that there is a poor correlation between IBMP concentration and 'green' attributes in wine (Preston et al. 2008; Scheiner et al. 2012). Other volatile candidates which are known to cause 'green' sensory attributes can be derived from C₆ volatiles such as hexanal, hexanol, (E)-2-hexenal and (Z)-3-hexen-1-ol (Escudero et al. 2007). However, these can be converted to their corresponding esters during the winemaking process, and are therefore thought to contribute to 'fruity' notes in wines (Forde et al. 2011). At a glance, it is evident that the relationship between so-called 'green' aroma and flavour compounds in grapes or wines is not clear cut.

From a commercial wine production standpoint, the presence of excessive 'green' characters in Cabernet Sauvignon wines is generally considered a negative attribute, and as such, considerable effort is taken to manage 'greenness' in wine. A common practice is to delay harvest date (i.e. to extend 'hang time') which is thought to reduce 'green' attributes. In addition, early leaf removal (Scheiner et al. 2010) or control of vine water status (Scheiner et al. 2012) may hold potential as vineyard management practices to reduce IBMP. However, despite the acceptance within the wine industry at large that such practices are effective, little published evidence exists which supports the practice of delayed 'hang time' to reduce 'green' sensory attributes, and improve 'fruity' attributes in Cabernet Sauvignon wines. Furthermore, for the study that reported the transition from 'green' to 'dark fruit' attributes in a ripening series of Cabernet Sauvignon wines, it was found that this transition was not observed consistently from year to year, which highlights the role of seasonal variation in determining grape compositional attributes which may affect wine composition, and therefore wine sensory profile (Heymann et al. 2013).

In order to manage the outcome of wine sensory attributes, and therefore wine 'quality', it is well recognised that the choice of harvest date is an important consideration. The wine sensory experience is the result of multiple synergistic interactions among wine volatile and non-volatile components, and for those components derived directly from the grape, these may be in a state of increasing, decreasing or remaining constant at a given point in grape development. Therefore, to identify sensory or compositional attributes which are important in defining an 'optimal ripeness' point for Cabernet Sauvignon is highly complex. As such, the question of the absence of 'green' characters in wines, or presence of 'fruity' attributes, as being important drivers of 'quality' cannot be viewed in isolation from other important sensory attributes. For example, palate weight ('viscosity'), 'astringency', 'acidity', 'bitterness' and 'hotness' are also important determinants of wine sensory 'quality' and these too can change markedly with ripening (Heymann et al. 2013).

What was unknown at the outset of the study was how closely changes in grape and wine composition associated with the ripening process could be related to defined wine sensory attributes. In particular, this study sought to understand whether a specific, ripeningrelated transition in the sensory profile of Cabernet Sauvignon wines could be related to target metabolites which could be monitored, or managed during the ripening period. A further, crucial question was whether changes in wine sensory attributes associated with delayed harvest could be perceived by consumers, and whether this influenced their preference for the wines. To address these questions, an experiment was designed to determine whether changes in wine composition associated with grape ripeness confer specific changes in wine sensory properties. A further aim was to determine whether a 'sweet spot' in terms of consumer preference exists for Cabernet Sauvignon wines produced from different grape ripeness levels.

Materials and methods

Grape samples were obtained from a commercial vineyard (Pernod Ricard Australia, Orlando Wines) in the Langhorne Creek growing region, South Australia, in the 2010 season. Five stages of ripeness (H1 to H5) were sequentially harvested over a 6-week period, producing alcohol contents ranging between 12.0% v/v and 15.5% v/v. Wines were made in triplicate under standardised conditions. Details of the winemaking procedure and compositional data are published in Bindon et al. 2013a, b. Descriptive sensory analysis was performed on the wines. Sensory panellists attended three training sessions and determined 24 appropriate descriptors for rating in the formal sessions; these are shown in Figure 1. The intensity of each attribute was rated in triplicate for each wine. A significant effect of harvest date was found for all sensory attributes except for 'vanilla' aroma and 'salty' taste. A consumer test was carried out in Sydney with 104 red wine consumers. Sensory and chemistry data for the wines were modelled using partial least squares regression (PLS).

Results and discussion

Wine compositional analysis

The wines made from grapes of different ripeness grades were characterised by variation in a number of chemical components. A summary of these changes is presented in Figure 2 as a percentage increase or decrease from the concentration detected in wine from the first harvest point (H1). Detailed analytical data have been previously published (Bindon et al. 2013a, b).

Wine ethanol concentration increased with successive harvest points, and this was accompanied by an increase in glycerol (Figure 2A). Acetic acid concentration in all wines was low, but also increased in wines from the last harvest dates, H4 and H5. As expected, concentrations of IBMP decreased with ripening, and dropped below sensory detection threshold during the ripening series. Interestingly, volatiles derived from C₆ precursors also decreased with ripening, notably the alcohols hexanol and Z-3-hexen-1-ol and the corresponding ester, hexyl acetate. Conversely, various esters increased in response to higher must sugar concentration. Since the grape-derived nitrogen was low in the grapes from this particular vineyard, most of the nitrogen available for yeast metabolism was from the addition of diammonium phosphate. It was therefore expected that differences in overall nitrogen between fermentations would not have been the underlying cause of changes in ester concentration in wines, but this possibility cannot be excluded. There was also a significant increase in dimethyl sulfide observed by harvest point, but this was below reported sensory detection threshold concentration at all points.

Since all wines were adjusted for pH, differences in pH and titratable acidity (TA) between sequential harvest treatments were small (Figure 2B). However, while small, the differences in pH and TA between the wines were statistically significant. Apart from a slightly higher acid in H1 relative to H2-H5, these differences were not related to grape maturity. Since the wines did not undergo malolactic fermentation, malic acid was present in the wines and decreased with sequential harvest points (data not shown, see Bindon et al.



Figure 1. Terms for 24 appearance, aroma and palate sensory attributes defined for the wine series made from sequentially harvested grapes; number out of total for each group of terms indicates the number of variables which were significantly affected by harvest date, descriptors highlighted in blue were not significant 2013a). In terms of wine phenolics, the latest harvest point H5 had higher total wine tannin compared with H1 to H4, and for wine colour, anthocyanin and bisulfite-resistant pigments, there were increases with successive harvest points. Despite only small changes in tannin concentration in the sequentially harvested wines, a shift was observed whereby increased skin tannin and reduced seed tannin were found in the later harvest wines, together with increasing tannin mean degree of polymerisation (mDP). It is therefore proposed that skin and seed tannin extractability were differentially affected by ripening. In terms of overall wine polysaccharide concentration, only minor differences were found between the harvest treatments. However, significant changes in polysaccharide composition were found, with earlier-harvest wines having higher grape-derived acidic and neutral polysaccharides and higher alcohol wines possibly having an enrichment of yeast-derived mannoproteins. This is identified by the changes in the proportions of monosaccharides within the wine polysaccharides across different wines (Figure 2B).



Figure 2. Change in wine composition from sequential harvest dates H2 to H5 expressed as a percentage increase or decrease from the first harvest date H1. A. Fermentation and grape-derived volatiles, glycerol, alcohol and acetic acid; B. Polysaccharides, colour, tannin, pH and TA (titratable acidity)

Wine sensory analysis

Sensory descriptive analysis showed a clear transition in aroma, appearance and palate attributes with the progression of ripening. This is shown as a principal component analysis (PCA) map in Figure 3. The wines from earlier harvest dates were strongly related to descriptors such as 'red fruit' (aroma and palate), 'red colour' and 'fresh green' (aroma and palate). Later harvest dates were rated higher in attributes such as 'hotness', 'pungent', 'opacity' (colour intensity), 'dark fruit' (aroma and palate), 'overall fruit' (aroma and palate) and to a lesser degree 'astringency', 'bitter' and 'earthy'.

In order to determine whether relationships, if any, existed between wine chemistry data and wine sensory attributes, the appearance and aroma terms were modelled separately from the palate terms and are shown in Figure 4 (appearance and aroma) and Figure 5 (palate). For appearance and aroma attributes, 'opacity', 'purple colour' and 'astringency' were strongly associated with higher total anthocyanin, wine colour density and SO₂-resistant pigments, tannin concentration, mean degree of polymerisation and % skin-derived tannin. For the 'pungent' attribute there was a strong positive association with wine ethanol content. Of the volatile compounds that were positively associated with 'dark fruit' aroma, significant positive relationships were found with dimethyl sulfide, and multiple esters. For the 'red fruit' aroma attribute, a negative relationship was found with the 'dark fruit' attribute (as also shown in the PCA analysis, Figure 3). As a result, 'red fruit' aroma was negatively correlated with ester concentration (apart from hexyl acetate). The 'green' volatiles IBMP and C₆ alcohol concentration were negatively associated with 'dark



Figure 3. Principal component analysis (PCA) analysis biplot of the mean scores of the significant (P<0.05) sensory descriptive analysis data for the 15 wines (H1-H5: harvest dates 1–5, and their individual fermentation triplicates). AT: aftertaste, a: aroma, p: palate



Figure 4. X and Y loadings plot from partial least squares (PLS) regression for appearance and aroma terms using selected chemistry data where X loadings (chemistry) are shown in blue, Y loadings (sensory) are shown in red. Overlaid scores distribution for wines from five harvest dates (H1-H5) is indicated by different colours.

fruit' aroma, but positively correlated with 'red fruit' and 'fresh green' aromas. However, the 'fresh green' attribute was not as well described by the wine compositional data as 'dark fruit' or 'red fruit' aroma in the partial least squares (PLS) model, as indicated by its position within the inner ellipse of the PLS diagram (Figure 4). Certain attributes were not well modelled by wine compositional data, and these were: 'cooked vegetable', 'sewage/drain' and 'earthy'.

In the PLS analysis for palate attributes (Figure 5) a similar model of wine compositional and sensory data was found as for appearance and aroma. However, 'dark fruit' flavour was not strongly related to increases in esters, unlike the result for 'dark fruit' aroma, but was nonetheless associated with higher concentrations of dimethyl sulfide, lower IBMP and lower C66 alcohol concentrations. Similar to the model for aroma, decreases in the concentration of so-called 'green' volatiles IBMP and C₆ alcohols were more significant in defining the decrease in 'red fruit' flavour in wines made from riper grapes than the decrease in 'fresh green' flavour. Despite this, the 'fresh green' flavour attribute was significant within the PLS model (within the outer ellipse) and was negatively correlated with a number of esters. The attribute 'viscosity' was positively associated with alcohol and glycerol, as well as yeast-derived mannoprotein (mannose), but also had a strong negative relationship with malic acid and grape-derived polysaccharide. 'Hotness' was associated with alcohol content, in a similar manner to the 'pungent' attribute. The correlation between 'viscosity' and 'hotness' with wine alcohol concentration is expected, and has been shown previously for Cabernet Sauvignon in a sequential harvest trial study (Heymann et al. 2013). Despite the effort made to adjust all the wines to similar pH, the acidity attribute was nonetheless associated with differences in pH and also titratable acidity. This shows how important it is to manage acid adjustments in the winemaking process, as only small differences in pH can produce a large response in terms of acidity perception. For the other palate attributes, 'astringency' and 'bitterness', these were positively associated with total tannin concentration, skin tannin concentration (% skin), and tannin mDP. Interestingly, 'astringency' was also positively associated with titratable acidity. A point of interest was that 'bitterness' was negatively correlated with grape-derived polysaccharides (galacturonic acid, arabinose, xylose, rhamnose and fucose).

Consumer testing

The results of the consumer study (Figure 6) showed that the wines were generally well-liked (score of 6 or higher), which was unexpected since the wines had not been through malolactic fermentation. A clear trend in liking was found in which the wines at 12% to 13% alcohol were the least preferred (Figure 6). Thereafter, liking scores reached



Figure 5. X and Y loadings plot from partial least squares (PLS) regression for palate terms using selected chemistry data where X loadings (chemistry) are shown in blue, Y loadings (sensory) are shown in red. Overlaid scores distribution for wines from five harvest dates (H1-H5) is indicated by different colours.

a plateau at 13.6% alcohol, after which no further increases were observed with wines from later harvest dates, up to 15.5% alcohol at the final harvest. The plateau point in terms of consumer preference was before wine compositional factors currently thought to be indicators of wine 'quality' (such as colour, tannin and esters) were at a maximum. A relevant observation is that wine alcohol content itself may contribute significantly to this trend in preference, where increases in 'hotness' and 'pungency' in the later-harvest wines had a moderating effect on otherwise positive wine characteristics, such as 'dark fruit' and 'viscosity'. As the results are based on only one season, one vineyard and a specific set of winemaking conditions, extrapolation of these findings is limited. Nevertheless, the results allow for the suggestion that harvest date H3 may represent an optimal harvest point in order to combine high consumer acceptance with a lower alcohol concentration in wine. A further natural conclusion, therefore, is that delaying harvest to optimise wine attributes may not necessarily achieve a higher wine quality target in terms of consumer preference, but simply result in higher-alcohol, hotter wines.

Conclusions

The results presented have shown a clear transition in key sensory attributes of Cabernet Sauvignon wines, which were directly or indirectly related to changes in wine composition with grape ripening. The decrease in 'green' (vegetative) attributes was notable in higheralcohol wines from later harvest dates. However, aside from this attribute, the transition from earlier-harvest wines with a predominance of 'red fruit' attributes, to wines with a greater contribution of 'dark fruit' attributes at later harvest was a significant result. This shift was related to the increased concentration of wine esters only for aroma. Dimethyl sulfide concentration also appeared to be of importance in defining 'dark fruit' characters. It was interesting that in the PLS models developed for both aroma and palate, the shift from 'red fruit' to 'dark fruit' attributes was well modelled by decreases in the so-called 'green' volatiles IBMP and C₆ alcohols. On the other hand, a strong relationship between 'fresh green' attributes and IBMP or C₆ alcohols was not found for the wine series, which was surprising. A similar lack of correlation between IBMP and 'vegetative' aroma and flavour has been observed in other studies (Preston et al. 2008; Scheiner et al. 2012).



Figure 6. Mean consumer liking response scores to wines from five harvest dates, where a value of 6 represents a significant liking effect. Blue highlighted area represents a plateau in the liking score.

Aside from wine aroma and flavour attributes, appearance and palate attributes were also affected by the ripening process. The study showed a good correlation between analytical measures of wine colour density, and perceived wine colour. As expected, wine 'purple colour', 'astringency' and 'viscosity' increased with the laterharvest wines, but 'hotness' and 'bitterness' increased at the same time. It is important to highlight that this may have moderated the acceptance of wines by consumers, as it would have been expected that the concomitant increases in positive attributes such as 'purple colour' or 'dark fruit' may otherwise have increased the liking for later-harvest wines by consumers. Since a plateau in consumer preference was reached before IBMP was at a minimum or phenolics were at a maximum, it appears that these grape analytical measures may not necessarily track with a targeted 'optimal ripeness' for Cabernet Sauvignon wine 'quality'. Although the results shown here represent a narrow range in terms of vintage or regional effects, they nevertheless indicate promise that earlier harvests, and lower target alcohol levels may be achievable in commercial wine production, while maintaining consumer satisfaction.

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Can non-conventional yeast be used for the production of wines with lower alcohol concentration?

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Summary

High alcohol concentrations can affect wine sensory properties, reducing the complexity of flavours and aromas. In addition, for reasons associated with health and economics, the wine sector is actively seeking technologies that facilitate the production of wines with lower alcohol content. Non-conventional yeasts, in particular non-Saccharomyces yeasts, have shown potential for producing wines with lower alcohol concentration. These yeast species are usually found on grapes and during the first stages of fermentation, but generally are not able to complete alcoholic fermentation. We evaluated 50 different non-Saccharomyces isolates, belonging to 24 different genera, for their capacity to produce wine with lower ethanol concentration when used in sequential inoculation with S. cerevisiae wine strain AWRI1631. Our results showed that sequential inoculation with non-Saccharomyces strain AWRI1149 produced white and red wines with 0.9% v/v and 1.6% v/v, respectively, lower ethanol concentrations than wines made with S. cerevisiae AWRI1631 alone. AWRI1149+AWRI1631 produced at least 20% more volatile compounds, such as esters and higher alcohols, than AWRI1631. Most of these compounds showed concentrations below their sensory thresholds, indicating a minimal impact on wine flavour profile. In conclusion, it is possible to obtain wines with lower ethanol concentration with non-conventional yeasts while minimising negative effects on wine flavour.

Introduction

Over recent decades the average ethanol concentration in wine has increased as a direct result of higher sugar accumulation in grapes. A few decades ago, wines that naturally reached more than 14% alcohol were rare, but now it is not uncommon to see alcohol levels of more than 16% indicated on wine labels (Robinson 2012).

The maturity of some of the main grape varieties grown in Australia, such as Chardonnay, Shiraz and Cabernet Sauvignon has advanced at a rate between 0.5 to 3 days per year (Petrie and Sadras 2008). Faster maturity has been compensated by early harvest in Chardonnay, but that is not always possible in Shiraz or Cabernet Sauvignon, because of the need for phenolic ripeness. Therefore, Shiraz and Cabernet Sauvignon are frequently harvested at high sugar concentrations, generating wines with high ethanol concentrations. Indeed, alcohol concentration in Australian red wines has increased approximately 1% v/v per decade since 1984 (Godden and Gishen 2005).

When not in balance, high ethanol concentrations can reduce flavour perception and affect wine complexity. Additionally, wines with high alcohol concentrations can attract higher taxes in some countries. These reasons, in concert with current health concerns related to elevated alcohol consumption, have shaped the focus of the wine industry on reducing alcohol concentration in wine.

Although several engineering approaches (such as reverse osmosis, sugar removal from grape must, vacuum distillation or evaporation) are used to reduce ethanol concentration in wine, such methodologies increase production costs and might affect wine flavour. It would be preferable to manage alcohol concentration by using wine yeast strains which are less efficient at transforming grape sugars into ethanol.

Saccharomyces cerevisiae is the main yeast responsible for wine fermentation. This yeast is able to complete alcoholic fermentation by consuming all sugar present in the grape must. *S. cerevisiae* is resistant to several stress conditions that occur during alcoholic fermentation, and for this reason it can displace other yeasts present in grape must. Although numerous *S. cerevisiae* wine strains are available commercially, they all show similar ethanol yields, which translate into comparable wine ethanol concentrations (Palacios et al. 2007; Varela et al.

2008). Attempts to generate *S. cerevisiae* strains with lower ethanol yields have included genetically modifying (GM) yeast metabolism and 'persuading' yeast to produce less ethanol using non-GM means. Although GM approaches have been very effective in generating yeast that produce less ethanol during fermentation (Varela et al. 2012; Cambon et al. 2006), negative perceptions of GM products from consumers have influenced the commercial application of such strains. It is also currently the Australian wine industry's position that no GM organisms be used in the production of Australian wine. Low-ethanol strains generated by non-GM approaches have not been as efficient as GM strains at reducing wine alcohol concentration (Varela et al. 2008), which indicates that further research is required in this area.

In addition to *Saccharomyces cerevisiae*, a range of other yeasts with diverse genera and species are naturally found in grape must and as a group these are usually referred to as non-*Saccharomyces* yeast. Previously, many non-*Saccharomyces* yeast were considered as spoilage microorganisms which negatively affected wine flavour and aroma. Further research has shown that non-*Saccharomyces* yeast are not necessarily spoilage microorganisms and that specific non-*Saccharomyces* strains have a positive influence on wine flavour and aroma composition (Ciani et al. 2006; Comitini et al. 2011; Di Maio et al. 2012; Domizio et al. 2011; Ehsani et al. 2012; Garcia et al. 2002; Magyar and Toth 2011; Soden et al. 2000; Toro and Vazquez 2002). Based on this research, commercially available non-*Saccharomyces* yeasts are now being inoculated into grape must by winemakers in order to increase flavour complexity in wine.

Indigenous non-*Saccharomyces* yeasts are usually present during the first stages of fermentation and generally are not able to complete alcoholic fermentation by themselves (Ciani and Maccarelli 1998; Fleet et al. 1984). Nevertheless, non-*Saccharomyces* strains with a lower ethanol yield could be used to reduce ethanol concentration in wine by sequential inoculation. Sequential inoculation involves inoculation of grape must with a non-*Saccharomyces* yeast, followed by *S. cerevisiae* allowing sufficient time for the less-competitive yeast to grow. Given enough time, the non-*Saccharomyces* yeast will consume part of the sugar present in the must leaving less sugar available for *S. cerevisiae* and simultaneously forming less ethanol. In this way, sequential inoculation could produce wines with lower ethanol concentration than wines produced by *S. cerevisiae* alone (Figure 1). A limited number of studies have reported lower ethanol yields when using non-*Saccharomyces* and *S. cerevisiae* strains in mixed or sequential cultures, translating to a modest decrease in ethanol concentration of between 0.2 - 0.6 % v/v (Comitini et al. 2011; Di Maio et al. 2012; Ferraro et al. 2000; Sadoudi et al. 2012). To date, only a small number of non-*Saccharomyces* species have been studied for their potential use in production of lower-alcohol wine.

Results

In the present work, 50 non–*Saccharomyces* strains of different genera and species were analysed for their ability to produce ethanol, using sequential inoculation with *S. cerevisiae* AWRI1631. Non–*Saccharomyces* yeasts were evaluated using a defined media which contained sugar, nitrogen and tartaric acid. Based on this analysis, four strains were then selected and evaluated in chemically defined grape juice (CDGJ) media. *Metschnikowia pulcherrima* AWRI1149 showed the lowest ethanol concentration in CDGJ media when sequentially inoculated with *S. cerevisiae* AWRI1631. Consequently, AWRI1149 was then tested in Chardonnay and Shiraz must.

In Chardonnay, AWRI1149+AWRI1631 produced wines with 0.9% v/v less ethanol than the control fermented with S. cerevisiae AWRI1631alone (14.2% (v/v) vs 15.1% (v/v)). Wines produced with AWRI1149 and AWRI1631 in sequential inoculation showed higher glycerol concentrations, but similar acetic acid concentrations compared with wines produced with AWRI1631 alone. Wines produced with AWRI1149+AWRI1631 showed a lower concentration of volatile acids than the control. In addition, sequentially inoculated wines showed increased concentrations of higher alcohols and esters, volatile compounds that contribute positively to wine complexity (Figure 2). However, wines produced with AWRI1149+AWRI1631 also showed elevated ethyl acetate concentrations. Although this compound contributes to wine complexity at low concentration, its impact is generally detrimental at concentrations higher than 150 mg/L, as observed for this particular Chardonnay. Excessive ethyl acetate concentration is associated with negative sensory descriptors, such as 'nail polish remover' (Jackson 2009).

In Shiraz, AWRI1149+AWRI1631 produced wines with 1.6% less ethanol than *S. cerevisiae* AWRI1631 alone (12.2% (v/v) vs 13.8% (v/v)). Similar to observations for the Chardonnay fermentations, Shiraz wines produced by sequential inoculation showed higher glycerol concentration, but similar acetic acid concentration compared with wines produced with AWRI1631alone. Wines



Figure 1. Sequential inoculation involves inoculation of grape must with a non-Saccharomyces yeast followed by inoculation with *S. cerevisiae*. The non-Saccharomyces yeast will consume part of the sugar present in the must leaving less sugar available for *S. cerevisiae* and simultaneously forming less ethanol. In this way, sequential inoculation can produce wines with lower ethanol concentrations than wines produced by *S. cerevisiae* alone.

produced by AWRI1149+AWRI1631 exhibited lower concentrations of volatile acids than the control and showed similar concentrations of higher alcohols and esters than AWRI1631 alone (Figure 3). Although sequentially inoculated Shiraz wines also showed higher ethyl acetate concentrations than the control, the levels did not exceed the sensory perception threshold and would not be expected to have a detrimental impact on wine aroma.



Figure 2. Concentration of ethanol and volatile compounds for Chardonnay wines fermented with AWRI1149+AWRI1631 and AWRI1631 alone



Figure 3. Concentration of ethanol and volatile compounds for Shiraz wines fermented with AWRI1149+AWRI1631 and AWRI1631 alone

Conclusion

The use of AWRI1149 in combination with *S. cerevisiae* AWRI1631 was an effective strategy to obtain wines with reduced ethanol concentration. Wines produced by AWRI1149+AWRI1631 showed lower volatile acids and increased higher alcohols than wines produced by AWRI1631 alone. Chardonnay and Shiraz wines fermented with AWRI1149+AWRI1631 showed higher ethyl acetate concentrations than wines made with AWRI1631; however the ethyl acetate concentration in the Shiraz was below the sensory detection threshold. In conclusion, it is possible to obtain wine with lower ethanol concentration using non-conventional yeasts while minimising negative effects on wine flavour.

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Effects of metals on the evolution of volatile sulfur compounds during wine maturation

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Abstract

Volatile sulfur compounds (VSCs) have a large impact on the aromatic bouquet of wines. They impart both positive varietal characters and negative characters, such as 'rotten egg', 'rubber' and 'sewage'. The negative and so called 'reduced' characters are associated with compounds such as hydrogen sulfide (H₂S), methanethiol (MeSH) and in some instances dimethyl sulfide (DMS) when the latter compound is present in high concentrations. Many potential precursors to VSCs are present in wine, making it important to not only understand the formation of VSCs from their precursors but also the mechanisms driving their release from various precursor molecules present in grapes and in wine. Investigating the role of metal ions as catalysts, as well as the synergistic effects of these metals during their catalytic action in the formation of VSCs, is fundamental to understanding the chemical processes involved in the formation of post-bottling 'reductive' aromas. In this study we have investigated the formation of VSCs, specifically MeSH from methionine during wine maturation as catalysed by five metals (Al, Cu, Fe, Mn and Zn) normally present in wine and that are known for their catalytic ability. The evolution of H₂S and DMS as a result of metal addition was also investigated. Wines were stored anaerobically and analysed over a 12-month period. Dissolved oxygen was monitored during the experiment to study the effect this had on the wine chemistry. The evolution of H₂S, MeSH and DMS was influenced by various metals, with copper showing a strong correlation with MeSH evolution. In some instances a combination of metals was responsible for the largest increase in VSC concentration.

Introduction

Wine is a continuously changing system and the most obvious changes take place during fermentation and the early parts of the winemaking process. However, the subtle changes that take place after bottling and during storage are just as critical in the establishment of the final product as those during the earlier stages of the winemaking process. One of the most important factors that influences the aroma, colour and mouth-feel of wine is the amount of oxygen it is exposed to post-bottling (Ugliano et al. 2011; Kwiatkowski et al. 2007; Ugliano et al. 2012; Lopes et al. 2009; Ugliano 2013; Wirth et al. 2010). Wines exposed to very low levels of oxygen during fermentation and postbottling can develop 'reductive' aromas that are associated with the presence of volatile sulfur compounds (VSCs) (Godden et al. 2001). VSCs naturally occur in wines in low concentrations but their contribution to the overall flavour and aroma of the wine are very important. Typical 'reduced' odours can be attributed to hydrogen sulfide (H₂S) and methanethiol (MeSH), and they are associated with aromas of 'rotten egg', 'sewage', and 'rubber'. When present in high concentrations, dimethyl sulfide (DMS) is known to impart 'canned corn', 'asparagus', or 'vegetal' aromas, although in low concentrations it can enhance wine aroma (Segurel et al. 2004). When present in low concentrations, even a compound associated with 'rotten egg' aromas, like H₂S for example, can add complexity to wine (Rauhut 2009).

The formation of VSCs in wine and food can be explained by a variety of chemical and biochemical mechanisms, although not all of these mechanisms are fully elucidated (Mestres et al. 2000; Swiegers et al. 2005). The main source of VSCs in wine is yeast metabolism and it involves the degradation of sulfur-containing amino acids and sulfur-containing pesticides, as well as the formation of VSCs from precursor molecules (Mestres et al. 2000; Swiegers et al. 2005). In some instances photochemical and thermal reactions have been found to be responsible for the formation of VSCs during storage (Mestres et al. 2000). Not all the factors involved in the formation of VSCs postbottling are fully understood, but recent literature has shown that H_2 S, MeSH and DMS increase in concentration post-bottling and that lower post-bottling oxygen exposure results in an increase in H_2 S and MeSH concentration (Ugliano et al. 2012; Ugliano et al. 2011; Lopes et al. 2009).

It is possible to deal with VSCs like H₂S and MeSH during winemaking. High concentrations of H₂S can be reduced by aerating the wine, although this practice carries a few risks. For example, white wines are susceptible to oxidative browning and in red wines dormant acetic acid bacteria could be activated (Jackson 2008). Even when H₂S odours are noticed in the wine glass they seem to be diminished by mild aeration in the glass. If mercaptans are present during winemaking, they can be treated by the addition of lees combined with gentle aeration of the wine. Yeast cell walls appear to bind selected VSCs and remove them from wine, but higher molecular weight sulfur compounds are more difficult to treat (Jackson 2008). Copper sulfate treatment can be used immediately after fermentation to reduce the concentration of unwanted thiols (i.e. H₂S and MeSH), however, copper (Cu) fining does not remove disulfides, thioacetates or cyclic sulfur compounds, potentially associated with off-odours in wine (Rauhut et al. 1993). Fining with Cu could also lead to a decrease in the intensity of positive wine aromas due to the Cu reacting with the varietal thiols (Ugliano et al. 2011).

Metal ions are naturally present in grapes and wine and they are essential cofactors in vitamins and enzymes that are important to the fermentation process. When metals exceed trace amounts it may indicate contamination through human activity, for example the use of pesticides, fertiliser, machinery in the winery or fining agents like bentonite and copper (Jackson 2008). Metals like tungsten (W), zinc (Zn), copper (Cu), cobalt (Co), iron (Fe), nickel (Ni) and manganese (Mn) have the ability to catalyse oxidation-reduction (redox) reactions, but only Fe, Zn, Cu and Mn are likely to have a catalytic role of functional significance when the metal concentrations in wine are considered (Larcher and Nicolini 2008). The importance of aluminium (Al) in limiting oxygen consumption has been shown, as well as the ability of wine compounds to chelate to Al³⁺ (Vivas 2002; Larcher and Nicolini 2008). Several of the metals mentioned above (Al, Cu, Fe, Mn, Ni, Zn) have already been associated with undesirable effects in wine (Tariba 2011) and their concentration can be a significant parameter affecting consumption and conservation of wine. Since metallic ions have an important role in oxide-reductive reactions resulting in wine browning, turbidity and astringency (Tariba 2011), wine quality depends greatly on its metal composition.
Moreover, metals in wine may affect human health. Consumption of wine may contribute to the daily dietary intake of essential metals (i.e., copper, iron, and zinc).

The effects of certain metal ions on the evolution of VSCs in alcoholic beverages have previously been investigated. The ability of H₂S to react with MeSH and ethanethiol (EtSH) in the presence of Cu to form symmetrical and asymmetrical trisulfides was demonstrated by Nedjma and Hoffmann (1996). Walker (1995) showed that the addition of Cu to beer significantly reduced H₂S and EtSH concentrations, but that Zn, Fe³⁺, Mn²⁺, Ni, lead (Pb²⁺) and tin (Sn²⁺) had no effects on H₂S, MeSH, EtSH, methyl thioacetate (MeSAc) or DMS concentrations when these metals were added at relatively low concentrations. Only when added at higher concentrations (1 g/L) did Zn, Fe³⁺ and Pb²⁺ bind reversibly to H_2S and EtSH (Walker 1995). It has also been demonstrated that the addition of Cu led to an increase in H₂S concentration in Sauvignon Blanc wines when these wines were stored anaerobically (Ugliano et al. 2011). Furthermore, agrochemicals that contain Mn and Zn have been associated with the development of VSCs in wines (Zoecklein et al. 1995).

There are many possible precursors to VSCs in wine, making it important to not only understand the formation of VSCs from precursor sources but also the mechanisms or chemical switches that are involved in the release of VSCs from their various precursor compounds. Investigating the role of metal ions as catalysts in the formation of VSCs as well as the synergistic effects of the metals during their catalytic action is crucial to gain a better understanding of the chemical processes governing the formation of post-bottling 'reductive' aromas.

Evolution of volatile sulfur compounds

We have investigated the formation of VSCs, specifically MeSH from methionine, as catalysed by five metals (Al, Cu, Fe, Mn and Zn) normally present in wine and known for their catalytic ability (Viviers et al. 2013). The evolution of H₂S and DMS as a result of metal addition was also investigated. Results were also correlated with the amount of oxygen present in the wine. To achieve this goal we spiked a Chardonnay and a Shiraz base with Cu, Fe, Mn, Zn and Al in all possible combinations and at two concentrations, one low and one high. The low concentration was the concentration of the metals already present in the base wine and the high concentration was ten times the concentration of the metals measured in the base wine. This experimental protocol resulted in 31 different metal combinations (metal treatments) and one control sample (n=32) and each treatment was prepared in triplicate (n = 96 samples). Samples were stored in an anaerobic atmosphere and analysed over a 12-month period. During the experimental set-up, oxygen was introduced into the samples (Chardonnay 1.106 ± 0.342 mg/L; Shiraz 1.429 \pm 0.354 mg/L) and this oxygen was consumed over the course of the experiment, with the dissolved oxygen (DO) of both Chardonnay and Shiraz samples reaching 0 $\mu\text{g/L}$ after 4 months of anaerobic storage.

Overall, the VSCs under investigation displayed significant changes in concentration over the course of the experiment, with the major changes in the Chardonnay samples being increases in H_2S and DMS concentrations, and the major changes in the Shiraz samples being increases in H_2S and MeSH concentrations. It has previously been shown that H_2S , MeSH and DMS concentrations in wines have a tendency to increase during bottle maturation, and that the greatest increases in concentrations for H_2S and MeSH are seen in samples with low oxygen exposure (Ugliano et al. 2012; Ugliano et al. 2011; Lopes et al. 2009).

The most remarkable results of this current study, however, were the effects observed due to metal additions (i.e. Mn, Zn and Al) that have not previously been considered in the context of wine VSCs, as well as

the interactions between the five metals. In some instances a reversible effect was observed. Initially, at high DO concentrations (0.150 – 1.50 mg/L) some metals, for example Cu, significantly reduced the concentrations of H₂S and MeSH. However, during wine maturation and when the oxygen concentration had decreased to 0 μ g/L, Cu was associated with a significant increase in MeSH concentration, regardless of the presence or absence of other metals. The metals and metal combinations that were associated with significant effects on the evolution of H₂S, MeSH and DMS at each time point are shown in Table 1.

Metal effect on H₂S

Not all metals had a significant effect on the evolution of H_2S throughout the experiment, and in some instances the metals were only associated with significant effects at one analysis time point. The metals and metal combinations that induced a significant effect on H_2S concentration in Chardonnay and Shiraz samples are summarised in Table 1. If both the Chardonnay and Shiraz samples are considered, only 7 of the 31 metal treatments significantly affected the evolution of H_2S in both wines, and they were Cu, Fe, Zn, Al, Cu*Fe, Cu*Mn*Al and Cu*Zn*Al.

To distinguish between the different significant metal effects, multivariate statistical methods were used. For example, the Chardonnay samples that displayed the largest decreases in H₂S concentration at Day 1 and Month 1 were samples treated with Cu. On Day 1 all the samples treated with Cu had an average H₂S concentration of 1.436 \pm 0.088 µg/L, and it seemed that Cu was the only metal associated with significant decreasing effects. However, using multivariate statistical analysis it was possible to distinguish between the effect of Cu on the evolution of H₂S at Day 1, and the effect of Cu*Fe, that was also associated with significant decreasing effects on H₂S concentrations at Day 1 in the Chardonnay samples.

Three metal treatments, namely Zn, Mn*Zn*Al and Cu*Fe*Mn*Zn, associated with some of the largest increases in H_2S concentrations in the Chardonnay samples at Month 10 are shown in Figure 1. Using multivariate statistical analyses it was found that the increases in H_2S concentrations were due to the significant effect of either Zn, Al, Zn*Al or Mn*Zn*Al in these metal combinations. The importance of Al as a catalyst involved in the evolution of H_2S from sulfur-



Figure 1. Line graphs showing three of the five metal treatments that were associated with the largest increases in H₂S concentrations in Chardonnay samples at Month 12 (a) and three of the five metal treatments associated with the largest increases in MeSH concentration in Shiraz samples at Month 12 (b). Control samples are displayed as blue lines, and the metal additions are displayed as red, green and purple lines. Odour threshold values are indicated by the dashed black line parallel to the x-axis at 1.1 to 1.6 μ g/L for H₂S and 1.8 to 3.1 μ g/L for MeSH (Siebert et al. 2010).

Table 1. Metal treatments with significant influence on VSCs formation in wine

			Chardonna	у						
цс	Day 1		Mo	nth 1	Mon	th 10	Mon	th 12		
п ₂ 5	p-va	lue	p-v	alue	p-v	alue	p-v	alue		
Cu	0.001		0.001		0.009		0.537	NS		
Fe	0.026	-	0.045	-	0.017	-	0.909	NS		
Zn	0.393	NS	0.139	NS	0.001	+++	0.600	NS		
AI	0.306	NS	0.376	NS	0.002	++	0.135	NS		
Cu*Fe	0.032	-	0.265	NS	0.011	-	0.278	NS	-	
Fe*Al	0.587	NS	0.762	NS	0.014	+	0.800	NS		
Zn*Al	0.882	NS	0.149	NS	0.005	++	0.678	NS		
Cu*Mn*Al	0.418	NS	0.908	NS	0.018	-	0.664	NS		
Cu*Zn*Al	0.562	NS	0.912	NS	0.013	+	0.913	NS		
Fe*Zn*Al	0.727	NS	0.215	NS	0.036	+	0.732	NS		
Mn*Zn*Al	0.222	NS	0.101	NS	0.033	+	0.279	NS		
	Day	/ 1	Мо	nth 1	Mon	th 10	Mon	th 12		
MeSH	p-va	lue	p-v	alue	p-v	alue	p-v	alue		
Cu	0.002		0.586	NS	0.288	NS	0.055	(0.1)+		
Zn	0.636	NS	0.096	(0.1)+	0.017	+	0.519	NS		
Fe*Mn	0.919	NS	0.711	NS	0.019	-	0.792	NS		
Cu*Fe*Mn	0.586	NS	0.695	NS	0.022	-	0.545	NS		
DMC	Day	/ 1	Мо	nth 1	Mon	th 10	Mon	th 12		
DIVIS	p-va	lue	p-v	alue	p-v	alue	p-v	alue		
Al	0.062	(0.1)+	0.186	NS	0.020	-	0.312	NS		
Zn*Al	0.045	+	0.491	NS	0.060	(0.1)-	0.589	NS		
Mn*Zn*Al	0.048	+	0.891	NS	0.245	NS	0.574	NS		
	Day	/ 1	Мо	nth 1	Мог	nth 4	Мо	nth 6	Mon	th 12
H ₂ S	p-value p-value p-va		alue p-value			p-v	alue			
Cu	0.000		0.157	NS	0.277	NS	0.681	NS	0.010	++
Fe	0.000		0.522	NS	0.641	NS	0.968	NS	0.580	NS
Mn	0.392	NS	0.036	-	0.440	NS	0.718	NS	0.486	NS
Zn	0.004	++	0.030	-	0.070	(0.1)+	0.671	NS	0.354	NS
Al	0.014	+	0.014	-	0.053	(0.1)+	0.544	NS	0.154	NS
Cu*Fe	0.000		0.844	NS	0.138	NS	0.327	NS	0.010	++
Cu*Zn	0.014	-	0.900	NS	0.313	NS	0.834	NS	0.526	NS
Fe*Zn	0.043	-	0.732	NS	0.998	NS	0.804	NS	0.429	NS
Mn*Al	0.006		0.105	NS	0.165	NS	0.742	NS	0.097	(0.1)+
Cu*Fe*Zn	0.114	NS	0.756	NS	0.890	NS	0.687	NS	0.015	+
Cu*Mn*Al	0.007		0.532	NS	0.110	NS	0.900	NS	0.324	NS
Cu*Zn*Al	0.056	(0.1)-	0.495	NS	0.904	NS	0.313	NS	0.050	+
Fe*Mn*Al	0.039	-	0.874	NS	0.158	NS	0.684	NS	0.065	(0.1)+
MacH	Day	71	Мо	nth 1	Мо	nth 4	Мо	nth 6	Mon	th 12
Mesti	p-va	lue	p-v	alue	p-v	alue	p-v	alue	p-v	alue
Cu	0.067	(0.1)-	0.007		0.015	+	0.068	(0.1)+	0.002	++
Zn	0.067	(0.1)-	0.884	NS	0.031	+	0.603	NS	0.570	NS
Cu*Zn	0.067	(0.1)-	0.654	NS	0.017	+	0.583	NS	0.520	NS
Fe*Mn	0.474	NS	0.317	NS	0.015	+	0.908	NS	0.342	NS
Zn*Al	0.067	(0.1)-	0.316	NS	0.047	+	0.605	NS	0.344	NS
Cu*Fe*Mn	0.474	NS	0.626	NS	0.015	+	0.949	NS	0.329	NS
Fe*Mn*Zn	0.474	NS	0.529	NS	0.035	+	0.625	NS	0.707	NS
Cu*Fe*Mn*Zn	0.474	NS	0.960	NS	0.029	+	0.681	NS	0.672	NS
Cu*Fe*Mn*Zn*Al	0.078	(0.1)-	1.000	NS	0.013	+	0.882	NS	0.783	NS
DMS	Day	y 1	Mo	nth 1	Moi	nth 4	Mo	nth 6	Mon	th 12
	p-va	lue	p-v	alue	p-v	alue	p-value		p-v	alue
Mn	0.048	-	0.081	(0.1)-	0.730	NS	0.129	NS	0.079	(0.1)-
Zn	0.006		0.808	NS	0.402	NS	0.410	NS	0.082	(0.1)-
Al	0.004		0.027	-	0.637	NS	0.048	-	0.003	
Zn*Al	0.004		0.920	NS	0.283	NS	0.176	NS	0.089	(0.1)-
Fe*Mn*Zn	0.430	NS	0.039	-	0.770	NS	0.635	NS	0.401	NS

p-value describes the significance for the effect; p-value \geq 0.10 is not significant (NS); p-value 0.10 to 0.05 indicates a possible effect at the 10% significance level (0.1); p-value 0.01 to 0.05 indicates a significant negative effect (-) or positive effect (+); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value \leq 0.005 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value \leq 0.005 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positive effect (++); p-value 0.005 to 0.01 indicates significant negative effect (- -) / positiv

containing amino acids in aqueous solutions has previously been shown (Gruenwedel and Patnaik 1971).

At Day 1 some of the spiked metals were associated with a significant reduction in the H_2S concentration under initial packaging conditions when the wine had not yet consumed all the introduced dissolved and headspace oxygen (Table 1, Figure 2). This reaction between thiols and metals is used in copper fining trials to reduce the impact of unwanted thiols in wines. The copper reacts with the thiols present in the wine, forming odourless copper compounds that precipitate (Ugliano et al. 2009; Walker 1995; Brenner et al. 1954). Copper fining should be performed at least a month before bottling to allow for the elimination of the precipitated copper complexes from the wine through racking and filtration (Jackson 2008).

In this study, the effects of some of the added metals that were initially associated with significant decreasing effects were later reversed after four months of anaerobic storage. A metal like Cu, for example, was initially associated with significant decreasing effects on the H_2S concentrations in the Shiraz samples, but after 12 months of anaerobic storage and after all the DO was consumed in the control samples, the effect of Cu was reversed and it was associated with significant increases in H_2S concentrations in the Shiraz samples (Table 1, Figure 2). The reversible effects of Cu, Fe and the metal combination Cu*Fe in the Shiraz samples are shown in Figure 2. Initially at Day 1, when samples were analysed directly after metal spiking, all three metal treatments (Cu, Fe and Cu*Fe) suppressed H_2S concentration, but after 12 months of anaerobic storage, the samples treated with Cu and with Cu*Fe displayed significant increases in H_2S concentration.

Metal effect on MeSH

MeSH concentration was significantly affected by nine metal treatments in the Shiraz samples compared to four in the Chardonnay samples. (Table 1). This could be due to higher concentrations of polyphenols and anthocyanins present in the red wine samples that are likely to be involved in reactions with the metal ions. Three examples of metal treatments associated with some of the largest increases in MeSH concentration in the Shiraz samples are shown in Figure 1b. The increases in MeSH concentration in samples with added Cu*Mn*Zn, Cu*Zn*Al and Cu were driven by the significant effect of Cu, and not due to the other metals (Table 1). In the Chardonnay and Shiraz samples the same reversible effect was observed for MeSH as was seen for H_2S , and this reversible effect is graphically displayed in a series of notched boxplots (Figure 3a to 3e). In Figure 3a to 3e the distribution of the MeSH concentrations (μ g/L) in Shiraz samples (n = 96) is shown for samples with and without added Cu, with the white line depicting the median, the star depicting the mean, the red area showing the 95% confidence interval for the mean, and the black dots representing outliers. At Day 1, (Figure 3a) no MeSH was measured in samples with or without added Cu, but after 1 month of anaerobic storage the ability of Cu to reduce thiol concentrations is seen in the reduced MeSH concentration in all samples treated with Cu (Figure 3b). However, as the wine consumed all available oxygen and the DO reached 0 μ g/L, the MeSH



Figure 2. Typical chromatograms for the Gas Chromatography – Sulfur Chemiluminescence detection (GC-SCD) analysis of H₂S and MeSH in Shiraz wine samples with added Cu, Fe and the metal combination Cu*Fe shown here at (a) Day 1 and at (b) Month 12. The metals Cu, Fe and Cu*Fe were associated with significant decreases in H₂S concentration at Day 1, but after 12 months of anaerobic storage Cu and Cu*Fe were associated with significant increases in H₂S and MeSH concentrations.



Figure 3. Notched boxplots indicating the distribution of the MeSH concentrations (μ g/L) in Shiraz samples showed a significant decrease after one month (b) and significant increases after 6 and 12 months (d) and (e) due to Cu addition. The lines parallel to the x-axis in (c), (d) and (e) indicate the odour threshold value for MeSH at 1.8 μ g/L (Siebert et al. 2010).

concentration slowly increased to nearly the same levels in both samples with or without added Cu (Month 4, Figure 3c). After 6 to 12 months of anaerobic storage the MeSH concentration had significantly increased in all samples with added Cu, reaching an average (\pm STDEV) of 6.39 (\pm 2.67) µg/L after 12 months of storage. This average MeSH concentration in samples treated with Cu was substantially higher than its odour threshold value of 1.8 – 3.1 µg/L (Siebert et al. 2010). These results show that the formation of MeSH is not only influenced by the presence of metals, but that the oxygen concentration in wine also significantly affects its evolution.

Metal effect on DMS

Overall, fewer metals produced significant effects on DMS concentration, and the effects of the metal treatments were mostly associated with an overall decrease in DMS concentration. The decreasing effects of the metals could possibly be due to metals inhibiting the formation of DMS from its precursor molecules already present in the wine, or due to the catalytic degradation of DMS. The only metal treatments associated with significant effects on DMS concentration in both Chardonnay and Shiraz samples were Al and Zn*Al. This is the first insight into the role of these metal ions in the evolution of DMS in wine.

Conclusions

Results have shown that the formation of VSCs from their precursors in wine is influenced by the presence not only of copper, but also by other metal ions that naturally occur in wine, when they are present in high enough concentrations. At the start of the experiment, when oxygen was introduced during the experimental set-up, certain metals significantly decreased the concentration of the thiols. During wine maturation, and as the oxygen concentration decreased in the control samples, the effects caused by some of the metals were reversed with their presence now being associated with significant increases in either H₂S or MeSH concentration. The metal treatments that significantly affected H₂S concentration in both the Chardonnay and Shiraz samples were Cu, Fe, Zn, Al, Cu*Fe, Cu*Mn*Al and Cu*Zn*Al. Metals that significantly affected MeSH concentration in both Chardonnay and Shiraz samples were Cu, Zn, Fe*Mn and Cu*Fe*Mn. The evolution of DMS in both Chardonnay and Shiraz samples was significantly influenced by Al and Zn*Al (Viviers et al. 2013).

This study has demonstrated the importance of keeping metal concentrations as low as possible in wine, as the metals can act singly or in combination to greatly influence the evolution of wine VSCs.

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SESSION 5: Extracting the full value



Learning from other industries – insights from coffee on advanced sensory-analytical correlations F. Mestdagh, E. Thomas, L. Poisson, J. Kerler, I. Blank

Using precision viticulture to extract value *M. Trought*

Adding value in the winery R. Glastonbury

Valuing and extracting grape quality – the scorecard and some big opportunities *R. Day*



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Learning from other industries – insights from coffee on advanced sensory-analytical correlations

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Abstract

Coffee aroma is very complex, involving more than 1,000 volatile compounds. Several studies have shown that only about 30 can be considered as key impact odorants, being mainly responsible for the unique coffee aroma. Although the odour qualities and perception thresholds of the impact odorants are well described, understanding their individual contribution to the aroma of a complex mixture such as coffee is still a challenge. Recently, untargeted and targeted analytical approaches were applied to relate coffee volatiles to sensory perception and thus get a deeper understanding of the contribution of important aroma and taste compounds to the overall coffee aromatic profile. An advanced predictive model was established correlating quantitative data of key odorants with sensory descriptors from an expert panel. This model generated valuable insights into the link between key aromatic markers and different blend characteristics. However, statistical correlations are sometimes counter-intuitive and contradict the flavour quality of individual compounds. Therefore, we have performed a qualitative and quantitative aroma gap analysis between pure roast and ground coffees having a distinct sensory profile, using a variety of sensory directed instrumental techniques such as GC/O, GC-MS and GCxGC-TOFMS. With this combined analytical approach, key aromatic markers having a significantly different concentration between the various coffees were identified and quantified. Knowing this aroma gap, a series of spiking experiments was performed in reference coffees to prove the causal link between key aromatic markers and sensory attributes, thus generating the knowledge required to modulate the coffee aroma into a distinct sensory direction.

Introduction

Besides the stimulating effect of coffee, the main drivers for its consumption are the complex aroma and the powerful taste of the beverage. Scientific knowledge of coffee has advanced considerably during recent decades. In the headspace of coffee, hundreds of substances have been identified, and the ones mainly responsible for the aroma, the so-called key impact compounds, have been elucidated by gas chromatography-olfactometry (GC-O) and omission experiments (Blank et al. 1992; Czerny et al. 1999; Grosch 1998; Mayer et al. 2000; Semmelroch and Grosch 1996). In addition, significant progress has been made in the identification of key taste compounds. Caffeoyl quinic acid lactones (Frank et al. 2006, 2008), 4-vinylcatechol oligomers (Frank et al. 2007), diketopiperazines (Ginz and Engelhardt 2001), and (furan-2-yl)methylated benzene diols and triols (Kreppenhofer et al. 2011) have been identified as compounds with a major impact on coffee bitterness. Many of these impact flavour components are generated through polyphenol oxidation and Maillard-type reactions.

Although the flavour qualities of the identified single compounds

are known, their individual contribution to a complex mixture such as coffee flavour remains unclear. Until today, sensory profiling remains the most accurate method for describing coffee flavour. However, it would be desirable to statistically link sensory descriptors to the concentration of flavour compounds (as demonstrated by Lindinger et al. 2008) in a statistical model for the prediction of coffee aroma based on sensory profiling and analytical headspace measurements.

To better understand the link between sensory perception of coffee and quantitative analytical data, coffee blends have been assessed (Baggenstoss et al. 2010) by instrumental analysis and sensory profiling, and the two resulting data sets were statistically correlated. Several aroma and taste compounds analysed in the study exhibited a good correlation with specific sensory descriptors and may therefore be used as chemical markers for the characterisation of flavour profiles. A similar approach may also be used in wine flavour research to establish correlations between analytical and sensory data.

Differences and similarities

At first glance, there are few similarities between coffee and wine. The raw materials, coffee beans and grapes, are processed in different ways. In coffee, aroma and taste are generated upon roasting of the green coffee beans at very high temperatures, above 200°C, whereas in wine, flavour and aroma are mainly generated during fermentation and ripening. As a beverage, coffee is usually consumed hot, while wine is consumed cold or at ambient temperature. But there are a few similarities between these two beverages as well. One is certainly the quality aspect; both beverages are appreciated by consumers in pleasurable social events. Additionally, certain publications also highlight antioxidants as beneficial components present in both wine and coffee, helping to reduce the risk of major chronic degenerative diseases (Svilaas et al. 2004).



Figure 1. Similarities between coffee chemistry and wine chemistry

There is also some similarity in terms of aroma composition; for example pyrazines, isoprenoids, and guaiacols are found in both beverages (Figure 1). Moreover, the role of sulfur chemistry is interesting, for example 2-fufurylthiol (FFT), which is quite well known in coffee research, has been identified in champagne by Tominaga et al. (2003). Similar off-flavour issues have also been found in both beverages. One example is trichloroanisole (Figure 1), a well-known off-flavour component in the coffee industry referred to as 'Rio' off-flavour (Spadone et al. 1990), and an off-flavour in wines often due to contamination of corks.

Many similarities between coffee and wine science are in the flavour area, therefore the focus in this paper is on the components which are important for aroma and taste. This paper will highlight the role of analytical chemistry to accelerate research and innovation resulting in products which are appealing to consumers. The first section deals with character impact flavour components, how to identify them and how to follow or monitor their formation. In the second section the focus will be on correlation, how we use advanced sensory and analytical techniques to develop a predictive model which helps achieve the right flavour profile using sophisticated analytical techniques.

Advanced analytical approaches

As shown in Figure 2, the complexity of coffee flavour is high. The different components are generated by Maillard-type reactions, caramelisation and fragmentation. Components like trigonelline, chlorogenic acids or organic acids, and corresponding smaller units



Figure 2. Key flavour impact compounds found in coffee, with the compounds that are also found in wine highlighted in yellow



Figure 3. Biomimetic in-bean study experimental design (Poisson et al. 2009)

are both aroma- and taste-active. Quite a few of the components shown, such as β -damascenone, guaiacols, and sulfur-containing components, are common to coffee and wine.

The best way to elucidate the formation pathways of these components is to work in model systems which represent the actual product well. In the coffee area, Poisson et al. (2009) developed the 'Biomimetic in-bean study' (Figure3). The coffee bean is used as a reactor as it is very solid and can work under high pressure. The approach consists of extracting the water soluble precursors from the coffee bean and then using this depleted coffee bean as a reactor by reintroducing flavour precursors into the bean and then roasting it under defined conditions. The sensory profile is then evaluated and the analytical composition of the modified bean is characterised to understand how flavour components are generated upon roasting.

Adding certain amounts of precursor compounds is one approach to study formation pathways. The idea is to learn how key components are formed, from which precursors, and in what amounts. The second idea is then to add just some of the water soluble precursor components. In that case the role of those components and their importance in flavour formation can be evaluated. Because a component can be generated by several pathways, the use of labelled precursor components is an elegant way to elucidate the real pathway or to see which pathway is most important. Finally, the spiking experiments can be combined with sensory evaluation to establish the sensory-analytical link. In summary, these experiments performed under well-defined conditions help in understanding how flavour components are generated upon roasting, which is a very complex phenomenon. A key step

> is to characterise the water soluble components in the green coffee bean to identify the flavour precursors, which are phenolics, organic acids, different amino acids and sugars. Some of these components are quite unique to coffee, such as trigonelline. As an example, we can omit a part of the phenols to study their role in flavour generation or similarly remove amino acids, sugars, etc.

> The formation of 2-furfurylthiol (FFT), the compound which is also present in champagne, is still not understood in coffee research and there are a lot of model studies indicating that it is generated from furfural and other compounds in the presence of sulfur sources such as H₂S. However, this formation pathway seems unlikely to be valid in coffee because it does not explain the high amounts of FFT found in coffee and because no real correlation was found between the amount of the flavour compound and the putative precursors. Therefore, we studied the formation of FFT using the 'in-bean' experiment approach. In the case where we removed the sugars from the system we generated less furfural and more FFT - contradictory to the model study predictions. This shows that the formation of this compound during roasting of beans is much more complex compared to assumptions based on the model study. Moreover, spiking experiments based on adding certain components like sucrose to the depleted green coffee beans resulted in a decreased amount of FFT - a finding which also cannot be explained by the model study. Finally, 'in-bean' experiments using labelled arabinose showed that arabinose is also not necessarily the precursor of FFT - again contrary to the model study - but that there must be other pathways, probably involving polysaccharides. This shows that formation of components in food systems is often different from model studies;

this is certainly also valid for winemaking. Model studies are suitable to obtain a first insight, but they are just a first step to elucidate a pathway of the formation of components under real food processing conditions.

In wine research, to study the formation of compounds like terpenoids, guaiacols and pyrazines is probably of equal relevance. The primary components can be identified by considering the different grape metabolic processes. In addition, similar experiments to those described above could be used to establish the formation of components linked to processing and ageing ('in-grape' or 'in-wine' experiments instead of 'in-bean'). This would help to elucidate the pathways and generate the right amount of the impact compounds required in the final product.

The use of advanced analytics is important; it helps save time and may lead to unexpected discoveries. Molecular understanding of processes is very helpful in general; labelling experiments can in a very short time provide important information about formation mechanisms. Two approaches can be used: the targeted approach (focusing on a single compound) and the holistic approach (looking at the whole composition).

Understanding the coffee 'melody'

Both targeted and holistic approaches can be used in the correlation of analytical and sensory data in order to predict the sensory profile using rapid analytical methods. The major challenge is to correlate these data sets which by nature are different. By using advanced analytics, sensory science and statistics/applied mathematics, one can establish a predictive model and improve that model with each experiment in order to ultimately predict with reasonable accuracy the sensory profile based on analytical data.

Coffee, like wine, is a very complex mixture of components. It can be compared to an orchestra with many instruments playing (Figure 4), giving an overall impression of balanced flavour, complexity and finesse. While sensory evaluation is relatively straightforward as we smell or taste all components which occur in the beverage, using analytics is more difficult. Therefore, the goal is to find some markers which correlate with the sensory profile; in other words, if you were 'to hear' just a few of the players of the orchestra you would hopefully perceive the whole complex sensory profile.

The major challenge here is the different nature of the data. In analytical chemistry the relationship between data is usually linear, for example the peak intensity and the concentration of the compound. The higher the amount, the more is indicated by mass spectrometry or other techniques. This is fundamentally different from sensory data, represented by Fechner's power law, which says that sensation is proportional to the logarithm of the stimulus intensity. That means the perceived sensory intensity and the aroma concentration show a logarithmic correlation. Thus, the main difficulty is correlating data sets of different nature. The challenge is to find a mathematical data treatment to align both data sets. Failures in the past with finding a



Figure 4. Understanding the coffee 'melody'

meaningful sensory-analytical correlation were mainly due to a lack of proper data treatment prior to correlation.

We conducted a systematic study using a certain number of coffee products prepared in different ways: a ristretto-type espresso and a 'lungo' (a more diluted coffee), the main difference being the volume of the water used to prepare the beverage. All samples were characterised by quantitative targeted and holistic methods, as well as sensory analysis, followed by correlation of the data sets.

In the sensory evaluation, the coffee samples were smelled and tasted and the aromas and tastes described. As for wine, both volatile and non-volatile compounds are important in coffee. Common aroma attributes were described as 'fruity-floral', 'green', 'vegetable-like', 'cocoa' and 'sweet', while common taste attributes included 'bitter', 'acid' and 'astringent'. On the analytical side, a set of volatile and non-volatile compounds was defined for quantitative analysis (Table 1). The idea was to see if some compounds that had been measured analytically correlated with a sensory descriptor, and if the sensory descriptor correlated with the sensory attributes of the individual component in isolation.

Table	1.	Com	pounds	in	coffee	targeted	through	anal	vtical	experiment	s

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45 4-O-caffeoylquinic acid –	45 4-O-caffeoylquinic acid	-
46 5-caffeoylquinic acid lactone bitter	46 5-caffeoylquinic acid lactone	bitter
47 4-caffeoylquinic-1,5-lactone bitter	47 4-caffeoylquinic-1,5-lactone	bitter
48 5-O-feruloylquinic acid –	48 5- <i>O</i> -feruloylquinic acid	-
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51 cyclo-Ala-Pro bitter	51 cyclo-Ala-Pro	bitter
52 cyclo-Pro-Leu bitter	52 cyclo-Pro-Leu	bitter
53 cyclo-Phe-Pro bitter	53 cyclo-Phe-Pro	bitter
54 caffeine bitter	54 caffeine	bitter

Quantitative analysis

Quantitative analysis was carried out using advanced analytical techniques. Due to trace amounts, successful experiments required highly sensitive instruments such as two-dimensional (GC×GC) gas chromatography using a time-of-flight mass spectrometric detector (TOFMS), techniques that are now readily available. Measuring the nature and exact amount of the individual compounds is very important to be able to correlate analytical data with sensory data.

To compare and correlate the data, the sensory data sets were normalised. The instrumental data were first transformed into a logarithmic format to align with the sensory data set, then they were also normalised and pre-treated using the same approach as used for the sensory data set with an intensity adjustment. Subsequently, the correlation of these data sets delivered a model which is able to predict sensory profiles. Proper data pre-treatment was required before trying to correlate data sets.

The finished data are usually presented in a principal component analysis (PCA) plot. Different sensory characters representing the overall two-dimensional PCA plot are superimposed onto the analytical data as shown in Figure 5, which highlights individual components that align with sensory attributes. For example, the 'fruity-floral' notes correlate with certain components. However, the existence of a correlation does not necessarily establish a causal relationship – it is not necessarily possible to say "This compound is responsible for this flavour note". It is reasonable to say "This component may play an important role for this sensory description". The same applies for the 'sweet', 'roasty', 'bitter', 'vegetal' and other notes. Clearly, certain markers play an important role and it is possible to identify those 'players in the orchestra' that may play a role for key sensory attributes.

The models also allowed prediction of both aroma and taste sensory attributes. The accuracy of the predictions is fairly good (Figure 6) and usually a good match can be obtained with the



Figure 5. Principal component analysis (a) of superimposed sensory and analytical data and (b) likely markers that result from this study



Figure 6. Predictions of sensory properties from the analytical data provided by the computational model compared with actual sensory data. Blue lines represent actual sensory data; solid colours represent predicted data.

sensory profile based on simple analytical data. Adding more coffee samples to this data set improved the prediction even further. About 40 coffees were included in this first model. The same exercise can be performed with a non-targeted approach, so one does not necessarily have to analyse specific components, but may obtain just a compositional fingerprint.

In summary, these mathematical models of coffee aroma and flavour are now available, allowing the prediction of the in-cup sensory profiles of a range of coffee blends. However, proper pre-treatment of the sensory data and the analytical data are very important. Moreover, additional insight into the link between sensory descriptors and aroma markers has been obtained. As next steps, the statistical correlations found in this study might be tested for causality by further sensory and olfactometric experiments. The predictive sensoryanalytical model developed in this study will have its applications in a more molecular-sensory guided development of coffee blends, which can equally be applied to other product categories such as wine.

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Using precision viticulture to extract value

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"It is not the strongest of the species that survives... Nor the most intelligent that survives... It is the one that is the most adaptable to change." Charles Darwin

Abstract

The decision to harvest is frequently considered the most important factor determining wine quality. The 'go/no-go decision' depends on the ripeness of the fruit, the style and price point of the ultimate wine, fruit health (e.g. the degree of shrivel/disease), predicted weather, availability of harvesting equipment, and space in the winery. While fruit composition (soluble solids content, titratable acidity, pH and colour) is frequently used to establish harvest date, fruit taste and flavour may override this initial analysis. This raises the question, what are winemakers looking for when tasting fruit? My experience is that a 'go decision' is not made when ripe flavours are present in fruit, but when there is a lack of unripe (often green) flavours. However, fruit composition varies in vineyards depending on where the vine is growing. Precision viticulture techniques have been developed and promoted to assist viticulturists in recognising regions of the vineyard likely to show differences in fruit composition, enabling improved vineyard design and/or in-season management via differential harvesting. At harvest, winemakers have a choice of either identifying the date at which the vineyard as a whole is at its optimum composition, or differentially harvesting sections of the vineyard. Differential harvesting adds costs to harvesting and processing and while quality may be improved, this will only be worth undertaking if the business conditions enable the wine company to add value to their overall product line.

The adoption of new technologies

In our modern world, the rate of change appears to be accelerating and technologies that we could only dream about ten years ago are now regularly used in vineyards and wineries. Nowhere is this more apparent than in computing power, where a megabyte of memory has decreased from approximately \$6,500 in 1980 to \$0.0054 in 2013 (Roger Boulton pers. comm.; McCallum 2013), with consequential effects on computing speed and sophistication of equipment. The decisions we make, both philosophically and practically on the adoption of new technologies, are based on our confidence in the information we are using to make those decisions and the potential consequences of getting them wrong. Adoption occurs when a person decides that a particular innovation is the best way to address a need and provide a business advantage (Rogers 2003; Cullen et al. 2013). The rate of adoption depends on perceived advantage, compatibility with the existing operation, complexity and ability to trial on a small scale (Rogers 2003). Many people will act only on their own observations and experiences. In an industry as old as winegrowing, experience is certainly important. However, for most this will be restricted to some 40 years and will not necessarily enable appropriate decisions to be made when one is exposed to events outside one's experience.

The adoption of new technology also depends on the willingness to take risk, and the potential consequence of 'getting it wrong'. As a researcher, I am expected to test the boundaries of accepted dogma. I am always excited by the experiment that challenges my hypothesis – i.e. what did I not understand? During my career I have had some calamities, but fortunately the experiments were conducted on a small scale and I learnt from these events! However, the same consequence to a grower whose livelihood depends on the productivity of the vineyard may mean the loss of the vineyard, bankruptcy and potentially the loss of a home. No wonder the grower needs to be convinced of the potential value and risk when adopting a new technology. However, being unwilling to adopt new technology will often result in stagnation of an enterprise and a progressive decline in profitability, while others 'move with the times'.

Early references to the use of precision viticulture (PV) in Australia were some 15 years ago (Rossel 1998). Rossel's paper suggested that producers will be the principal users, optimising quantity and quality of the grape and providing feedback through decision support

systems on yield, composition and management at a site and withinsite level. Since that time, the value and use of PV has been extensively researched, particularly in Australia, with Rob Bramley and David Lamb in particular, leading the way. A recent survey in Web of Knowledge indicated that there were some 207 references in which PV was a keyword. The key question is "How is the improved knowledge generated by PV techniques adding value to the grape and wine industry?" My questions to you are:

- How is that information transferred?
- How has PV technology affected your business?
- Why do some people embrace change, while others do not?

The emergence of global positioning systems (GPS), aerial and satellite photography, multispectral images, and rapid soil electrical conductivity (Bramley et al. 2011c) provide growers with maps of the vineyard often showing variation in plant growth. Today many growers will have an aerial map of their vineyard, even if it is a Google Earth[™] map. The maps, combined with rapid fruit composition measurement using hand-held, non-destructive sensors (Bramley et al. 2011a; Gonzalez-Caballero et al. 2011) have enabled viticulturists to better understand and potentially manage the consequences of variability in vineyards. While some progress has been made in linking techniques such as near infrared (NIR) spectroscopy to fruit composition (e.g. soluble solids, pH, titratable acidity, malic and tartaric acids) (Gonzalez-Caballero et al. 2010, 2012), research is still needed to relate these (and other measurements) to wine style and structure.

The use of PV techniques can be broadly divided into three key areas of activity:

- Better informed decisions when establishing or re-planting vineyards
- Improved management decisions of established vineyards
- Enhanced harvesting decisions.

Planting a new or re-planting an existing vineyard

Today few vineyards are established without an understanding of soil type variability (Bramley et al. 2009, 2010; Bramley 2010). This enables within-block variability to be minimised, while separating key differences of the land into different vineyard blocks. Conventionally a soil survey, generally at 75 m spacing, is used to assess the boundaries of soil type variation; these methods do have limitations (Bramley 2003). More recently, EM38 sensing has been extensively used to map existing or new developments and this can add value at little cost to a soil survey, for example by identifying soil type boundaries. Using these surveys together with data on vineyard aspect and slope, before planting, will improve the overall long-term efficiency of a vineyard by, for example, optimising the uniformity of fruit development and the size of fruit parcels for winery efficiency, and minimising the number of short rows.

The practical value and greater precision of using high resolution spatial data to better predict vineyard design was summarised recently (Hinze and Bramley 2013). While using these data is easily justified on a new development, other factors occur when redeveloping a property. For example, re-orientation of rows requires the removal of posts, wires and often irrigation infrastructure, requiring major capital expenditure. Convincing accountants of the long-term benefits (>30 years) of a major restructure is a challenge, particularly in the modern fluctuating market. For example, between 2011 and 2012 three blocks were restructured in the vineyard shown in Figure 1. It is apparent from the map that the soil types run approximately north-south, at right angles to the original row direction. Re-orientating the rows in blocks B and C to run with soil type variation potentially enables the growers to manage the soil variation. However, block A was not re-orientated, possibly because the areas adjacent to this block were not destined for replanting in the near future and the management of the resulting relatively short rows would add to the cost of machinery operations in this block. Of course there may be other, commercially sensitive issues, but there is unlikely to be another opportunity to re-orientate the rows for approximately 30 years.

With an understanding of variation, there is potential to alter establishment variables within a vineyard block. For example, withinrow vine spacing, rootstocks and/or irrigation rates may potentially be altered to take into account variations in soil type. In practice, I suspect that this will add to the complexity of a vineyard, and it is probably safer to look at manipulating the management of vines within a single block once in production.

Managing a vineyard

Once established, the variability in vine growth and fruit composition will be expressed. In general, regardless of the method used to assess vine-to-vine variability, the map produced will be similar (Figure 2). Relating this variation to differences in fruit composition enables targeted management to be used to deliver more uniform parcels of fruit. However, this requires an integration of the magnitude and spatial separation of soil variability and then the degree to which alternative management protocols will influence vine growth and fruit composition. The use of any technology will depend on the cost:benefit ratio that is likely to be accrued from their adoption. Given the expected 30-year life of a vineyard, a small increase in profitability, through a better understanding of variability, will more than offset the small (approximately \$35/ha) cost of the acquisition of the imagery.

Vigour and yield management:

One of the major contributors to variation in fruit composition at harvest is vine yield. Individual vineyard yield maps have typically shown eight- to tenfold variation in yield (Bramley and Proffitt 1999; Lamb and Bramley 2001). These differences are frequently associated with changes in fruit composition. Interestingly, yield variation in a Marlborough Sauvignon Blanc vineyard was only twofold (Bramley et al. 2011c), much less than that observed in Australia. We attributed this to differences in pruning methods. Vines in Marlborough were cane pruned to a consistent cane diameter and node number, resulting in similar bunch numbers per shoot regardless of vine vigour. In contrast, spur selection does not typically occur where vines are machine pruned, enabling vines to express yield differences caused by soil type variation.

Mapping vineyard variation enables other strategies to be introduced to improve fruit composition uniformity, for example, the application of mulch to low vigour areas to improve water availability, or deep-rooted competitive species (e.g. chicory) planted in the interrow of deep fertile profiles to reduce vigour (Caspari et al. 1997). The adoption of such floor management strategies is valuable when the benefit of such management practices is high. The effort required to identify and then apply treatments to specific areas needs to give a suitable return, for example, replacing an existing ryegrass inter-row with a cereal/legume mixture enhanced yield and vigour to half a vineyard area (Panten and Bramley 2012). Unfortunately the effect on anthocyanin and phenolic composition is less clear, as the differences in yield potentially confound the results. However, in practice

> mapping the Plant Cell Density (PCD) and/ or vine vigour helps to delineate regions of the vineyard most likely to respond to these management practices. For a researcher, it also highlights the need to clearly understand the soil variability in vineyards before embarking on field trials, and the extent to which differences may influence the response to, and interpretation of field experiments (Panten and Bramley 2012). This information assists in improving experimental design of field trials.

Nutrient and pesticide application:

Proximal sensors that measure reflectance from canopies have a potential use in vineyards. The application of fertilisers and pesticides to specific areas of the vineyard may reduce their use overall. Variable rate fertiliser application is becoming increasingly widely used in the pastoral and grains industries. However, fertiliser generally represents only 1–2% of the cost of production in vineyards, much less than in the pastoral and grains industries. So unless significant value



Figure 1. Redevelopment and re-orientation of grapevine blocks in Marlborough between 2011 and 2012. Arrows show the row orientation of the three blocks.



Figure 2. Variation in indices in a 5.9 ha Sauvignon Blanc vineyard. See Bramley et al. 2011c for details (PCD = Plant Cell Density).

can be shown by improvements to fruit composition or reductions in nutrient leaching following the strategic application of fertiliser, precision fertiliser use is unlikely to be widely used in the near future.

In contrast, reduced pesticide use is of particular interest to the grape and wine industry. Fungicides in particular represent a significant cost of production in many vineyards and the industry strives to lower their use. Fitting an air-blast sprayer with sensors to modify the flow rate of nozzles to reflect differences in canopy dimensions has been reported to improve fungicide coverage and reduce use by 58% (Llorens et al. 2010).

Harvesting a vineyard

The decision to harvest is possibly one of the most important factors determining ultimate wine composition. If one reads the back label of many wine bottles, "harvesting is undertaken when fruit is at optimum ripeness". Exactly how and when that decision is made, is vague (what is the alternative?), but harvesting date is the consequence of a number of factors:

- Fruit composition
- Flavour
- Fruit health (disease/shrivel etc.)
- The flexibility of the winery and availability of processing space
- The availability of harvesting/transport equipment and staff.

The importance of fruit composition in determining the flavour and aroma characteristics of wine was summarised by Bryce Rankine when he said that "the potential quality of the wines is established in the vineyard and carried to fruition in the winery" (Rankine 1989). Conceptually, growers and winemakers have fruit composition targets. Some targets are well defined (e.g. disease status, soluble solids content, pH, titratable acidity, colour and yield) and often form the basis of payments to growers. Other targets are less clear (e.g. fruit flavour determined by secondary metabolite concentrations). Fruit sampling in the period up to harvest is generally used to estimate the mean fruit composition and to anticipate harvest date. However, vineyards are variable and large samples are needed to achieve a reliable estimate of the mean fruit composition, and this does not estimate the variability in composition around the mean. The variability changes with time as the fruit matures (Figure 3), but when variation is large, it is likely that over- and under-ripe



Figure 3. Changes in the soluble solids contents and titratable acidity distribution with time in the Sauvignon Blanc vineyard shown in Figure 2

flavours will be present in the juice and subsequently in the wine (Trought 1997). The importance this has in determining overall wine quality largely depends on the style and variety being considered. For example, typical Marlborough Sauvignon Blanc displays 'ripe' and 'unripe' characteristics in the wine (Parr et al. 2007). The same 'unripe' character in Cabernet Sauvignon may be considered undesirable. In my experience, when considering the flavour potential of a vineyard, winemakers are assessing the amounts of 'unripe' or 'green' characters of the fruit rather than the 'ripe' spectrum, and a small proportion of 'unripe' fruit will cause a delay in harvest. As a result, greater uniformity may result in earlier harvest, at lower soluble solids content, resulting in lower final alcohol concentrations in the wine.

While growers and winemakers have a conceptual fruit composition target, there are few examples of quantifying the value of different parcels of fruit. To attempt this, the pooled opinions were collated of over 50 Marlborough winemakers and viticulturists on the relative value of juices at a range of soluble solids content (SS), pH and titratable acidity (TA) at harvest to produce a 'typical' Marlborough Sauvignon Blanc. The scales of SS values (between 18 and 27°Brix in 0.25 steps), TA (between 5 and 14 g/L in 0.25 g/L steps) and pH (between pH 2 and 5 in pH 0.1 steps) were presented to the participants and covered values well to either side of the expected optima. Participants were asked to give a value to each point on the scale, where 1 was not preferred and 5 strongly preferred. The participants gave a weighting (w) to each component (0.49 to soluble solids, TA 0.28 and pH 0.23). The results were combined to develop a Juice Index (*JI*) (Figure 4):

Juice index (JI) = $(SS_{ps} \times SS_w) + (Ta_{ps} \times Ta_w) + (pH_{ps} \times pH_w)$



Figure 4. Soluble solids contents, titratable acidity and pH value scores. Fifty-two experienced industry personnel were asked to rate juice to make a 'typical' Marlborough Sauvignon Blanc on a value scale of 1=poor to 5=good (Trought and Bramley 2011). The maximum Juice Index (JI) is shown by the blue lines (SS 22.2; TA 9.2; pH 3.2 = (4.5 × 0.49)+(4.3 × 0.28)+(4.7 × 0.23) = 4.5). The red lines represent less ripe fruit (SS 20.5; TA 11.0; pH 3.0 = (2.9 × 0.49)+(2.1 × 0.28)+(3.2 × 0.23)=2.75)

The *JI* was then mapped in space and time in the vineyard (Trought and Bramley 2011) (Figure 5). While absolute values may change with season, the relative distribution of the *JI* will remain constant, reflecting changes in soil texture. In this example, the winery has a number of options available to it when harvesting. The *JI* map and distribution enable change in the relative composition to be mapped and relative changes in composition anticipated from fruit analyses taken shortly after veraison (Figure 5).

Identifying the variability in fruit composition may enable wineries to better stream fruit of similar composition in terms of both the mean and the variability around that mean. However, there are probably a number of provisions that need to be taken into account:

- The time taken to identify the streamed blocks
- The size of each block, in particular the scale of production and value of the difference in the production
- The price differential between the various streams
- · Understanding the change in the variability with time
- Understanding the change in the fruit composition with time and maturity.

Intake planning can start several months before harvest, particularly where wineries are dealing with large volumes of fruit and or contract wineries.

In recent years, there has been discussion on the potential benefits that may come from using spatial analysis to identify zones of similar fruit composition to allow selective harvesting. The presence of unripe 'green' character can, depending on the grape variety, markedly downgrade fruit and wine composition and value.

Value for money or the cost:benefit equation – some final thoughts

Understanding the motivation that causes growers to adopt new technologies is fundamental to the uptake of a new technology. Motivation is often overlooked when developing a research program and in particular associated extension activities. The increased complexity of innovation and the extra time and new skills required to implement these technologies can create a barrier to their adoption. However, the integration of extension practices to deliver research outcomes is challenging. For example, the non-adoption of deficit irrigation practices by growers in the Sunraysia wine-grape industry was due to the concern growers had that it would reduce yield and business viability, despite an extensive research program (Ambrosio et al. 2008). Similarly, changing orchard irrigation practices occurred



Figure 5. Spatial changes in calculated juice index at different stages of fruit ripeness in a Sauvignon Blanc vineyard (Trought and Bramley 2011).

when the new practice resulted in greater management flexibility or when orchards were being redeveloped (Kaine et al. 2005). Improving water use efficiency on existing orchards proved to be a low motivation (Kaine et al. 2005).

I suspect that there is little argument that PV techniques will enable wine companies to identify parcels of fruit to produce better wines. Unfortunately, my discussions with industry on this topic have generally resulted in the response "I really do not have time to integrate these techniques into my already busy day, particularly at harvest" or "Our financial controller feels that the benefit is unlikely to outweigh the additional cost". Of course, financial controllers possibly have a relatively short-term view of benefits.

Technology adoption is most rapid where an 'integrated package' is provided to a grower (see the changes in machine harvester technology), providing real (or at least perceived) benefits in fruit composition with little additional effort. The next stage enabling the adoption of precision viticulture is the integration of technologies into a package that can be easily used by growers and winemakers, for example, the prediction of fruit composition based on automated sample collection. The fruit composition must be related to wine quality outcomes.

At the same time, the extra value that comes as a result of the adoption of technology must be clearly shown. Few research programs integrate a financial component into the results. In an attempt to rectify this, Rob Bramley and colleagues demonstrated an increase in fruit value of 5.6% when a Murray Valley vineyard was selectively harvested; this was reduced to a net benefit of 1.8% when the additional harvesting costs were taken into account (Bramley et al. 2011b, 2012), and Mark Krstic suggested that a price differential of \$69/t (\$492 versus \$423/t) would be needed to break even and justify the additional selective harvesting costs (Krstic 2012). I suggest that this research needs to be taken further to model the consequences that different proportions of and prices for each fruit grade have on the net return to the grower. For example, a simple spreadsheet exercise, using the data presented in Bramley et al. 2011b and 2012, suggests that a decrease in the value of the premium fruit, for example a downgrade from grade B to C, as a result of removing the A grade fruit from the sample, will have a marked negative effect (-7.4%) on the overall value of the fruit, suggesting that selective harvesting can be detrimental (Table 1). At the same time, a small (\$80) increase in the super-premium grape price has a significant effect on the value that may be obtained from selective harvesting, and much greater than a doubling of the super-premium area in the vineyard.

Conclusions

The decision to harvest is frequently considered the most important factor determining wine quality. Understanding the degree of variation in fruit composition in a vineyard and the effect this potentially has on wine quality enables growers and winemakers to make better harvesting decisions. A relatively small investment in mapping soil variability during the development of a vineyard can provide increased financial returns during the life of the vineyard. Once vineyards are established, the value of precision viticulture methods to the wine industry and selective harvesting will largely depend on the price differential between the various grades of fruit, the ease with which the various quality areas can be harvested, and the ability of a winery to use the superior fruit at a higher price point. Superior fruit are not necessarily reflected in higher value if a winery is unable to utilise the benefit in their range of wines.

 Table 1. Influence of grape price and the proportion of the grape grade in the vineyard on the net benefit of selective harvesting. Note: the harvest volumes, cost of harvesting (\$90/T Super Premium and \$30/T) and fruit value (\$520 Super premium, \$423 premium) were those presented in Table 3 of Bramley et al. (2011b, 2012). The sub-premium price was included at \$375/T for comparison.

	Selective harvest		Single harvest	Gross return less harvest cost (\$)				
	Super premium	Premium	Premium	Select harvest	Single harvest	Net benefit (\$)	additional value (%)	
Rob Bramley (Bramley et al. 2011b, 2012)								
Harvest volume (T)	51	155	206					
Grape value (\$/T)	520	423	423	82,386	80,958	1,428	1.8	
	Increase % super-premium grapes							
Harvest volume (T)	102	104	206					
Grape value (\$/T)	520	423	423	83,814	80,958	2,856	3.5	
	Decrease the value of premium fruit in the split-harvest option from \$423 to \$375/t							
Harvest volume (T)	51	155	206					
Grape value (\$/T)	520	375	423	74,946	80,958	-6,012	-7.4	
Increase the value of super-premium grapes from \$520 to \$600/t								
Harvest volume (T)	51	155	206					
Grape value (\$/T)	600	423	423	86,466	80,958	5,508	6.8	

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Adding value in the winery

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Abstract

In the current market, it is a cruel reality that to improve cash flow, cost reduction and value adding are far less demanding than the extra effort required in selling more wine. In this paper I would like to take you through our experiences at De Bortoli Wines, reviewing our approach to managing costs, value adding and waste reduction. We have also had a lot of help on the way; various State and Federal Government Departments have incredible programs to support regional businesses and we have made full use of what is available. That said, let's dive into options we have to cut costs and add value in the winery.

A sales manager recently said to me: "It used to be Price = Cost + Margin, but now it's Margin = Price – Cost". The statement reflected his obvious frustration at the changing state of the wine market. In simple terms the cruel reality is that if your profit margin is 10%, the effect on profit of cutting \$1 of cost is the same as creating \$10 of extra sales! So it logically follows that cutting costs is much easier than creating extra sales. The usual concern is that cutting costs will lead to a reduction in quality, but thankfully only in a perfectly optimised process are cost and quality directly related.

The alternative is 'adding value'. Adding value requires shifting the focus of the business and its processes to ensure that they provide outcomes that the customer WILL pay for and avoiding activity that the customer WON'T pay for.

Let's have a look at our experiences at De Bortoli Wines. We have developed a series of operational guidelines which our managers are expected to follow:

- Understand the legal framework within which you work.
- Manage compliance and risk management systems appropriate to your role.
- Find and manage your Gold Data.
- Manage your capital (CAPEX).
- Manage your operating costs (OPEX).
- Hunt down and incorporate good ideas useful to the business.
- Develop a 'Learning Organisation'.

Legal framework

We are all familiar with acts such as Workplace Health and Safety, Environmental Law, Food Safety, Competition and Consumer, and Road Transport – and it is common that these laws apply a "No knowledge is no defence" clause. Additionally, any breach of law is a costly event. It is important to know which laws apply to your business activity and that the requirements of those laws are communicated to the business so that employees act within the law to avoid the 'pain' of non-compliance.

We use a web-based notification system to track changes to legislation and regulations from international law right down to local government regulations and policies. Any applicable changes are then forwarded to the appropriate 'functional manager'. For example, changes to Industrial Relation Acts are forwarded to the Human Resources Manager for actioning.

Risk and compliance systems

Our business is audited regularly! Since November 2012, we have been subjected to three Supermarket Factory Condition audits, two Supermarket Bench audits, a Supermarket Security audit, a Supermarket Corporate Social Responsibility audit, a Food and Drug Administration Food Safety and Security audit, a British Retail Consortium audit, two HACCP audits, two Workcover audits, a Department of Environment audit, a Road and Transport Authority audit, a Freshcare Environmental audit, an Organic audit and an Australian Packaging Covenant audit – and on average the cost of each audit is approximately \$10,000!

It is important to avoid creating a different system for each different law or requirement. With every new law or regulation, customer or insurer requirement, we review the requirement and then adjust or add it back into a single Integrated Risk Management System and then communicate the requirements to our operational staff.

Gold Standard data

There are a number of very powerful and commonly used data groups in any business: vendor details, raw material information, asset information, employee data, product information (items, bills of materials, routes), suppliers, customers, CAPEX (cost of capital), OPEX (cost of operations).

The acid test: have a look at your business – how many spreadsheets are your people using? Every spreadsheet represents a problem: data is maintained separately from its source, it is not validated, it is usually duplicated and its value is lost to the business as only one person at a time can access the file.

Our first step was to move many of our files to 'the cloud' so they could be accessed by multiple users; however our preference has always been to return good data to our corporate systems. We have spent the last five years driving this data wherever possible back into our enterprise resource planning (ERP) system (Figure 1) to ensure there is one truthful source of data! The astounding thing for us is that the core data has provided us a mechanism to integrate what were previously disparate systems.



Figure 1. Example of feeding a range of data into a single enterprise resource planning (ERP) system

Capital expenditure: CAPEX

There are, for us, two important aspects to CAPEX: directing spending to areas where there is a defined payback (return) and using that capital as efficiently as possible.

Return on investment (ROI)

In a private company our goal is to provide the owners a better option than just putting their money in the bank. To do this we need to calculate:

(gain from investment-cost of investment) (cost of investment)

Our employees assemble the cost of the project and the proposed improvements from the project and then conduct a detailed financial analysis of the intended project before submitting the project for approval.

Reliability

Once operational it is important to track how equipment runs by reviewing overall equipment efficiency (OEE) which is: availability \times performance \times quality. For an eight-hour shift with one hour of breaks, availability is seven hours. If we assume the equipment performs at 90% of its rated speed and has 1 quality reject per 1000 units, then: A(8-1) \times P(90/100) \times Q(99.9/100) = 6.2 effective hours or 77.5% OEE.

Let's take a look at a simple three step process (Figure 2):



Figure 2. OEE (overall equipment efficiency) example for a three step process

This is the ugly side of OEE! Now extrapolate this to wine where it is not uncommon to handle a wine up to 15 times! The key to value adding is to only touch your product when you can add value to the product, then keep processes running, make those processes reliable and importantly make processes repeatable. repeatability. It is even better to convert cost centres to profit centres; for example our waste treatment system which converts our waste-water to crops and is in fact self-funding.

Hunt down good ideas

Before heading down any road to business redevelopment it is important to check that you are not reinventing a wheel. There are a number of great resources for the wine industry: customers, suppliers, other industries and government bodies. Our wastewater system is loosely based on Meat and Livestock Corporation work! Winery visits, AWRI Roadshows and supplier interactions are all valuable sources of information.

Government support is also readily available to regional industries and we have been the beneficiaries of state government support programs such as the Sustainable Advantage program and of national and direct investment from AusIndustry and the Clean Technology Food and Foundries program.

Learning skills

There is always a slow loss of valuable business intellectual property as tasks are handed from person to person (similar to OEE). We have been through several iterations to arrest this process. We first used the traditional Quality System approach, document the process (Standard Operating Procedures). We then moved to Lean Manufacturing which had the unintended consequence of creating a heavy workload for management as we had not developed the appropriate skills in our production staff. We also implemented the concept of the Visual Workplace; however the skills did not persist, so we went back to the basics.

Training within industry (the TWI program) is the predecessor of many of today's quality programs, such as TQM, Lean and Toyota Systems. TWI was developed during World War II as a training program for new staff in factories which had been de-manned to support the war effort. The program has three major elements: Job Instruction (how to teach a task), Job Methods (how to analyse tasks and make improvements) and Job Relations (problem solving and supervisory skills) (Figure 3). A brutal process but as the quote says "If the worker hasn't learned, the instructor hasn't taught."

Operational expenditure: OPEX

Reliability and operational efficiency are the foundations of OPEX. Our next focus is our Gold Data: data which enable you to understand your costs and then act to reduce those costs. It seems trite but it is in fact what underpins Lean Manufacturing principles:

- Avoid doing things that the customer does not pay for.
- Do it right, do it once!
- Don't take it, don't make it, don't send it.
- Avoid the eight deadly sins of motion (moving/production without adding value).

Search for and remove over-production, waiting, transportation, over-processing, excess inventory, unnecessary movement, defects, and unused employee capability. Then convert fixed costs to variable costs. Examples include: the use of a casual workforce to support peaks of production, seeking alternatives to CAPEX such as rental or leasing and using automation to improve reliability and



Figure 3. Poster summarising the three major elements of the TWI (training within industry) program

Value adding and learning outcomes

A breach of environmental law, although costly to our business, led our thinking in a new direction. The learning process is best demonstrated by the application of findings from our Environmental Assessment. The two major issues in the Murray Darling Basin are sodium salinity and water availability, so within the first week of our Environmental Assessment we made a decision to completely change our industrial ecology by becoming a no sodium site and to re-farm our wastewater. The challenge to our thinking then led us through changing:

- our pH dosing from magnesium hydroxide to lime and then ammonia
- our 400 kW aerators, to 8 kW fish stones and then aquaculture leaky hose
- potassium hydroxide recovery from wash water.

The net result of these changes included a \$200K pa reduction in power costs, crops valued between \$80 and \$150K pa and a \$450K reduction of capital deployed to wastewater treatment.

Current major projects

As a direct result of State and Federal Government support we are currently installing:

- 230 kW solar photovoltaic, 0.5 MW solar hot water
- cross-flow filtration and smart pumps
- refrigeration system redesign
- compressed air controls
- power factor correction
- potable water filtration
- office and warehouse lighting
- a new packaging line.

The targeted net results are:

- electricity variation: -2,500,500 kWh/pa
- natural gas variation: –3,000 GJ
- consumable variation: -\$27,000
- waste variation: -2,100 tonnes/pa
- total CO₂ variation –2,300 tonnes CO₂-e
- cost CAPEX: \$15m
- cost OPEX variation: -\$3m
- return on investment (ROI): 20%
- payback: 5 years
- none of which will harm wine quality!

Conclusion

Take a deep breath ... Break the thought that quality and cost are tightly linked, understand what drives your customers, review how you apply operational management principles and do what adds value to your customer.



Valuing and extracting grape quality – the scorecard and some big opportunities

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Abstract

Little progress appears to have been made in the last decade in the quest to measure and pay for the quality of grapes. The casualty in the relationship between buyer and seller is the trust between the two parties. Holistic schemes and field flavour assessments generate no clear cut relationship between measurement and quality. Experiments with leasing of vineyards and payment by hectare have not proven universally successful. Some improvements could be expected by addressing science issues, quality and style definition issues, the discontinuous price ladder and the location and ownership of agricultural and market risk. There is a strong case for industry peak bodies to address the issues relating to measurement and payment for quality. Extraction of quality relating to white grapes appears to be resourced adequately, with no glaring anomalies producing compensatory market opportunities. In contrast, for red wine production, system failure is clearly demonstrated by the existence of a number of secondary market opportunities which have recently evolved. If properly resourced, significant opportunities exist for lifting the quality of red wines produced in overburdened production systems.

Valuing quality

On a superficial examination we are no better at valuing quality than we were a decade or more ago. Well-defined, objective and measurable flavour and character requirements were identified by Allan and Strachan (2002) as still being work in progress. Unfortunately they still are. In an article on this subject (Day 2010) I commented that:

... protocols and supporting behaviours have been developed well ahead of the science being capable of delivering broadly useful quality measurements. It is arguable that in this particular grail quest, we hardly even have the scientific equivalent of the battered stetson and the stock whip.

Broad-based holistic systems have been a relatively common substitute for an ideal quality measurement, giving the benefit of delivering a method of raising the quality cut-off at the bottom end of the scale but largely failing to deliver realistic relationships between measurement and payment. In parallel, many wineries have implemented systems of field assessment based on visual checklists and berry tasting by winemakers in vineyards. The latter is a nice idea but at best is extremely subjective, even under the control of the most well-intentioned of tasters.

A decade on, there is no compelling reason to argue with any of these contentions. Holistic systems of quality assessment have continued to be useful in cutting off the bottom end of the quality range but have failed to deliver meaningful quality/value relationships. Field assessments of grape flavour continue to be used but their tenuous relationship to final quality raises issues of distrust between seller and buyer which are confirmed by anecdotal commentary on the imperfections of this relationship. Systems based on final wine quality assessment take control past the point of crushing the grapes away from the seller, delivering it entirely to the purchaser where the treatment can vary from honest and in good faith to duplicitous exploitation.

Experiments with payment per hectare have largely come and gone without satisfactory resolution of the issues of identifying where the agricultural risk rests, how to value it and the issues of resourcing the additional management inputs needed to run a vineyard on a pseudo-lease basis. Additionally, there seems to have been little real progress with the improvement needed to the dispute resolution process. A broad-based independent assessment and resolution scheme is still somewhere in the future.

There is no mistaking it – the scorecard looks pretty dismal with no real tangible progress in a decade! A number of problem areas can be identified in the systems currently in use.

Problem area 1 - the science 'lag'

The search for the scientific holy grail of a meaningful measure of quality continues. The problem is that the research is likely to yield results that are inaccessible and therefore barely relevant to quality assessment and valuation in a field context. A \$0.75 million price tag on an HPLC/ MS (high performance liquid chromatograph/mass spectrometer) combination guarantees inaccessibility for timely routine assessments of quality. The science funders and researchers need to embrace the need for affordable and accessible quality measurement. The science snobbery which eschews 'fingerprint'-type analytical approaches is a key factor in holding back progress on this front.

Problem area 2 – quality definition

Quality is defined as fitness-for-purpose, yet specifications of quality have been poorly developed. Discourses on quality are dominated by the approach that quality is only viewed from one level; that of ultimate icon wine quality. Grade is the category or rank given to different quality requirements for products having the same functional use. The problem is that quality specifications have not been developed for the acknowledged differences in grade of wine.

Problem area 3 - style issues

Unfortunately, style is being used as a refuge of scoundrels (Boswell 1986).

Case 1: Barossa Shiraz grapes sold to a small winery

- Price to be set on assessment of final usage
- Wine declassified based on 'style' requirement
- · Payment rate notified accordingly
- Bulk wine sold subsequently for \$5.50 per litre.

Case 2: Sauvignon Blanc grapes

- · Winemaker indicated need for more tropical flavours in grapes
- Impossible to define descriptors were specified, e.g. 'pristine'
- · Volatile thiol chemistry outlined to vineyard manager by consultant
- Reassessment of grapes resulted in increase in payment of \$75,000.

As an aid to reducing uncertainty in this area it is important to try to define wine style. I propose the following definition as a starting point:

Wine style – the aggregate of structural and flavour attributes which enable groups of wines to be identified with respect to their similarities and to distinguish them from other groups of wines. For the past 50 years or more the Australian wine show system has produced tight and workable specifications of wine style as a guide to exhibitors and judges. If Australian wine shows can come up with usable definitions of wine style, why can't grape buyers and winemakers?

Finally and very importantly, a proven case exists for 'fingerprinting'type measurements to be used for style assessment. For example, the Pinot Gris/Pinot Grigio MIR analysis developed by the AWRI is a fully resolved example of how style can be measured using 'fingerprinting'.

Problem area 4 – the discontinuous price ladder

Case 3: Parcel of quality cool climate grapes

- Target quality level and price indicated by buyers' representatives as 'easily achievable'
- Field assessment indicated a quality rating of 'high' at the next level down, a 43% lower price
- Strident negotiation
- Fixed price at half way between the two levels an eleventh hour compromise in effect a 'take it or leave it' offer.

Problem area 5 – location and ownership of agricultural and market risk

This area is not being addressed at all. As a starting point, there needs to be an industry forum to canvass the issues and possible solutions. This could be incorporated into an initiative by industry peak bodies to develop a broad-based independent assessment and resolution scheme.

Extracting quality

In order to obtain an overview of how well quality is being extracted, a macro approach of how well resources are being allocated was used. It seems that as an industry there is a view that for white grapes, if you crush it, you need to press it and if you press it you need to ferment it. Extraction of quality relating to white grapes appears to be resourced adequately, with no glaring anomalies producing compensatory market opportunities. In contrast, for red wine production, system failure is clearly demonstrated by the existence of a number of secondary market opportunities that have recently evolved.

Case 4: Production of red grape skin extract

- Extraction of red grape marc to produce a quality grape skin extract
- · Extract used as a 'fine tuning' item in red wine blending

• Sales demand spikes upwards, reflecting difficult harvest conditions where overall industry red fermentation capacity is insufficient to handle processing in a timely manner (e.g. the 2011 harvest).

Case 5: Bespoke red wine producer

- Focus on optimum grape maturity
- Optimum extraction of colour and flavour
- Traditional approach to fermentation handling including no time constraints on maceration time
- Sale of bulk wines to fill demand for icon wines at prices generating significant value adding.

The validity of the market opportunity outlined in case 5 is endorsed by

- 1. a large company reverting to investment in quality small-and medium-scale red fermentation capacity
- 2. allocation of red fermenter capacity outside of computer modelling guidelines for specified high quality grape parcels by a large producer.

However, significant opportunities still exist across enterprises of a range of sizes for lifting the quality of red wines produced in overburdened production systems.

Summary

- Little has changed in a decade or more.
- Industry peak bodies need to develop a broad-based independent assessment and resolution scheme and address issues relating to risk ownership.
- The science funders and researchers need to embrace the need for affordable and accessible quality measurement the continuation of current approaches guarantees the waste of levy-payer funds.
- Quality specifications and style descriptions need to be developed for different levels of quality.
- Addressing the discontinuous price ladder would remove much of the distrust embedded in current payment arrangements.
- Scope exists for lifting red wine quality by better resource provision for red wine fermentation capacity.

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SESSION 6: Nurturing our natural assets



Creating value from by-products – an industry review and insights into practical case studies

R.A. Muhlack, K.K. Forsyth, N. Scrimgeour, P.W. Godden

Ecosystem services and viticulture: finding common ground *M. van Helden, J. Guenser*

How will the carbon farming initiative affect the vineyard? R.J. Eckard, E.N. Barlow



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Creating value from by-products – an industry review and insights into practical case studies

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Abstract

Grape and wine producers are facing growing economic and environmental pressures. Rapidly rising energy and labour costs, together with currency strain and credit availability are all impacting on bottom-line profitability. Supply/demand imbalance and the impact of extreme weather on agricultural production and regional prosperity both continue to cause concern in many Australian communities. Amidst this uncertainty, it is vitally important that key resources such as energy and water are sourced and managed in the most efficient way possible. Equally important is the ability to extract full value from by-products and waste streams as well as from fruit and raw materials, as only then will the full efficiency potential of production systems be realised. For example, the Australian wine sector generates substantial quantities of biomass, such as grape marc and stalks, yeast lees and wastewater sludge. These would all normally be considered organic waste; an unavoidable but necessary part of the grapegrowing and winemaking process. In some cases these by-products might be recycled as compost, or perhaps given away for extraction of tartrates and ethanol by a third party. But what if there was an alternative which could realise some previously unknown potential that would add significant value to wine production? Instead of being seen as waste products, these could be used for a range of purposes that would create additional value, such as renewable energy, heating and refrigeration, or farming applications such as composting, biochar and stockfeed supplements. Many of these applications have carbon as well as economic benefits, providing Australian wine producers with additional 'green' credentials as well as a potential new revenue stream.

Grape marc as a carbon-mitigating stock-feed supplement

As one example of an alternative value-adding opportunity, The Australian Wine Research Institute (AWRI) has been funded through the Department of Agriculture, Fisheries and Forestry (DAFF) Carbon Farming Futures program for a project investigating the possibility of using grape marc in animal feed to reduce methane emissions generated by enteric fermentation. This project will work on identifying and characterising the active ingredients (believed to be tannins) in grape marc responsible for reducing emissions from ruminant animals. The project will quantify, through understanding tannin chemistry and mechanisms, the potential of using grape marc and other tannin-rich food sources as a supplement for reducing ruminant emissions. The benefit to grape and wine producers is that if the methane reduction aspect can be understood and quantified, then grape marc may provide additional value in terms of it being a carbon farming product.

New generation power

Renewable bioenergy from winery waste materials represents a major opportunity for the grape and wine sector. Technologies such as anaerobic digestion, Organic Rankine Cycle (ORC) engines, pyrolysis and gasification provide a means to convert an organic residue (i.e. an agricultural waste product) into an energy resource.

Bioenergy is already well established in other rural industries in Australia, with the sugar industry probably the biggest success story. In the past, sugar cane farmers would burn the sugar cane 'trash' in the cane field. This would leave just the sugar cane itself, which given the older harvesting technology of the time was a means to improve harvesting efficiency. Only the required product (the cane) was harvested with the remaining waste and stubble left on the farm. Now with modern harvesting equipment and sorting machinery at the sugar mill, the trash and the cane are harvested together, separated at the mill, and then the trash is used in purpose-built combustion and gasification equipment to provide heat and electricity for the process. Fruit processing and canning producers are also looking to bioenergy for cost savings. Figure 1 shows a prototype 10kWe biomass gasifier that was commissioned by a fruit processing client to convert peach stones into electricity.

In the Australian meat and dairy industries, liquid waste streams undergo anaerobic digestion in covered lagoons, not only providing low cost water treatment, but converting the organic waste products to methane gas that is then used to run-purpose built engines, that in turn drive a generator to produce electricity (Figure 2). For a smaller installation like this, offsetting the need to buy grid energy by producing electricity onsite is far preferable to just sending the electricity back to the grid, because of the difference between purchasing electricity at a retail price, but only being permitted to sell electricity to the national grid at the wholesale price. Therefore a process arrangement which prioritises offsetting onsite electricity usage over a simple feed-in arrangement will greatly improve the economics of a potential project.



Figure 1. Portable trailer-mounted downdraft fixed grate biomass gasifier

A number of municipal wastewater treatment (WWT) plants also employ similar anaerobic digestion technology. At the Melbourne WWT plant (Werribee, Vic) a biogas plant operated by AGL Energy uses biogas generated by the anaerobic digestion water treatment process to power a V16 gas engine, delivering just over 1.2 MW back to the national grid (Figures 3a and 3b).



Figure 2. 600kw V12 engine running on anaerobic digester gas from a livestock rendering plant in south-east Queensland



Figure 3a. Anaerobic digester gas plant at Melbourne WWT plant (gas pre-treatment stage)



Figure 3b. Anaerobic digester gas plant at Melbourne WWT plant (1.2MWe V16 gas engine)

Emerging opportunities across Australia

So while already established in other rural and process industries in Australia, bioenergy has been largely overlooked by the wine industry even though it has the opportunity to economically convert organic waste such as grape marc into a high value resource.

To address this, technical and economic evaluation of potential renewable energy scenarios for consideration by the wine industry has (until June 2013) been an area of focus by the AWRI's Riverina Node. Various scenarios for energy cost reduction have been considered, with a detailed study performed on one promising technology (gasification) with assistance from collaborators such as the University of Adelaide's Centre for Energy Technology. Both well-established and emerging technologies have been assessed, as well as combinations such as biomass technology together with solar thermal, to identify whether any synergies exist that will multiply technology benefits.

A summary of results from the AWRI's techno-economic evaluation of renewable energy options is shown in Table 1. Assumptions for capital costs used in this analysis are cautious, using process engineering metrics to scale capital requirements to facility size. Allowances for operating and maintenance costs are also included, however finance and land have been excluded as these will vary from producer to producer. Transport costs are also excluded (as it is assumed that the biomass will already be onsite following processing in the winery) as are biomass storage costs as these requirements will vary from site to site depending on facility size and the biomass technology chosen.

However, as all of these assumptions have been applied consistently across all scenarios, the analysis provides the means to rank technology options and identify configurations that are the most viable for further investigation by wine producers.

Scenario	Description	Simple payback (years)	Projected Grid Energy Savings (%)
1	Non-fermentation refrigeration electricity supplied by biomass energy	5.7	25%
2	All refrigeration supplied by biomass energy	14.5	44%
3	Solar Thermal to supplement Ferment Cooling	47.7	8%
4	Biomass powered Absorption Chiller for ferment cooling only	18.3	19%
5	Biomass powered Absorption Chiller for non-vintage refrigeration	4.6	19%
6	Site electricity supplemented by biomass energy using gasification technology	5.6	49%
7	Solar Thermal to supplement ferment cooling and non-vintage refrigeration	19.3	14%
8	Solar Thermal to supplement non-ferment refrigeration	12.1	7%
9	Solar Thermal to supplement non-ferment refrigeration via absorption refrigeration (with energy storage)	11.4	25%
10	Solar Thermal + ORC Engine to supplement non-ferment refrigeration (with energy storage)	29.2	25%
11	Supplementary electricity supplied by an anaerobic digester	8.1	15%
12	Supplementary refrigeration supplied by an anaerobic digester-powered refrigeration compressor	4.5	25%
13	Site electricity supplemented by biomass using ORC technology	5.2	49%

Process scenarios

Scenario 1

In this process scenario, a biomass gasifier is used to convert grape marc into syngas, which is then fed to an internal combustion engine to drive a generator. The installation has been sized to meet the non-fermentation electricity requirements for refrigeration (i.e. all refrigeration throughout the year, except for the additional demand during primary fermentation). The financial benefit is therefore the reduction in grid-supplied electricity which would otherwise be required for non-ferment refrigeration.

This process will require that the marc is dry before use. Spreading the marc out for solar drying is the preferred option. A flue-gas economiser (which dries the feedstock as it enters the gasifier with hot flue gases exiting the gasifier) is an alternative option. This scenario assumes sufficient biomass production at the winery site.

Scenario 2

This scenario is as per Scenario 1, except that the equipment has been sized to accommodate the total maximum refrigeration demand during vintage, which is base-load refrigeration plus refrigeration required to offset fermentation load. Sizing equipment in this manner dictates that there will be idle capacity during the non-vintage period.

Scenario 3

This scenario considers the use of solar thermal technology to generate heat which then drives an absorption refrigeration unit to provide fermentation cooling. Solar collectors under this scenario would require sun tracking and could be either a parabolic design or a linear Fresnel mirror configuration. This scenario does not consider thermal storage, so this scenario operates during daylight hours only during vintage.

Scenario 4

In this scenario, a biomass boiler is used to supply heat to an absorption chiller, sized to meet ferment refrigeration demand.

Scenario 5

This scenario is similar to Scenario 4, except that the plant is sized to meet base-load non-ferment refrigeration needs, and operates all year.

Scenario 6

This scenario is similar to Scenario 1, except that the plant is sized to meet all base load (non-vintage) electricity needs across the entire site – not just refrigeration, but all non-fermentation electricity demand.

Scenario 7

Scenario 7 is similar to scenario 3, except that the unit is sized for vintage ferment demand but operates all year during daylight hours.

Scenario 8

This scenario is as per scenario 7, except that the plant is sized for non-vintage ferment demand.

Scenario 9

Scenario 9 is as per scenario 8, except that a thermal storage unit (analogous to a thermal 'fly-wheel') is also included to allow the plant to store heat energy and therefore operate throughout the entire day.

Scenario 10

Scenario 10 is similar to scenario 9, except that the solar thermal plant is used to supply heat to an Organic Rankine Cycle (ORC) engine. The ORC engine generates electricity which is used to meet non-ferment base-load refrigeration demand and operates all year.

Scenario 11

This scenario considers the use of an anaerobic digester which is used to produce biogas that is directed to an internal combustion engine to drive a generator. The plant is sized to meet all base load (non-vintage) electricity needs across the entire site – not just refrigeration, but all non-fermentation electricity demand – and operates all year.

Scenario 12

This scenario considers the use of an anaerobic digester which is used to produce biogas that is directed to an internal combustion engine to directly drive a refrigeration compressor. The plant is sized to meet base-load non-ferment refrigeration demand and operates all year.

Scenario 13

In this final scenario, biomass is fed to a combustion furnace, with heat from the furnace used to drive an ORC engine to produce electricity via a generator. The plant is sized to meet all base load (non-vintage) electricity needs across the entire site – not just refrigeration, but all non-fermentation electricity demand – and operates all year.

Conclusion

Biomass options for electricity generation that appear to be the most economically attractive at this point – with the shortest simple payback together with the greatest electricity cost savings (upwards of 25–50% in some cases) – include gasification, or combustion together with an ORC engine. These options are highlighted in Table 1. Meeting refrigeration demand with an anaerobic digester powered refrigeration compressor shows a similar payback scenario. Analysis suggests that solar thermal options which focus on non-fermentation energy loads are less economically attractive than biomass at this time; however the technology is more mature and easier to deploy. Renewable energy technology options which cover ferment loads appear far from economic (simple payback in excess of 20 years in most cases).

Energy price increases far in excess of CPI trends have been experienced across the country, with further increases expected over time as a result of carbon policy and energy commodity price movements. Depending on the renewable technology used, producers could potentially reduce their energy costs by 50% or even more. Under these circumstances, the business case for bioenergy is particularly compelling in regional areas where energy costs have risen sharply. Legislated Direct Action Measures and associated assistance packages for early adopters of renewable energy will also assist with adoption of clean energy technologies as genuine cost reduction alternatives for progressive wine producers.

Ecosystem services and viticulture: finding common ground

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Abstract

In intensive perennial cropping systems such as grapegrowing, conventional agricultural management quickly shows its limits, when ecosystem services such as natural biological control and soil conservation decline and environmental problems (such as erosion, salinisation, soil compaction, biodiversity loss and environmental pollution) occur. Finding efficient long-term sustainable solutions to these problems goes beyond the normal spatial and temporal scale of agricultural management. Farmers should be encouraged to develop simple, acceptable and efficient actions for conservation and restoration of such ecosystem services. Awareness of the long-term synergy between ecosystem services and agriculture is essential to improve sustainability, but is often insufficient to motivate farmers to adapt their management practices. Acceptance is much more likely when short-term advantages can be identified, not necessarily directly linked to the long-term restoration of ecosystem services. Such actions include hedgerow planting, ground cover and fallow management, having both agricultural and ecological value, but guidance is needed for optimal efficiency. Land managers should try to develop pragmatic and realistic goals and indicators to monitor continuous improvement and thus inspire stakeholder engagement in a positive way. Demonstration actions and communication with all local stakeholders will strengthen collective motivation to adhere to the long-term goals needed to achieve significant improvements at the landscape scale. Such actions can even lead to marketable regional benefits.

Introduction: trends in agricultural land use

Wine-grape production areas can be found in many different landscape configurations, with strong contrast in landscape structure between historical winegrowing regions (Figure 1a) and more recent expansion of growing areas (Figure 1b); the two are sometimes combined in the same region.





Figure 1a and b. Example of landscape composition (scale bar = 100m) between 'historic' areas such as Saint-Émilion (France) (a) and more recent production areas (McLaren Vale, Australia) (b). Source: Google Maps

Farmers are continuously 'scaping the land' but their direct interest has been focused on the farm scale and its economic sustainability, and has not taken into account the overall functioning of the landscape. Moreover, modern agricultural practices and land-use planning tend to privilege 'technical' approaches, and scale enlargement to increase profitability and overcome environmental constraints: larger plots, larger farms, slope reduction, mechanisation etc.

Understanding the current state of a landscape requires historical knowledge (Antrop 2005). In the centuries-old winegrowing areas of Europe such as Bordeaux, viticulture in the last 25 years has tended to concentrate more and more in the most 'rewarding' areas (Appellation d'Origine Contrôlée (AOC) wines, Figure 2). Economic interests then make farmers extend the planted area as much as possible within the limited available space. In those landscapes historical land uses such as cereal growing and animal husbandry have now completely disappeared. After having conquered all agricultural land the last remnant patches of natural habitat slowly disappear (Figure 3).

In recently 'conquered' agricultural land the situation is quite different. Here land use can be 'optimised' from the very start creating 'optimal' rectilinear divisions of the land; examples can be found in the recent Dutch polders (Figure 4), and also in vine growing areas such as those found in Australia (Figure 1b).



Year 2 Jacobies in the surface area of with the Bardon warea of Frances

Figure 2. Increase in the surface area of viticulture in the Bordeaux area of France since 1985, showing an increase in area of the AOC wines. Adapted from CIVB (2006)

Economy versus ecology?

The overall result of both situations is the same: an economically profitable but very much simplified landscape with low habitat richness and low abundance of semi-natural habitat, where biodiversity and ecosystem services decline can induce problems like erosion, salination, pest outbreaks, pesticide runoff, water and soil pollution. Where and when such events arise and how 'problematic' they are considered to be, is generally not very clear. How far can landscape decline go, or should ecosystem services first break apart, before we will act?

In this paper I will use 'biodiversity' as an example associated to ecosystem services such as pest control. Nowadays biodiversity decline is generally admitted (too) late, when species become rare and finally go extinct. Such events are preceded by a slow but sure decrease that can last many years, going unnoticed. Some worrying examples of long-term monitoring studies are the French STOC (Temporal monitoring of common birds) showing a 35% reduction of nesting birds in agricultural areas in the last 25 years (Jiguet 2010) and the Dutch butterfly monitoring system, showing a 70% (!) reduction of overall abundance of butterflies in agricultural landscapes in the last 20 years (Plate and van Swaay 2013). Such results are in clear contradiction to older publications on the high biodiversity of extensive agricultural landscapes due to the opening up of the landscape (Kaule 1991).

Growing awareness of biodiversity decline is leading to great concern (Pimm et al. 1995) and gives rise to many conservation actions, habitat protection or restoration programs, mainly focused on nature reserves managed by expert conservationists. These actions are essential for endangered species protection and can save endangered populations, but long-term effects should aim at maintaining functional (meta) populations (Levins 1969; Hanski 1999) which requires a landscape scale approach (Fahrig 2003).

But why should a farmer care about endangered species protection, nature reserves and biodiversity? Rare species are rarely present in his backyard and seldom play an essential role for him.



Figure 3a and b. Erosion of semi-natural habitat as observed in the Saint-Émilion area between the area of Grand Cru Classé (Saint-Émilion) and Saint-Émilion 'Satellites' (Puisseguin and Lussac) (b). Source: Google Maps

However because agricultural land often represents a very large proportion of land use (50% in the case of France) (Agreste 2010) many species find habitat, or disperse, in agricultural landscapes. Appropriate, adapted management of agricultural space can greatly improve its value for biodiversity conservation. In integrated production guidelines (Boller et al. 1997, 2004; Tscharntke et al. 2005) and many national schemes, maintaining a minimal amount of space as 'ecological compensation areas' is requested (generally 3 to 10% of the land area) but rarely applied. Such guidelines are so far not adequately supported by experimental proof (that seems to indicate that such low percentages are very insufficient), and no precision is provided on (1) the type of semi-natural habitat and (2) the required landscape structure. Motivating farmers to change practices in favour of nature conservation is not a simple task, adding what they consider as new constraints without being able to identify positive effects, will rarely be well received.

Functional landscape management for ecosystem services?

To motivate farmers towards more sustainable agricultural landscapes, decision-makers and scientists are looking for clear proof of advantages provided by a more appropriate management. One of the most used approaches is the prospect of **functional** biodiversity. Semi-natural habitats are potential sources of natural enemies that could control the crop pests, so maintaining a minimum of prairies, woodlots, hedges, etc. should be able to reduce pest pressure. This seems however a somewhat over-simplified interpretation of Elton's (1958) ecological theory, stating that high species diversity increases ecosystem resilience. High resilience of an ecosystem (the ability to recover from disturbances) means indeed that an ecosystem can return to a stable (read natural) state, but applying this concept to an agricultural landscape would probably mean that the agro-ecosystem would return to a 'natural' state, meaning a sheer loss of agricultural production. The more recent concept of 'ecological intensification' (Hochman et al. 2013) still seems optimistic about the possibility to obtain food security, increase agronomical yield through intensification, and simultaneously ensure conservation of the environment and biodiversity. This seems not very realistic (Tscharntke et al. 2005)

Many research papers (Levins 1969; Kareiva 1987; Fahrig 2003; Bianchi et al. 2006; Tscharntke et al. 2007; Rossing et al. 2008; Rusch et al. 2010; Thomson and Hoffmann 2010; Kleijn et al. 2011; MacFayden et al. 2011) tend to show interest in semi-natural habitats as sources of insect biodiversity and natural enemies. They show that contribution of semi-natural habitat for biodiversity conservation is undeniable with even some clear indication for specific landscape



Figure 4. Landscape configuration in newly claimed land, the Dutch Noordoostpolder. Scale bar = 100m

structures (such as connectivity) required for some species. There is even abundant proof on the high presence (both in species diversity and abundance) of natural enemies (both predators and parasitoids) in semi-natural habitats (Bianchi et al. 2010; Chaplin-Kramer et al. 2011) and sometimes even inside the crop. However there is a big missing link, the proof that these natural enemies do indeed contribute to the downward regulation of the pest: their **functionality**. Very few publications actually show an increased impact of the natural enemy leading to lower population levels of the pest.

To have a functional impact natural enemies should disperse to the crop at the right moment (when the pest starts to build up functional response, Holling 1959) and be present in sufficient numbers to reduce the pest population before it goes over the economic injury level (numerical response, Solomon 1949). Both generalist natural enemies (most predators) and specialist (often parasitoids) will rarely find sufficient resources inside the crop, unless their prey is already abundant. There are exceptions, such as the well-known example of predatory mites. These are able to feed on pollen and alternative prey, capable of maintaining high population levels even in the absence of plant parasitic mite populations with a quick host shift if they do appear (Helle and Sabelis 1985). This however almost seems to be an exception to the rule.

Landscape does influence pest populations!

This however does not mean that landscape management cannot influence pest population levels. There is nowadays ample evidence that landscape diversity and structure do influence pests. Very often increased landscape diversity, reduced abundance and fragmentation of agricultural habitat at landscape scale are correlated with reduced pest pressure (Bianchi et al. 2006; van Helden et al. 2006; van Helden and Pain 2008b). Such positive proof is mostly obtained through correlation studies between landscape parameters and pest abundance, not aiming to demonstrate a cause-effect relation through an increased impact of natural enemies; the 'service provided' is reduced pest numbers, the service provider is not identified.

However observing such statistically significant relationships does not mean they have a 'significant' (read sufficient) influence for the farmer. As an example, the abundance of the European Vine Moth (*Lobesia botrana* Den. and Schiff.) is strongly influenced by the total abundance of viticulture in a 1 km circle (buffer) around the observed plot (van Helden et al. 2006). When vine plots occupy less than 30% of the total land surface, leafroller populations generally stay below intervention thresholds. We simultaneously showed that the green leafhopper (*Empoasca vitis* Göthe) responds inversely to the same landscape parameter, reducing their abundance in monoculture landscapes (Decante and van Helden 2006; Decante et al. 2009; van Helden and Pain 2008b).

Such scientifically valid results cannot easily be translated to management strategies (van Helden and Pain 2008a; van Helden et al. 2012); results are opposite for different pest insects, and reducing vine plots below 30% is anyhow an unrealistic option in AOC areas.

From functional biodiversity to ecosystem services (ES)?

A more realistic and down-to-earth approach seems needed to encourage more sustainable landscape management. Research therefore has shifted towards the study of 'ecosystem services' (Tscharntke et al. 2005), trying to quantify the service **provided** rather than studying the service **providers**. This allows for a more holistic approach where different services (pest control, reduction of erosion and runoff, pollination) can be studied to identify optimal management of a set of services rather than maximising (each) one of them. Even rather indirect services such as 'landscape attractiveness for tourism' can be taken into account in such approaches, thus also including social sustainability. Today several research groups tend to model such ES at the landscape scale (Baveco et al. 2008, Bianchi et al. 2010). From a scientific point of view it is however less satisfactory if underlying mechanisms for differences in ES are not explained. The European program QUESSA (Quantification of Ecosystem Services for Sustainable Agriculture) is currently trying to measure a large set of ecosystem services in eight different cropping systems and contrasted landscape configurations.

Lessons learned in land management projects?

Attempts towards more sustainable land management in viticulture through landscape action have been initiated in many situations (water pollution from pesticides; protection of rare species linked to the Natura 2000 EU program) in Europe (van Helden et al. 2012) unfortunately often without good results. A 'top down' approach with negative incentives (criticising the farmers; aiming at changing farming practices to protect some rare unattractive animal) can even make farmers dig their heels in, the opposite of the objective.

If political incentives and scientific studies so far have not been able to convince land managers, other options should be considered. Farmers are experiencing 'threats' to their land such as urbanisation and planning of large infrastructures. In the area of Saint-Émilion the project of a motorway going through the area in the 1990s raised a big protest movement ultimately leading to the nomination and inscription of the area as a UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Cultural Landscape in 1999. This indeed successfully protected the area for winegrowing, but unfortunately it did not necessarily provide sufficient protection at the landscape level. But awareness of landscape protection was clearly raised.

The international 'Charter of Fontevraud' (http://www.charter-offontevraud.org/) was created in 2003. Its aim is "to encourage all the players in winegrowing territories, local authorities, winegrowing syndicates, culture and tourism operators, universities and laboratories to commit to voluntary and concerted landscape approaches that bring together, based on sustainable development reasoning, the optimisation of wine production and the cultural and tourism enhancement of these landscapes, in the framework of an international network of excellence". Such voluntary (moral) engagement of all stakeholders is indeed very positive, but does not necessarily raise enough ambition and clearly identified goals, and individual farmers do not necessarily adhere. It does however aim at creating a multi-stakeholder approach, which is useful to collect ideas from everyone without 'imposing' too single-sided practices, and to establish a mutual exchange of ideas, identifying opportunities and understanding constraints.

Learn together with the actual landscape managers

Learning from our many faults and mistakes we nowadays approach landscape management 'bottom up', trying to find ways to engage farmers through a more active dialogue. This still involves all possible stakeholders, from farmers to conservationists, from bird protectionists to hunters, from schools to policy-makers but the starting point is that the actions should have a direct positive for the land managers (farmers) and therefore farmers' associations should initiate and pilot such programs. The 'steering committee' in which farmers have a majority is therefore completed with a 'technical advisory board' where all imaginable stakeholders are invited.

This approach has shown its efficiency first in the Saumur-Champigny area since 2007 and started with more ambition in 2010 in the Saint-Émilion area. In both cases the farmers' association requested our university and transfer unit Vitinnov to accompany them in the management of a landscape project. One of the first tasks for such a project is to identify the needs, opportunities and impossibilities, through interviews with all stakeholders and by mapping the actual landscape using a Geographical Information System.

In the Saint-Émilion area we were thus able to identify that in spite of the apparent intensive use of the landscape there were still several opportunities where 'space' was available for actions:

- The small size and irregular form of the vineyard plots in the area lead to a lot of 'interstitial space' such as headlands, slopes etc. (7% of the 'vineyard' space).
- Grassy ground cover is already present in many plots and can be 'improved' through natural colonisation of wild plant species.
- Between the uprooting of an old diseased plot and its replanting farmers allow a fallow period of several years (4% of the area, a very 'dynamic' space changing every two years) (Figure 5).
- Parks and gardens of the many chateaux cover 8% of the total surface of the area (Figure 5).
- Forests and meadows persist in the less prestigious areas with a total of 8% each (Figure 5).

From this result we identified several possible options such as hedgerow planting (on slopes and other interstitial space), ground cover installation and (reduced mowing) management (in plots and on headlands), sowing of 'biodiversity covers' (on fallow plots) and more 'ecological' gardening of often very formal French parks. From our research and other publications, but also from exchanges with the farmers, we are trying to identify (actual or potential) 'agronomic' advantages of actions such as slope fixing of hedgerows and soil improvement by fallow covers.

One of the most successful actions is the sowing of fallow land. Advantages of sowing fallow plots for the farmer are: 1) avoiding erosion and runoff 2) improving soil organic matter (water storage capacity, avoiding soil compaction, carbon sequestration) 3) fixing nitrogen and avoid lixiviation of minerals thus providing a good starter fertiliser for the new vines 4) reducing the negative impact of pollutants such as copper and herbicide residues 5) reducing soil-borne diseases such as virus-transmitting nematodes 6) avoiding colonisation of the plot by invasive weeds and 7) to providing pollen and nectar resources for pollinating insects and some natural enemies. The direct agronomical 'ecosystem services' are quite efficient to motivate farmers. Carbon sequestration is too abstract to motivate, but the 'biodiversity' issue is a clear positive bonus. In this specific case a mix of legumes and cereals is proposed that seems to be the best compromise. Installing a 'natural' species rich meadow with only wild flower species might be even better for biodiversity, but is impracticable for agronomic and economical reasons.

This 'down to earth' approach is also useful to avoid 'ecological driff' where mixtures of colorful exotic flowers (*Cosmos, Zinnia*,



Figure 5. Overall landscape composition in the area of Saint-Émilion

Escholtzia) are installed on fallow plots with claims on biodiversity, honeybee protection and pest control. Such 'greenwashing' might be commercially marketable (mainly for the seed supplier) but is agronomically ineffective and ecologically 'unserviceable' and sometimes even has negative effects with exotic plant species becoming a nuisance.

Capacity building

In such landscape programs not every farmer will be motivated. Attitudes vary from 'active drivers' to 'brakemen' with a large midfield of more cautious 'wait and see'. To avoid such programs coming to a standstill, brakemen are simply ignored and pilot actions should focus primarily on actively involved 'drivers', insisting on positive effects and positive communication. This will be most efficient to keep the engine running and get the midfield joining in the action, thus creating social sustainability. Ignoring the 'negative attitude' of the brakemen is not as 'natural' as it seems, but focusing on positive action will optimise the use of available resources.

Starting off with volunteer farmers involves actions at the farm scale (the real existing management scale) which is unfortunately not the more appropriate 'landscape' scale. So after a number of successful actions at the farm scale with those 'drivers', the next stage is to convince the 'cautious' ones to join in. Here a very active attitude is needed to nudge them into action (Thaler and Sunstein 2008). At this stage 'landscape scale' strategies such as creating overall connectivity can really take off, allowing a considerable increase in the amount of landscaping actions; in the Saumur-Champigny project it tripled the amount of hedgerows planted per year (van Helden et al. 2012).

The European Life+ program BioDiVine (www.biodivine.eu) is an attempt to export this approach to other winegrowing areas in Europe. Through local communication with stakeholder groups such as extension services and advisory groups, the first stages of this program have indeed confirmed the initial difficulties in getting farmer groups involved, but good progress has been made over the years.

Funding and sustainability

Such actions inevitably require money. It is in general amazingly simple to obtain external funding for the actual 'hardware' for such actions (seeds, plants, and other materials), sometimes even up to 100%. Full external funding of such supplies should however be avoided since farmers should also directly pay for part of them. Only if they 'pay' for such services will they see them as an actual personal investment that needs maintenance. Management of conservation actions (mowing, hedgerow trimming) is also an 'investment' (with the associated costs), but more easily justified if the farmer identifies the value of the action.

But 'hardware' is just a fraction of the actual costs. Up until today it appears very difficult to obtain money for the actual management (planning, governance, communication, visits, and meetings) of such programs. This problem is often underestimated but the sustainability of a program clearly depends on it. Therefore the best option seems to combine landscape actions with other more directly appreciated (and thus worth paying for) technical actions such as pest and disease monitoring. This allows justification of the costs of the action (and the management) in the short-term while maintaining its efficiency in the long-term. This however requires either involvement of extension workers (that often are more focused on technical aspects such as pest control than on ecosystem services) or 'conservationists' that have little technical knowledge of crop management. I consider that solving this 'detail' is in fact the major challenge required for successful action on sustainable agriculture and landscape management.

Goals and indicators

As in each program there should be clearly identified goals, thus allowing the monitoring of indicators of results. This is also generally required by the organisations providing funding. At the beginning of 'landscape' scale programs it is best to focus on process/resource indicators (number of stakeholders involved, kilometres of hedgerows planted, number of publications) since effects on ecosystem services (the actual final goal) will probably take a long time to achieve, and might not depend only on the actual action (Kleijn et al. 2011). Goals such as stopping overall biodiversity decline are an almost impossible task since today's biodiversity in a landscape is also a result of history (Bowman 2001) and might in fact be 'lagging behind' the effect of landscape degradation (or improvement).

Still it is useful to identify a number of specific 'result' indicators that will be monitored from the very start (to establish a baseline) and throughout the program. This however often implies rather heavy time and money investments and therefore should be limited to the most appropriate species that should respond to landscape changes. Other solutions should be looked for such as crowd sourcing for biodiversity monitoring (Brabham 2008), or maybe just on a limited number of (attractive) 'flag species'.

Sell it!

So far several aspects of internal communication (steering committee, technical advisory board) have been mentioned but external communication should not be neglected. Care should be taken to do this appropriately, to avoid 'greenwash', but also to create a primarily positive image. If landscape actions would allow reducing pesticide drift to surface water this is clearly a good result for internal motivation, but it should not be used to 'sell' this to the general public that has a very negative image on pesticides.

External communication is essential, not in the least to motivate the 'cautious' and critical land managers. Therefore, in every step of such a program and every conservation action planned, it should be asked if this is suitable for external communication, and sometimes actions mainly focusing on external communication and capacity building of stakeholders (such as the use of nest boxes) can still be extremely useful. All of this should aim at gathering more momentum for the program. Active involvement and communication of farmers during on-farm events, involvement of program managers in public events (open days, school visits), clear in-field signalling of conservation actions for people passing by, are all 'non-directlyrewarding' investments that will give long-term results.

Selling the action is one thing, but the farmer is more interested in selling his production. Here viticulture has a very clear advantage. Wine is not a bulk product sold on the world market but a bottle with a label that carries a message to the buyer. Careful communication on environmental engagement can be a means to maintain or increase market share. But this part can be left to the farmers.

Conclusion

Viticulture landscapes suffer from intensification, adversely affecting several ES, which might affect economic and environmental sustainability in the long term. Setting up landscape actions to restore such ES is a complicated process where understanding the actual state of the landscape requires historical knowledge (Antrop 2005). Scientific knowledge on landscape functioning is insufficient (Balvanera et al. 2006), the actual effects of individual conservation actions are often not well known, and a multitude of stakeholder groups have very different goals and constraints. Identifying simple agro-environmental schemes having direct advantages for the farmers should be a priority. Efficient internal and external communication among all stakeholders in a project piloted by farmers is a key factor (van Helden et al. 2012). Positive communication should be aimed at motivating farmers. Successful project management and long-term engagement might be reached when farmers' perceptions shift from 'environmental constraints' to a positive ambition backed up by public recognition, leading to personal satisfaction or even improved economic performance; in other words, only when economic, environmental and social sustainability are achieved.

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How will the carbon farming initiative affect the vineyard?

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Abstract

The Carbon Farming Initiative (CFI) is an incentive-based mechanism allowing farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. There are two possible ways in which the viticulture industry can directly engage in the CFI. The most obvious is the generation and sale of offset credits, through reductions in emissions of either methane or nitrous oxide and increased storage of carbon in soils or trees. However, the viticulture industry is not a particularly large source of emissions per unit area, generating some nitrous oxide from nitrogen inputs to soils, and minor quantities of methane from waste management. Opportunities to change soil management to improve carbon storage are limited because of relatively small vineyard areas. Some opportunity may exist to store carbon in trees established on marginal or adjacent areas of the farm, where this is part of a strategy that combines carbon sequestration with other benefits including wind breaks, biodiversity and riparian restoration. A less obvious option for engagement in the CFI is that the viticulture industry generates products that can assist other industries to reduce their emissions. Recent research has shown reduced methane emissions from livestock supplemented with grape marc, providing a potential market for what is currently a vineyard by-product. The paper will expand on this option and discuss its relative merits in the context of the vineyard. Another indirect use of the CFI for the wine industry is as a mechanism to quantify and demonstrate its environmental credentials, as part of an overall wine marketing strategy to sectors of society wishing to purchase an environmentally friendly discretionary beverage.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) fourth assessment report states that "the warming of the climate system is unequivocal", and that "most of the observed increase in global average temperatures since the mid- 20^{th} century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC 2007). Atmospheric CO₂ was around 280 ppm in pre-industrial times but has now risen to 400 ppm as of May 2013 (Tans and Keeling 2013).

This rise in atmospheric CO_2 will have physical and, eventually, policy impacts on all aspects of society, but agriculture in particular is highly dependent on predictable rainfall, irrigation water and temperature for crop growth. Of relevance to the wine industry is that recent research shows wine-grapes ripening earlier in Australia in recent years, attributed to warming and declines in soil water content, together with crop-yield reductions and evolving management practices (Webb et al. 2012). This earlier ripening has implications for wine-grape specifications and winery logistics because of the compression of vintages. Thus both reducing emissions generally and adapting to the inevitable impacts of a changing climate are important for the Australian wine industry.

The Kyoto Protocol was the first of a series of attempts to develop an international agreement for countries to reduce their emissions of greenhouse gases (UNFCCC 1998). While these international efforts have struggled to bring about meaningful and equitable global action, individual countries are introducing legislation and policy to limit their impact on the climate system. In response to international agreements, Australia submits an annual greenhouse gas emissions inventory to report to the United Nations Framework Convention on Climate Change. In the 2010 report, Australian agriculture produced around 14.6% (79,486 Gg CO₂-e) of national greenhouse gas emissions (DCCEE 2012a), with 67% of these emissions coming from livestock enteric methane. The viticulture industry generates less than 1% of agricultural emissions in Australia (DCCEE 2012a), mainly through nitrogen fertiliser use.

In Australia a range of policies have emerged including the Carbon Pollution Reduction Scheme in 2008 (Australian Government 2012), the Clean Energy Futures legislation (Australian Government 2012), and potentially the Direct Action policy (The Coalition 2010) following the next federal election.

One policy that appears to have bipartisan support in Australia is the Carbon Farming Initiative (DCCEE 2012b). The Carbon Farming Initiative (CFI) is an incentive-based mechanism allowing farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. The greenhouse gas emissions and sinks that can generate offset credits under the CFI include enteric methane from ruminant livestock, methane from waste management and landfill, nitrous oxide from agricultural soils and the storage of carbon in soils and trees.

Options for the wine industry to engage in the CFI

The CFI is a voluntary, incentive-based scheme and thus one option for the wine industry is not to engage in the CFI and to maintain focus on productivity. Given the value of carbon credits generated through the CFI is likely to be quite modest relative to main farm income, this is the most likely decision for the majority of growers in the industry.

Direct engagement in the CFI

A second option is for viticulturists or winemakers to identify areas in their production system where offset credits can be generated costeffectively, through reductions in emissions of either methane or nitrous oxide and increased storage of carbon in soils or trees. An Australian Wine Carbon Calculator tool has been developed by the Winemakers' Federation of Australia and the South Australian Wine Industry Association to allow viticulturists to estimate their current carbon footprint.

Vineyards are also not a particularly large source of emissions per unit area, generating some nitrous oxide from nitrogen fertiliser applied to soils, and perhaps a small amount of methane from storage and handling of grape marc (although this is not reported in the national greenhouse gas inventory). At the time of writing (May 2013) a CFI offset method was being developed to recognise reductions in the rate of nitrogen fertiliser use, but this method is not yet approved and is unlikely to reward viticulturists in any significant way.

In addition, within vineyards there is limited opportunity to change soil management to improve carbon storage. Thus the only direct CFI offset method available to the wine industry is through environmental plantings. However, to make this cost-effective it would need to be part of a strategy that combines carbon sequestration in trees with other multiple benefits including wind breaks, biodiversity and riparian restoration.

Indirect engagement in the CFI

The third and less obvious option for engagement in the CFI is via products the viticulture industry generates that can assist other industries to reduce their emissions. Recent research in Australia has shown up to 20% reduction in methane emissions from dairy cattle supplemented with dry or ensiled grape marc (Moate et al. 2012). This finding will be the subject of further research before it can be developed into a formal CFI offset method, but could present a new opportunity for the wine industry.

It will also need to be subjected to a comprehensive analysis on the relative merits of alternative uses for grape marc in a future carbonconstrained world, as organic waste can be used for second generation biofuels (assuming ethanol extraction has already taken place), biochar production or simply adding organic matter back to soils.

Carbon offsets as part of a carbon footprinting strategy

A further indirect option is for wine businesses to use the CFI methodologies as part of a general carbon footprinting and offsets strategy. This could cover offsets generated and verified through the CFI, both from the vineyard and adjacent carbon sinks, plus those from by-products such as grape marc. Although the magnitude of the carbon credits generated in individual vineyards is not likely to be large, on a whole wine production and marketing supply chain scale, a general business strategy to minimise the overall carbon footprint may be significant in providing low carbon footprint credentials to the wine industry.

Policy – research timing mismatch

What becomes obvious from the discussion in this paper is that there is a timing mismatch between the immediacy of policy demands and research. Politically, a new policy like the CFI has to be shown to be delivering against promises for agriculture and thus there is an imperative to develop as many CFI offset methods as possible. However, research commonly takes decades from concept to adoption, and the focus on greenhouse gas abatement in agriculture is relatively new – the national Climate Change Research Program and associated nationally coordinated research programs started in 2009, and the subsequent Carbon Farming Futures Program started in 2012.

It is no surprise then that the majority of CFI methods approved to date focus on areas like landfill gas, methane from waste management and tree planting, where the science is mature and has been understood for many years. Conversely, CFI methods relating to broad acre agriculture – for example, on methane from livestock, and nitrous oxide from soil – are still in the research phase, with cost-effective solutions a few years off in the research timeline.

How will a change of government affect the CFI?

An obvious question is how a change of government will affect the CFI? The Liberal/National Coalition has released their Direct Action policy (The Coalition 2010) and plan to both support and expand the scope of the CFI. However, the Coalition also plans to repeal the carbon tax, effectively removing the demand for CFI offsets from the

market by eliminating the need for entities to purchase offsets against their emissions.

Under the Direct Action policy the government will purchase emissions reductions using their Emissions Reduction Fund (The Coalition 2010), which means that they become the buyer of offsets from the CFI (apart from buyers in the voluntary market). However, Direct Action will use a reverse auction approach to buy the emissions reductions at the lowest cost to the tax payer. In this process entities compete to sell their emissions reductions, with government usually buying the cheapest option that meets the minimum integrity requirements. Businesses that reduce their emissions below their individual baseline ('historic average') will be able to offer this emissions reduction for sale to the government. At current prices most farmers are unlikely to engage in the CFI, unless it aligns with other strategic objectives being planned. Therefore engagement in the CFI under reverse auction could be even less likely to incentivise engagement, unless funds were reserved for direct action within sectors.

While the details of this are not clear, the policy does state "To ensure the Fund supports a broad range of direct action initiatives, measures considered for support by the Fund will be assessed against similar proposals from similar sectors" (The Coalition 2010). Under the Direct Action policy, government would therefore consider projects that not only reduce CO_2 -e, but deliver additional practical environmental benefits (value-added offsets, for example improved biodiversity, reduced water use and waste recycling), avoid price increases to consumers, protect Australian jobs, but would not proceed without Fund assistance.

Conclusions

While climate change will be an issue for the future viability of the wine industry in some parts of Australia, the industry's emissions profile is relatively modest compared with other more emissionsintensive agricultural systems. However, this also means that opportunities for participation in a policy like the CFI may well be limited to planting trees and trading grape marc for carbon offsets, where this aligns with other strategic objectives, and managing nitrogen in soils, where this can be cost-effective in its own right. What the CFI may provide is a new market for grape marc, through selling this as a dietary additive to the livestock industry to reduce enteric methane.

The CFI will continue to be supported even under a change of government with the scheme potentially expanded in scope and coverage. However, under Direct Action government will be the main buyer of these emissions reductions at lowest cost through reverse auction. To incentivise action a future CFI will need to include valueadded offsets, where an offset can demonstrate additional environmental benefits like water savings and improved biodiversity and can therefore be traded at a price sufficient to incentivise action.

These broader environmental benefits as well as some carbon offsets to lighten the carbon footprint may be of interest to wine producers seeking market advantage in the area of environmental credibility.

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SESSION 7: Grapegrowing in challenging climates



Knowing the odds – managing weather risks in a changing climate A. Coutts-Smith

Predicting and preparing for heatwaves P.T. Hayman, D.S. Thomas, M.L. Longbottom, M.G. McCarthy

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Knowing the odds – managing weather risks in a changing climate

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Abstract

Australia's climate can be harsh and frustrating to work with. Knowing how and why regional climates vary, what forecast information is available and how climates have changed or may change in the future is critical to making short and long-term decisions and managing any associated risks. Averages of rainfall, temperature and other variables actually tell us very little about the climate and whether a particular agricultural enterprise, when all other things are considered, can be profitable. This is because there can be significant year to year variability and change over longer timescales. For Australia there are a number of large scale drivers that contribute to climate variability within a season, such as the Southern Annular Mode, or from year to year, such as the El Niño Southern Oscillation. To assist decision-making on seasonal timescales each month the Bureau of Meteorology provides a seasonal forecast of rainfall and temperature for the coming three months. In addition to climate variability, Australian average temperatures have warmed by around 0.9°C since the early 20th century, with most of that warming occurring since 1950. Rainfall changes have also been apparent in some parts of the continent in recent decades. Such changes can affect long-term decisions and long-term viability. Again the Bureau of Meteorology has information available that identifies how temperature and rainfall have changed across Australia and the recent update of our high quality daily temperature record demonstrates that extreme temperatures are on the move.

Introduction

I have been asked to talk today about managing weather risks in a changing climate. In this presentation I intend to cover: Australian temperature trends, trends in extremes, heatwaves, synoptic drivers of heatwaves and whether those drivers are changing over time. If we have time I'll also look at the forecast information that's available on the Bureau of Meteorology website.

Temperature trends

Australia has warmed over the last 100 years. The Bureau has a very comprehensive network of instruments, some of which have been operating since before the 1900s. Average temperatures, minimum temperatures (which are the night-time temperatures) and daytime temperatures have all been increasing over that 100 year period. Figure 1 shows that these increases have been occurring decade on decade – each decade has been warmer than the last since the 1970s.

Not only have the temperatures over the land mass been increasing but so too have the sea surface temperatures around Australia (Figure 2). They haven't been rising as much, and that's related to the amount of heat that water can absorb, but the increases do influence local climates.





Extremes

Figure 3 shows increases in mean temperatures, and a shift in the frequency of record setting daytime and night-time temperatures, such that we are now seeing much more of a bias towards warmer temperature records, particularly in the last decade. In order to understand that trend, we need to explore why the increase in average temperatures has led to such an increase in record setting events.







Figure 4 shows a standard probability distribution, with the years 1950 to 1980 shown in blue and the most recent 30 years shown in red. We can see that there has been a shift in the average over that time. This means that we are still seeing the same everyday weather but with far fewer cold events and with warm weather that's outside of our experience.

To put some numbers around that, in Figure 5 we have actual data from all our stations across Australia. The data have been normalised – which means that we've tried to make them similar in terms of the shape of the distributions. If we focus on the really warm days, we see that rather than being really warm 2% of the time it's now 10% of the time – a fivefold increase in how often really warm days are occurring, for only a fairly small shift in average temperatures. So the key message here is that a small shift in average temperatures can lead to fairly large shifts in the amount of extreme weather. And that plays out for the night-time temperatures as well (Figure 6).

Heatwaves

Extreme temperatures are not necessarily one-off events. We tend to see clustering of extreme temperatures on consecutive days and we term these 'heatwaves', although definitions of heatwaves vary. The Bureau generally uses criteria of three consecutive days above the 99th percentile daytime temperature and five consecutive days above the 95th percentile daytime temperature to define a heatwave. As an example, for Rutherglen those critical thresholds are 38.9°C for the 99th percentile and 35°C for the 95th percentile. Figure 7 shows that in Rutherglen there have been quite a few situations with multiple days in a row above the critical thresholds.



Figure 4. Shift in the frequency of warm and cold weather - general trends



Figure 5. Shift in the frequency of warm and cold weather - for maximum temperatures



Figure 6. Shift in the frequency of warm and cold weather – for minimum temperatures

Now if we look at these thresholds across some different areas of Australia (Table 1) we see that broadly speaking in inland areas the 95th percentile is around 35°C and the 99th percentile is around 39 to 40°C. If we consider areas that are very close to the coast, we tend to see much lower threshold temperatures as a result of sea breeze activity which can cool down extremely warm days and prevent them from getting really hot. We can see that effect in both Robe and Sydney, but if we compare Sydney (on the coast) with Western Sydney (about 40 km inland) there is quite a substantial difference in the thresholds. The key point is that what determines a heatwave varies depending on your situation, your purpose, and what you can tolerate.

Drivers of heatwaves

So what drives heatwaves? The key ingredients are a build up of heat over central Australia and high pressure systems that then take that heat and move it to different parts of the continent. With high pressure systems, the air masses move in an anti-clockwise direction and that means that close to the coast temperatures are generally reflective of sea surface temperatures. As the high pressure systems start to move over the land mass of Australia they get warmed up and then they get funnelled. Highs then move across the country and the direction of hot winds starts to shift. As highs move into the Tasman Sea they start to affect Adelaide and South Australia and the north-west corner of Victoria, and as they move further into the Tasman they start to affect the south-east corner of Australia.

High pressure systems can actually 'stick' in position – we term this 'blocking' – and so if we start to hear communication messages in summer about 'blocking highs' we need to start thinking "OK, we're going to see some prolonged heat" because that's essentially what it leads to. This blocking tends to occur over areas that are relatively cool in comparison to their surrounding environment, for example the Great Australian Bight and the Tasman Sea during the summer.

Typically for the south-east, not so much for the south-west, there's a bit of a sting in the tail of these heatwaves. This comes about from the weather systems that eventually clear the massive heat across the continent – the cold fronts. Cold fronts tend to generate really strong winds from the north as they move through the south-east. They bring extreme heat, low humidity and very strong winds. This increases the evaporative demand but also increases dangerous fire weather. So it's always something to be mindful of in the termination of these types of heatwaves.



Figure 7. Example of multiple days with temperatures above critical thresholds

Table 1.	95th a	and 99th	percentile	e maximum	daytime	temperatures	at a ra	nge of
location	s aroui	nd Austra	alia					

Region	95th percentile	99th percentile
Adelaide	35°C	40°C
Nuriootpa	34.1°C	39°C
Robe	27.5°C	32.3°C
Sydney	29.2°C	35.6°C
West Sydney (Richmond)	34.1°C	39°C
Rutherglen	35°C	38.9°C
Just to take an example, Figure 8 shows the beginning of the heatwave which commenced on 25 December 2012 in south-west WA. The red arrow pointing out of the high pressure system shows where hot winds are coming from – they are directing right into the south-west corner of WA. Taking a step forward a couple of weeks, Figure 9 shows the heatwave starting to affect South Australia and Victoria and again the red arrow shows where air is being drawn from the central land mass of Australia.

Figure 10 shows the fairly strong cold front that arrived at the termination of the heat event, generating strong winds particularly in NSW, and some high fire danger weather. It also resulted in Sydney setting its record maximum temperature of 45.8°C. In that particular situation there were winds ahead of the change that were strong enough to snuff out the sea breeze which generally keeps things cool. Over the time frame of this heat event, large areas of Australia recorded some very extreme heat conditions. Figure 11 summarises the highest maximum temperatures experienced across the country during the three week heatwave period, with temperatures above 45°C shown in dark brown and temperatures between 42 and 45°C shown in lighter brown.

Changes in drivers?

So are we actually seeing a change in the drivers of heatwaves? Since around the 1950s (when we have fairly good records for observations of mean sea level pressure), we have observed an increase in the number of high pressure systems that are coming across southern Australia (Figure 12), which does mean an increase in the drivers of heatwaves.

Forecasts

Now I'll just move on to some of the forecast information that the Bureau has available on its website. We have our official forecast which is Day 1 right out to Day 7. I would also say never underestimate the value of listening to the forecast on local ABC radio, on the Country Hour. On that program the senior forecaster for the day communicates with the regional community about the weather and in those conversations you can pick up on the level of certainty that the Bureau has in that particular outlook. Key other resources on the Bureau's website include 'Water and the Land' (http://www.bom.gov. au/watl/) which pulls together information that has an agricultural focus as well as a new tool called MetEye (http://www.bom.gov.au/ australia/meteye/). MetEye taps into the graphical forecast system that has recently been implemented around the country. It provides a graphical picture across the whole of the country of temperature and rainfall forecasts, storms, snow, frost, and evapotransporation. It also covers humidity, wind, and if you're close to the coast, wave forecast information. The other beauty of this new product is that it's based on a 6 km grid, which means that if you're not located near a town centre traditionally covered by forecasts, you now have access to a 7-day forecast. You can click anywhere on the map and bring up the forecast for that particular location. We believe that this is a real advancement in our capability to deliver forecasts to the Australian people.

There is also a seasonal forecast system which gives an indication of the probabilities of rainfall being above or below average in the three months ahead. The Bureau recently made a switch in the underlying system that implements the seasonal outlook; it's now a dynamic computer-based model, which provides multi-week and monthly forecast capability. We're in the process of testing the system to ensure that when we forecast an 80% chance of above average rainfall that it actually happens 80% of the time, giving confidence in the probabilities. That's a critical step in the whole process. The new system also introduces the opportunity to implement not only monthly and weekly rainfall forecasts but also new variables beyond rainfall and temperature. It opens up a lot of scope for continuing improvement, as we have done with the weather models, we can now also continuously improve the seasonal forecast model.



Figure 8. Beginning of heatwave, 25 December 2012



Figure 9. Middle of heatwave - 4 January 2013



Figure 10. End of heatwave - 18 January 2013



Figure 11. Highest maximum temperatures across Australia during this heatwave

Trend in summer anti-cyclone density (1950–2009)

Summer mean anti-cyclone density - Southern Region (1950-2009)



Figure 12. Increase in number of high pressure systems

Summary

In summation I think the first key point from this presentation is that we have seen an increase in mean temperatures, we've seen a commensurate increase in extreme temperatures and when we look at how often extremes are now occurring, they're increasing at a greater rate than we might expect purely based on the shape of the temperature distribution. It's an important message that a small change in average temperatures can result in substantial increases in the extreme weather. The second key point is that the Bureau of Meteorology has some really great new products for people to use to inform themselves of the situation ahead.

Predicting and preparing for heatwaves

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Abstract

We use a common framework to explain the vulnerability of the wine-grape industry to heatwaves that considers the exposure, sensitivity and adaptive capacity. The sensitivity of grapevines to heatwaves requires a clarification of what a heatwave entails. Heatwaves can be analysed through a series of four key questions: 1) "how hot?" (intensity) 2) "how long?" (duration) 3) "when?" (timing) and 4) "how drying?" (humidity). Given the damage caused by drying and desiccation during a heatwave in most Australian wine regions and the importance of irrigation as a major way to manage heatwaves, we examine the relationship between temperature, rainfall and evaporation for 20 mainland Australian sites. Finally we give an overview of management options with an emphasis on responding to warnings of heatwaves, recognising that these warnings will not be perfect and there will be an occasional false alarm.

Introduction: damage comes from extremes rather than the mean

The vulnerability of wine-grape growing to a climate stress such as a heatwave can be seen as a balance between the impact of the heatwave and the adaptive capacity of the vine, the viticulturist and the winemaker. Figure 1 shows a common framework which considers sensitivity (response of a system to climate event) and exposure (degree to which a system is subject to the event). In recent vintages almost all winegrowing regions in Australia have been exposed to heatwaves. Even cool climate regions such as the Mornington Peninsula and Tasmania are exposed. The damage from heatwaves in these cool regions has been as great, or at times greater than in the warm inland regions.

Vulnerability in Figure 1 is best considered as the residual vulnerability. This is the vulnerability remaining after cost-effective steps have been taken to manage the impact. Obviously the cost of any adaptation should not exceed the gains from adaptation. For winegrape production, variable grape prices make assessing the returns from adaptation options difficult. The fact that grape prices are not only variable but also low has reduced the capital available for adaptation options such as a new irrigation system. The challenges of heatwaves for wine-grape production can be considered at the level of the vine, vineyard and winery. The focus of this paper is at the level of the vineyard but the impacts and adaptation for heatwaves will be different at the level of the winery or large company than a single vineyard. For example, a winery may source fruit from other regions, an adaptation option that is obviously not available to a vineyard.

At the level of the vine, high temperatures will inhibit photosynthesis and berry overheating leads to loss of quality and in some cases yield. The challenges at the vineyard level involve short-term decisions on irrigation, medium-term decisions on pruning and longer-term



Vulnerability

Figure 1. A common framework for vulnerability to a climate event. Adapted from Schröter and ATEAM consortium (2004)

decisions on row orientation and trellising. Heatwaves immediately before harvest lead to extreme pressure both in the vineyard and the winery. As bushfires are associated with heatwaves there is an additional risk of smoke taint. Although harder to quantify, media coverage of a heatwave may influence consumers' perception of wine quality from a vintage. Associating a region with regular heatwaves may influence the reputation of a region.

Although most viticultural work during the hotter time of the year is conducted in air conditioned vehicles, there are tasks that have to be done in the heat with significant work health and safety concerns. The frantic pressure in the harvest process, handling and delivery to the winery also presents work health and safety risks. Ramsey (1995) found that unsafe acts in the workplace were constant in the comfort zone of 17 to 23°C WBGT (Wet Bulb Global Temperature) but increased when temperatures were 23 to 35°C. The WBGT considers the humidity, incoming radiation and wind as well as the temperature. Relative humidity is usually lower than 10 to 20% during heatwaves in Australian wine regions. Under this low humidity an ambient temperature of 30°C corresponds to 23°C WBGT (assuming high radiation and a light wind) and an ambient temperature of 40°C is equivalent to about 30°C WGBT. The important point for the Australian wine industry is that prior to the direct physiological danger of heat stress, there is ample evidence that decision-making is impaired during high temperatures (Hancock et al. 2007).

The sensitivity of wine-grape production to temperature can be considered at the timescale of the six-month growing season or individual heatwaves. Most indices used in viticulture are relevant to the seasonal time scale and are used to compare vintages and determine whether varieties are suitable for a region in current or future climates. Common examples include Mean January Temperature (MJT), Growing Season Temperature (GST), temperature of the month prior to ripening (Iland et al. 2011), growing degree days or biologically effective degree days (Gladstones 1992). Recent vintages have highlighted the sensitivity of grapevines to heatwaves and drawn attention to extremes rather than the seasonal mean. Deriving a simple indicator for heatwaves is difficult but some of the key characteristics are described in the next section.

Defining heatwaves relevant for viticulture

There is no universal definition of a heatwave beyond the understanding that a heatwave is a run of very hot days. For wine-grape production, what is considered hot differs by region partly because vines acclimatise to certain conditions but also because viticulturists have a sense of what is normal or expected when they design the irrigation systems and manage vineyards. The three common dimensions of a heatwave are intensity, duration and timing. This can be posed as three questions: "how hot?", "how long?" and "when?" An aspect of the first question of "how hot?" that has emerged from work in human health is also to ask "how much heat?" This notion of heat load rather than maximum temperatures includes a consideration of the night temperature as well as maximum temperature. Because a heatwave in Australia is usually associated with hot dry winds from the interior, a fourth question which is especially pertinent to managing vineyards is "how drying is the heatwave?"

1. Intensity ("how hot?")

The intensity of a heatwave can be absolute or relative. Many viticulturists in southern Australia relate to the definitions used by the South Australian Regional Office of the Bureau of Meteorology of either five consecutive days with maximum daily temperatures above 35°C or three consecutive days with maximum daily temperatures above 40°C. Most studies comparing heatwaves nationally or internationally use a percentile as the threshold, typically 90%. Because a heatwave is by definition at the extreme tail of a probability distribution of maximum temperatures, a shift in the distribution will greatly increase the number of hot days. This can be illustrated using historic data from Nuriootpa in the Barossa Valley and assuming a climate change projection for the Growing Season Temperature (October to April) to increase by 2°C from 18.3 to 20.3°C by 2050. Under this assumption, the number of days over 30°C increase by more than one-third from 51 in the current climate to 71 in 2050, the number of days over 35°C almost doubles from 16 to 29, and the number of days over 40°C triples from 2 to 6. (Thomas and Hayman 2014).

Although the maximum temperature is an indicator of the heat in the system, the number of hot hours is driven by the minimum temperature as well as the maximum. A feature of heatwaves in southern Australia is that a few days into the event the minimum temperature can be over 30°C. Under these conditions the day heats up quickly and remains hot well after sunset. In discussion with viticulturists, night temperatures above 20°C were ranked as damaging, especially when combined with hot days.

The damaging impact of a run of hot nights and hot days leading to excess heat is a key feature for human health. This has led the Bureau of Meteorology to develop a heatwave index which is available as a series of maps for the current day extending out for the next four days (http://www.bom.gov.au/australia/heatwave/). The severity of the heat index is determined by comparing forecast maximum and minimum temperatures over a three-day period with the long-term record. The index also takes into account how hot it has been over the last 30 days. This means that a second heatwave in a month would have to be slightly hotter to rank as severe. This is sensible for human health and there is likely to be an element of vines being 'hardened' and vineyards more prepared if the previous 30 days had been unusually hot. However, a key feature for viticulture is how dry (lack of rain) and how drying (high evaporation) conditions have been in the lead up to the event. Some caution should be applied by viticulturists using the index. Although the main drivers of the index are the forecast maximum and minimum temperatures, the inclusion of the temperature during the previous 30 days means that an unusually hot and dry lead up would tend to reduce the index whereas milder conditions would increase the severity of the index.

2. Duration ("how long?")

Most wine-grape growers have strategies that can cope with one or two hot days, it is the run of hot days that causes problems. In all Australian winegrowing regions, very hot days are generally associated with a wind bringing heat from the interior of the continent. This is not only true for coastal regions on the mainland but also for Tasmania. Even in warm inland regions heatwaves are associated with northerly winds from the desert. For much of the winegrowing regions of southern Australia, the summer season is dominated by high pressure systems which are about 2,000 to 3,000 km in diameter usually taking five to seven days to cross Australia from west to east (see Figure 2). One of the keys to reading a weather map is to follow the anti-clockwise movement of air around high pressure systems and the clockwise movement around low pressure systems. The leading edge of a high pressure system will be bringing cool air from the Southern Ocean, the following days warm up as the middle of the high pressure system brings stable still conditions and the trailing edge brings the hot inland air.

The weather patterns at the tail end of a high pressure system explain a hot day but do not explain a run of exceptionally hot days. For winegrowing regions in south eastern Australia the high pressure system needs to stay in the same position in the Tasman Sea. This is what meteorologists refer to as 'blocking'. This is where the pattern in Figure 2b persists and is strengthened. Heatwaves are rarely a surprise to weather forecasters. The synoptic conditions that lead up to a heatwave are well understood and easily recognised. Exactly how hot it will be and the length of a heatwave is much more difficult to predict.

Grace et al. (2009) studied the persistence of hot days across southern Australia (the chance of a hot day following a hot day). This study showed that persistence was higher in inland regions than coastal regions. An extreme example is to compare a coastal site like Robe with an inland site like Renmark. Obviously Renmark is much hotter than Robe, but when a relative threshold such as the 95th percentile is used to define a hot day, the chance of a second or third hot day is more likely in Renmark. In other words, there is more persistence in Renmark whereas in Robe there is a chance of a sea breeze breaking up the run of hot days.

3. Timing ("when?")

Most studies on heatwaves focus on intensity and duration rather than timing. One reason for this emphasis is that the timing of the event is relevant but secondary to considerations for human health and of bushfires. For viticulturists however, the timing of a heatwave relative to the development stage of the vine is crucial. This can be illustrated by two contrasting heatwaves: an unusually late event (March 2008) and unusually early event (November 2009). The March 2008 event was of little concern to hot inland regions where most of the crop had been harvested but of major concern to cooler regions and late ripening varieties. Vines were defoliated and grapes suffered from sunburn and heat damage. Ripening was temporarily delayed and harvest intake schedules were thrown into disarray. The mid-November 2009 event was early and the main impact was poor fruit set and subsequent low yields on varieties that were flowering at the time; for example Grenache in the Barossa and Merlot in the



Figure 2. Schematic of airflow across SE Australian wine regions when high pressure system is in the a) Great Australian Bight or b) Tasman Sea. Note that a high pressure system will move across land quite quickly. Adapted from Grace et al. (2009)

Limestone Coast. In general terms, heatwaves occurring at flowering will reduce yield while heatwaves from veraison to harvest will have an impact on quality and yield. The 'Black Saturday' heatwave in late January and early February 2009 was widespread and the impacts across different regions and varieties are explained in part by the different stages of the crop (Webb et al. 2009).

In any region wine-grape growing evolves to match critical periods with the environment. In many cases the ripening period is in cooler months of early autumn. As pointed out by Webb et al. (2007), as warmer temperature (and drought) advances phenology, the sensitive stage of ripening will be shifted to a hotter time of the year. This is especially the case when ripening is shifted from early autumn (March) to late summer (February). Although there are heatwaves in March, notably in southern Australia in March 2008, the risk of a heatwave is greater in February than March.

4. Humidity ("how drying?")

An obvious contrast between human stress and plant stress during a heatwave is the dryness of the air. While hot humid conditions create the most stress for humans, the desiccating aspect of heatwaves can cause the greatest stress for plants. As shown in Figure 2, heatwaves are usually associated with a flow of very dry air from the inland which leads to low humidity as a feature of heatwaves for most Australian winegrowing regions. An interesting comparison can be made between Bordeaux and Adelaide. On 17 August 2012 Bordeaux experienced a very hot day (39°C). Adelaide had a similarly high temperature of 40°C on 23 December 2012 (www.weatherspark. com). The contrast between these hot days is the relative humidity. In Bordeaux on 17 August the relative humidity was 20% (dew point 13°C) whereas in Adelaide on 23 December 2012, the relative humidity was 2% and the dew point was minus 10°C. This means that to achieve condensation on the hot day at Bordeaux the air would need to be cooled by 26°C down to 13°C, whereas in Adelaide it would have to be cooled 50°C to minus 10°C.

There are exceptions to heatwaves being associated with dry heat in regions such as the Hunter Valley and Stanthorpe. For example between 30 January and 6 February 2011 the Hunter Valley experienced a heatwave that was not only hot, but also exceptionally humid (Bureau of Meteorology 2011). The next section of this paper explores the relationship between the questions "how hot?" (temperature) and "how drying?" (rainfall and evaporation).

Analysing the relationship between temperature, rainfall and evaporation in Australian wine-grape regions

Temperature is the main climatic factor used to classify Australian wine regions. This is sensible given the importance of temperature in distinguishing regions and the fact that almost all Australian vineyards have access to some irrigation. As shown in Table 1, there is considerable diversity in not only the temperature but also the growing season rainfall and evaporation of Australian wine regions.

In their review of the impact of diseases at a regional level, Scholefield and Morrison (2010) combined a Mean January Temperature (MJT) of 21°C as a threshold for hot and 19°C for cool, with October to April growing season rainfall (GSR) of 300 mm as a threshold between wet and dry. The last column in Table 1 is the ratio of precipitation to potential evapotranspiration (ETo) over the growing season which can be used as a simple aridity index. A P:E ratio of 0.5 is used to distinguish between semi-arid and dry sub-humid. In Australian wine regions a P:E ratio of 0.35 to 0.4 is close to the GSR threshold of 300 mm proposed by Scholefield and Morrison (2010).

A clear distinction can be made between hot and dry regions where disease is a low frequency event and canopies are managed for heatwaves and wet regions where spraying for disease is part of the normal management program and canopies are managed for light and spray penetration. Along with irrigation capacity and experience in dealing with heatwaves, the different ways that canopies are managed explain some of the challenges of dealing with heatwaves in cooler regions.

Table 1. Temperature, rain and potential evapotranspiration (ETo) for 20 mainland locations. The growing season is 1 October to 30 April. P:E ratio is the ratio of precipitation (rain) over the growing season to potential evapotranspiration over the growing season

		Mean January temperature (°C)	Mean annual rain (mm)	C	Potential evapotranspiration		D.F. antin in
Location	Elevation (m)			rain (mm)	Total for growing season (mm)	Mean daily in growing season (mm / day)	growing season
Healesville, Vic	131	17.0	1131	590	718	3.4	0.82
Kyneton, Vic	526	18.5	767	356	809	3.8	0.44
Hamilton, Vic	200	18.8	648	305	791	3.7	0.39
Mt Barker, WA	300	19.7	697	276	834	3.9	0.33
Orange, NSW	922	19.9	927	516	861	4.1	0.60
Lenswood, SA	480	20.0	1011	339	889	4.2	0.38
*Mt Barker, SA	363	19.7	724	273	872	4.1	0.31
Bright, Vic	319	20.2	1137	528	877	4.1	0.60
Margaret River, WA	80	20.4	1095	252	843	4.0	0.30
Padthaway, SA	37	20.4	507	205	884	4.2	0.23
Stawell, Vic	203	20.6	543	256	900	4.2	0.28
Bridgetown, WA	150	21.4	774	206	918	4.3	0.22
Nuriootpa, SA	275	21.5	492	203	973	4.6	0.21
Stanthorpe, Qld	784	21.5	766	564	892	4.2	0.62
Donnybrook, WA	63	22.7	938	213	1001	4.7	0.21
Edinburgh, SA	17	23.0	429	182	1024	4.8	0.18
Mudgee, NSW	454	23.2	708	447	976	4.6	0.46
Loxton, SA	30	23.4	271	142	1067	5.0	0.13
Cowra, NSW	300	23.9	603	363	1030	4.9	0.35
Mildura, Vic	50	24.5	291	165	1112	5.2	0.15
Griffith, NSW	134	24.9	409	237	1094	5.2	0.22

*Mt Barker, SA is nearest operating station to Lenswood, SA and used to represent the Adelaide Hills region.

The sites in Table 1 are sorted from coolest to warmest by MJT. Cooler sites tend to be wetter sites with lower evaporation and high P:E ratios in the growing season. Of the 20 mainland sites in Table 1, there are five with unusually high summer rainfall for the MJT. All five sites are in eastern Australia and include Bright in Victoria, the NSW sites of Orange, Mudgee and Cowra, and Stanthorpe in Queensland.

Most viticulturists are more interested in the relationship between how hot and how drying for a single day rather than the long-term averages. Figure 3 plots the relationship between daily maximum temperature and ETo for four sites ranging from a cold wet site (Healesville MJT 17°C, P:E 0.82), a cool dry site (Mount Barker, WA MJT 19.7°C, P:E 0.33) a warm dry site (Nuriootpa MJT 21.5°C, P:E 0.21) and a hot arid site (Mildura MJT 24.5°C, P:E 0.15).

As expected, higher daily temperatures are associated with higher daily evaporation. Perhaps a little more surprising is that the shape of this relationship is so similar at all sites. Not only is there little difference in the slope of the line of best fit, the scatter of points is similar and shows a 'feathering' at higher temperatures. On a relatively cool day during the growing season of 25°C, the average evaporation is about 4 mm but it could be as low as 2 mm or as high as 6 mm. In contrast on a hot day of 40°C, evaporation will be high with a narrow range.

The correlation coefficients shown in Figure 3 range between 0.67 and 0.76. This correlation should not be interpreted as hot days necessarily causing high potential evaporation. The extra energy input from higher solar radiation will cause both higher maximum temper-



Figure 3. Relationship between daily potential evapotranspiration (ETo) and daily maximum temperature during the growing season (1 October to 30 April). Each day is shown as an individual point. The line of best fit and regression equation is shown on each graph.

atures and higher potential evaporation. Potential evaporation will increase as solar radiation, temperature, or wind speed increase and will decrease as relative humidity increases. In Table 2 we compare the number of points above the linear regression line between maximum temperature and potential ETo. There is a strong seasonal pattern with about 80% of points above the line in December and less than 3% in April. As expected, for the season as a whole about 50% of points are above the line.

Table 2 can be explained by the fact that solar radiation received in any day will vary depending on factors such as cloud cover but also with day length. Day length is longest at the summer solstice (21 or 22 December) and shortest at the winter solstice (21 or 22 June). Therefore during the growing season (1 October to 30 April) day length will be longer during December and January than in March and April. Day length also depends on latitude and for much of the grapegrowing regions of southern Australia will range from about 12 hours on 1 October to 14 hours on 21 December and between 10 and 11 hours on 30 April. This means that for any given temperature, cloud cover, relative humidity and wind speed, a day in December will have higher potential ETo than the same conditions in November or April. The practical implication of this is that mid-summer heatwaves are likely to have the greatest desiccating potential. Not only is the day longer, the night (which is so important for recovery) is shorter.

Managing heatwaves – preparing and predicting

The management of heatwaves has been summarised by the authors in a fact sheet (Hayman et al. 2012). Although there are differences between regions, the essence of managing heatwaves remains the same: minimising incoming radiation and maximising transpirational cooling. A critical decision in the lead up to a heatwave is to apply water. The industry has increasingly relied on warnings from the Bureau of Meteorology for this pre-emptive irrigation.

 $\ensuremath{\text{Table 3}}\xspace.$ Taylor-Russell diagram showing forecast heatwave and outcome for viticulture

	No heatwave forecast	Heatwave forecast		
Heatwave occurred	False negative (Failure to warn) Severe damage from heatwave as action was too late to minimise the damage	True Positive (Ideal warning and action) Some damage from heatwave but loss is reduced by extra water applied prior to the event		
No heatwave occurred	True negative (Ideal 'all clear') No damage and no cost	False positive (False alarm) No damage from heatwave but grower bears cost of extra water applied		

 Table 2. Percentage of points above line (greater ETo for the given maximum temperature than expected by a single linear regression equation between the variables).

 Data from 1957-2011. GS refers to growing season.

Location	MJT (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	All GS
Hamilton	18.8	65.0	75.3	79.4	76.1	51.7	12.6	1.8	52.0
Mt Barker, WA	19.7	64.7	77.0	83.1	75.4	53.7	15.0	1.4	53.2
Mt Barker, SA	19.7	64.0	75.8	78.0	79.0	54.8	16.2	1.6	53.0
Orange	19.9	68.7	72.2	73.0	64.8	43.5	18.5	7.3	50.0
Lenswood	20.0	66.5	77.6	77.2	77.9	55.3	16.7	1.5	53.5
Margaret River	20.4	64.6	75.8	82.7	79.5	57.8	14.3	0.6	53.8
Nuriootpa	21.5	65.0	78.2	77.8	78.5	55.1	16.5	2.5	53.6
Donnybrook	22.7	66.6	80.4	84.8	78.8	51.3	14.4	1.7	54.3
Mudgee	23.2	67.7	74.1	74.0	65.5	43.6	16.7	5.6	49.9
Cowra	23.9	62.6	76.2	78.2	70.7	47.5	16.1	4.8	51.2
Mildura	24.5	66.2	76.1	80.6	77.4	54.4	16.0	1.2	53.4
Griffith	24.9	65.7	75.3	77.8	73.2	47.9	17.6	2.7	51.7
All locations		65.6	76.2	78.9	74.7	51.4	15.9	2.7	52.5

Table 3 shows the four outcomes if a weather forecaster is predicting a heatwave and a wine-grape grower is acting on the warning. The two rows show the predictions and the two columns show a hindsight view of what happened. The most favourable outcome is the bottom left hand corner where there is no forecast of a heatwave and no losses from a heatwave - this ideal 'all clear' is what is hoped for in a comfortable vintage. When heatwaves occur, both forecasters and grapegrowers wish to experience the top right hand corner where warning is given and appropriate action is taken. The worse outcome is the top left hand corner where a heatwave is a surprise to the grapegrower. The bottom left hand corner is often called false alarms and although preferable to a failed warning, this is also non-ideal. An important aspect of forecast and decision theory is that for a given level of accuracy of a forecast, there is a trade-off between false negatives and false positives; in other words a trade-off between not warning of an event and providing false alarms. This trade-off exists in all predictive systems including medical tests and is much discussed in terms of bushfire and cyclone warnings. In statistics the trade-off is often expressed as Type 1 (false positive) and Type 2 (false negative).

If we consider a heatwave as defined by the South Australian Regional Office of the Bureau of Meteorology as 5 days over 35°C or 3 days over 40°C, we would expect that there would be a high proportion of events in the top right hand corner (ideal warning and action). If there was a 'miss' it would tend to be that there were 4 rather than 5 days over 35°C or a day was in the high 30s rather than 40°C. Because the process that ends a heatwave can be relatively difficult to predict, we would expect that there will be many more false alarms than failures to warn.

It is something of a paradox that climate scientists would be much more confident to bet on there being more heatwaves in 2030 than being able to say anything about the next 2 years. As the world warms, the frequency of heatwaves is likely to increase, but there will still be variability on a year by year basis. One of the advantages of the large amount of resources going into understanding climate change is that there will be improved models of local climate. Because of the human cost of heatwaves, efforts to improve forecasting accuracy and communication will be a high priority.

There is no doubt that the wine-grape industry is continuing to learn and improve the management of heatwaves. A key factor in this is the prediction and communication of heatwaves from the Bureau of Meteorology to the industry. Nevertheless, heatwaves remain a significant challenge for the industry. This is especially the case of heatwaves in the lead up to harvest which can cause large losses and logistical challenges even in the best managed vineyards and wineries. Improvements in viticultural techniques and warning systems will continue. However, continued warming of the climate will mean that the frequency of these damaging rare weather events is likely to increase.

Notes on climate data

Climate data (1957–2011) were obtained from the SILO database (http://www.nrw.qld.gov.au/silo/) as patched point data (PPD). The PPD contains 'observed' data of historical weather records from the particular meteorological station and 'patched' data. Observed data

are the actual measured data. Patched data are used where no data exist. In effect, missing data are patched. Missing data may occur for several reasons including intermittent days when weather data were not observed, periods prior to opening a meteorological station or after its closure, or patching data for a climate variable that is not directly measured at the meteorological station. Information on which data are 'observed' and which are 'patched' and have been interpolated at each location is available from the SILO website. Potential ETo data were obtained from SILO where potential ETo was calculated using the FAO Penman-Monteith formula as in Allen et al. (1998).

The stations used in analysis include: Bridgetown Comparison (station number 9510), Bright (83067), Cowra Research Centre (63023), Donnybrook (9534), Edinburgh RAAF (23083), Griffith Airport AWS (75041), Hamilton Airport (90173), Kyneton (88123), Lenswood Research Centre (23801) Loxton Research Centre (24024), Margaret River (9574), Mildura Airport (76031), Mount Barker SA (23733), Mount Barker WA (9581), Mudgee (72021), Nuriootpa Viticultural (23373), Orange Agricultural Institute (63254), Padthaway (26089), Stanthorpe, Leslie Parade (41095) and Stawell (79080).

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Vine performance under modified climate scenarios – practical impacts on grapes and wine composition

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Abstract

The impacts of climate change in the vineyard are likely to be many and varied, but they will be primarily driven by three environmental factors, climate warming, elevated atmospheric carbon dioxide concentration (eCO_2) and more frequent extreme weather events. Climate change research in viticulture has focused on atmospheric warming, with changes in phenology and fruit quality parameters of particular concern. Analysis of vintage records, modelling exercises and manipulation of air temperature in the vineyard have all suggested that grapevine phenology will advance as the climate warms. The implications of this for the winery are generally well understood, but it is less clear what the impacts on fruit and wine quality will be. It is difficult to assess fruit composition data at harvest or wine scores over appropriate timescales and field experiments have found complex effects on berry quality parameters, with cultivar and seasonal interactions. We may not know if climate variability will increase, but today's extreme conditions will certainly become more commonplace and occur earlier in the season. The impact of heatwaves, or other weather extremes, will interact with existing management. For example, a heatwave during deficit irrigation, regulated or otherwise, will result in a much greater stress for the vine than either factor alone. The effects of eCO_2 on plants are well understood, but the same cannot be said for viticulture. For example, carbohydrate reserves almost invariably increase in response to eCO_2 but this could result in high vigour and/or effects on phenology and berry sugar accumulation. Plants growing under eCO_2 may use less water, but have higher leaf temperatures. The lack of data available for grapevines, particularly in Australian conditions, or for the combined effect of eCO_2 and warmer air temperatures, limits our ability to provide innovative management options.

Introduction

While the 15th Australian Wine Industry Technical Conference was taking place the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) was being finalised, with the first working group contribution, Climate Change 2013: The Physical Science Basis, being approved on 27 September 2013. This report confirms the conclusions of the previous IPCC assessment reports, in that it is "unequivocal" that climate warming has been occurring and that this warming is anthropogenic in origin. The driver of the observed warming is radiative forcing, that is, a change in the Earth's energy budget. AR5 estimates that the anthropogenic radiative forcing in 2011, relative to pre-industrial times, was 43% higher than in 2005: 2.29Wm⁻². The largest single cause of this was emission of carbon dioxide (CO₂), which accounted for 1.68Wm⁻² of the total (IPCC 2013).

The phenology of most crops is influenced or driven by temperature and this is also true of wine-grapes (Pearce and Coombe 2004). Consequently, climate warming has the potential to impact the timing of key phenological stages of grape development, including harvest date. Photosynthetic rates of C3 plants, including grapevines, are generally limited by the concentration of CO₂ within their leaves, due to the inefficiency with which the enzyme Rubisco fixes that CO₂ (Hudson et al. 1992). As a result, any increase in atmospheric CO2 concentration over current concentrations is likely to increase the photosynthetic rate of any given C₃ plant. Many other factors can be co-limiting, however, notably nutrient availability (Edwards et al. 2005), so increases in photosynthesis as a result of eCO₂ may not be as large as might otherwise be expected. Any rise in the photosynthetic rate of grapevine canopies is likely to lead to higher carbohydrate availability within the vine for processes such as growth, fruit filling and higher storage reserves over winter, as happens in many other species (Stiling and Cornelisson 2007).

The changes occurring in our climate are not limited to an increase in atmospheric CO_2 and warmer air temperatures. An improved understanding of the Earth's climatic systems is leading to greater understanding of potential impacts of climate change on many aspects of our weather. Two aspects likely to be particularly important for viticulture are changes in climate variability and reduced winter rainfall. Predicting climate variability is notoriously difficult, but, even if there is no change in day-to-day variability, the demonstrated warming that is already occurring will result in events that would currently be considered extreme becoming more frequent in the future. Changes in winter rainfall will affect freshwater availability in Australian river systems, leaching of salt from vineyards and, potentially, grapevine growth in the subsequent season.

Climate warming

AR5 concludes that "it is **very likely** that Australia will continue to warm through the 21st century" and that "the frequency of very warm days is **virtually certain** to increase through this century" (IPCC 2013). The 50% of the predicted range is for 0.7°C warming by 2035, 1.3°C by 2065 and 1.8°C by 2100. Warm or 'hot' climate viticulture is often defined as regions with a mean January temperature (MJT) in excess of 23°C. A rise of 0.7°C would bring the Hunter Valley region into this category, a rise of 1.3°C would bring the Barossa Valley into this category and a rise of 1.8°C would see Margaret River on the verge of a 23°C MJT.

Given that thermal time is often used in crop development models, it is perhaps unsurprising that the impacts of climate warming on crop development are the most studied aspects of climate change in viticulture. Modelling studies have examined the potential for warming to affect grape phenology and production in viticultural areas around the world, including North America (Wolfe et al. 2005), South America (Jorquera-Fontena and Orrego-Verdugo 2010) and several European countries, including Italy, France, Germany and Spain (Tomasi et al. 2011; Pieri et al. 2012; Bock et al. 2011; Garcia-Mozo et al. 2010). In Australia a number of studies have used vintage records to predict the response of grapevine phenology to increasing air temperatures. Petrie and Sadras (2008) examined maturity data from 18 regions of Australia for Cabernet Sauvignon, Shiraz and Chardonnay, concluding that between 1993 and 2006, maturity had advanced in all three varieties and that for two of the three, this advancement in maturity correlated with increasing air temperatures over the same period. The advancement was between 0.5 and 3.1 days per year, equating to 9.3 days per °C on average. Webb et al. (2007) used a grapevine model, VineLOGIC, to estimate the likely effect of three climate scenarios to predict the advancement of harvest in Cabernet Sauvignon and Chardonnay. The results suggested a large regional effect, with harvest in the Coonawarra likely to advance 21–45 days by 2050, compared with only 6–10 days in the Murray Valley for instance, but in general the results were comparable with the observations of Petrie and Sadras (2008).

A second study using vintage records, from 1895 to 2009, in 44 vineyard blocks, was conducted by Webb et al. (2011). This study found an average advance of maturity of 1.7 days per year between 1993 and 2009, but only 0.8 days per year between 1985 and 2009 in the subset of blocks for which longer-term data was available. In all cases advancement of phenology was associated with climatic warming. This study was followed by a more detailed modelling exercise (Webb et al. 2012) that utilised the data to more directly examine the underlying causes of the change in maturity date, employing not only air temperature, but yield (as a surrogate of management practice) and soil wetness indices. The conclusion was that approximately half of the observed change in maturity could be attributed to warming with the rest attributable to other factors.

With the large number of potential variables, including largescale changes in viticultural practice since the onset of detectable anthropogenic climate warming, it is clear that direct experimental evidence is required to support the analysis of vintage and winery records. Two studies in Australia have examined the impact of experimentally manipulated atmospheric warming on mature grapevines managed with current commercial practices, both studies including multiple varieties of grapevine. Sadras and Moran (2013) conducted a series of experiments using a system of under-vine 'tent' open top chambers (OTCs) that used passive warming (Sadras and Soar 2009), or combined passive and active warming, to increase the air temperature of the canopy, directed at the fruiting zone in particular. They modelled an expected shift in maturity based on the vintage record analyses described above, but found that, over two seasons, the actual shift was only a fraction of the modelled shift. This was due to temperature driven shifts in phenology being greatest during the middle of the fruit maturation period, reducing towards harvest. The cause of this appeared to be twofold, being a result of the ripening process being shifted to a cooler part of the season in the warmed vines and impacted by source-sink relations, with carbon assimilation limiting the speed of fruit development.

The second study utilised a number of more traditional OTCs, each enclosing approximately 62 m³ of air, with a fully active warming system (Edwards et al. 2012). This approach was more limited than that of Sadras and Moran (2013) in the number of vines that each OTC enclosed (one panel of 2–3 vines), but allowed the entire vine to be maintained in the same atmospheric conditions. The results from this multi-seasonal work, with the same vines being warmed continually for three years, demonstrated that the entire phenology of the vine could be shifted forward by atmospheric warming, with all stages, from budburst to veraison to harvest, occurring earlier.

Analysis of fruit and wine composition in the first study found small differences in fruit composition, despite the limited effect of warming on maturation at harvest (Sadras et al. 2013), particularly in juice pH. Significant impacts on wine sensory parameters were also observed, with seasonal effects driving which parameter and in which direction these impacts occurred.

The direct evidence suggests that while the changes in phenology and harvest date may not be as large as predictions based on analysis of vintage records have suggested, climate warming will indeed bring grapevine phenology forward and potentially affect wine quality parameters, albeit with a strong effect of seasonal variation.

Heatwaves and climate variability

It is difficult to determine whether extreme events, such as heatwaves, have become more frequent, not least because 'extreme' events are infrequent by definition. However, comparisons of 10th decile extremes of long-term data sets, suggest that in many areas of the world, warmer days and nights have become more common (IPCC 2013). This suggests that what we term a heatwave currently is likely to increase in frequency in the future; however it does not provide any information on whether climate variability itself is likely to change. AR5 examines this with the use of a number of variability indices, but concludes that currently changes in climate variability cannot be determined with any confidence.

Heatwaves can affect grapevines in a number of ways, including: inducing water stress by increasing vine water use via an increase in vapour pressure deficit (VPD), a direct impact on canopy physiological processes such as photosynthesis and by affecting fruit composition. However, where a vine has access to adequate water and has a hydraulic conductance capable of delivering the required volume of water to the canopy during heat stress, stomatal conductance can be maintained at the same (Edwards et al. 2011) or even higher levels (Sommer et al. 2012) as vines at much lower temperatures. The result is that, although transpiration rates of vines at air temperatures of 45°C require as much as four times the water of vines at 28°C, well-watered vines are able to maintain cooler leaves, which minimises impacts of heat on photosynthesis and respiration. However, when heatwaves occur during periods of water stress, such as during periods of deficit irrigation or when adequate irrigation is simply not available, much more severe impacts can be seen, such as those reported as a result of the 2009 heatwave (Webb et al. 2009). Direct effects on the leaf are compounded when leaf turgor cannot be maintained and wilting occurs, resulting in direct exposure of the fruit to the sun, potentially resulting in berry death (Figure 1). Whilst anecdotal reports (Webb et al. 2009) and pot experiments on young vines (Edwards et al. 2011) have demonstrated the greatly increased impact of combined heat and water stress over either stress individually, studying these effects in the field is difficult due to the necessity to artificially generate a heat event or reduce the air temperature during a natural heat event in the vineyard. Furthermore, assessment of naturally occurring heat stress in the field or management techniques to mitigate it is difficult due to the limited warning that meteorology can provide of such conditions and the requirement of significant amounts of work under adverse conditions.

Understanding the mechanisms whereby heat stress may have different effects depending on phenology and prior exposure of the vine to heat therefore requires assessment techniques that do not rely on field-based physiology measurements. It is hoped that molecular biology tools such as analysis of gene expression and transcriptomics (Liu et al. 2012) may offer the required methodologies.



Figure 1. Cabernet Sauvignon vines and bunches following the January 2009 heatwave where they were exposed to temperatures in excess of 40°C for 13 consecutive days. The images on the left are from vines irrigated for at least four hours daily and the vines on the right received no irrigation during this period.

Whilst it is clear that simply providing **enough** water to a vine during a heatwave will likely prevent a major impact of that event, in many situations it may not be possible to provide enough water or the vine may not be able to take enough water up. Consequently, other management techniques still need to be developed. In addition, heat per se may have impacts on fruit composition, even when no water or radiative stress occurs, due to temperature effects on desirable secondary metabolites, such as anthocyanins (Mori et al. 2007).

Elevated carbon dioxide

Although changing atmospheric CO_2 concentration is the largest driver of climate change and it has long been known to have a direct effect on photosynthesis and plant growth, it has received relatively little attention within viticultural research. Predicting future CO_2 concentrations is difficult, not so much due to unknown interactions within the biogeography of the planet, but because it depends on many socioeconomic factors and how they will change in the coming decades. The IPCC fourth assessment report (AR4), included a number of model socioeconomic scenarios with predictions of atmospheric CO_2 that would result from those (IPCC 2007). To date, emissions have tracked the scenarios with the highest emissions, which would result in atmospheric CO_2 concentrations of between 501 ppm (A1T scenario) and 567 ppm (A1F1 scenario) by 2050 and between 582 ppm (A1T) and 970 ppm (A1F1) by 2100.

The response of grapevine photosynthesis to the CO₂ concentration within the leaf (C_i) is shown in Figure 2, with actual data from a typical Cabernet Sauvignon leaf together with the fitted response from the C3 photosynthesis model of Farquhar et al. (1980). There is a direct, positive, relationship between C_i and atmospheric CO₂ concentration, albeit dependent on the conductance of the leaf surface to CO₂, which is primarily governed by the opening of stomatal pores. Photosynthetic rates at current atmospheric CO₂ concentration (389 ppm) and a predicted future concentration (550 ppm) are marked on Figure 2. The difference in photosynthetic rate was equivalent to a 29% increase in carbon assimilation by the leaf and is typical of the response seen in many other plant species (Ainsworth and Rogers 2007). Although a number of processes can occur in the longer term to reduce photosynthesis under eCO₂, such as down-regulation of Rubisco (Cheng et al. 1998), changes in stomatal density (Rogiers et al. 2011) or severe nutrient limitations (Edwards et al. 2005) which can also negate any positive biomass response to eCO₂, higher carbon assimilation than under current atmospheric CO₂ is generally maintained. Greater rates of carbon assimilation in a grapevine, or any other plant, provide more carbon for sink processes such as growth, reproductive development and building storage reserves. In viticulture this would be likely to result in higher yields and higher



Figure 2. The response of photosynthetic rate in a grapevine leaf to changing \mbox{CO}_2 concentration

vigour, perhaps particularly in the early part of the season where growth is primarily utilising stored carbohydrates (Holzapfel et al. 2010), so effects of increased photosynthesis and increased storage reserves may be combined.

Although there are thousands of published studies examining aspects of plant response to eCO₂ and their interaction with other environmental factors, very few have utilised grapevines. Further, whilst grapevines may be expected to respond to eCO₂ similarly to other C₃ plants, the specific impacts of eCO₂ on viticulture, and how to adjust management techniques to ameliorate those impacts, are virtually unexplored. The only major study to date was undertaken by Bindi et al. (2001a), who established a Free Air CO₂ Enrichment (FACE) facility in an Italian vineyard, which operated for two seasons. A FACE system increases atmospheric CO₂ concentration by injecting CO₂ into the air in a field environment without any sort of enclosure, relying on natural air movement to mix and distribute the high CO₂ air. This FACE system generated two different eCO₂ levels, 550 and 700 ppm with two replicates containing seven vines each. Although no difference between the two levels of eCO₂ was observed, growth was increased by 45-50% and yield by 40-45% under eCO₂ (Bindi et al. 2001b). Fruit composition was altered by eCO₂ during development, but there were no significant effects on measured parameters at harvest. Of particular interest was a significant increase in anthocyanins and other flavonoids in the wines made from fruit produced under eCO₂, but this only occurred in one of the two seasons of the study.

A second study, in Portugal, utilised an OTC approach to examining the response of field grown grapevines to eCO_2 and ran for three seasons (Gonçalves et al. 2009). For work with eCO_2 an OTC requires less CO_2 than FACE and is, therefore, significantly less costly to run. However, an OTC approach is likely to result in more 'edge effects' than FACE, due to the presence of the chamber walls. The Portuguese study used two OTCs, one for ambient CO_2 and one for eCO_2 , at 500 ppm, each encompassing ten vines. Yield was again increased under eCO_2 , by up to 50%, with the largest increase occurring in the season with the lowest yields, and pruning weights were also higher under eCO_2 (Moutinho-Pereira et al. 2009). However, this study found the opposite of the Italian study in wine composition, with wine anthocyanins being reduced under eCO_2 (Gonçalves et al. 2009).

These studies observed other trends indicating differences in the vines under ambient or elevated CO_2 which were not statistically significant. As replication in both cases was limited, presumably due to the cost of running such experiments, it is not possible at this stage to know whether further impacts of eCO_2 in the vineyard will occur, nor to clarify the potential impacts on wine composition. Clearly further studies are required, particularly under vine management more typical of the Australian industry. Furthermore, given the biennial nature of inflorescence/fruit development, where the primordia for the following season are laid down early in the current season, these studies must be run over more than two to three seasons.

Interactions: elevated CO₂, climate warming and other climatic changes

Whilst the interest of the Australian wine industry has been much more strongly on the impacts of climate warming than on other aspects of climate change, particularly compared with eCO_2 , none of these aspects will occur, or are occurring, alone. The most obvious interaction to study is that of warming and eCO_2 , as we know that both are occurring simultaneously and both can have significant effects on the plant. What is not obvious is just how these two factors will interact. A glasshouse-based study of combined eCO_2 and warming using fruiting canes found that maturation time was reduced (Salazar-Parra et al. 2010), however, the study did not include either factor individually and was far from field conditions, so extrapolating to commercial viticulture in Australia is difficult. Other studies combining eCO₂ and warming on grapevines are yet to be completed or published. In other species the interaction can vary. Volder et al. (2004) found no cumulative effect of warming, but a positive effect of eCO₂ in a model *Phalaris* pasture, Albert et al. (2011) found interactions between temperature and eCO₂ in a heathland system, with eCO₂ and warming additively stimulating growth but only during spring and Hovenden et al. (2008) found that flowering phenology in grasslands was affected by a combination of eCO₂ and warming irrespective of plant type. Whilst these studies hint at potential impacts on viticulture they do not provide clear answers.

There are a number of other potential impacts of climate change that may have an effect on viticulture and these may also interact with effects of warming and/or eCO₂. One example is the predicted decrease in winter rainfall over much of the viticultural area of Australia (IPCC 2013). Reduced winter rain is likely to affect leaching of salt from the soil in saline prone areas which may be exacerbated by changes in water use under eCO₂. Less apparent is the potential for the lack of winter rain over the entire vineyard floor to affect the vine during the subsequent season, with reduced growth and impacts on grape and wine composition reported even where full irrigation is provided during the growing season (Mendez-Costabel pers comm. 2012). Other interactions may be more counter-intuitive, for example, in some species at least, eCO₂ can reduce frost tolerance early in spring (Loveys et al. 2006) and as, despite climate warming, frost incidence may not reduce in many areas (Crimp et al. 2013), the incidence of frost could increase.

Conclusions and future R&D

A number of unanswered questions have been highlighted in this article, along with others that need more study before the Australian wine industry can be confident of applying the answers in their vineyards. However, some of the work required is already underway, in particular a number of projects recently funded by the Grape and Wine Research and Development Corporation. A project led by the Department of Environment and Primary Industries (DEPI) in collaboration with CSIRO Plant Industry will use OTCs at the DEPI field station in Mildura to simulate a future climate by combining an active heating system with a system to elevate CO_2 concentrations in the chambers (Figure 3). The project will examine not only the combined effect of warming and eCO_2 , but will also include the two factors individually so that any interaction between the two can be fully elucidated. This will be the first time that a facility to combine



Figure 3. Open top chamber with heating and CO_2 injection system at DEPI Mildura

those two factors in a study of mature grapevines in a field environment has been established anywhere in the world. In Germany, the Hochschule Geisenheim University has built a FACE system more sophisticated than any previously used with grapevine and established new vines within it (Figure 4). The system has yet to be operated, but when switched on it should provide a valuable insight into grapevine CO₂ responses in cool climates.

Methods for industry adaptation to a warming climate and compressed harvests are being examined in a project led by the South Australian Research and Development Institute (SARDI) with the collaboration of Treasury Wine Estates, which will use the under-vine 'tent' OTCs to examine whether implementing late pruning can be used to delay grapevine phenology in the future.

The potential for reduced winter rainfall in a future climate to affect Australian viticulture and wine composition is being studied in a project led by SARDI in collaboration with CSIRO Plant Industry. This work is using rain-out shelters to eliminate winter rainfall (Figure 5) and will then use micro-sprinklers to simulate different levels of rainfall over the winter, together with mitigation strategies using traditional irrigation infrastructure. A further SARDI-led project will assess the viability of innovative irrigation techniques to physically cool vineyards during heatwaves.

The probable major impacts of climate change on viticulture in Australia are known: warmer temperatures, increased frequency of heatwaves and elevated atmospheric CO_2 ; experimental work is underway, or has been completed, to establish the impacts and potential mitigation strategies for these. More difficult to predict are the interactions that may occur between these factors, edaphic factors, such as the soil environment, and biotic factors, such as pests and diseases. This research is often technically difficult and the results may be unpredictable. Some of these interactions at least are now being studied, but no doubt as our climate changes, other interactions and effects not yet predicted will occur and continue to require an agile research capability together with an agile industry to overcome them.



Figure 4. Grapevine FACE system at Geisenheim, Germany



Figure 5. Rain-out shelters for studying the effects of reduced winter rainfall

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The business of benchmarking – a market perspective on innovation, branding and sustainability

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Abstract

Consumers are increasingly aware of material issues surrounding brands; horse meat, ethics in banking and poor labour conditions in the fashion industry are just a few burning examples that have recently appeared in the headlines. Combined with sustainability being placed higher on retailers' agendas, there is an evident need for a more strategic approach to sustainability. Between-us developed GLOBE-US, a process tool that describes the alignment of sustainability with business strategy in seven steps. Starting with the current business model according to the 'Business Model Canvas', it proceeds with the definition of sustainability issues in the sector, and selecting and ranking of material issues according to both the company and its stakeholders. Sector research results in mapping the competitive environment in a value curve, which enables the setting of ambitions and targets for future progress. Opportunities in strategic areas are identified, and, finally, feedback is delivered for a potential business model re-design. An example of a winery that has incorporated sustainable innovation into its traditional family business is Torres. Based upon its family values dating back to the 17^{th} century, the Catalonian winemaker has taken numerous actions in response to changing climate and market conditions. For example, environmentally responsible vineyard practices have been implemented for over thirty years. The 2020 objective is to decrease CO_2 by 20% and to increase wastewater re-usage to over 40%. Torres' dedication to preserving the environment and protecting its value for future generations shows an integrated and strategic approach to sustainability.

Introduction

There are four key points I would like to cover this afternoon:

- The (perceived) sustainability of a brand is largely determined by the quality of stakeholder interaction.
- To drive innovation from sustainability, it makes sense to focus on key facts and measure progress.
- External benchmarks such as the Dow Jones Sustainability Index (DJSI) are powerful allies in the required change coalition.
- A structured, recognisable process (such as GLOBE-US) is an important catalyst for creating business impact from sustainability.

I will talk about benchmarking, present a case study about Torres Wines, using the GLOBE-US process tool and last but not least I'll come back to the conclusions.

To begin, I'd like to tell you a little bit about Between-us. We started 16 years ago, working on sustainability and deriving value from sustainability. We are not wine industry experts but we do a lot of work with stock-listed and family companies throughout Europe with a small team based in the Netherlands.

Why is benchmarking relevant for sustainability?

One of the most well-known and credible tools for benchmarking sustainability is the Dow Jones Sustainability Index (DJSI). Why is this important? Last year, Harvard Business School conducted a longitudinal study examining the effect of a culture of sustainability. The study compared 100 companies with a culture of sustainability with 100 peer companies without such a culture. The outcome was that return on equity was 4.8% higher for those companies with a culture of sustainability. And while correlation is easier to prove than causality, there are a lot of indices of sustainability and it seems that people who are choosing stocks and managing share portfolios are interested in sustainability performance. For example, if we look at food markets, a total of 3,300 companies worldwide are invited to participate in the DJSI. In Australia alone, 193 companies are invited to participate based on their free cap flotation and company size. Large companies like Unilever, Nestlé, and Danone are all involved.

Benchmarking against other industry sectors provides insights for companies and the future. Data looking at the EBITDA (earnings before interest, taxes, depreciation, and amortisation) versus the potential external costs of sustainability of the sector are shown in Figure 1. The graph explains why companies in the food industry are concerned with their sustainability profile. The total external environmental costs as a percentage of EBITDA for food producers in 2010, account for a considerable proportion of their earnings. The total EBITDA of the food industry would be wiped out if the potential external environment costs were applied.

So what can you do if you are not stock market listed? Well, there is a way of looking at it if you move from Wall Street to Main Street. Figure 2 shows an example of a Belgian telecommunication company. The figure shows that when the company saw a 58% increase in its sustainability performance in the DJSI it also saw a 14% increase in the sustainability drivers of its reputation.







Figure 2. Perceived and actual sustainability over three years

Sustainability and the consumer

Consumers are starting to get more interested in sustainability. Between-us did research in the Netherlands with two banking businesses – Rabobank and ING – and saw that both banks have a very solid customer base in the Netherlands. However Rabobank's customers had a completely different preference on social and environmental issues than ING customers (Table 1). The marketing department for ING might create more value in finding renewable energy products, whereas Rabobank might want to do something in the area of personal health.

It is also interesting to see that in general benchmarking is becoming more popular. For example, on the internet there are several travel websites and restaurant sites with consumer ratings. We have noticed that sustainability ratings are coming up as well. Between-us conducted some research in the area of tourism and started a project called the 'Sustainable Golf Project' which benchmarks European PGA tour golf events and golf courses across Europe. Results show that for golf travellers, especially some segments of the golf traveller market, sustainability forms an important part of their decision-making.

Between-us conducted a very detailed analysis of data from five golf

courses in Catalonia, Spain. Figure 3 shows that for the biggest cost drivers (energy and water) the best in class outperforms the worst in class by 50%. This is a perfect example of a case where benchmarking provides precise insights into potential areas for improvement.

Tradition and innovation at Torres Wines

A good example comes from the wine industry. I have worked closely with Torres Wines from Catalonia, Spain and applied the GLOBE-US model using Torres as a case study. Torres is a family wine company, with three international sites in Chile, California and Spain. Torres is a frontrunner on sustainability; its CEO Miguel Torres is a big campaigner for industry action on climate change. If you ask Miguel for his company's value proposition he says "It's a wine you can trust". The values behind the brand experience are: it is Spanish, it is about quality and it is about value for money. Like other wine companies around the world, Torres is facing the obvious problems related to climate change. Their Pinot Noir grapes are getting too hot so they have to move to higher altitudes if possible, and the harvest is ten days earlier than it used to be. One of Torres' challenges is that many growers are not really convinced about climate change and the climate change adaptations that Torres wants them to make.

What can be done to make stakeholders more aware of what we're doing about sustainability and to bring our activities on sustainability more into our brands and decision processes? There is a book on business modelling and strategy called *Business Model Generation* (http://www.businessmodelgeneration.com/book) and Between-us constructed a model based on this book. Before explaining the model step by step for the Torres case, let's first look at a familiar example from a different industry – hamburgers (Figure 4).

Table 1. Differing priorities amongst the customers of ING and Rabobank

SOCIAL ISSUE					
Starvation and Poverty	8.6%	14.9%	14.7%		
Stewardship	14.8%	14.2%	15.2%		
Health Promotion	9.9%	12.6%	10.2%		
Infant Mortality	2.5%	8.5%	5.9%		
National Energy Sources	13.6%	7.8%	8.4%		



Figure 3. Comparison of five golf courses in Spain, the gaps illustrate room for improvement



Figure 4. Business model canvas for McDonald's



Figure 5. Business model canvas for Torres Wines

The model is quite simple. If you start with the value proposition for a hamburger chain: it is all about predictability, speed and knowing what you get fast. The customer segments for McDonald's are families with kids, youngsters and single adults. Their strategic partners are mainly the franchisees, and if you look at the sources of revenue, the majority are the franchisees again plus about 10% company-owned stores. This gives a sketch of how the business model canvas works and how companies try to design new businesses and more sustainable business models. It is also the first step of the GLOBE-US model: 'How are we making money in general?' The same process for Torres (Figure 5) shows there is nothing really surprising there, it might be that they have a pretty good wine tourism business and a lot of merchandising products, but in general it is pretty standard for a bigger winery.

The next step after determining how money is earned is to look at 'Who are our stakeholders? Who are the people around us that we think are important and whose opinions we value? Figure 6 shows the map of stakeholders for Torres. Between-us analysed the map and answered the questions 'How far are these stakeholders away? Which connections is Torres good at, which connections need improvement and where are the critical connections?'

Continuing the process it is important to research with these stakeholders what issues they think are important and how strongly they feel about them. It is also important to see what the impact of those issues is on the business concerned. Combine these factors and together they form a materiality matrix.

Materiality matrix

The materiality matrix depicts the importance of the stakeholders' specific issues and then looks at the impact on the business. In the example of Torres there is a small group of five issues selected (Figure 7).



Figure 6. Map of stakeholders for Torres Wine



Figure 7. Materiality matrix for Torres' stakeholders, depicting their top five issues

In general if we make a materiality matrix for a specific company we would start out with about 50 possible issues and then bring it back to 15, which you research with your stakeholders. For instance, in the case of McDonald's, Between-us conducted research with franchise holders, end consumers, employees and suppliers. The next thing is to map the issues in a structured way as shown. In the case of Torres there are five issues selected and for these five you can say 'Ok, what is Torres doing about it?' For example, Torres has a global foundation which is used to address social issues but Torres has also invested a significant amount of money into renewable energy.

The next step is to take this materiality matrix which identifies the most important issues and then find out 'How are we doing competitively?' For example, it does not make any sense if you have a big customer and you are addressing CO_2 quite severely but for the customer, the purchasing manager is being incentivised on reducing the amount of packaging. Those two interests need to be aligned. We can look at specific customers and say 'How are they doing on their sustainability program? What is important to them? What is important to us? How good are we? And how good is our competition?' The results will be something like Figure 8.

With this concept the material issues are compared with competitors. You can determine where your company wants to excel. If we know where we want to excel, we know where to put our money and effort and we know where we can have the biggest bang for our buck. So this is typically how we work with Torres. Next you have to look at your targets – you could look at the DJSI or reputational measurement and also specific benchmarks for specific industries (e.g. the building sector has its own greenhouse benchmark).

Targets and objectives

It's important to set targets. If we look at Torres, they have a clear set of targets and objectives that they measure and communicate externally. These targets include specific reductions in CO_2 emissions, increased use of wastewater, packaging changes and rainwater harvesting. Why is external communication of targets important? The Harvard research mentioned earlier found that a culture of sustainability is much more effective if there is external engagement because peer pressure helps to drive the company forward in its sustainability efforts. If it is clear what we want to do, we know what is material to our business and our stakeholders and we also know where we want to focus. From there we can look at value creation.

Value creation

There are four ways of generating value out of sustainability. The first is risk management: how compliant is your company? The second is operational efficiency or eco-efficiency. The third is engaging or being more intimate with your stakeholders; and the last is driving product innovation based on sustainability. Between-us tries to cover



Figure 8. Relative sustainability reporting performance of competitors against researched topics

all four bases. In the example of Torres, they look at CO_2 research and they've done a lot of work on indigenous grapes and canopy management. They have also reduced their water and energy usage, and they've changed their storage facilities making them much more fuel efficient. On stakeholder engagement, they've introduced a small green label and they've won an award from the United Nations as the most sustainable winery. They are also quite active in mobilising their employees and their contract growers. Finally, on the innovation side, Torres has launched a very low alcohol product called Natureo; they are trying to recapture CO_2 from the fermentation of algae; and they have introduced lightweight Bordeaux-type bottles. Figure 9 summarises Torres' efforts in value creation.

Start from scratch: virtual business re-design

The last step in the model is to check your business model by virtually redesigning it 'from scratch'. Doing this may bring 'out-of-the-box' solutions that the iterative approach of the previous six steps might have overlooked.

Conclusions

1. The (perceived) sustainability of a brand is largely determined by the quality of stakeholder interaction.

This means that while it is important to work hard on your sustainability it is also very important to take into account how you are going to convey that message to your stakeholders. It is perceived sustainability in the end that might influence the consumer's or the retailer's choice.

2. To drive innovation from sustainability, it makes sense to focus on key facts and measure progress.

Typically this means that companies need to stop measuring sustainability topics that might be trendy but are not really relevant to their business.



Figure 9. Development of opportunities at Torres that create value and contribute to sustainability

3. External benchmarks such as DJSI are powerful allies in the required change coalition.

External benchmarks can be very helpful to generate information about where you are, how you are doing relative to others, and might in the future also be useful for consumers to choose products. That scenario is not that far away because consumers in certain industries are already choosing products based on a fully transparent sustainability profile of the products in that industry.

4. A structured, recognisable process (such as GLOBE-US) is an important catalyst for creating business impact from sustainability. Last but not least I think that if you want to take an approach to a sustainability program that's not only covering risks but also trying to capture the opportunity on the business side, a structured step by step approach is helpful in creating a common language.

SESSION 8: Cool things coming over the horizon



Next-generation DNA sequencing and its application by the wine industry A.R. Borneman

New vines for new times I.B. Dry, A. Feechan, M.R. Thomas

The US approach to accelerated grape cultivar development E. Takacs, H. Walter-Peterson, L. Cadle-Davidson, B. Reisch

Harnessing genomics to ensure a 'Brett'-free future for Australian wine C.D. Curtin, A.R. Borneman, R. Zeppel, A.G. Cordente, R. Kievit, P.J. Chambers



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Next-generation DNA sequencing and its application by the wine industry

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Abstract

DNA is the blueprint of life. It resides within every living organism, from bacteria to complex plants and animals, where it represents an encrypted repository of the thousands of individual instructions that are required for cells to grow and respond to their environment. Genomics is the science behind decoding and understanding these instructions. However, until very recently, the broad application of genomics was limited by the enormous time and cost requirements for obtaining and translating the genomic information of even the simplest life forms, such as bacteria or yeast, into a usable form. Next-generation DNA sequencing is now revolutionising biological science by eliminating these historical barriers of cost and time. This growing flood of genomic data is allowing for the links between the DNA of an organism and any relevant traits to be explored, even in complex plants and animals. This information can then be harnessed for practical application through cutting-edge technologies such as personalised medicine or genome-assisted breeding of crops or animals. Applying these technologies in the wine industry promises to provide an unprecedented ability to accurately understand, select and track the living organisms involved in the grapegrowing and winemaking process, encompassing soil microbiota, grapevines, vineyard pests and diseases, desirable and undesirable yeast and bacteria – and even consumers. This will manifest in many applications, from allowing precision breeding of new grape cultivars or strains of yeast and bacteria that can tailor wine flavours, to providing grapegrowers and winemakers with the ability to monitor microbial populations in vineyard soils, wineries or wild fermentations and to correlate these with viticultural practice, soil health or wine quality.

Introduction

The biology of all living organisms is determined by the biochemical compound deoxyribonucleic acid, commonly referred to as DNA. However, rather than being a single, homogenous chemical, DNA is comprised of chains of four slightly different types of individual subunits (commonly referred to as DNA bases and represented by the letters A, C, G and T), that are joined together to form very long polymers (Figure 1).

All of the instructions for the growth and development of an organism are encoded by the precise order of the DNA bases along the DNA strand. For a typical human genome, this comprises at least 20,000 individual instructions (genes) spread across a genome of 3 billion DNA letters (equating to roughly 100,000 A4 pages of 12 pt text). The science of genomics seeks to determine the precise order of DNA bases that make up the genome of an organism and then to decode these instructions into a human-readable, and therefore useful, form.

The next-generation sequencing revolution (genomes for the masses)

The field of biological research was revolutionised in 1977 by the pioneering work of Sanger et al. (1977) in providing an 'efficient'



Figure 1. The structure of DNA. DNA is comprised of two long chains of chemical building blocks called DNA bases (A, C, G and T) that associate via hydrogen bonds (dotted lines) to form a double helix.

means of sequencing DNA. However, despite nearly 30 years of significant improvements, the low output combined with high labour and instrument costs that were associated with even the improved methods for Sanger sequencing limited the study of entire genomes to large, multinational collaborations and specialised sequencing centres.

This exclusivity was changed forever in 2005 with the introduction of massively-parallel pyrosequencing (Margulies et al. 2005), heralding the next-generation in DNA sequencing. Since that time, there has been incredible progress in the development of DNA sequencing technologies, with the introduction and rapid improvement of several competing DNA sequencing instruments that have been collectively referred to as next-generation sequencers (Table 1) (Mardis 2013). This competition has driven down the expense of DNA sequencing at a tremendous rate, with the raw, per-base sequencing cost dropping by a factor of 10 every 18 months, while simultaneously increasing the output by orders of magnitude (Figure 2) (Wetterstrand 2013).



Figure 2. Dramatic drop in the cost of DNA sequencing. Prior to the introduction of next-generation sequencing, the cost of DNA sequencing was reducing at a rate approximating 'Moore's law' (halving in cost every two years; red line). Since its introduction, next-generation sequencing has driven the per-base cost of DNA sequencing down by a factor of 10 every 18 months (Wetterstrand 2013).

Collectively, these advancements have 'democratised' genome sequencing, allowing for genomics to be applied by individual laboratories for little cost. This has enabled the application of genome sequencing in clinical diagnostics and agricultural research, on a scale that was simply not economically viable as little as 12 months ago.

Genomics and the wine industry

Winemaking is arguably the oldest biotechnology, dating back over 7,000 years, and in the past century has actively applied cutting edge scientific research to improve wine production (Borneman et al. 2013). Given that soil microbiota, pests, diseases, grapevines, yeast and bacteria all shape the composition of finished wines, it is not surprising that genomics is poised to play an ever-growing role in unlocking the potential of these organisms (summarised in Figure 3) – it will also ultimately inform wine consumers.

Table 1. Current sequencing technologies

The area of largest impact on the wine industry will be in connecting phenotypic characteristics (i.e. observable traits) with specific genomic features for organisms that influence wine style. A direct application will be in identifying and linking genetic variation in the specific soil microorganism, pest, disease, grapevine, yeast and/ or bacteria with the production of desirable (or the abatement of undesirable) winemaking characteristics.

Microbial strain development

Due to their relatively small genome sizes and importance in winemaking, both the wine yeast *Saccharomyces cerevisiae* and the malolactic bacterium *Oenococcus oeni* have already been the subject of significant genomic research. Genome sequences are available for over 80 strains of *S. cerevisiae* (although the vast majority of these strains are not found or used in winemaking) and over a dozen strains

Company	Machine	Relative machine cost	Output per day (number runs)	Effective yeast genomes per day ^b	Reads/run
ABI	AB3730xl	\$	0.0016 Gbª (24)	0.013	96
Roche-454	GS XLR70	\$\$	1.08 Gb (2.4)	10	1 million
	GS Junior	\$	0.084 Gb (2.4)	0.46	100,000
Illumina	Hiseq 2000	\$\$\$	55 Gb (0.09)	90	6 billion
	Miseq	\$	4.5-5.1 Gb (0.6)	25-30	24-30 million
Life Technologies	Proton	\$\$	60-120 Gb (6-12)	100-200	60-80 million
Pacific Bioscience	PacBio RS II	\$\$\$	2.64 Gb (12)	22	42,000

^aGb refers to Gigabase (one billion bases)

^bEffective number of genomes takes into account read length as shorter sequencing reads require higher coverage for assembly. AB3730xl and PacBioRS II output is based on 10x coverage; Miseq and Roche-454 sequencers are based on 15x coverage; and Hiseq and Proton sequencing on 50x coverage.



Figure 3. Summary of the impact of next-generation sequencing on the wine industry. Next-generation sequencing will impact most areas of winemaking – now, soon, or in the extended future. One of the most powerful forms of data will result from genome-wide association studies (GWAS), which will connect phenotypic outcomes, such as flavour production by yeast or aroma anosmia in winemakers with their genetic causes and provide the means for genetic testing and phenotypic prediction.

of *O. oeni* (Borneman et al. 2013). Comparison of these small number of genome sequences has already identified genomic differences within each species that may be linked to wine-relevant traits such as fermentation robustness or flavour production (Bartowsky and Borneman 2011; Borneman et al. 2011).

However, it is now possible to sequence large numbers of yeast and bacteria, even with single sequencing runs on low cost benchtop sequencing machines such as the Miseq from Illumina (Table 1). As genome sequences for more strains within a species become available, there is an increased ability to associate common phenotypic characteristics with specific genomic differences (commonly referred to as genome-wide associations). Once identified, these genomic differences can be used as molecular markers to accurately predict the expected phenotype of strains without costly and laborious manual phenotyping. This dramatically increases the speed at which strains can be selected for commercial application.

Genomics in the study of pests, diseases and contaminants

"Know thy enemy" is commonly paraphrased from *The Art of War* by Sun Tzu. The genomic analysis of pests, diseases and contaminants that commonly afflict the wine industry will provide the means to truly understand these enemies. Genome sequences are currently available for a small number of vineyard pests and diseases including the causative agents of *Botrytis* rot (Amselem et al. 2011) and Pierce's disease (Simpson et al. 2000) and of winery contaminants such as *Brettanomyces* (Curtin et al. 2012). However, genome information for important pathogens such as the grapevine powdery and downy mildews, and phylloxera, or multiple strains of already sequenced pathogens and contaminants are still lacking. Fortunately, the advances provided by next-generation sequencing should see these knowledge gaps filled in the near future.

Agrochemical resistance is an ever-present problem in agriculture, and viticulture is no exception. In regions with wet summers, constant pressure from pathogens such as powdery and downy mildews, and Botrytis rot, can be exacerbated by the development of resistance to many fungicides that are commonly used to control these vineyard diseases. Next-generation sequencing offers the ability to identify and then accurately track the prevalence of known markers for agrochemical resistance (e.g. the G143A mutation in cytochrome b and strobilurin resistance in powdery mildew) in a vineyard population (Wicks and Wilson 2012). Development and deployment of this information will provide viticulturists with accurate data regarding the likely levels of agrochemical resistance within the endemic disease population and the means to track the emergence of resistance over time. Data of this type will be invaluable for strategically planning the combinations of agrochemicals to provide the best control efficacy within a single season, in addition to managing the emergence of resistance to specific classes of agrochemicals in the long-term.

Genomics in the study of diversity, regionality and terroir

Metagenomics describes the sequencing of DNA isolated from environmental samples (e.g. water, soil, air, faeces) composed of complex mixtures of microorganisms. The use of metagenomics has been highlighted by two large consortia, 'The human microbiome project' and 'The earth microbiome project' that have sought to determine the microbial composition of thousands of samples from various sites in and on the human body and from natural environments, respectively (Jansson and Prosser 2013; Proctor 2011). As for single species studies, the ultimate aim of metagenomics is to enable the correlation of the presence of specific microbial genomes (or metabolic pathways) with specific traits.

However, due to the complexity of many microbial communities, true metagenomic sequencing cannot currently be achieved, even

when using the most cutting-edge of current next-generation technologies. In many of these situations, a scaled-back form of metagenomics, often termed phylotyping, can be employed to efficiently measure the proportions of microbial species present by using a small portion of the genome as a 'genomic barcode' (often portions of the ribosomal DNA).

For the wine industry, metagenomics will be of significant benefit to the study of vineyard microbiota and the microbial composition and variation in wild fermentations. Regarding vineyard microbiota, obvious targets will be in comparing the microbial population from conventionally farmed, organic and biodynamic vineyards or by comparing similarly managed vineyards in different geographical locations. This will provide firm scientific data regarding the effects of geography combined with different vineyard practices on the soil microbiota while also providing a means to assess the effects of viticultural interventions following baseline measurements. Insights may also be gained regarding possible relationships between soil microbiota and regional terroir.

Monitoring the composition of wild ferments may be one of the most useful applications of metagenomics. Wild ferments are typically characterised by a progression of diverse microbial species that, due to a combination of selective forces, including lack of oxygen and increasing levels of ethanol, generally converge on *S. cerevisiae* as the dominant species at the end of fermentation (Fleet 2008). However, it is the varied metabolic contributions of the non-*Saccharomyces* yeasts at the beginning of wild fermentations that are thought to provide the complex characteristics that, for some producers and consumers, make wild ferment wines desired over many inoculated counterparts.

The labour-intensive methods previously available for analysing microbial communities could not efficiently identify the presence of low proportion but high impact species in complex microbial mixtures. This has resulted in limited data being available concerning the precise species makeup of diverse wild ferments. Applying metagenomic tools such as phylotyping to the study of wild fermentation will provide data on the composition of wild ferments that can subsequently be used to correlate species composition of individual fermentations with final wine composition, or to judge the effect of geography or viticultural/winemaking intervention (harvest method, temperature, SO_2) on wine microbiota. Initial application of this technology has proven useful for tracking both the bacterial and fungal composition during wine production (Bokulich and Mills 2013; Bokulich et al. 2012).

While the extension of phylotyping analysis of wild fermentations into true metagenomic sequencing will require increased outlay in both sequencing and analysis costs, this approach will provide not only estimates of species contribution but also allow for tracking the contribution of species at the level of individual strains. This extra level of data will be invaluable in situations where the presence of specific strains of yeast or bacteria results in unexpected (either desirable or undesirable) oenological outcomes or if winemakers wish to know if commercial microbial strains are dominating their 'wild' fermentations. Alternatively, it may become apparent that specific wineries or geographical locations harbour unique strains of wine yeast and bacteria that contribute to any distinctive terroir.

The future

Genomic sequencing technology continues to progress at an astonishing rate. New sequencing technologies, such as nanopore-based techniques (e.g. www.oxfordnanopore.com) promise to continue to make sequencing cheaper, faster and, perhaps, even able to be transported into the field as a simple USB stick attached to a laptop computer. The application of such technologies will enable close-toreal-time data to be gathered on pathogen loads and likely levels of agrochemical resistance in the vineyard, providing the means for tailored viticultural intervention. Likewise, the ability to analyse the composition of wild ferments in real-time will enable winemakers to intervene in individual fermentations that are displaying sub-optimal mixtures of microflora or that contain unwanted microbial contamination, thereby saving potential write-offs from 'failed' wild ferments.

As the number of large genome wide association studies (known by the acronym GWAS) in humans increases and the field of personalised genomics (predicting an individual's likely disease spectrum from their genome sequence) becomes more accessible, there will be many genetic differences identified that impact human phenotypes that are not associated with medical outcomes. Some of these phenotypes will include differences in potential for the perception of flavour and aroma compounds, of which there are already recognised genetic variants associated with the perception of bitterness (Kim et al. 2003) or in perceiving a 'soapy' taste in coriander (Eriksson et al. 2012). As more of these genetic associations are made, it may be the case that an individual's taste preferences could be predicted at birth from a standard genome sequence analysis. At the very least, future winemakers may be alerted to genetic predispositions to a specific anosmia or insensitivity, such as the common inability to perceive various taint compounds that may ultimately impact the quality of the wine they produce (AWRI Annual Report 2011).

Conclusion

Next-generation sequencing is poised to revolutionise many aspects of grapegrowing and winemaking. Embracing new genomic sequencing technologies will enable fresh insights to be made into the organisms that contribute (positively or negatively) to wine style, providing the means of improving the lot of grapegrowers and winemakers and the competitiveness of Australian wines on the world stage.

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New vines for new times

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Abstract

Grapevines are highly susceptible to a wide range of pests and microbial pathogens. Historically, grapegrowers have relied heavily on the use of pesticides and fungicides in combination with various management techniques to minimise the impact of these pathogens. There is, however, increasing financial, regulatory and market pressure on grapegrowers to minimise the application of agrochemicals in the vineyard. In the face of these increasing pressures, the development of new grapevine cultivars with improved genetic resistance to pathogens is a high priority. In other crops, such as cereals, similar diseases have been controlled by breeding to incorporate resistance genes. However, previous attempts to introgress resistance into grapevines by conventional breeding strategies have been hampered by slow generation times and the costs required to propagate and screen sufficiently large numbers of progeny to identify resistant cultivars with acceptable wine quality. The most economically important diseases of grapevine cultivation worldwide are caused by powdery mildew and downy mildew. These pathogens, endemic to North America, were introduced into Europe in the 1840s and have subsequently spread to all major grape-producing regions of the world. The wild North American grapevine species Muscadinia rotundifolia was recognised as early as 1889 to be resistant to both powdery and downy mildew. This paper will give an overview of progress we have made both in the identification of the genes responsible for powdery and downy mildew resistance in M. rotundifolia and the introduction of these resistance genes into existing wine-grape cultivars either by genetic transformation or marker-assisted selection. Future deployment of these new disease-resistant cultivars will also be discussed.

Introduction

The Australian wine industry faces a number of major economic and environmental challenges to enable it to maintain its share of the global export market through the production of a high quality product at a competitive price point in an environmentally sustainable manner. In the face of increasing competition for export markets from other New World wine producers, such as Chile, Australian wine-grape growers and winemakers will need to reduce input costs in the vineyard and the winery to maintain sales and profitability. They also face major viticultural challenges as a result of the effects of climate change on berry quality, harvest scheduling and water availability. Finally there are increasing regulatory, environmental and social pressures to reduce the use of agrochemicals in wine-grape production.

The Australian wine industry is based predominately on varieties of the Eurasian grape species, *Vitis vinifera*, which were bred in Europe some 200–600 years ago (Table 1). However, the growing conditions under which these varieties were first selected are very different to those that we currently find in Australian vineyards in terms of temperature (average and maximum), moisture availability

Table 1. The top four white and red wine-grape varieties grown for Australian wine production in 2011/2012 season and earliest mention of these European grape varieties in historical records

Variety	Australian production 2012 (tonnes)1	First mentioned in historical records ²
Chardonnay	348,283	1583
Sauvignon Blanc	81,442	1534
Semillon	77,890	1736
Muscat Gordo Blanco	54,155	1500s
Shiraz	362,217	1781
Cabernet Sauvignon	207,558	1777
Merlot	117,383	1783
Pinot Noir	34,574	1386

¹Australian Bureau of Statistics 1329.0.55.002 - Vineyards, Australia, 2011-12 ²Robinson et al. (2012) and salinity. Furthermore, at that time, many of the major grape pathogens that now significantly impact on wine-grape production were not present in Europe. Pathogens such as powdery mildew (Erysiphe necator) and downy mildew (Plasmopora viticola) are endemic to North America and were only introduced into Europe in the mid-19th century (Gessler et al. 2011; Gadoury et al. 2012). As a result, the classic French varieties that dominate the Australian wine industry, and indeed the world wine industry, have little or no genetic resistance to these pathogens. Consequently, grapegrowers rely heavily on the use of agrochemicals to minimise the potentially devastating impact of these pathogens on grape yield and quality. This translates into high costs for grapegrowers. A survey of the Australian grape and wine industry estimated that these two fungal pathogens accounted for ~55% of the total economic cost of all endemic pests and diseases in terms of lost production, and increased costs associated with disease control (Scholefield and Morison 2010). The application of agrochemicals to control these diseases also has significant implications for the environment, not only through the potential direct impacts of agrochemicals, but also through carbon emissions generated during their frequent application. Thus, with the increasing financial, regulatory and environmental pressures on grapegrowers and winemakers to reduce the use of agrochemicals in wine production, the development of grapevine cultivars with improved genetic resistance to pathogens is essential.

New strategies for the development of wine-grape cultivars with enhanced resistance to powdery and downy mildew

As described above, the highly susceptible nature of *V. vinifera* varieties to powdery and downy mildew can be explained by the fact that this species is native to Eurasia (This et al. 2006) and has only been exposed to powdery mildew and downy mildew since their accidental introduction into Europe in the 1800s. This is only a very short period of time in evolutionary terms and certainly not long enough for the evolution and natural selection of any genetic resistance in the *V. vinifera* species. In contrast, many wild grapevine species endemic to North America display significant levels of resistance to these pathogens. Previous attempts to introduce disease resistance genes from wild North American species into premium *V. vinifera* varieties by conventional breeding techniques have proven difficult. One of the major constraints is that the North American grape species often have negative grape and wine quality characteristics and, when hybrids have been generated, they lack the high quality of the original *V. vinifera* variety, making them generally unacceptable to growers and winemakers. The adoption of these 'French-American' hybrids has therefore been very limited throughout most viticultural regions of the world apart from eastern and mid-western regions of North America (Pollefeys and Bousquet 2003).

In other crops this can be rectified by undertaking a backcrossing program whereby the resistant hybrid plant is crossed multiple times with the original V. vinifera parent, eventually leading to removal of any negative quality characteristics. However, the long generation times and expense associated with maintaining and phenotyping large numbers of mature vines has meant that such backcrossing programs for grapevine breeding are normally not undertaken. To overcome this major bottleneck in grapevine genetic improvement we have developed two complementary strategies to develop new wine-grape germplasm with enhanced resistance to powdery and downy mildew. Both strategies involve the transfer of resistance genes from Muscadinia rotundifolia, a wild grapevine native to the southeastern United States, which is highly resistant to a range of pathogens of cultivated grapevines including powdery mildew, downy mildew, phylloxera and nematodes (Olmo 1986) and, as such, is a rich source of potential disease resistance genes. One strategy is based on the introduction of mildew resistance genes into existing premium varieties by genetic transformation. The second strategy involves the development of entirely new wine-grape varieties with disease resistance using advanced breeding techniques.

Generation of premium wine-grape cultivars with enhanced resistance to powdery and downy mildew by genetic transformation

In 1919, L.R. Detjen, a grape breeder working at North Carolina Agricultural Experiment Station was successful in generating hybrids between the V. vinifera variety 'Malaga' and M. rotundifolia. One of the hybrids produced, NC6-15, was shown to be resistant to powdery mildew and was later used by French breeder Alain Bouquet working at the French National Institute for Agricultural Research (INRA) to generate mapping populations in which resistance to powdery mildew was found to be inherited as a single, dominant locus named MrRUN1 (for Resistance to Uncinula necator 1; (Pauquet et al. 2001)) and resistance to downy mildew was controlled by a major dominant locus named MrRPV1 (for Resistance to Plasmopora viticola 1; (Merdinoglu et al. 2003)). Significantly, screening of over 3,500 progeny from these mapping populations did not identify a single plant in which both MrRUN1 and MrRPV1 were not inherited together, indicating that these resistance loci were co-located in the Muscadinia genome, making it feasible to identify both genes in a single positional cloning effort.

To undertake the mapping and cloning of these two genes, a bacterial artificial chromosome (BAC) library was constructed using genomic DNA extracted from a single mildew-resistant *M. rotundifolia* \times *V. vinifera* breeding line (Barker et al. 2005). This library was then screened with genetic markers linked to the *MrRUN1/MrRPV1* locus and a region of genomic DNA was identified that contained a cluster of seven closely related genes, each of which encoded a putative resistance protein which may confer resistance to powdery and/or downy mildew (Feechan et al. 2013). In order to determine which of these candidate genes was responsible for mildew resistance, each candidate gene was introduced separately into a range of susceptible *V. vinifera* wine-grape varieties, including Shiraz, Tempranillo and Portan, by Agrobacterium-mediated transformation (Iocco et al. 2001).

Transgenic grapevines containing the individual M. rotundifolia resistance gene candidates were first evaluated for resistance to powdery mildew collected from vineyards in Australia and France. The results demonstrated that only one of the seven candidate genes conferred complete resistance to powdery mildew isolates from Australia and France and this gene was designated MrRUN1 (Feechan et al. 2013). Figure 1 illustrates the response of transgenic Shiraz plants containing MrRUN1 to inoculation by powdery mildew in comparison to a susceptible plant lacking MrRUN1. Trypan blue staining of leaves seven days post-inoculation shows extensive E. necator hyphal growth and sporulation on the susceptible leaf (left panel) but little development of the fungus on the MrRUN1 transgenic leaf. It is also clear from the trypan blue staining that epidermal cells on the MrRUN1 transgenic leaf which have been penetrated by the powdery mildew fungus have undergone a process called programmed cell death (PCD). The rapid death of the grapevine cells following powdery mildew penetration deprives the biotrophic fungus of nutrients causing its further development to be halted.

Transgenic vines were also challenged with downy mildew isolates collected from vineyards in Australia and France. As in the case of powdery mildew resistance, only one out of seven of the M. rotundifolia resistance gene candidates tested conferred resistance to P. viticola, which was independent from the powdery mildew resistance gene MrRUN1 (Figure 2). This gene was designated MrRPV1 (Feechan et al. 2013). It can also be seen that whereas the resistance conferred by MrRUN1 is complete (qualitative, Figure 1), the resistance conferred by MrRPV1 is quantitative with some sporulation still observed under these experimental conditions (Figure 2). This is in agreement with the incomplete downy mildew resistance displayed by the parental *M. rotundifolia* × *V. vinifera* breeding line from which MrRPV1 was cloned. Interestingly, however, transgenic MrRPV1 grapevines displayed a higher level of quantitative resistance than the parental line with sporulation reduced by 92-98% on average in MrRPV1 transgenic lines compared to an average reduction of 72% in the parental line.

Shiraz-untransformed

Shiraz-MrRUN1



Figure 1. Comparison of the growth of powdery mildew (*E. necator*) fungus (stained blue) on the surface of leaves of a susceptible *V. vinifera* var. Shiraz grapevine (left panel) and a transgenic Shiraz grapevine containing *MrRUN1* (right panel). The arrows in the right panel indicate examples of epidermal cells which have undergone programmed cell death following penetration by the powdery mildew fungus.



Figure 2. Comparison of downy mildew (*P. viticola*) sporulation on leaf discs of a susceptible *V. vinifera* var. Tempranillo grapevine (left panel), a transgenic Shiraz grapevine containing *MrRUN1* (middle panel) and a transgenic Shiraz grapevine containing *MrRPV1* (right panel)

MrRUN1 and MrRPV1 are the first resistance genes to be cloned from a grapevine species (Feechan et al. 2013). Furthermore, we have demonstrated that these genes can be introduced into existing V. vinifera varieties by genetic transformation to produce the first mildew-resistant premium wine-grape varieties in the world. The obvious question is - what does the wine from these transgenic vines taste like? Under the current legislation in Australia we are unable to consume grapes or wine derived from grapes of these transgenic vines without special permission from the Office of the Gene Technology Regulator (OGTR). Even so, given our knowledge of the mode of action of the resistance genes, we believe it highly unlikely that the introduction of these genes will have any significant impact on wine quality or style of the transformed varieties. Thus, such vines can be considered as genetically-enhanced forms of the original premium varieties which offer the Australian wine industry an opportunity to produce wine of the same style and quality without the need for high levels of agrochemical inputs. However, while it remains the policy of the Winemakers' Federation of Australia that no genetically modified organisms (GMOs) are to be used in the production of Australian wine (http://wfa.org.au/activities/environment-andbiosecurity/environment-policies/), the commercial deployment of such disease-resistant transgenic premium varieties in Australian vineyards is not possible.

In the face of the ongoing moratorium on the use of GMOs in the production of Australian wine, we have turned our attention to developing an alternative strategy for the development of new disease-resistant wine-grape varieties using efficient, rapid breeding techniques.

Development of new wine-grape cultivars with enhanced resistance to powdery and downy mildew using smart breeding techniques

The cloning of MrRUN1 and MrRPV1 not only allowed us to demonstrate their role as mildew resistance genes in functional assays (Figures 1 and 2), it also provided us with sequence information that could be used to design genetic markers to rapidly and accurately follow the inheritance of these genes in large breeding populations without the need to undertake pathogen assays on individual vines. These MrRUN1/MrRPV1- specific markers were used in combination with other genetic markers which enable us to predict grape berry colour (Walker et al. 2007) and the production of perfect flowers (i.e. fruiting vines) (Chaib et al. 2010) to select new disease-resistant varieties with potential industrial application at the seedling stage. This so-called 'Marker-Assisted Selection' (MAS) technique significantly reduces the time and cost associated with classical breeding by ensuring that only those progeny vines that have the required genetic characters are transferred to the vineyard for further evaluation of vine performance, disease-resistance and wine quality. Crosses were undertaken between a fifth generation backcross line obtained from INRA containing the MrRUN1/MrRPV1 locus and eight different premium red and white varieties. Seedlings were screened by highthroughput DNA amplification techniques to identify those progeny plants which contained both the MrRUN1 and MrRPV1 resistance genes and these were planted in an unsprayed block in the Barossa Valley. Results to date indicate that the vines are significantly more resistant to powdery and downy mildew than existing premium winegrape varieties and some of the selections are showing potential based on the evaluation of small-scale ferments.

It is important to note, however, that the selections being evaluated represent only the first generation of improved wine-grape varieties and that continual genetic improvement and evaluation will be necessary to meet the challenges facing the Australian wine industry. For example, it is well known from breeding in other crops that the incorporation of a single dominant resistance (R) gene may not provide durable resistance in the field (Parlevliet 2002). Resistance may be lost through mutation and natural selection of pathogen isolates that are no longer recognised by the R protein. This is of particular concern for grape breeders, given that individual vines would be expected to remain in the vineyard for at least 20 years. It is also not feasible for wine-grape growers to rapidly introduce new grape cultivars with different R genes, as is the case for annual crops such as cereals, should existing R genes fail.

Indeed, we have recently identified a powdery mildew isolate (Musc4) in North America that breaks the resistance conferred by MrRUN1 (Feechan et al. 2013). Musc4 belongs to a genetically distinct group of isolates (group M) which is presently found only in the south-eastern region of North America (Brewer and Milgroom 2010), and as such, would not represent an immediate threat to the durability of resistance of wine-grape varieties containing MrRUN1 should they be deployed in the major wine-grape growing regions of Europe, North America and Australia. However, this discovery highlights the need for continued research to identify new sources of genetic resistance to grapevine powdery and downy mildew, from other wild grapevines such as the Chinese Vitis species V. romanetii (REN4; Ramming et al. 2011) and V. amurensis (RPV8; Blasi et al. 2011) to combine or 'pyramid' with MrRUN1 and MrRPV1, in the same wine-grape variety, to maximise the durability of diseaseresistant vines in the vineyard.

Botrytis bunch rot is another disease that is a major issue for winegrape growers in cooler regions where ripening takes place later in the season when the possibility of precipitation is increased. While plant species, including wild grapevines, have been successful in evolving genes such as MrRUN1 and MrRPV1 to confer strong resistance against biotrophic pathogens such as powdery and downy mildew, they have been less successful at developing strong resistance against necrotrophic pathogens such as Botrytis cinerea that colonise dead or dying cells. Previous research has demonstrated that one effective strategy to reduce the incidence of Botrytis bunch rot is to reduce the level of humidity around the mature bunch, following a rain event, by increasing the air circulation through the bunch (Shavrukov et al. 2004). Therefore we have recently initiated a project, funded by the Grape and Wine Research Development Corporation, to identify genetic markers that can be used to select for vines at the seedling stage that will have more open bunches at maturity, therefore reducing their susceptibility to *Botrytis* bunch rot.

We anticipate that there will be a dramatic increase in the number of genetic markers that will soon become available to incorporate into the high-throughput MAS process especially relating to grape style/ quality. For example, Emanuelli et al. (2013) recently described the development of genetic markers for the accurate selection of muscat flavour at the seedling stage. Similarly, it will be possible to screen progeny populations for methoxypyrazine production (Dunlevy et al. 2013).

The use of MAS techniques in wine-grape breeding, as described above, clearly offers tremendous increases in breeding efficiency by enabling breeders to rapidly identify those progeny, from a cross, that have inherited the key genes responsible for conferring enhanced properties or characteristics such as disease resistance or drought tolerance without having to determine this by phenotypic evaluation of large numbers of mature progeny vines in the field. However a major bottleneck to the development of enhanced wine-grape varieties remains – the long generation time of 24–36 months. To address this bottleneck we are proposing to use a new rapid breeding system based on a naturally occurring Pinot mutant discovered by CSIRO Plant Industry (Franks et al. 2002). This mutant vine has a number of characteristics which will facilitate much faster rates of germplasm improvement. For a start, the mutant vine is dwarf in stature which means it can be grown at a high density in the glasshouse or in growth rooms. Furthermore, under these controlled environmental conditions, it flowers all year round and has a generation time of only six months. This mutant known as the 'microvine' (Chaib et al. 2010) will enable us to combine desired genes or traits within the same vine in a much shorter time frame and at much less expense than would be possible using conventional breeding techniques. Furthermore, the semi-dominant nature of the microvine mutation means that once the desired genes have been combined in a single microvine parent they can be readily transferred back to a normal 'tall' grapevine by crossing with existing premium wine-grape varieties.

In conclusion, we have demonstrated that it is now feasible to introduce desirable traits, such as mildew resistance, from wild grapevine species, into existing premium wine-grape cultivars by genetic transformation. This approach is likely to have minimal effect on winegrape quality. We also demonstrate that with the advent of new smart breeding techniques the possibility exists to generate new winegrape varieties with enhanced genetic capability to meet the major economic and environmental challenges facing the Australian wine industry over the next 50 years.

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The US approach to accelerated grape cultivar development

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Abstract

Grape breeding efforts have resulted in numerous improved wine, table, raisin and rootstock varieties, but are complicated by long generation times, large plant size, and the requirement for a perennial infrastructure. To enable early selection of elite seedlings combining disease resistance, stress tolerance, and fruit quality, US grape breeders and geneticists developed a coordinated strategy for DNA marker discovery and application in a project involving 25 principal investigators. The approach uses centralised trait analysis and high-resolution genetic map development via a next-generation sequencing technology known as genotyping-by-sequencing (GBS). In this new project (known as VitisGen), over 7,000 breeding lines were genotyped in the first year to track alleles introgressed from eleven Vitis species. Our current approach to the analysis of GBS marker data results in the mapping of up to 20,000 genetic markers per population, including alleles not present in the V. vinifera reference genome. These dense genetic maps combined with centralised trait analysis will lead to the development of at least 30 marker sets for alleles controlling traits of current and future interest for grapevine improvement. In addition to the cutting-edge GBS markers, traditional Simple Sequence Repeats (SSR) marker analyses contributed to marker-assisted breeding (MAB) efforts in the first year, as the project works to develop direct MAB decisions from GBS data. Together, the 25 principal investigators are seeking to maximise the impact of what is to become an unprecedented level of genetic mapping data relevant to grapevine improvement. Additional information can be found at http://www.vitisgen.org.

Introduction

Grapevine improvement programs in the United States have until now acted as separate programs, each with their own regional and crop-specific goals and objectives. North American breeders meet every other year to share research progress and results, and have often tested each other's selections and shared pollen in the past. However, every program has been run independently and with separate funding streams. This situation has changed substantially with the initiation of the *VitisGen* project. This project was launched in September 2011 with five years of grant funding from the USDA-National Institute of Food and Agriculture – Specialty Crops Research Initiative. *VitisGen* is a collaborative effort among 11 research institutions (Table 1) and is supported by an Industry Advisory Panel with 25 grapegrowers, winemakers, processor representatives and others from private industry (Figure 1).

Overview

The vision for the VitisGen project has four primary elements:

- to identify high priority vine performance and fruit quality traits with documented economic value to the grape industry and to the consumer
- to discover, identify, and improve high priority traits using both traditional and modern biological approaches
- to implement this strategy through development of molecular trait markers and improved grape varieties
- to enhance communication regarding the value of improved knowledge of grape genomics, new varieties, new technologies, and evolving needs of the grape industry and consumers.

So what does all of that really mean? In a nutshell, we are trying to develop new genetic (DNA-based) markers that indicate the presence or absence of genes controlling traits such as powdery mildew resistance, low temperature responses, and various fruit quality characteristics. These genetic markers can be used to identify or select plants as seedlings that will retain high priority traits. This will help to speed up the breeding and evaluation process, so that these traits can be incorporated into new grape varieties more quickly, benefiting both consumers and the grape industry. The US grape industry, particularly in areas where *V. vinifera* grapes are difficult to grow, is not at all resistant to trying entirely new varieties. Consumers are willing to

try them, and wine-producing industries in some regions rely heavily upon grapes developed for areas with extremely cold winters, or areas with unusually high disease pressure. So whatever can be done to accelerate the identification and development of new varieties has the potential for great economic impact.

Much of the work of the *VitisGen* project is focused upon 19 different 'mapping populations'. These populations are groups of fullsibling seedlings resulting from matings made by various breeders in the project. Each mating was done with certain strategic goals in mind, such as to study the genetics of disease resistance, nematode resistance, or low temperature response. By creating genetic maps from each population while at the same time characterising traits

 Table 1. The 11 research institutions involved in the USDA-ARS Specialty Crops

 Research Initiative project known as VitisGen

Cornell University United States Department of Agriculture - Agricultural Research Service (USDA-ARS) University of Minnesota South Dakota State University Florida A&M University Missouri State University University of California, Davis Oklahoma State University Oklahoma City University Mississippi State University Dalhousie University



Figure 1. VitisGen project workflow

of interest for each seedling, the project intends to develop a solid base of information on the association of genetic markers with genes affecting traits of interest to breeders.

An Executive Committee with five members, each of whom leads one of five project teams, heads the VitisGen project. Dr Bruce Reisch leads the Breeding Team, which includes nine breeders from six states (California, South Dakota, Missouri, Minnesota, Florida, and New York). The major roles of this team are to maintain the plants that make up the VitisGen mapping populations and to provide this plant material to the Genetics Team, which is responsible for the genetic analysis of the plants, and to the Trait Evaluation Team, which evaluates plants for traits of interest. Altogether, 12 Vitis species are represented among the populations maintained by the Breeding Team. In the project's first year, the Breeding Team submitted samples from more than 7,000 vines to the Genetics and Trait Evaluation Teams. Locally, breeders are also evaluating traits such as flower type; flowering time; resistance to various fungal diseases, foliar phylloxera, and nematodes; and several fruit attributes (e.g. berry size, berry shape, skin colour, and seedlessness).

Dr Anne Fennell of South Dakota State University leads the Trait Evaluation Team. The team has established three 'centres', or sets of scientists in different locations, to evaluate the mapping populations for low temperature responses, powdery mildew resistance, and fruit quality. The group focused on low temperature responses is based in South Dakota, and measures freezing tolerance, chilling fulfilment, and the rate of budbreak. The powdery mildew centre is based at Cornell University and USDA-ARS. This group maintains a genetically diverse collection of grape powdery mildew strains and looks at how effective plants with different genetic profiles are at preventing fungal infection (Figure 2). Leaf tissues are infected with a single strain of powdery mildew, and the response of each leaf to the fungus is characterised at the microscopic level. Grape varieties that can resist disease and tolerate low temperature stress often have undesirable aromas and flavours. The scientists at the fruit quality centre, also based at Cornell University, are working on how characteristics like negative aroma and flavour compounds, organic acids, and other undesirable characteristics in fruit are influenced by genetics.

Dr Lance Cadle-Davidson of the USDA-ARS Grape Genetics Research Unit leads the Genetics Team, which is centred at Cornell University. This group is able to take advantage of advanced laboratory and computational facilities such as the Cornell University Biotechnology Resource Center, the Institute for Genomic Diversity, and the Bioinformatics Facility. The Genetics Team includes molecular biologists, plant geneticists, and computational biologists, and is using a new technology called genotyping-by-sequencing (GBS) to discover new genetic markers that are closely associated with genes controlling certain traits. In just the first year of the project, the Genetics Team processed 7,200 GBS samples, generating more than one billion data points. In addition to generating this large amount of data for new markers, the Genetics Team also generated data for genetic markers already known to be associated with traits (e.g. genes for powdery mildew resistance, downy mildew resistance, flower sex and seedlessness) that breeders were using (Figure 3). This data set was returned to breeders and is already being used to improve speed and efficiency in grape breeding programs.

Dr Julian Alston of the University of California, Davis, is the lead for the Trait Economics Team, with a primary focus to identify top priority traits and document their value. To accomplish this, the Trait Economics Team is conducting research on the value of disease resistance in viticulture and is developing surveys for grape breeders, growers, industry, and consumers. Thus far, the research has concentrated on Pierce's disease and powdery mildew disease resistance. Determining the value of powdery mildew resistance in viticulture is twofold. First, the prevalence of powdery mildew must be identified across different segments of industry and the country. Second, the consequences in terms of yield losses, investment in preventative efforts, or other costs imposed are determined. The first *VitisGen* survey was aimed at identifying grape breeders' priorities in grape genetics research. Future surveys are being developed for grapegrowers, industry members, and consumers.

The Extension and Outreach Team is led by Hans Walter-Peterson from Cornell Cooperative Extension. This team is responsible for educating consumers and the industry about the project and the benefits that this work will have for both the industry and consumers. So far, the group has developed publicity materials for the project, including a logo and project brochure, and is working on a new website for the project as well. In the near future, the group will be developing more materials highlighting certain aspects and accomplishments of the project, including online videos, webinars, newsletters, glossaries (Table 2) and more.

Conclusion

How do all five of the teams work together? The Breeding, Trait Evaluation, and Genetics Teams function together as a research and development unit. Trait evaluation and genetic data are integrated to generate new trait-associated markers. Breeders use these markers to screen progeny and discard those that do not have the desired trait(s). This reduces the overall costs related to vine evaluation. The Trait Economics Team identifies top priority traits through breeder,



Figure 2. Powdery mildew infected leaf



Figure 3. Bruce Reisch (right) and Steve Luce harvest leaf samples from seedlings to submit to the genotyping centre.

grower, industry, and consumer surveys, which help to steer the focus of the research and development unit. The Extension and Outreach Team communicates with industry and consumers to provide education about new technologies and genomic resources. Overseeing the entire project is an Industry Advisory Panel, which provides guidance and matching funds to support the *VitisGen* project. This type of collaborative effort will result in the development of new tools and techniques that will lead the way in developing the next generation of grape cultivars. For more details on the *VitisGen* project, visit the project's website at http://www.vitisgen.org. Table 2. A glossary of terms used to describe the VitisGen project

Genetic markers: pieces of DNA with a known location on a chromosome

Molecular-trait markers: genetic markers linked to traits

Genomics: the study of genomes or an organism's complete hereditary information

Genotype: the genetic make-up of an organism

Genotyping-by-sequencing (GBS): a next-generation DNA de-coding technology used to analyse an organism's DNA

Phenotype: the observable characteristics of an individual organism

Progeny: offspring

Mapping population: a group of related organisms used to construct a genetic map

Harnessing genomics to ensure a 'Brett'-free future for Australian wine

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Abstract

The yeast species Dekkera (Brettanomyces) bruxellensis shows up in many fermentation systems, but is particularly well known for its role in shaping the style of wine, beer and cider. In wine, growth of Brettanomyces post-alcoholic fermentation is associated with production of volatile phenols that impart 'medicinal' and 'barnyard' aromas. Better known as 'Brett' character, these aromas detract from varietal/regional expression and decrease consumer liking of wine. Despite the economic importance of Brettanomyces, surprisingly little is known concerning its biology. This is in sharp contrast to its fermentation ecology partner Saccharomyces cerevisiae, the first yeast to have its genome sequenced (accomplished in the 1990s). To further our understanding of what enables Brettanomyces to survive for long periods in wine, in a world-first we sequenced and assembled the genome of the predominant spoilage strain found in Australian wineries. Comparative genomics conducted on different 'Brett' strains revealed that different strains vary in their genome copy number, and some regions of the genome appear to be under selective pressure. This provides insight into what genes are important for survival in wine, and what molecular mechanisms are driving evolution of the species. Taking advantage of access to the 'Brett' genome sequence, we studied which Brettanomyces genes are switched on during growth in wine, and whether any re-programming occurs upon exposure to a key component of the 'Brett'-control strategy, sulfite. Harnessing data sets arising from this and additional complementary work performed at the Australian Wine Research Institute (AWRI), the potential for emergence of more 'difficult to control' Brettanomyces strains can be more readily estimated, and control strategies updated to ensure a 'Brett'-free future for Australian wine.

Introduction

Yeasts of the genus *Brettanomyces* and its sexual (sporulating) form *Dekkera* have a long association with production of fermented beverages. In 1904, N. Hjelte Claussen of New Carlsberg Brewery isolated yeast he described as "essential for production of English 'stock' beers" and named them '*Brettanomyces*' – '*Brettano*' for British, and '*myces*' for fungus. Intriguingly, a simultaneous discovery of the same species of yeast occurred in the Kalinkin brewery of St. Petersburg in Russia (Seyffert 1904). The authors failed to assign a catchy name to the newly isolated yeast, however, and their finding did not receive as much attention.

So why are the names *Brettanomyces* and *Dekkera* used interchangeably to describe the same wine spoilage yeast species – *Dekkera (Brettanomyces) bruxellensis?* The genus *Dekkera* was not defined until the 1960s when sporulation was observed for some *Brettanomyces* isolates (Van der Walt 1964). Subsequently, the application of DNA technology to yeast taxonomy yielded a reclassification of species, such that we now focus our attention upon a single species, *Dekkera bruxellensis*, which incorporates all isolates formerly known as *Brettanomyces bruxellensis* – they are for all intents and purposes the same, even if sexual reproduction (sporulation) has not been observed for all strains.

Although first isolated from beer, *D. bruxellensis*, has been associated with a range of other fermentation systems including biofuel, cider, kefir, and kombucha – it generally shows up after the more favourably viewed industrial yeast, *S. cerevisiae*, has initiated alcoholic fermentation. Both species have evolved similar traits to cope with high sugar and then high ethanol environments, enabling them to outcompete most other yeast species associated with fermentation. As the ultimate survivor, *D. bruxellensis* could be considered the cockroach of the yeast world.

Despite its broad association with fermentation, *D. bruxellensis* is most widely known in the wine industry as a spoilage yeast. It has been isolated from wines made around the world, including 31 winemaking regions of Australia (Curtin et al. 2007). Once growing

in wine, these yeast impart 'Brett' character: an aroma generally described in terms such as 'Bandaid[®]', 'phenolic', 'leather', 'sweaty', 'medicinal' and 'barnyard'. 'Brett' may also be described as 'metallic' on the palate. It is well known that the compounds 4-ethylphenol and 4-ethylguaiacol are responsible for imparting these characters to wine, and that they are predominantly formed from non-volatile hydroxycinnamic acid precursors present in grape must or wine through a metabolic pathway present in *D. bruxellensis* (Chatonnet et al. 1992).

'Brett' in Australian wine

'Brett' was a major problem for the Australian wine sector during the late 1990s and early 2000s – most red wines contained some 'Brett' spoilage compounds, often at levels subsequently shown to be perceptible by uninformed consumers (Curtin et al. 2008). Extensive communication of a practical 'Brett' control strategy (Coulter et al. 2003) facilitated widespread efforts to minimise 'Brett' impact on red wine style, whereby typical 4-ethylphenol levels in major Cabernet Sauvignon producing regions fell from ~1000 ppb¹ for vintage 2000 to less than 100 ppb by vintage 2005. Problem solved?

A key indicator of changed winemaking practice could be observed in the ratio of free to total sulfite in finished wine, itself an indicator of how sulfite has been used throughout the wine's life. Low ratios (e.g. 0.2) typically mean that sulfite has been added to the wine repeatedly in small amounts, and that a microorganism is or has been growing and producing sulfite-binding compounds. The average ratio of free to total sulfite for wines analysed by the AWRI's Commercial Services group from 2000 to 2005 increased from ~0.3 to ~0.45 (Godden and Gishen 2005), indicating improved sulfite management practices and cleaner wines. *D. bruxellensis* isolates from 31 winemaking regions of Australia, gathered during this same period, were genotyped using a DNA fingerprinting method (Curtin et al. 2007) and tested for sulfite tolerance (Curtin et al. 2012b). Strikingly, most isolates belonged to a

⁻ ⁻ The perception threshold for 4-ethylphenol ranges from 300-600 ppb, depending on wine style.

sulfite-tolerant genetic group, and the relative proportion belonging to this group obtained from wines in 2004–2005 was higher compared with the earlier analyses.

An accepted phenomena in the medical world is that of emergent antibiotic-resistant bacteria – place a fast growing microbe under a selective pressure and it will evolve a survival mechanism. Could this be happening for *D. bruxellensis* in response to sulfite? It doesn't grow nearly as quickly as bacteria, so perhaps we could assume a longer time frame, but with limited knowledge of how *D. bruxellensis* has evolved how can we estimate the risk of new strains emerging and rendering current control strategies ineffective?

Strategic genomic sequencing: decoding the *D. bruxellensis* genome

S. cerevisiae is not only the preferred yeast species for wine production (and useful in many other industrial settings), it continues to be the model system of choice for fundamental and medical research. This led, in 1996, to it being one of the first organisms to have its genome fully sequenced. Approximately ten years later the same DNA sequencing technology (known as 'Sanger' sequencing) was applied to determining the DNA sequence of the D. bruxellenis genome (Woolfit et al. 2007), however due to cost constraints this study yielded a partial and heavily fragmented genome sequence - useful for understanding where D. bruxellensis fits into the tree of life, but insufficient to shed light on how it had evolved. Around the same time, genomesequencing technology was advancing at a dizzying pace, exponentially increasing output at decreasing cost. By 2008, the rapid improvement in next-generation sequencing platforms made it possible to re-sequence the S. cerevisiae genome for less than one per cent the cost of the original data set. Simultaneous advances in bioinformatics made it feasible to use next-generation sequencing data for assembly of new genomes, which is a more difficult task than re-sequencing a species for which existing 'genomic scaffold' data exists.

In our work, we chose a representative *D. bruxellensis* strain (AWRI 1499) that exhibited relatively high levels of sulfite tolerance, and its DNA was sequenced using a platform known as 454 pyrosequencing which generated ~1.8 million reads. The full assembly of this data required automated bioinformatics tools, customised computer scripts and hours of manual checking. The end result – a world first – was a relatively unfragmented assembly (324 contigs²) of 12.7 million base pairs carrying ~6000 genes.

What did we find in this assembly? *D. bruxellensis* has more genes that encode membrane transport proteins and oxidation/reduction enzymes than other yeast species. These may confer enhanced ability to take up nutrients in nutritionally barren environments, providing greater capacity to survive for extended periods under anaerobic conditions.

The *D. bruxellensis* genome was similar in size and gene content to that of *S. cerevisiae*. Unexpectedly, the assembly inferred that AWRI 1499 had a triploid genome (three copies of its chromosomes, (Curtin et al. 2012a)), whereas most species that have a sexual cycle harbour two sets of chromosomes (one from each parent). Furthermore, the DNA sequence of the apparent third set of chromosomes appeared to be quite different from the other two. Analysis of 60 genes revealed an average nucleotide similarity between the third set of chromosomes and the other two sets in the vicinity of that seen when comparing the DNA of humans and chimpanzees. This type of genome composition is similar to that observed in *Saccharomyces* interspecies hybrids, such as the commercial wine yeast Anchor Vin7 (Borneman et al. 2011), a hybrid between *S. cerevisiae* and *Saccharomyces kudriavzevii* – two species with DNA sequences as different as human and mouse.

To delve further into the genome composition of D. bruxellensis, we sequenced two additional Australian strains that represented 'intermediate' and 'sensitive' sulfite tolerance groups, while genomic data for a French wine isolate was also available (Piškur et al. 2012). The sulfite 'sensitive' strain (AWRI 1613) and the French wine isolate were similar in genome sequence and both contained two copies of their chromosomes. They each exhibited large regions of their genomes where both chromosomal copies had the same sequences - this phenomenon, called 'loss of heterozygosity', is suggestive of relative importance of a gene for survival and reproduction. The other Australian isolate (AWRI 1608) was triploid, again comprising two sets of chromosomes that were similar to one another, and a third set that was divergent. Examination of seven genes for all four strains revealed that the divergent sequences in AWRI 1608 were not the same as those found in AWRI 1499. What does this mean? Given that AWRI 1499 and 1608 together represent ~92% of all isolates recovered from Australian wineries, the results imply that triploid D. bruxellensis may be 'more fit' for survival under current Australian winemaking practices. It would also seem that the generation of these triploids happened independently; they clearly have different evolutionary histories. Given the divergent sets of chromosomes in both strains are not the same, it is unclear at this stage whether the presence of this 'third genome' enhances 'fitness' merely by adding to the number of gene copies, or whether additional copies of specific genes offer particular advantage.

D. bruxellensis and sulfite tolerance

Our first foray into D. bruxellensis functional genomics has focused on sulfite tolerance, a trait well understood for S. cerevisiae, both in terms of what genes are involved and what determines the relative tolerance of different strains (Park and Bakalinsky 2000; Aa et al. 2006; Goto-Yamamoto 1998). Central to this trait in S. cerevisiae is a sulfite pump encoded by the gene SSU1, which can be found across many fungal species and is present in single copy in the D. bruxellensis genome. If this gene is deleted from the S. cerevisiae genome the modified strain becomes sulfite sensitive. While there are no molecular biology tools enabling such analysis to be performed in D. bruxellensis, we can test whether the same gene from D. bruxellensis (DbSSU1) complements deletion of SSU1 in Saccharomyces. Preliminary results show that expression of DbSSU1 in a S. cerevisiae SSU1 deletion strain reconstitutes sulfite tolerance. Unexpectedly, the degree to which this pump is 'switched on' in D. bruxellensis - determined by studying the transcriptome3 after exposing cells to sulfite was no different in sulfite tolerant and sulfite sensitive strains. Current work involves comparing the different sequences of DbSSU1 found in these strains to determine whether one version of the pump confers more sulfite tolerance than another. This will provide insight into the potential for emergence of new D. bruxellensis strains with enhanced sulfite tolerance.

Conclusion

To ensure the continued efficacy of 'Brett' control strategies it is essential to understand how *D. bruxellensis* has evolved to survive in wine, and how it might adapt to changing winemaking practices. We applied next-generation sequencing technology to decode the genomes of three Australian *D. bruxellensis* isolates, revealing that formation of triploid genomes through hybridisation may be important in determining their relative 'fitness' in the context of Australian winemaking practices. We then used next-generation sequencing platforms to catalogue the *D. bruxellensis* transcriptome which, combined with gene function analysis, will provide a better understanding of what

 $^{^2\!}A$ 'contig' is a contiguous segment of DNA, built from a few to many thousands of individual overlapping sequence 'reads'.

³The transcriptome is the set of all RNA molecules produced in one cell or a population of cells.

makes *D. bruxellensis* sulfite tolerant. This new knowledge in turn is enabling robust evaluation of the risk that new strains may emerge, rendering existing control strategies ineffective.

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SESSION 9: Future vineyards and wineries



Reflections on 50 years in the Australian wine industry P. Laffer AM

Vineyard operations of the future – exciting developments on the horizon *B. McClen*

Emerging technologies in the modern winery – key insights into developments on the horizon *R. Boulton*

Continuous improvement: a winery case study

D. Williams



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The Australian Wine Industry Technical Conference Inc. Hartley Grove cnr Paratoo Road, Urrbrae, South Australia 5064, Australia

Reflections on 50 years in the Australian wine industry

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I graduated at the end of 1962 and, as the 'gap year' had yet to be invented, started work in Corowa NSW on 5 January 1963 as assistant winemaker with Lindemans. Having spent the previous four vintages, whilst still a student, learning how to fork off grapes and wax concrete tanks, I was looking forward to some 'real' winemaking. I quickly discovered that assistant winemakers still had to fork off a standard seven tonnes of grapes each morning before starting 'real' winemaking. On the positive side, after two vintages of forking grapes I was inspired to build the first mechanised unloading system in the district.

Two other early lessons were learnt during my first harvest in the vineyards at Corowa. Dry grown defoliated bush vines in 22-inch rainfall country offered little privacy. Lindemans, an enlightened company, had built what I believe to be Australia's first mobile vineyard dunny. It was a corrugated iron edifice mounted over a half 44-gallon drum sitting on top of the axle and shafts from an old jinker, and drawn by an old Clydesdale who ambled along behind the pickers. A set of stairs was necessary to climb up to the door which was a couple of wheat bags stitched together. Sent out to learn 'people management, I was supposedly in charge of a group of itinerant pickers but was absolutely no match for their leader: she was my height, twice my weight, obstreperous, a bully and she scared me. Fortunately she treated her team likewise, such that when she had occasion to climb the stairs to the dunny, after allowing time for her to settle, someone threw a clod at the horse which promptly bolted to the end of the vineyard. The lessons learnt were twofold: firstly, the value of providing appropriate staff amenities, and secondly, the value of effective industrial relations - we had no further difficulties with this picker.

By way of introducing this session which is all about the future, I thought I might look at some of the changes the industry has seen over the past 50 years which coincides with my life in wine. The changes, evolution and advances I will briefly cover include grapegrowing, winemaking, packaging, consumption and industry structure.

In 1963 the area planted to wine grapes was 54,000 ha; today it is 180,000 ha. In 1963 Australia crushed 170,000 tonnes of grapes (it was an unusually small vintage, the mean for that period was about 200,000t); this year we crushed 1.8Mt. Yield per hectare has greatly increased and the varietal mix in 1963 was dominated by the dual purpose varieties Gordo and Sultana. Chardonnay was still nearly 20 years away. We are inclined to forget that prior to 1969, quarantine controls, first established in the 1880s to prevent phylloxera entering Australia, meant that our available grape varieties had changed little from James Busby's original imports. Accredited sources of planting material, initially California, and secure quarantining in Australia allowed the first new varieties and new clones to be released in 1969, and for the first time we had Chardonnay, Merlot, Pinot Noir, Gamay, Sauvignon Blanc, Zinfandel and others, the first three ultimately having an enormous impact. The commercial impact of these varieties in the late 70s and early 80s coincided with the change from generic nomenclature to varietal labelling of Australian wine. This was happening by natural progression but was certainly encouraged by the obligation for varietal labels on wines destined for the European market. Amazingly in not much more than 20 years Chardonnay had gone from non-existent to the most widely planted variety in the country.

In 50 years we have seen the introduction of machine harvesting, machine pruning, drip irrigation, and equally important a vastly improved understanding of vine physiology and the grape genome, water management, spray technology and fungicides and pesticides. There is no longer a need to shower off lead arsenate at the end of the day. Arguably Australia has led the world in viticultural research over the last 50 years through the efforts of state Departments of Agriculture, the CSIRO and two successful Cooperative Research Centres.

Winemaking per se has changed little in 50 years but the tools available to us are dramatically different. I seem to recall that in 1963 only five wineries had any form of refrigeration, but by the early 70s ammonia-based refrigeration plants were widespread. Temperature controlled warehousing was introduced more gradually and has only become the norm in quite recent times.

Aged oak casks, many a result of reparation from two World Wars, brick and concrete tanks and a few 'modern' Munkador-lined mild steel tanks were the accepted storage vessels. The first stainless steel tanks appeared in 1968, they were corrugated and made from 22 gauge coil. Despite being affordable because of their extremely thin walls, corrugated tanks were difficult to clean and were quickly replaced by conventional flat steel; interestingly but not surprising those first tanks are still as serviceable as when first built.

Diatomaceous earth filters started to replace paper pulp and plate and frame filtration for general cellar work in the 60s, a good thing as paper pulp filtration required pre-coating with asbestos. To do this cellar hands and assistant winemakers crumbled blocks of asbestos into slurry tubs; we have a very different view of asbestos today. And now diatomaceous earth filters are being replaced with cross-flow and other types of membrane filtration. With slip-skin varieties like Sultana and Gordo playing such an important role in Australian winemaking, we led the way in developing juice separation equipment: MAC drainers, Lindeman drainers, Miller drainers and Willmes presses were widely adopted, nearly all now replaced with semi-automatic tank presses or similar.

In the 1960s most red fermentation was via open concrete and brick fermenters, with labour-intensive and messy emptying systems, and often chilled with blocks of ice which also improved yields and delivered more attractive alcohol levels. Legislation and the flexible designs offered by stainless steel, for example the ubiquitous Potter fermenter, have delivered the efficient and effective ferment vessels of today. Centrifugation and low vacuum low DO (dissolved oxygen) fillers are other examples of imported technology and the spinning cone is a great example of a home-grown invention.

Alongside this has been the winemaking advances resulting from local world class research and development, spearheaded for nearly 60 years by our own Australian Wine Research Institute (AWRI). This is a remarkable institution initiated by the industry in 1955, still owned and directed by the industry and of course responsible for this, the 15th Australian Wine Industry Technical Conference since its inception in 1970. Developments in microbiological management, taint elimination, flavour development, as well as colour, cold, flavour and protein stability are just a few of the benefits the AWRI has given winemakers, with perhaps the most valuable being the AWRI's role in providing advice, solving problems and extending knowledge. However, we can never overlook perhaps the three most influential impacts on winemaking in Australia, which came in the 1950s courtesy of John Fornachon, the inaugural director of the AWRI and Ray Beckwith of Penfolds: the introduction of cultured microorganisms, the effective use of SO_2 and the understanding of pH management. They remain the basic tools of our winemaking today.

In 1963 all wine was packaged in glass, 26 fl oz bottles made in amber or flint, with green glass just emerging, and in half gallon flagons, all predominately collected, washed and refilled. As an example of Aussie innovation we had invented the metal capped square flagon which, although fragile, made for efficient distribution. So called 'champagne' was all méthode champenoise and the very popular 'pearl' wines were sealed with a plastic insert under a cap. The inserts guaranteed a pop but were responsible for numerous injury claims and were subsequently replaced with retain plugs that hissed rather than popped. Since then there have been three major developments in wine packaging:

- The first was 'Bag-in-box' in 1971, when the Victorian inventor Charles Malpas designed the first cheap resealable wine valve making flexible packaging a commercial reality. For the first time wine could be kept and dispensed over time with minimal deterioration; this revolutionised wine drinking in Australia.
- The second was the introduction of self-adhesive or pressure sensitive labelling in the 1980s which gave creative marketers and label printers a design freedom not previously available.
- The third, of course, was the successful introduction of airtight screwcaps in 1998. Interestingly, the Stelvin cap, developed in France in the mid 1960s, commissioned the AWRI at that time to prove its efficacy. The trials were conducted under the guidance of Bryce Rankine, who, on what proved to be poor industry advice, used a contemporary Moselle wine for the trial. The results were spectacular but seemed to tie the concept to cheaper wines; this was commercially unacceptable and notwithstanding some gallant efforts by Yalumba and Hardys, it wasn't until 1998 that consumers really started to truly appreciate the screwcap advantage. A few of those original trial bottles still exist; I last tasted one about five years ago and the wine remained fresh and attractive.

Changes in consumer fashion, either industry-led or marketdriven, are perhaps the most interesting of the differences from 1963 to today. In 1963 fortified wines still definitely dominated the wine market - a residual effect from the surge in fortified wine consumption after prolonged beer shortages following World War II. Wine bars today have an attractive image, with connotations of sophistication and responsibility. The wine bars of Sydney in the 60s were anything but, had a young lady entered such a place her reputation would have been shot forever, however, they were one of the few drinking places in Australia you could order a glass of table wine without being derided.

Despite the predominance of port, sherry and muscat, table wines were growing at a spectacular pace, albeit from a small base. Leo Buring started the trend in the late 1940s with a light, sweet, white table wine called Rhinegolde – not the Sparkling Rhinegolde that it morphed into years later. This was followed in the mid 50s with Colin Gramp's Orlando Barossa Pearl and Ray Kidd's Lindemans Ben Ean Moselle. The latter two dominated bottled table wine drinking through the 1970s; in 1976, I think, it was calculated that one in every three bottles of wine consumed was Ben Ean Moselle. Australia briefly experimented with pop wines in the late 60s, flavoured, coloured and with predictable names: Passionfruit Pop, Pineapple Pop and perhaps best of all Penfolds Blue Rhapsody (true to its name it was bright blue). Perhaps fortunately they came and went, with only a few Cold Ducks hanging on for several years.

By the mid 1970s the so called cask-wine was creating the next revolution in Australian wine drinking. Casks were predominately white and sweet—for every glass of red wine consumed we drank seven glasses of white—casks had an acceptable image and probably every wine drinking household had a cask in the fridge, even if they were predominately bottled wine drinkers. This was also the age of television advertising: Wynn's Winecask, Lindemans Cellar Pack, Penfolds disastrous 'bag in a can', everyone who had a cask advertised, most famously Orlando Coolabah with the equally famous "Where do you hide your Coolabah?" advertisement.

Then we discovered sophistication and started to drink red wine with gusto. By the late 80s we were short of red grapes, red wine casks became a dark shade of pink and not surprisingly lost respectability. Also in the 80s we adopted varietal labelling, Chardonnay dominated the whites and our previous favourite, Riesling, declined. Shiraz led the reds and a concurrent explosion in exports led to wine shortages and massive vineyard development. Poor old wine casks, by the late 90s they were still diluted but this time with Spanish and Chilean imports.

In 1963 Australians drank 5.5 litres of wine per capita, within 10 years that had grown to 10 litres and by 1983 to 20 litres. I don't remember it, but this must have been a herculean effort; responsibly, consumption has settled at around 22 litres per capita. Recent years have seen further quite dramatic changes: the decline of Chardonnay, the phenomena of New Zealand Sauvignon Blanc which dominates our white wine drinking, a small but growing interest in alternative varieties and the mixed impact of two powerful domestic retailers, wonderful for consumers, maybe less so for some winemakers. We've also seen difficult export markets, the impact of an unusually strong Australian dollar, decline in US demand for Australian wine and growth in exports to China.

Finally, I'd like to say a few words on industry structure. We are a mix of proprietary winemaker/vignerons and so-called independent grapegrowers who have typically produced over 80% of our grape requirements. This seems to have been a pretty static and satisfactory arrangement, noting that no arrangement can be satisfactory for growers operating below cost of production when we have too many vines and too many grapes.

When I joined the industry in 1963 there were two publicly listed wine companies, Lindemans and Penfolds, and grower cooperative winemakers were major producers if not major marketers. By 1973 close to 50% of Australia's branded wine was foreign owned: Heinz owned Stanley, Philip Morris owned Lindemans, Reckitt & Colman owned Orlando, Rothmans owned Reynella and Reed Paper owned Hungerford Hill. These were highly successful marketing companies who saw great opportunities in marketing Australian wine domestically and in time internationally, but over time wine lost its gloss and by the end of 1990 all had departed. They did however leave a legacy by way of investment that at the time Australia lacked. Interestingly we are again seeing a rise in foreign ownership but this time by businesses that understand wine. We have our home-grown international wine businesses, Treasury and Accolade, the grower cooperatives have been absorbed, there is a strong successful group of large and mid-sized winemakers and a myriad of small to very small businesses: in total close to 2,000 enterprises, a long way from the 140 winemaking businesses in 1963.

Vineyard operations of the future – exciting developments on the horizon

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Abstract

Australian viticulture has a strong history of innovation and rapid uptake of new technology. From the first mechanical harvesters, to mechanical pruners and through to the most recent technologies, the Australian wine industry has been at the forefront of technology development and adoption. In spite of continued innovation and development, labour remains the biggest single cost input for a vineyard operation. This is particularly the case in cooler climate vineyards where there is a greater reliance on manual pruning, canopy management and harvesting. As such, there is a constant need to find novel ways to reduce costs of production, without compromising the quality of the end product. This presentation will provide an insight into technologies and equipment that are currently in development or in an early implementation phase within industry, and their future implications for vineyard management. Particular focus will be placed on technologies that have the potential to significantly reduce costs in areas which have a high labour requirement, without detracting from the quality of the task performed. The presentation will also provide some global perspective on emerging technologies from other manufacturing industries which have potential for incorporation into viticultural management, and may be part of the next realm of technological development in the wine industry.

Introduction

In spite of the ups and downs throughout its history, the Australian wine industry has been an exceptional success story. It has been a story of courage, know-how, hard work and extraordinary tenacity.

One of the significant features of our industry throughout the journey has been our rapid and industry-wide adoption of innovation and technology (Anderson 2010). If we look at the evolution of vineyard technology over the past 100 or so years, we have been able to make quantum leaps in our productive capacity along the way.

After the adoption of phylloxera-resistant rootstocks and the incorporation of improved varietal resources, we were able to undergo rapid expansion through the 1970s and 80s thanks to the era of mechanisation of high-labour operations like harvesting and pruning. Since then we have made big advances in the efficient use of water resources and more recently moved into new areas like precision viticulture. We have really been 'world-first' in the extent of adoption of some of these technologies throughout the journey.

I believe that if we are to continue to see the sort of success we have achieved then this discipline will need to continue. And the reason for that is that looking into the future there are numerous challenges that we are going to have to deal with.

Challenges ahead

Climate change/Environment

Recently there has been a lot of industry focus on climate change. The general scientific consensus seems to indicate that we are going to experience:

- Hotter summers and more extreme heat events
- Changes to the timing and amount of rainfall which will influence soil water and foliar diseases
- Rapid and earlier ripening (Hayman et al. 2009).

All of these phenomena are expected to have significant effects on grapevine biology and physiology (Sadras et al. 2012), and hence will have implications for vineyard management practices.

Production costs

Despite the continued mechanisation of many high labour-input vineyard operations, labour is still by far the biggest expense in running a vineyard. It can be anywhere from 30% of vineyard costs for a warm inland vineyard with a high degree of mechanisation (Retallack 2012), to 60% in the case of a cool climate vineyard with a lot of hand labour such as pruning, canopy management and handharvesting (WGGA 2008). Sourcing skilled labour willing to do some of the physically challenging work in vineyards is getting harder and harder.

Global competition

We operate in a global environment. Not only are we competing with wine, and hence grapes, from around the world, but the reality is that New Zealand, USA, South America and South Africa all have much lower costs of labour than we do, and hence lower costs of production (Davidson Viticulture 2010). China is also rapidly increasing its winegrape production.

In the context of these challenges, the bottom line is that vineyards are an agricultural business, and they are a financial entity. In order to survive they have to provide some sort of a sustainable return on investment within the context of agricultural risk. Looking into the future I see it as greatly important that we continue to look at ways to improve profitability through the adoption of new technology. What



Figure 1. Schematic diagram summarising likely changes to climate. Sourced from Steffen (2013)

follows are areas which I consider worthy of focus for improvements in vineyard productivity in terms of both quality and profitability.

Machinery

There are a number of new vineyard equipment innovations that are either currently on the market or in the development phase. I'd like to focus on a few items of machinery that I think have the potential to reduce the cost of production without overly compromising quality. In other words, mechanical innovations that are not just designed for crude cost cutting or a 'cheap and nasty' approach. I'd also like to stress that I'm not pushing any particular brands or advocating any particular technology. The success or otherwise of these technologies will depend on the economic value they add relative to their cost, the quality of the job they do, market demand, environmental benefits etc.

Robotic pruners

Remembering that labour is anywhere from 30 to 60% of the total cost of running a vineyard, and that pruning is one of the biggest single labour inputs, it makes sense to focus on potential automation of this process.

Efforts are underway to develop a robotic spur pruner, and a summary of this was presented at the 14th AWITC (Morikawa 2011). The prototype presented takes photographs of the vine, and the software determines where it needs to make its cuts. It has cutters located on robotic arms, and cameras mounted below the cutters which enable them to home in and make the actual cut. In terms of economics, figures presented indicated an annual reduction in the variable costs of spur pruning of around 35%. This particular innovation does not appear to have quite developed to the timeline which was indicated at the 14th AWITC; however, it is progressing and its pruning speeds appear to have increased. If this type of machine could be developed to the point of commercial release it may be a considerable step forward in terms of cost reduction and efficiency gains.

Mechanical cane pruning technology

This is something that has come onto the market in the past few years. There are a couple of versions of this type of innovation, and they have been designed and developed in New Zealand (Bartsch 2010). They are now starting to make some inroads in Europe.

Across the industry we do a lot less cane pruning than we once did, and that is largely because cane pruning is typically more than twice as expensive as spur pruning. However, in cool climates in particular, there are advantages with cane pruning in terms of increased fruitfulness and consistency of yield, particularly in the case of, say, Sauvignon Blanc.

Brown Brothers purchased a mechanical cane stripping machine in 2011 and it has reduced our cane pruning cost by around 30 to 40%. It is still not quite as cheap as spur pruning, but in our cooler climate vineyards the yield and quality advantages from cane pruning strongly outweigh the extra cost. The concept is that you go through and make your strategic cuts of last year's canes, which is the skilled part of the job. This machine then basically does all the pulling out, which if done by hand is the laborious and most expensive part of the job. After the machine has been through, the replacement canes can be trimmed and wrapped down as per normal. So there's less overall labour required, and hence the task can be completed with a smaller and more skilled crew.

I think this is a great example of thinking creatively about a problem (in this case the significant expense of cane pruning) and coming up with a novel solution.

Mechanical harvesting/De-juicing

The Juiceliner (ERO-Gerätebau GmbH) is a combination of a mechanical harvester and a decanter. So instead of grapes coming out of the machine into a bin, you get juice coming out into a tank towed by a tractor. The grapes are picked, go through a de-stemmer and then into a decanter, which spins at 3,500 revolutions per minute, creating 3,000 Gs of force. That separates the juice from the skins and vineyard waste. The revolutions can be varied to increase or decrease the extraction rate from 500 to 700 L/tonne. The juice is pumped to a tanker which is pulled beside the harvester instead of a grape bin (Berry 2011). Enzymes and sulfur can be added. The skins, pomace etc. are dumped onto the ground. It can do over 10 tonnes an hour, yielding up to 7,000 litres of juice, and reportedly has achieved rates of 10,000 L/h.

So my hope would be that this would remove the majority of hand picking that's still done, particularly for sparkling grapes, because it is taking the juice off skins immediately. It would have the advantages of enhanced efficiency, less grape transport weight (skins, rachis, etc. go onto the ground) and enhanced quality due to reduced skin contact. The disadvantages are that clearly it would only benefit white, rose or sparkling wines, and the prototype machine is very heavy (12 tonnes). The company that is developing this machine expects to have it on the market in 2017.

Autonomous tractors

Autonomous tractors and self-propelled sprayers and harvesters are on the horizon. Several companies are working on this including John Deere, Case, and Fendt. A level of this technology is already being used in the grains industry where driverless slave tractors will follow a lead tractor in sowing operations. Auto-steering with global positioning system (GPS) guidance is now commonplace in broad acre cropping.

So with auto-steering and internal engine management you could think of it as the tractor being on autopilot. I think that is a step along the pathway towards autonomous vehicles. A tractor that operates itself, or is in effect on autopilot, takes away the need for the driver to focus on driving it. This would enable an operator to focus very closely on the implement itself, and perhaps the implement could have additional controls for close fine tuning. This could really enhance the outcomes of an operation. The technology exists such that this could probably be done now.

But there are further applications of this technology in the area of autonomous tractors. If we consider, say, a warm climate vineyard, a significant portion of the labour we employ sits in a tractor and acts like a long-haul truck driver driving up and down rows performing tractor-based operations.

As a further progression, John Deere is working on a prototype futuristic tractor which uses computers and signals from satellites to drive programmed routes without a human driver aboard. The vehicle receives signals from global positioning system satellites via two six-inch domes on top. Two antennas on the rear receive signals from a computer on the ground that holds the master plan for the machine's assignment and allows a human to monitor the work remotely and act as a supervisor.

We can then have the ability for a supervisor to monitor and control three or four sprayers at the same time, while sitting in an office, away from the chemicals etc. The antennas can also be used if the operator wants to use a joystick to steer the vehicle in or out of its storage shed because the satellite signals will not penetrate buildings or heavy foliage. Out in the open, the tractor will follow programmed routes and electronic maps of the work area, using information from satellites to determine its location and driving at speeds preset by the computer.
Driverless cars are now legal in Nevada (Arthur 2012). It seems the technology exists for autonomous tractors to become a reality for us at some stage. The biggest issue is safety, and then cost.

Automated yield estimation

While this could certainly result in some cost cutting, it is probably more about value adding. The accuracy of yield estimation is a big issue for the wine industry. We make fruit sourcing and pricing decisions based on yield estimation. We make yield management or thinning decisions based on it, and there are the obvious winery intake logistics based on it.

The general current approach to yield estimation is based on either the gut-feel of the grower, block history, or more objective measures like randomised bunch and berry counts. Across the industry our average performance in terms of accuracy is $\pm 30\%$ (Dunne 2010). The need for better performance is well documented. But in reality the only way to achieve greater accuracy is to be able to drastically increase our sample size, and to do that manually would become highly expensive.

There is a collaborative research effort going into an automated method of yield estimation (Nuske et al. 2011). This is a non-destructive method which uses camera images taken from a quad bike that drives along the vine rows. Computer vision algorithms are applied to the images to detect and count the grape berries. Shape and texture cues are used to detect berries even when they are of similar colour to the vine leaves. A ratio is applied to allow for hidden berries (e.g. the back side of bunches). Nuske et al. (2011) reported total block yield estimate accuracy within 5%. Similar experimentation has also recently been conducted in Spain (Diago et al. 2012; Tardaguila et al. 2013).

Varietal diversity

To this point I have focused mainly on the cost side of the ledger. Now I'd like to focus on the production side of the equation. I see increasing potential for introducing more genetic diversity into our varietal mix. By that I do not mean genetically-modified organisms, although I think we need to remain aware of what is happening globally in that space, but I mean specific breeding using existing varietals. CSIRO has been doing this for quite some time.

Commodity wines

In the face of climate change and an ever-increasing focus on our environmental impact, I see real potential for alternative varietals with various desirable attributes, particularly in the commodity wine end of the market. And by alternative varietals I do not necessarily mean the latest imported Spanish or Italian varietal, I mean varieties specifically bred to suit our industry and our conditions. For instance, focus could be placed on greater disease resistance, improved water use efficiency, improved quality attributes and yield.

By way of example, in 2010 Brown Brothers planted six experimental grapevine varieties at Mystic Park near Swan Hill in Victoria. These varieties were bred by CSIRO. Harvest of all six varieties occurred in 2013. One of the red varieties was harvested in early February 2013 at 13.5 Baume, approximately 2.5 weeks ahead of Shiraz from the same vineyard. The fruit had a significantly higher berry colour than Shiraz (as per Brown Brothers' Berry Colour Density Index measurement method) and a higher yield. If we can pick a variety at full physical maturity in late January or early February, instead of a month later, we can realise significant water savings compared to later harvested varieties.

Also, as a broad statement, for reasons of grape quality I consider we have largely constrained ourselves to 20 t/ha for traditional red varieties in warm inland areas. However if we can grow new red varieties at 40 t/ha with equivalent or even improved quality (e.g. colour, aroma and mouth-feel), then why not? Yield is arguably the most significant driver of vineyard profitability in these climates.

It is also possible that varieties could be developed which have enhanced disease resistance characteristics. One of the scenarios being raised under various climate change scenarios is increased summer rainfall. To this point in time, the industry does not have a reliable late season chemical control option for bunch-rot. Perhaps varieties with loose bunch structure, or thicker skins, which make them more resistant to bunch-rot without the need for chemicals could be developed.

Fine wines

I can imagine it is a much harder task to take a new and unknown variety and sell it for \$40-\$50 dollars a bottle. So I see that traditional varieties will dominate the fine wine category. In recent years we have been seeing a rapid expansion in clonal diversity, on account of companies like Yalumba and others importing improved clones. I can see the identification of superior clones based on quality and other desirable attributes (e.g. yield, bunch structure, berry size) remaining an area of focus in this end of the market.

What if?

Before I finish up, I'd like to throw caution to the wind a bit and think fairly broadly about future technologies in vineyard operations. It is impossible to predict exactly what technologies are going to emerge in our industry in the future. It is likely that in time something will emerge that very few of us have even thought of yet.

One emerging technology that is increasingly being researched for its application in agriculture is nanotechnology. Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. To provide some sense of perspective, a sheet of newspaper is 100,000 nanometers thick (NNI 2013). Nanotechnology has been described as the new industrial revolution and both developed and developing countries are investing in it heavily. For example the US Government budget for research into nanotechnology in FY13 was close to \$1.8 billion (NSTC 2012).

Within the agricultural sector, research is underway on a wide variety of products based on nanotechnologies. These include the use of 'smart dust', in the form of a network of wireless nanosensors, to monitor temperature, humidity, and perhaps insect and disease infestation and relay that information back to a computer in the farmer's office (Busch 2008). Research is also underway into applications for nanotechnology in both early detection and control of plant diseases (Sharon et al. 2010).

Perhaps one day a network of wireless nanosensors could be distributed throughout vineyards to provide virtually real-time intelligence on the presence and location of grapevine diseases. Could this type of technology negate the need for human monitoring and subjective assessment? Remote sensing of disease could be the next major step forward in precision viticulture. Knowing the exact location of fungal pathogens in real time would have major benefits for effective disease control.

There is also research underway into potential applications for nanotechnology in the control of fungal pathogens. For instance, nano-sized silver-silica has been shown to inhibit spore germination of *B. cinerea in vitro* and also to control powdery mildew in cucurbits in-field (Park et al. 2006). So perhaps nanotechnology could not only provide a means for remote disease sensing, but one day also provide control options as well without the need for inorganic chemicals.

Clearly it would be drawing a long bow to claim that something like nanotechnology is going to be the next big thing in our industry, and this is by no means intended to be a definitive suggestion. It is possible that nanotechnology will be just a flash in the pan (Busch 2008). But I think it is worthwhile to occasionally ask the question "what if?"

Conclusion

When pondering what vineyards of the future will look like, it is essential to consider what our future challenges will be. Although the challenges are numerous, I consider that adapting to climate change and maintaining vineyard profitability are amongst the most important. It is essential that we remain focused on the vineyard as an agricultural business which has to be both environmentally and economically sustainable for the long term. There are a number of exciting developments on the horizon which will help deal with the challenges that we currently face.

In terms of costs of production, labour continues to be the largest expense in running a vineyard. We are also at somewhat of a disadvantage to other wine-producing countries because of our relatively high cost of labour. There are a number of different vineyard equipment innovations which have recently become commercially available, or are in the development phase, which have the potential to significantly reduce the cost of production by way of labour savings. However, it is important that such innovations do not overly compromise the quality of the operation and the final grape quality.

I consider that there is potential for increased genetic diversity within our varietal resource to help deal with the challenges being posed by climate change. This could be by way of improved disease resistance, water-use efficiency, quality, yield or cost. While I do not envision that such varieties will ever completely replace traditional varieties, they may be used to complement our existing production base.

In the much longer term, there may be potential for innovations that are occurring in other areas of science and industry to provide solutions to further drive our technological capability.

Throughout the history of the Australian wine industry, our ability to share information and invest in research and development has been a significant feature. Our ability to evaluate and rapidly adopt appropriate innovation on an industry-wide basis has also been a key success factor. I think there is little doubt that this will need to remain a feature of our industry as we look to the future.

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Emerging technologies in the modern winery – key insights into developments on the horizon

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Abstract

The emerging technologies for current and future wineries are being driven by the continual increase in the speed and capacity of mass storage, and the miniaturisation and smaller power requirements of electrical and optical devices. Those devices are now coupled with wireless communication and in most cases time and position information. At a larger scale, lower cost solar power generation for supplementary or self-sustainable energy applications is increasingly available. The use of such power for capturing, filtration and reuse of cleaning solutions and the sequestering technologies for fermentation carbon dioxide, are both examples of the energy-water-carbon nexus that will determine the long-term business viability of many wine companies throughout the world. The rates of change in the cost and performance of the underlying hardware, such as data storage and wireless communication, have typically changed by 100-fold over the past decade, and such rates that are often hard to comprehend in annual business terms. A review of existing technologies that are expected to undergo at least an order of magnitude reduction in scale, together with the development of several desirable and useful 'smart' sensors that might be applied to winemaking, winery systems and new winery projects will be presented.

The challenges

The most significant challenges in the future of winemaking will be the scarcity of water for winemaking operations and the move towards renewable and/or non-carbon energy systems. The global challenge will be the improvement of tracking and effective delivery of wines to market, specifically the environmental control of bottled wines from winery to point of sale. The future will call for a 'best before' indication on the label and those not able to estimate this will probably be less favoured or not handled. The environmental and climate challenges will develop beyond our control but they will need to be managed more closely and intelligently in the near future. The absence of a 'best before' indication has placed the wine industry at least a decade behind less valuable products such as milk, soft drink and beer, and suggests that no company (or national industry) has yet developed a model for the interaction of temperature, bottle oxygen transfer and wine chemistry, perhaps the greatest limitation to improvement of delivered value.

The drivers of change

The drivers of change will be the continual reduction in size and price of semiconductors and the persistent decline in the price of photovoltaic (PV) panels. These will provide the basis for enhanced measurement and power generation capabilities, locally and remotely, far beyond what could have been expected by most optimists only a few years ago. Of more significance than the drivers themselves are the rates at which they are changing.

Rates of change: cost of solar PV, semiconductor memory and lithium-ion batteries

The progression in the prices of semiconductor memory, solar PV panels and lithium-ion batteries, have been on a path of exponential decline for many years as can be seen in Figures 1, 2 and 3. The price data has been adjusted into 2012 US dollars.

The rate of change of the cost of a megabyte of memory has been consistently decreasing at 41% pa for in-line memory modules and 55% pa for small memory devices since 1960. This is equivalent to a halving of the cost, or a doubling of the capacity, every 16 to 20 months. This rate has resulted in a 100 billion times the memory capacity at the same cost during the past five decades. Such extent and rate of change is almost impossible to comprehend in business and budget terms even with the widespread use of computers and cell phones in



Figure 1. Cost of memory modules since 1950 (redrawn from Lafayette 2007)



Figure 2. Cost of Photovoltaic modules since 1970 (redrawn from Breyer and Gerlach 2013)



everyday business. The more significant aspect for the future is the reduced size and power requirements of smart sensors and the role of wireless communications in delivery of winery process, analytical and environmental data.

A similar pattern is observed in the unit cost of solar photovoltaic modules. In this case, a 40-fold reduction has taken place over three decades at an average rate of almost 9% pa or halving every eight years. Much of this change is due to the increased production as installed capacity increases exponentially, rather than to improvements in cell efficiency, and expectations are that it will continue into the near future at efficiencies of 20 to 22%. The adoption of solar is further encouraged with installation subsidies and accelerated depreciation in many places. While the general trend line in Figure 2 would expect the \$1/Watt milestone to be reached by 2020, prices in 2012 had fallen to \$0.80/Watt after a global shortage of silica was overcome.

The correspondence of price declines (19% pa, halving every four years) (Figure 3), and advances in vehicle-scale lithium-ion batteries also make the storage of excess solar power more possible as well, extending the effective day-length of solar systems and overcoming limitations of returning an excess to the grid, an impediment that many solar installations presently face.

In a Shell Lens Scenario report of the world energy picture (Shell Scenarios Team 2013), solar energy is expected to be a major energy source by 2070, typically four times any other source and almost 40% of the total by 2100 (Figure 4). A future in which most wineries are off the grid in daytime, especially during harvest due to a continually decreasing price of solar panels is no longer a pipe dream and should be planned for. This will also prompt a more serious consideration of storage of excess energy, something that has not been a possibility in the past, and these trends have major implications in design of future wineries and the retrofitting of existing ones.

Advanced sensors, precision and timeliness of measurements

The rapid changes in semiconductor capacity and speed, and the physical miniaturisation of sensors and loggers together with the advent of affordable wireless communication capabilities, opens up possibilities for major improvements in gathering production, analytical and shipping data for planning and management, as well as ensuring more reliable and acceptable shipping and delivery practices. These capabilities include more acceptable temperature limits for wine shipments, and this in turn could lead to less severe, extensive and wasteful stabilisation practices, together with tracking and traceability that will provide true quality certification for the complete delivery chain, from grape to glass, locally and globally. Today there are several commercial USB-based temperature loggers that operate on what are essentially watch batteries, and these can track bottled wine history



Figure 4. Estimated energy mix in 2100 (redrawn from Shell Scenarios Team 2013)

by the case and position in a stack, truckload or shipping container. When coupled with a small data hub that records global positioning system (GPS) location, detailed temperature-time histories can be gathered at the case level, for hundreds of positions in a shipment.

The miniaturising of existing temperature, pressure, density, composition and flow sensors will enable more precision and frequency in data gathering. It will aid the development of measures such as footprints, with the ability to log data directly into databases immediately, rather than manual entries into spreadsheets and other applications, some of which experience significant delay, quite apart from erroneous entry. From simple tank transfers, starting and ending timestamps, starting and ending volumes and verified tank locations, to reporting back into a work scheduling, activity database, which automatically changes inventory and location information and updates composition and volumes (corrected for temperature) if blending was involved. This would allow all winemaking and scheduling decisions to be based on accurate and up-to-date information, with error flagging of questionable data. This could be accomplished tomorrow with commercial, inexpensive, compact, low power transducers at the base of each tank and low cost, in-line density meters.

Footprint measurements

The concept of the footprint of a product, at least for carbon, is now fairly widely understood and the next stage is the parsing of the total footprint into the various stages of its production and delivery. There are several certification programs already in existence, but few which have gone to the point of requiring actual footprints rather than just practices. With a significant sector of wine consumers now asking for some sustainability metrics to be provided with wines at the point of sale, and some retailers beginning to ask for sustainability indices as a part of placement considerations, there is an immediate need for comprehensive gathering of not only carbon data, but water and energy measures in the winery (and vineyard) as well. In the future, real-time reporting might include the year-to-date versus past year's values and numbers for the biological oxygen demand (BOD) and chemical oxygen demand (COD) for wastewater; sodium, potassium, nitrate and phosphate; and COD for cleaning solutions and solid waste such as grape skins and seeds, wood pieces, etc. As an example of what is possible, the annual report of the Pernod Ricard group (Anon. 2005, 2012) presented the annual footprints for water, electricity, natural gas, fuel and carbon for more than 60 locations. They also report carbon dioxide from combustion and fermentation, outside use of treated water, recycled solids and other measures. All of these measures could be collected in real time today, from many locations across the globe due to advances in networks and smart sensors.

Winemaking applications

While progress has been made in the rapid estimation of major juice components, these are at best able to estimate spoilage or grape defects at the major level. True measures of grape flavour or flavour potential remain elusive for all cultivars. Perhaps the use of such a major component analysis method to estimate the 'non-reducing sugar' extract to establish a relationship between juice extract and wine extract might be possible, even taking into account the formation of glycerol and succinate and the possible conversion of malate to lactate. This measure would provide more reliable estimates of final ethanol from initial density measurements before fermentation begins. It would also provide a wine-specific relationship between wine density and wine volume, which could be verified by in-line density measurements, so that pressure transducer measurements of liquid weight in tanks could lead to an immediate, accurate estimate of wine volume. Recent developments in fermentation monitoring such as direct density measurements (and their correction for temperature) and subsequent wireless data transfer, Figure 5, now exist after years of trials and relatively expensive, wired, bulky sensor solutions. With simple software additions, the rate of fermentation can be estimated and even model fitting in faster-than-real-time is possible. Such measures would enable the prediction of cooling requirements and carbon dioxide evolution in the hours ahead, useful information that smart refrigeration and energy modelling software would like to know. Perhaps such measurements and modelling would detect delays in the onset of fermentation, due to oxygen or other nutrients, slower than expected growth rates of yeast and early detection of conditions that could lead to incomplete fermentation.

The development of multivariate models that can estimate various phenolic measures from UV-visible spectra led to the possibility of following extraction patterns during red wine fermentations. One example of such a model (Skogerson et al. 2007) estimated the components of the Harbertson-Adams assay, and Figure 6 illustrates the tracking of these components. This example is for a Cabernet Sauvignon-Cabernet Franc co-fermentation that has received four days of a cold soak prior to fermentation.

At the research-scale, a sensor for the direct, i.e. undiluted, measurement of total phenolics and colour during red wine fermentations using a 100 micron pathlength cell and a series of inexpensive light emitting diodes, has recently been developed at UC Davis (Shrake 2013). Figure 7 shows the extraction patterns for total phenols and colour as a function of temperature for a set of Shiraz fermentations during the 2012 harvest, using this sensor. Similar diode arrays could be developed to look at the ratio of 280 nm to 320 nm and used to distinguish the extent to which skin phenolics (A280) are increasing relative to the juice-based cinnamates (A320) during pressing, and this could lead to the separation of press fractions, based on in-line phenolic measurements, especially for white grapes.

Other projects in progress involve the development of a frequencybased, flow-through sensor for the estimation of yeast cell numbers in the background of bubbles and grape cell fragments. This would enable not only the tracking of yeast growth rates and population size but particularly the detection of the first cell division and the onset of yeast growth, before any significant density change can be detected. The implications of recognising nutrient deficiencies or yeast stress at the earliest stage of white wine fermentations are obvious.

In all of these cases, the data will be available wirelessly throughout the winery, not only on a webpage. Winemakers could look at the fermentation, phenolic extraction and yeast growth on their smart phone. They could decide to change the temperature or pump-over settings and could add notes or comments in seconds.

In-tank process technologies

The limitation of water for tank washing will require that in the future we will have to move towards in-tank treatments so that cleaning is not required due to a tank-to-tank transfer. The adoption of in-tank treatments for heat and cold stabilisation, fining and blending, will require the adoption of alternative technologies that enable such treatment and return to the same tank. The development and adoption of column-based fining and stabilisation treatments, ideally with regenerable materials, will be central to this migration. Studies of materials suitable for regenerable columns that could replace bentonite (and the usual in-tank treatment and clarification) have been completed more than a decade ago (Sarmento et al. 2000) and await pilot-scale development. This approach might be extended to include the phase out of additives and a move towards non-residue treatment technologies so that residues due to additives are not a concern in the marketplace.

Other examples would be the development of high-throughput flotation systems such as Jameson cells, for in-line clarification of white juices that will replace the usual holding and settling, often with significant energy load if it is cooled. The thinking is to avoid the settling and racking that requires the washing of a tank that was filled less than a day before. The case could be made in terms of labour, the requirement for two tanks, the cooling load, oxygen pickup or lees volume, but it will be the water for washing that will probably determine its adoption. Jameson cells have the potential for better control of the gas to solids ratio, they could have throughputs similar



Figure 5. a) Brix and juice temperature curves in a white wine; b) Brix, skin cap, juice temperature in a red wine



Figure 6. Estimated Harbertson-Adams assay components from UV-visible spectra



Figure 7. LED sensor measurements of total phenols (A280 nm) and colour (A525 nm)

to centrifuges and can be scaled in parallel, and they have no moving parts. While they are widely used in mining applications, there is a need for flow pattern studies to choose geometric proportions more suitable for white juice clarification.

There are related in-tank treatment possibilities for a) potassium bitartrate stability using fluidised crystal beds or other flow-through systems and b) blending systems that pull wine from several tanks at different flow rates to determine the blend proportions and return the blend to the same tanks at the flow rate which they left. In slightly more than one tank turnover, the final blend will be in all of the starting tanks without the need for tank cleaning. Both of these practices would eliminate the tank washing associated with conventional in-tank treatments. The fluidised-bed crystalliser needs further pilot-scale testing for control strategies, while examples of the blending system have been in use for several years in at least one major winery and simply need adoption.

In a more general view, maybe all future fining treatments will be with immobilised proteins, tannins, enzymes and chelates or adsorption materials, that would fit the in-tank column treatment approach for water saving. At the same time this would eliminate treatment residues such as proteins, active enzymes, copper sulfate and ferrocyanide. Such an approach might also be able to employ chemistries that are not permitted, such as bound silver contact surfaces for sulfide removal as an alternative to copper sulfate and iron-chelating resins, to slow down the initial rate of oxidation.

Sustainable cleaning practices

At the interface between significant reductions in water use and less wastewater treatment, lies the adoption of simpler cleaning practices. These will eventually require the adoption of clean-inplace technology and in the future, spent cleaning solutions might have to be captured, filtered and reused many times compared to the one-time use that is universally practised today. At the same time potassium-based salts, hot water and hydrogen peroxide will become the chemistries of choice so as to reduce the BOD and COD contributions of cleaning compounds, and eliminate sodium from discharged wastewater.

The selection of alternative cleaning chemistries is hampered by the lack of any standard for acceptable cleaning such as wine reference organisms and the decade reductions of viable cells. Obviously we need to establish disinfection standards for wine organisms, especially for stainless steel surfaces of tanks and process equipment. In the absence of data for relevant wine microorganisms, the use of E. coli can be used to illustrate the possibilities for cleaning practices based on a combination of hot water, low pH and hydrogen peroxide. Figure 8 shows the reduction in the viable fraction with time using water and a pH=2.0 buffer. The calculations are based on the equations of Cerf et al. (1996). Hot water at 60°C can reduce the viable fraction by three decades in 100 seconds and by four decades in about 150 seconds. By comparison for a pH=2.0 solution at the same temperature the times are 60 and 80 seconds respectively. The corresponding times for these solutions at 50°C are 1800 and 2200 seconds for water and 1000 and 1400 seconds for the pH=2.0 case. The 50°C case corresponds to 30 and 36 minutes for water and 17 and 25 minutes contact time for the low pH case, all times that are reasonable for automated cleaning cycles (not including drying times) and at temperatures that passive solar hot water systems can easily generate.

By comparison, the adoption of hydrogen peroxide as the sanitising chemistry poses some special possibilities in that peroxide is one of the few agents which is active at both high and low pH conditions. This would enable longer contact times since it could be in both solutions, or even longer contact times if it is added to the initial rinse solution and drying is taken into account. Hydrogen peroxide avoids the exposure and phenol degradation products associated with ozone, and in dilute form, 1 g/L, is capable of a three-decade reduction in 90 minutes in ambient temperature water and a four-decade reduction in 120 minutes, as shown in Figure 9. The calculations are based on the model developed by Labas et al. (2008).

While we have no data for the sanitising activity of hydrogen peroxide on *E. coli* at high or low pH or at temperatures of 50 or 60°C, the possibility exists for acceptable reductions in viability at lower concentrations or with shorter times. If hydrogen peroxide was combined with dilute potassium bisulfate (pH=2.5, 100% peroxide activity) and dilute potassium hydroxide (pH=11.5, 50% peroxide activity) acceptable disinfection contact times are possible during basic and then acidic rinsing cycles. Such solutions could be recovered and reused multiple times and would eliminate any sodium, phosphate or nitrate from eventual land applications. Eventually, when mixed for discharge, a dilute pH=7.0 potassium sulfate solution, without any BOD or COD contributions is the outcome.

The delivery environment and post-winery quality control

Perhaps the most significant impact on growing value will come not from changes in grapegrowing or winemaking but rather from addressing the degrading handling environment that wines experience once they leave the winery and providing a guarantee of quality in delivery to consumers by printing a 'best before date' on the package.

The application of temperature-time measurements during shipments will become an essential feature of wine distribution in the future. There are a range of affordable battery powered loggers commercially available for this purpose. There will need to be some estimation of degree-day summations above (or below) some datum temperature and a defined threshold value beyond which the wine is not to be placed on the shelf for sale. This would relate more to non-oxidative reactions such as ester hydrolysis, bottle age development or free sulfur dioxide loss by high temperature diffusion or the likelihood of crystal formation and freezing at low temperatures. A second criterion might be the peak-to-peak temperature variation as this relates to the expansion and contraction effects that cause free sulfur dioxide to be lost (by expansion) and oxygen to be drawn in (by contraction) at rates far greater than those of diffusion alone. This will be an indicator of oxygen ingress, which will drive the loss of sulfur dioxide by oxidative reactions, with obvious appearance of acetaldehyde when the free sulfur dioxide is lost.





Figure 8. Viable fraction with time for E. coli at pH=2.0 and 7.0 at various temperatures

In order to put these temperature effects into context, wineries will have to establish predictive 'shelf life' models based on wine chemistry and package oxygen transmission rates at standard temperatures. These shelf-life spans should be the basis for a 'best before' date from the date of bottling. The ability to relate rate of oxygen uptake to wine chemistry remains perhaps the greatest dilemma in wine science and should be the major research initiative at all research institutions in the next five years. Our poor understanding of the mechanism and kinetics of these reactions will limit the progress that can be made towards developing compositional models for estimating the shelf-life of each wine. Perhaps there should be large investments in trying to understand the relationship between the rates of change in hydrogen peroxide, oxygen radicals and wine composition, as well as similar studies on the rates of radical scavenging or quenching reactions in relation to composition. The long-term objective should be the prediction of the free and total sulfur dioxide levels in the package with time, under defined temperature conditions, for each winepackage combination.

Some unexpected outcomes

Perhaps in a future in which wine temperature is monitored during shipment, there will be data available to set more reasonable standards for the limits of exposure of wines to temperature. This will have significant implications in the adoption of more reasonable stability tests based on temperatures such as 35 or 40°C for heat stability and 5 or 10°C for cold stability. This in turn will alter the winemaking practices and extent of treatments that are centred on these tests and deliver more of the grape and wine quality that was initially delivered in the production chain, primarily by the elimination of the degradation caused by poor transport and storage conditions. Maybe there will be different stability temperature conditions for white and red wines and for wine of different price points, or package types or markets.

Sustainable winemaking

The future will require that wineries and vineyards openly provide information related to their environmental footprints. These will include not only the obvious water, energy and carbon footprints, but are likely to include a chemistry footprint that might include subsets for sodium, chlorine, phosphate, nitrate, and maybe the BOD, COD of wastewater. Other metrics that might help demonstrate the use of good practices include the number of times water is used within the winery (and 1.0 will not be a good number), the average number of wine transfers or movements, and the extent to which the winery is self-sustainable in water, energy and the extent to which carbon dioxide is sequestered. The first two do not have to be 100%, but knowing the number will be important, and improving it over time will likely be viewed positively and be expected.

The design of future wineries

In the future there will have to be a greater emphasis on water and energy systems as an integral part of winery design and construction. The investment in on-site rainwater capture and storage, and in on-site or nearby solar and wind electricity generation, will be needed and hopefully incorporated into the building architecture and site considerations. The future of fermentation halls will probably require that fermentation vapours be collected and delivered to locations at which future sequestration technologies might be connected.

There will be a number of downstream outcomes, some of them not immediately apparent, of choices such as rainwater collection. These will show up in time, because softer water for cleaning will lead to lower chemical input to prevent deposits on equipment. Consequently the performance of membranes that recover the cleaning solutions and the extent of recovery of these solutions will improve, less water will be required, and the extent of wastewater treatment will be smaller. These all come out of softer water and its recovery and reuse. A similar cascade could be developed for electrical energy; if warmer refrigerant temperatures were chosen, this would lead to higher efficiencies. This goes further; if less cold settling of juice is employed due to in-line clarification, refrigeration systems would become smaller rather than larger. When coupled with solar energy and cold reserve storage, the systems will be even smaller again.

There is a winery being built at Davis which will eventually be both energy and water positive, carbon zero by sequestration, and operating on a solar-hydrogen-fuel-cell hybrid. It will operate only on captured rainwater and will use water at least 10 cycles, targeting 90% recovery of all cleaning solutions. This, together with the peroxide potassium buffer system previously described, will have one-fifth the water and chemistry footprint of a conventional winery of equivalent size. A diagram of the systems involved is shown in Figure 10.

Conclusion

The future holds significant potential and promise for wineries that choose to adopt the water-energy-carbon-chemistry nexus and the openness that future consumers and parts of the wholesale and retail chains will demand. The cost of adopting the critical components of this picture are changing rapidly and this is true for monitoring



Figure 9. Viable cell reduction with time for *E. coli* at pH = 7.0 with various concentrations of hydrogen peroxide



Figure 10. Schematic of a winery operating on rainwater and solar energy, with potassium-based cleaning solutions and sequestering all carbon dioxide from fermentations

everything from fermentations to shipment and storage temperatures. These measurements will empower further changes in delivered wine quality at minimal investment while at the same gaining considerable trust and respect that the wine industry has never really captured. The future design of wineries will require a far deeper understanding of energy generation and use, and a parallel regard for water availability and use. The future will inevitably involve significant degrees of on-site capture of water, energy and carbon, and the sharing of footprint information with consumers and global reporting agencies.

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Continuous improvement: a winery case study

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Abstract

Rosemount has a long, proud history and is home to some of Australia's most successful brands. The winery at McLaren Flat, SA was established in 1888, became the home to Rosemount in 1992 and in 2010 became part of Treasury Wine Estates. The winery employs 35 permanent staff, has a crush capacity of 20,000 tonnes and a storage capacity of 23 million litres. At the beginning of 2009, Rosemount initiated a program of continuous improvement (CI) founded on long-standing principles that are highly developed and well applied in many manufacturing industries, in particular the automotive industry. However, structured and well organised CI processes are not widely applied throughout the wine industry. The basis of all CI programs is improved performance. Consistently challenging current performance – seeking to do more, do better, search for and eliminate waste and inefficiency. A successful implementation of CI results in a culture change. As with any approach to culture change the success or otherwise is largely dependent on a handful of critical elements. Rosemount's success was underpinned by:

- Business strategy supporting the initiative from the board down
- Belief and leadership from the CEO, winery management, winemaking and cellar teams
- People. It starts and ends with people respectfully empowering the right people in the right places.

With a structured and simple approach, CI has linked everyone's day-to-day activities to the broader goals of Rosemount Winery and the overall ambition of Treasury Wine Estates, "To be the world's most successful and celebrated wine company". The heart of Rosemount is our people who feel valued and appreciated at work with a passion for wine and an entrepreneurial spirit.

Introduction

Today I'd like to share with you the Rosemount improvement story. I'm going to cover:

- · Cultural change the need and desire to change
- What is CI?
- What we did at Rosemount; how we did it
- Some audience participation
- Video footage of before CI was introduced at the winery, talking to people that work at the winery, and some video footage after, talking to the same people about how it has been since the introduction of CI
- And finally, I'll explain some of the results to date.

The take-home message put simply is, "You can do this! Any business can do this." It's all about cultural change and engaging your people.

Rosemount history

Rosemount has a long, proud and successful history and is home to some of Australia's most successful wines. The winery was established in 1888 – it certainly goes back to horse and cart days. Wind the clock forward 100 years, and the winery became the home of Rosemount in 1992. It's a great business, with great people making great wines. Operationally we employ 35 staff, we have a crush capacity of 12,000 tonnes and juice holding capacity of 23 million litres. But we wanted to challenge ourselves, could we do things better?

Now every business has pressures placed on it whether it's environmental, cost, suppliers or competition, all driving us to rethink how we go about our day-to-day business. Certainly at Rosemount we weren't immune, we needed to understand "How can we do things better?"

We recognised the need to change, we didn't have a burning platform, we were successful and we were making good wine. We wanted to challenge ourselves and the status quo – could we do things better? The six most expensive words you can hear anyone or any business say are "We've always done it this way." I grew up on a family market garden in the Adelaide Hills where both my Dad and Grandpa also grew up. You grow up just knowing that things are done in a certain way and that's how Dad and Grandpa have always done it, but really we need to be challenging ourselves and understanding why we do things the way we do.

What is CI?

First, I can tell you what CI is not. CI is not a 'one-off' or 'cost reduction' program, and it's certainly not the result of a training session. You can't just send some people away and think "right, they're trained in CI", have them come back to your business and then implement CI. It's much more than that. And it's not new to many industries. It's widely applied, being well-known in the automotive industry but also in medical centres and in agriculture. It's alive and well. You'll also find the finance industry starting to use principles of CI as well.

What is it? It's focused on improving performance and it's about cultural change – a new way of thinking and working. Think about behaviours like teamwork, challenging the status quo, having mutual respect for each other, and the notion of 'go, look, see'. It's not just troubleshooting behind a desk; go out to where the real value is being added to your business and talk to the people who are adding that value – and continue learning.

The major objective of CI– it's not a capital program, it's not a 'splash the cash' – is to utilise your existing equipment and facilities, your methods of working and your people. How can you tap into your people's intellect and your resources? It's about simplifying your processes - why do we have complicated processes? Just strip away the waste.

We knew some of our basic measures but for us to improve we needed a better understanding of the operational measures which drive performance. We knew what our operating budget was, we knew injury rates, the number of near misses, but what were the real drivers of performance? We needed to engage our people and give them input into day-to-day decisions. And did we have a plan? And do we measure ourselves against that plan? Well, you'll hear me talk about 'plan' versus 'actual' as well.

What did we do and how did we do it?

What did we do and how did we do it at Rosemount? We had business strategy from the board down endorsing the initiative, so this is where

we introduced the discipline of continuous improvement. Then we had consistent messaging and mutual vision; we had leadership and belief from our managing director and our CEO, all the way down to the winery and vineyard managers, right down to the guys that operate on the cellar floor and in the vineyards. Consistent messaging is critical for engaging your people. Once we engaged our people we introduced some simple tools. These included visual management and 5S - I'll talk a little bit more about those shortly. We provided the tools so that we could start to build capability in our people. Once we were at that point, building their capability, we could then improve effectiveness and the rest starts to come, and that's what we're starting to see at Rosemount now. The results and benefits start to come, the efficiency gains will come, and the productivity gains will come. And engaging your people, engaging the right people in the right roles is critical as well.

Our business

We recognised the need to understand the drivers of performance. What were our operational metrics? For example, safety – did we do it well? Did we do it at all? Were we good, bad, or indifferent? What was our cost per litre produced – do we know that? Could we do better? Efficiency - litres of wine moved or produced per labour hour? Did we have a grip on that? Probably not. Did we measure ourselves against these daily, weekly, monthly or not at all? It's pretty hard to improve if you don't have a target or measure to benchmark yourself against! So a lot of what we did in 2009 when we started this process was benchmarking ourselves so we could measure our performance and our improvement from then on.

Fundamentals of CI

Once we had an understanding of these operational metrics we started to introduce the fundamentals of CI – the way we think about our work, the way we go about our day-to-day activities:

- Visual management it's exactly that, rather than the information sitting behind a PC somewhere on some manager's desk, let's get the information out there so we have some transparency with our team.
- Standard work is really just trying to get repeatability in the process we do. If you have a standard operating procedure, half a dozen people might do that six different ways, whereas with a standard work document it will be done the same way every time. This gives you repeatability and much less rework.
- 5Ss these are: sort it out, set it in some sort of order, shine, standardise it, and sustain. If you think of how much time is lost in labour when you can't find things, whether it's in the office and you can't find stationery, or in the winery and you can't find fittings or pumps it's a real issue with a lot of time and labour lost looking for things.
- Daily stand ups it's exactly that. It's not a sit down meeting with a cup of coffee talking about the football; it's a quick structured ten-minute meeting: How did we go in the last 24 hours? What are we doing in the next 24 hours? Against those metrics of safety, quality, efficiency, sustainability and your people. Quick snapshots, just a quick pulse-check of your business and how it's going.
- Problem solving how do we solve problems? Do we just throw darts at them? How many people here have heard themselves say "Oh, not again"? As soon as you hear yourself saying that you know you've just applied a bandaid or short-term containment – you've stopped the bleeding but you haven't really got a long-term countermeasure

in place. We're trying to do effective problem solving using the Deming cycle – 'plan', 'do', 'check', 'act' – trying to understand: what's the problem?, what's the containment? and what's the long-term countermeasure? Hopefully if you get your countermeasure right you won't have to come back to that problem again. You won't have to say, "Oh &#%!, not again!"

Using those simple tools will drive alignment to your operational metrics, your operational goals, and what your business is trying to achieve.

Questions

There are four important questions in Figure 1 for the business owners out there. Every business has opportunity for improvement. That's where you need to be to introduce the principles of continuous improvement.

I'll now play a video of the guys at the winery talking about what it was like before CI was introduced:

Video transcript

We asked Rosemount employees what it was like before continuous improvement was implemented.

Ben Johnson, Cellar Operator: "Before CI and the problem and response system was implemented there was no formal avenue for people to raise a problem and have it solved and looked at by the right people."

Michael Bateman, Cellar Operator: "Before CI we used to spend a lot of time looking for portable tanks and this wasted a lot of time and was very frustrating."

Paul Ewins, Cellar Coordinator: "Before CI was introduced here at Rosemount Estate we'd quite often go off and visit other wineries or other businesses within the group but their approach was quite generalised and often we wouldn't have any key learnings come back or any real objectives to the visit. You didn't feel like you had much influence on how to change day-to-day operations and you didn't feel empowered, or didn't really want to get involved in the end because you didn't feel like your ideas or improvement suggestions were actually going to go anywhere."

John Gledhill, Winemaker: "We used to encounter problems and issues out in the winery, at that stage though there was no availability, no access or opportunity to capture these issues and as a result they quite often led to frustrations from both a winemaking and an operational perspective."

Graeme Galletly, Health, Safety and Environment (HSE) Coordinator: "I guess some of the frustrations might have been in the earlier days challenging process or even trying to find equipment to a point simple 5S-ing techniques. There would be fittings scattered around the winery or you'd go to one of the fittings racks and not be able to find a basic piece of equipment that should be readily available."

Question for you...

How well do you know your business and the drivers of performance?



Figure 1. Questions to ask about your business and its drivers of performance

The first thing the team did back in 2009 was the establishment of this CI corridor, part of visual management (Figure 2).

It is just a quick snapshot of safety, quality, efficiencies, sustainability and people. That's really us trying to be transparent with the team to let them know how we're going with all those day-to-day issues. The beauty of this corridor is that everyone has to walk through it to go out into the winery so the information about the business and how it's going is seen by everyone. It's live data if you like. Any issues that get raised, or if the cellar has concerns that need to be escalated, we have a whiteboard here that provides some accountability and ownership of issues, rather than having a one-on-one conversation with your manager and then thinking that issue is lost, it's gone into space somewhere. This gives some transparency of what those issues are.

I'll now play a video of people talking about what it was like at the winery after the introduction of CI:

Video transcript

We asked Rosemount employees what it was like after continuous improvement was implemented.

Ben Johnson, Cellar Operator: "One of the great things about having a visual work place is someone can raise a problem and put it on the board behind me and everyone can see the problem and they can become proactive and help to find the solution. It can really lift the morale of the workplace because people get a bit of ownership and they feel like they are part of the process and a part of the solution. And they feel appreciated and valued."

Michael Bateman, Cellar Operator: "Behind me we now have our portable tanks in bays. We sign them in and out whenever we need them and this has reduced frustrations throughout the whole site. This has made finding the portable tanks a lot easier and it has demonstrated to the site the simple process of 5S and how effective and useful it can be."

John Gledhill, Winemaker: "One of the key things that we did was visualising what our task was using things like a value stream map, as I've got beside me here, which really identifies each step of the process of what we do and highlights where our efficiencies are and probably more importantly highlights where we are deficient as well. Where we're deficient means there are opportunities there for improving our process, and where we are efficient maybe that's ways which we can pass on that knowledge to other parts of the business and improve their efficiencies as well."

Graeme Galletly, HSE Coordinator: "The benefits are the fact that from the ground floor up people can actually get involved in continuous improvement. That's probably been the biggest benefit - the fact that it's actually come from the shop floor. It's not a manager or a senior manager pushing CI, it's guys shouting out from the shop floor saying 'I would like to see this improve my working life' or 'improve this process'. So I guess that's probably one of the best fundamentals of the continuous improvement program."



Figure 2. CI corridor established at Rosemount Winery as part of visual management

Ben Johnson, Cellar Operator: "One great example of CI in the workplace is our designated forklift bay. We now have a designated bay where the forklifts are returned so you know exactly where you're going every time you want a forklift. And if the forklifts aren't there they're noted on a board who has them – it makes it a lot easier to find the forklifts and there's a lot less radio communication and walking around trying to find a forklift."

Paul Ewins, Cellar Coordinator: "After the implementation of CI here at Rosemount people were asking what the CI really looked like. So key people from Rosemount went off and visited best practice with the objective of bringing that back to Rosemount Estate. On return the change agents were able to sit down and discuss key learnings and develop plans to implement them into Rosemount Estate with things such as the CI corridor and daily stand up meetings. CI has had a pretty big change on our culture here by introducing basic processes where operators can write frustrations or improvement suggestions down on boards, they're clearly visible throughout the site. Then management can go and review those boards, have a chat with operators, get an idea of how they think their idea can be improved or how it will help improve the process and it also gets operators involved so they can see where their idea starts from and where it ends up at so they can see the whole process. But they can also see if we can't do it, they get an understanding of why it can't be done, whether it be budgeting or resources, whether it's just a big capital project - it gives them some transparency into decisions that are made without just hearing a yes or a no."

Matt Koch, Chief Winemaker: "The heart of Rosemount is our people. What CI's been able to deliver to our site is really teamwork. We've seen the ability for our employees now to open up. For them to be able to voice their ideas and concerns, but also for us to be able to listen to them and I think that's fantastic. From a winemaking perspective what we've seen really with the initiatives of daily stand ups and practical problem solving ideas is really the team coming together collating all the information and then working as one which has been fantastic. What success we've had with the wine show circuit, you know a lot of that comes down to our teamwork here, our people. The ability for these people to be able to challenge the process, to be able to voice their concerns, and then for everyone to be able to get on and get the job done. That's what we're seeing really the initiative of CI, the purpose is there so the future looks really promising."

Results

What are the key results to date? Should we rest or continue to challenge ourselves? For tonnes crushed since 2009 to now we are up 20%, our repairs and maintenance activity has gone up 4%, and our cost per tonne – one of those operational performance drivers – is now down 10%. So no extra cash, no extra money, we're just more efficient in how we go about our day-to-day activities. And for safety incidents, we've had a dramatic improvement, all attributed to our continuous improvement program journey so far.

We have just started the journey and continuous improvement is long-term, – you need to be thinking 5, 10, 50 years down the track of how you're going to be going about your business. You heard Matt Koch say "the future's promising" – it certainly is. For us we're very excited, the team is very excited and we're moving away from "We've always done it this way" to a culture of "Why do we do it this way?" So that's what we've seen with continuous improvement. It has had a huge impact on the winery – you heard the guys talking about it before. It's given people greater ownership and accountability. They have a passion for wine and an entrepreneurial spirit.

CI has been able to link the day-to-day activities to the broader goals of Rosemount to the overall ambition of Treasury Wines to be the most successful and celebrated wine company. So, we're pumped.

What does it mean to you in the audience? What's the take-home message? It's all about understanding the drivers of your business performance and engaging your people.

SESSION 10: Creating value



Wine – a luxury for dynamic markets D. Dearie

Capturing value in the marketplace – making wines that consumers want to drink B. Walsh

Price vs value: consumer perception of value C. Spence



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Wine – a luxury for dynamic markets

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Abstract

The future of the Australian wine industry must be characterised by a relentless pursuit of quality and an increased focus on adding value back into the category. The world of wine is changing, and all the available evidence suggests that fundamentals are strong. Across the world the demand for luxury and premium wine is increasing; after three decades of excess global production we are moving into a balanced supply position – with a shortfall in premium wine production predicted over the next few years. In developed markets, such as the United States, ageing populations are drinking more wine, and demanding wines of a higher quality. In developing markets younger consumers are engaging much earlier with wine, and when they do they are demanding iconic western brands. So conditions are favourable, but the question remains how best to seize the opportunities of rapidly growing, wine thirsty markets like China? Australian wine stands at a crossroads, it can embark upon a 'race to the bottom' cutting cost, stripping out value and commoditising its product, or it can follow a path of premiumisation, creating a high quality, value-added product that commands price, prestige and brand loyalty in a world hungry for luxury goods.

Good afternoon, it's great to be here today. In fact after the week I've had it's better than ever to be surrounded by such an esteemed audience of winemakers, viticulturists and wine lovers, rather than journalists!

It's fair to say it's been a pretty tough week. Looking at some of the coverage in the newspapers following our announcement on Monday, that Treasury Wine Estates (TWE) was taking the painful but necessary steps to address excess inventory and bulk wine issues in the United States, I thought long and hard about the implications of my remarks today. But on careful reflection I'm convinced that our actions in the US reinforce, rather than weaken, what I had already intended to speak about today. Put simply, TWE's recent actions in the US demonstrate, more clearly than ever, that quality comes at a price. I remain totally convinced that strong brands can command a higher price, will generate greater consumer trust and trade loyalty, and will ultimately provide superior shareholder returns.

I view this conference as incredibly important. The technical aspects of our industry are sometimes forgotten in the everyday hurly-burly of discussions on wine, and the state of the Australian wine industry. However, I'm in no doubt that our technicians and viticultural practitioners are the unsung heroes of our industry, without whom we wouldn't have so many great Australian wines and wine brands.

Today I want to talk to you about a building a premium future for Australian wine by embracing quality and realising full value for the products we sell, and the wines consumers enjoy. And I want to express my views on what I believe our industry needs to do if it is to maximise the opportunities of near insatiable demand for premium brands by consumers in almost all developed, and a great many developing, markets around the world. To talk luxury you first need to understand value. Because what differentiates a luxury product is an inherent ability to command price; and consumers must see the value, which could simply be the trust and prestige they see in the brand name, for the extra they are being asked to pay. Wine as a luxury good still has much to learn, and you don't have to go too far within the drinks industry to uncover some interesting lessons for our sector.

Take vodka, for instance – the technical specification really isn't much to boast about. As the official description of the product in the US federal regulations states: "vodka is neutral spirits so distilled, or so treated after distillation with charcoal or other materials, as to be without distinctive character, aroma, taste, or color". As a result the spirits industry needs to work hard to build brands and tell consistent stories about the quality of those brands. And yet that is exactly what some companies have done. Take a look at the phenomenal success Diageo has had with its Ciroc vodka brand in North America. As featured in Marketwatch's recent 'Hot Brands' edition, Ciroc has gone from 340,000 cases in 2009 to over 1.83 million cases in 2012, off the back of some great brand building and very clever marketing.

It is also worth considering the current dominance of spirits within the international showcase of global travel retail; think about the brand building and storytelling major spirit brands have embraced in order to profile their products; and ponder why certain spirits bottles are instantly recognisable in contrast to the 'wall of sameness' that exists in wine. Taking these factors into account, you start to understand the significant price difference between yet another \$20 private label vodka and a bottle of premium vodka sold at five times that price. Even within established spirit brands, leading companies are continuing to innovate, to develop their thinking and products to deliver greater commercial value and brand prestige. They recognise, rightly, that the creation of value remains a constant challenge if a brand is to retain its luxury status.

So spirits provide wine with some valuable lessons in the consumer positioning and brand building of their product. Indeed, critics would allege, with some degree of justification, that the wine sector has been far too passive and far too slow in creating the value that supports a focus on premiumisation. Put bluntly, we've all been guilty in the past of commoditising Australian wine and ultimately eroding brand value. Let me be abundantly clear: I know the Australian wine industry continues to make fantastic products, but I passionately believe we need to drive the marketing, shelf appeal, and value creation behind our products. Our focus on technical and viticultural excellence has not been matched by a comparable effort on brand building, with an insufficient share of research funding and a lack of imagination characterising our efforts. Too often the calibre of the wine itself has been lost in a sea of commoditised marketing that treats a 21st century consumer in a similar manner to their counterparts from the 1980s. Time has moved on, and so must we. The only constant is that the consumer remains king.

One example where I believe TWE got this right was the Penfolds Ampoule. Now I know that the Penfolds Ampoule created a fair amount of comment, not all of it positive, when it was unveiled last year. Some thought charging \$168,000 for any wine was inherently wrong; others felt it was a gaudy and unsophisticated approach to seize the title of the world's most valuable wine; and most thought we would struggle to sell them. Of course, I acknowledge and respect these views, but the reality has been quite different, with the Penfolds Ampoule demonstrating just what is possible from a branding and price perspective when fine wine meets sculpture and is presented as a scarce and exclusive resource. Within six months all twelve ampoules were successfully allocated with several showcased at leading international airports and high-end retail stores. Consumer interest was also phenomenal with over seven million media impressions globally since launch. And while I understand that the Ampoule might not have been everyone's cup of tea, everyone in our industry needs to carefully consider the alternatives to building brands and creating value.

I passionately believe that we have an opportunity to create a profitable and sustainable industry, where all parties - from the farmer to the retailer - benefit and are rewarded for their efforts. Our alternative future is one characterised by private labels, bulk wine and people exiting the wine industry; a future where we become simple purveyors of 'grape juice'. We also need to face up to the fact that some in our industry currently strip out value from, rather than add value to, Australian wine. Some 'winemakers' have given up on quality and value creation to focus simply on lowest cost production. Yes, efficiency is - and should remain - a vital ingredient in any business but charging full value for a quality product that has been lovingly crafted by highly skilled tradesmen is not something our industry should shy away from. Wine remains a complicated and intimidating product for most consumers and price is a major factor in determining value and quality. Low cost production is characterised not just by poor marketing and a focus on cheap grape supply but also led by a lack of investment in the technical aspects of our industry, in R&D, in viticulture and production. Such behaviour ultimately exposes the Australian (and global) consumer to a cheap, commoditised product. It destroys 'Brand Australia' and reinforces a vicious circle of value destruction rather than creation.

The recent history of Australian wine in the UK provides a sobering example here. From the high point of being a 'hot' country of origin offering brands consumers craved, to Brand Australia being characterised by '3 for £10' offers and the now infamous 'critter labels'. When you consider the approximate tax and duties involved of roughly \$2.60 per bottle, how can this possibly be regarded as sustainable? All parts of our industry shoulder the responsibility to build Australia's reputation for excellence and quality in wine - it really doesn't matter if you're a large winemaker or a family-run business. We are blessed with fantastic winemakers, viticulturists and technical experts who need to be rewarded by charging full value for the quality wines they produce. Profit is not, and should not be regarded as, a dirty word. There should also be real profit for the retailer too. Winemakers don't run charities and our industry has no future if it cannot generate sufficient commercial returns. The best way to do that is through quality, the finest raw ingredients, passionate stories around our brands, and innovation in everything from blends to packaging. Naturally, supply and demand also have a big role to play in our industry's future, and as these cycles change so do perceptions of value.

New Zealand Sauvignon Blanc in Australia provides an interesting case study here. Initially a limited amount of Kiwi brands came to our shores, and those that did commanded higher price points; price in many ways was a reassurance of quality. This initial success in Australia should not have come as a surprise, because for an average price of \$15 per bottle consumers knew they could buy a wine that was consistently reliable from a taste and quality perspective. But as a 'gold rush' mentality took hold, New Zealand made too much Sauvignon Blanc, crashing the average price to under \$10 per bottle and eroding their reputation for quality. Only now, after careful reflection, are they building back. In contrast, at the luxury end the situation has been much more consistent and impervious to swings in supply/demand. Put simply, over the last two decades there has remained a significant shortage of luxury wine. This situation is only likely to be exacerbated as we move into a more balanced supply position globally, and we must take the opportunity provided by this to move Australian wine up the value curve.

Adding value back in to our industry also requires a frank and honest appraisal of the tax regime we operate in, and the Government support we require. And on the Wine Equalisation Tax (WET) rebate I will pull no punches. I understand why some in our industry react with dismay at the prospect of losing a \$500,000 handout from the Federal Government. But the fact remains that the WET rebate blatantly fails to meet its original policy intent, is widely rorted, underpins the excess supply that has blighted Australian wine and is enjoyed with relish by our competitors from across the Tasman! From a cost of circa \$200 million in 2008/2009 the WET rebate is now forecast to hit \$310 million in 2015/2016, something that should dismay us both as an industry and individually as Australian taxpayers. I firmly believe that we should be working with Government to identify new and useful investments to help rebuild 'Brand Australia' in international markets and entice more consumers to our cellar doors. Instead too many in our industry plead for the continuance of a good old-fashioned subsidy - one that we would rightly challenge were it applied to other sectors and one that does nothing to support the necessary structural reform, and route to premiumisation, that Australian wine so badly needs. So, sadly, our recent history is a story of value destruction rather than value creation. A race to the bottom rather than a race to the top.

One prominent Australian wine critic recently told me how Australian retailers used to brag about the returns they made from the Penfolds annual bin release, and now they brag about how low their price is. He stated "how can this possibly be good for either the Australian wine industry or retailer shareholders?" Good point. Over the 1980s and 1990s Australian wine moved from having a reputation for great value to simply one of being cheap. The great Aussie shopping basket provides further confirmation of this trend, with wine one of the rare products to be suffering from deflation – in sharp contrast to bread, milk and, importantly, beer and spirits. Quality must remain our byword; only by telling the quality story can our industry thrive. It is by embracing quality that we will seize the opportunities the burgeoning global demand for luxury products provides.

Wine is a global industry and more than 60% of all Australian wine is exported. If we don't build inherent value behind a quality story, backed by smart marketing and brand building then we will be damned to be at the eternal beck and call of currency fluctuations. We must charge full price for our wines but can only do so if the quality justifies it. A sustainable value chain is critical for long-term success. The growers and farmers need to make a return, the retailers should make an acceptable cash margin, and the consumer (based on our research) is prepared to pay more for a wine brand that constantly delivers on quality and brand image. A quality wine is therefore both a complex and balanced offering. It must provide an experience and a real sense of enjoyment, and it should not hide from commanding a price that reflects what it delivers. All the evidence demonstrates that consumers know quality, and when they recognise it they will pay more. Accordingly we must never compromise on quality. Above all we must stop thinking of wine as a commodity, and start thinking of it as a premium offering that consumers will, and should, pay more for the handcrafted product it is. There is no benefit to our industry in chasing multi-buy offers, and we must never be ashamed to charge full price for a fantastic product.

On the contrary, we must be unrelenting advocates for the quality and value of our wines, explaining to the consumer the investment, the passion and technical skill that goes into the creation of top quality Australian wine. Wine has a high cost of capital, significant R&D requirements and underpins vast swathes of employment upon which many rural communities depend. It is an industry of which we can be justifiably proud. As indicated earlier, I am far from dismissive of those who work in other parts of the drinks industry. Indeed I am envious, and encourage winemakers to learn from the brand building excellence displayed by many in the spirits sector and, dare I say it, the beer sector. I am particularly dismayed by the 'cleanskins' offering from our own industry - the ultimate, sanitised, commoditised wine offering. In my opinion, no one wins on cleanskins. It is not sustainable for the growers, and the consumer is faced with huge fluctuations in quality. In short, it damages the entire wine industry. Why would anyone with a love of wine want to produce such a product? And can anyone sustainably and fairly deliver profit and value from such a model? My belief is that rather than seeking to attract consumers by stripping out value from our products we should be looking at each and every opportunity to build perceived and real value in Australian wine.

What does premiumisation and luxury in wine really look like? Well, given my strength of feeling on this issue you won't be surprised to learn that we are doing a few things at TWE: a ground breaking partnership with leading fine wine supplier Bibendum in the UK; a serious and ongoing investment program in raising the calibre of our grape intake through Project Uplift; establishing TWE, and Australian wine, as an international force in global travel retail; and, as previously mentioned, the unveiling of our incredible Penfolds Ampoules. Consumption trends continue to reinforce the need for Australian wine to move up the quality and value curve. First growth, rare and collectible wines that can be enjoyed now, in the future, or on special occasions increasingly are highly sought after. And consumers are prepared to pay more, to borrow a phrase from a well-known premium consumer brand, because "they're worth it". Part of the journey we need to take in wine if we are to foster a culture of quality and premiumisation is the need to address the tall poppy syndrome that exists in sections of our industry. There is nothing wrong with being big, premium and successful. Some in wine, and no doubt even some in this audience, still wrongly believe that 'big is bad'. Yes there are a plethora of niche luxury brands but those who dominate the luxury space are actually large, commercially successful, organisations. Brands like Louis Vuitton, Johnny Walker, and Gucci are all big, incredibly successful and growing rapidly.

The immense opportunities presented by China provide the clearest example of why Australian wine should relentlessly pursue a strategy of quality and premiumisation. Chinese luxury consumption is predicted to grow 18% year-on-year; China already accounts for over 20% of the world's luxury consumption. It also recently exceeded Japan as the country with the highest spending on luxury goods. So the size of the prize remains huge, despite economic turbulence and a more austere Government approach. Other luxury brands are already moving (and are well ahead of wine):

- In 2005, Louis Vuitton had 10 stores in China; today it has over 36 stores in 29 cities.
- Gucci started with six stores in 2006 and had grown to over 40 stores by 2011.
- China, already the largest car market in the world, is now one of the top three markets for Rolls Royce, Bentley, and Porsche in 2005 a total of 857 Porsche cars were sold in China, last year that number had reached over 30,000.

TWE's own research on wine in China has reinforced these trends, clearly showing that luxury and premium brands remain paramount in Chinese consumers' minds. The Chinese consumer is also considerably more sophisticated and educated on wine, and wine brands, than most in Australia give them credit for. The Chinese consumer likes order, and this needs to be factored in if we are to make Australian wine a sophisticated offering for which brand conscious Chinese consumers are willing to pay a premium. We need to make it easier for Chinese consumers to identify the hierarchy of our brands - to help them find both an entry point and our premium offerings. Unfortunately some winemakers need a reality check on China and the Asian consumer. In my humble opinion you can't take an unknown brand to China and expect it to succeed just because it's a big market with growing demand. You also can't inflate your prices and kid the Chinese consumer that a \$20 wine is now worth \$200. The Chinese consumer is too knowledgeable for that.

Open your eyes. The Chinese are great travellers and over 42 million Chinese are forecast to travel overseas this year. We also have long-standing Chinese communities in most major Australian cities. So Chinese consumers see what is presented in airports around the globe, and know what is served and tasted in the great restaurants and hotels of the world. They are voracious explorers of wine education materials (particularly online). So they know when they are being sold a pup! My worry is that when Chinese tourists arrive in Australia they pick up daily newspapers containing page after page of wine discounts. Yet wine remains an important driver of liquor retail profit, so this deflationary approach impacts both the image of Australian wine and retailers' own returns. Those of you that have had the opportunity to directly experience China will know that what really matters is quality - that the wine you are purchasing is the 'real deal'. Assurances that the wine is genuine and of high quality are paramount; as is the endorsement of a friend or flagship brand that you already trust. And it is not just China; it is many emerging markets and more frequently in developed markets too. Wine sales in Australia, USA, Canada, etc. are growing at premium price points faster than at commercial/entry level. Consumers are working out that by paying more their experience and enjoyment is greatly enhanced.

I don't believe I'm being overly dramatic to state that our industry stands at a crossroads. After years of a global supply imbalance the fundamentals are looking much more positive. And wine demand is growing in both developed and developing markets. Put simply, the industry we all love now faces a stark choice: is Australian wine to become yet another commodity resource in a 'sea of sameness' or a premium, luxury product that commands price, prestige and brand loyalty on the global stage? I know which scenario I'd prefer. So let's go make it happen.

Capturing value in the marketplace – making wines that consumers want to drink

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Abstract

Making wines that consumers want to drink assumes that producers know what consumers want to drink. Some market preferences appear to be more cyclical and/or fashion-driven than influenced by flavour, texture or varietal make-up. Historically, winemakers have tended to make wines to suit their own purposes and then set about finding customers. That approach seems out of step with current consumer-focused thinking, where consumer research and insight directors guide winemakers in tailoring new wine offerings to suit potential customers' needs. The latter approach is more likely to prevail in larger wine companies, where a multiple list of offerings spanning the gamut of the price ladder is common. Short-term value could be measured by net profit and positive cash-flows while longer-term value would include the intellectual property value of the brand. To consistently capture value (profit and cash flow) over time, one must increase sale price and/or decrease production costs. Increases in sale price can only be achieved if customers agree with the value proposition. There is a strong case to be made for the majority of winemakers to intelligently stick to the traditional wine industry approach of crafting wine, particularly, but not exclusively fine wine, that suits their particular philosophy, geography and climate – then set about 'recruiting' consumers and 'teaching' them to appreciate and value their wine. The offering should be authentic in its differentiation and it may not be immediately lauded by all, but if one's wine and the accompanying story are real, one is presented with the opportunity of finding loyal customers and capturing long-term brand value.

Introduction

Capturing value in the marketplace could be interpreted as establishing and maintaining a profitable wine business. Value is not finite – it can come from growing the market, growing your market share and growing your unit value. History would suggest that we have not excelled at predicting the future expectations of consumers. In this country at least, our planting frenzies have followed, not preceded, a consumer uptake. And as we know, 'overnight success' often comes after a 20- or 30-year gestation. Winemaking is correctly identified as a capital-intensive industry, demanding patience and resilience to achieve financial success.

Capturing value has different demands and results in the short and long term. To address the topic, it is intended to interrogate the sources of value and to develop some insights into the understanding of consumer wants. While I will reference and acknowledge the great research done by many in recent years to better understand consumer taste preferences, I will concentrate on less empirical matters and where possible seek to learn from semi-luxury products other than wine.

The historical wine approach where one makes wine to fulfill a personal ambition could easily be criticised as 'production-driven', appearing to display scant regard for, or knowledge of, the consumer's needs. I would respond that every great, sustainable wine brand in the world has been created in the first instance by a viticulturist/ winemaker taking this path, based on a desire to create something of substance and leave a legacy; subsequently multiple business disciplines (over and above viticulture and winemaking) are required for sustained success. My hypothesis is that, particularly at the higher unit value end of the wine market, taste is not the key determinant of success and captured value, but one of a suite of key consumer benefits. To paraphrase Hamel and Prahalad (1996), "Some [wineries] ask customers what they want. Market leaders know what their customers want before customers know it themselves".

Sources of value: winery value and customer value

To set the value scene, I reference Botos' work of the 1990s (Botos 2001) suggesting that not all wine styles fit into a typical price pyramid. Diagrammatically, the shape of the price hierarchy varies

through pyramid (white wines), hourglass (sparkling wines) and oval for red wines. If his assertion is correct – and intuitively it seems sound – it provides an opportunity to better understand where the value may or may not lie for your wine or wines and allow planning to better capture that value.

Recurrent winery value is derived from the margin gained between sale price and all costs, including overheads. Over the longer term, brand intellectual property value can be accrued with sustained recurrent success. Consumer value is generally accepted as the quotient of perceived benefits, over the price paid. Customer value is thus enhanced at a lower price paid, whilst winery value is potentially lost, presenting an apparent conflict between the need of the enterprise and the desires of the customer. In wine, the perceived benefits can include many attributes, although we tend to focus on the muchmisrepresented word – quality – generally relating to the taste of the wine. Given the choice, most people would opt to pay a lesser price for two seemingly identical products, or two products that appear to deliver identical 'benefits'.

I don't intend to dwell on major global retailers' commitments to lower prices for their customers, or the pushback that may have on producers, other than to say that productivity will always be important. More compelling is the need for brand owners to increase the perceived benefits to the consumer. This helps restore the customer value equation by elevating the numerator and still providing a level of value 'comfort' at a higher unit price. There are similar levels of basic functionality in motor vehicles, but a huge variation in what customers are prepared to pay for enhanced benefits and the badge (brand). Wine's key difference and advantage relative to motor vehicles, as well as soft drinks, beers and spirits, is that our involved consumers are quite 'wine promiscuous'. Keen wine drinkers can embark on a life journey of discovery, always seeking out wines from new places, new varieties, new makers and new styles. They are not as wedded to one favourite wine brand as they may be to a preferred car, beer or Scotch. The wine we drink today or tomorrow will not necessarily be the same that we drank yesterday, just as the restaurants we choose to patronise will not always be of the same food style or ethnic origin.

Occasion

Before interrogation of perceived benefits, a quick reminder of two basic types of wine we drink, driven largely by occasion. Occasions can be broadly categorised as 'everyday' and 'special' – and generally, but not exclusively, these terms are aligned with price. One person's special occasion wine can easily be another's everyday wine. The customer value proposition for everyday wines tends to focus on the denominator (price paid) of the value equation, whereas it could be argued that the numerator (benefits) is more important for special occasion wine.

Perceived benefits and taste

Perceived benefits may include the taste of the wine as well as attributes such as price (where higher price may be seen as a benefit, if out to impress), brand awareness and reputation, trust, label and packaging, expert opinion, word-of-mouth recommendations, awards and other accolades, exclusivity, rarity, and so on. Paradoxically, the taste of an everyday wine may be a more important cue to a novice or non-drinker than to a regular or involved wine consumer. 'Easy tasting' wine might be important where winemakers are trying to encourage drinkers of other alcoholic beverages to gravitate to wine – for all the positive reasons that we would encourage. It continues to be the most civilised and civilising of alcoholic beverages, generally being consumed in a convivial setting.

Therefore consumer research to discover how we might modify wine flavour to attract non-wine drinkers (viz. make wine soft, sweet, and smooth!), has merit as part of a 'trainer wheels' approach. My concern with this style of wine (what The Wine Spectator's Matt Kramer (Kramer 2010) would call 'Wines of Fear', as distinct from 'Wines of Conviction') is that it has the potential to move all wine towards a common flavour, texture and style, a 'world wine', not unlike a world car - made to the same design but badged differently for each market. It becomes harder if not impossible to differentiate one wine or one brand from another through taste and texture, leaving price (how low can you go?) and marketing/promotion (how much can you spend?) as the keys to commercial success - and often leaving very little money left to pay the bills. Where is the captured value? It is acknowledged, however, that 'easy-tasting' wine has the capacity to help grow the pie and, importantly, make wine more accessible. The challenge is to ensure that our wine retains a degree of 'specialness' and avoid a 'dumbing down' of the wine category which would potentially undermine the great enterprise value proposition of many makers of both fine and everyday wine.

Some research (Goldstein et al. 2008) has indicated that when non-wine experts taste both expensive and inexpensive wines, they tend to prefer the less-expensive option. This indicates that we 'learn' to appreciate what might be generally described as 'fine wine'. If as practitioners we believe in the fundamental concept of 'superior' and 'high' as adjectives for quality in wine, then there is an opportunity through education to take our consumers on a journey of enhanced wine experience. The work of Francis et al. (2011) in showing that many Australian consumers are very sensitive to low levels of faults or 'off' flavours, including oxidation, gives hope to the premise that sound winemaking practice still has validity in the face of a small but vocal movement towards natural wines, some of which are intriguing and some of which are unsound.

The opportunity through education is to move beyond making a safe and comfortable-tasting wine to providing a great wine experience. 'Wines of convenience' and 'wines of conviction' – both have their place in society, as do fast food and fine dining. However, we eat the great cuisines of the world because of their 'differentness', not because the flavours and textures appeal to a narrow preference band. They provide an experience, not just nourishment. The same

opportunity prevails with wine – to provide an enriching experience (a benefit), not just a beverage (a product). Just as we have learnt through childhood, adolescence and adulthood to appreciate certain foods and methods of cooking (or non-cooking in the case of raw fish), so we can learn to appreciate varied wines and winemaking styles.

There is not one winning flavour

A short analysis of wine sales in the domestic Australian market over the last 40 or 50 years shows regular and significant change in consumer preferences, just among the broad categories of red, white and sparkling wine, let alone between varietal preferences within those categories. This is more indicative of a cyclical or fashion driver of consumption than a change in consumer tastes. As Alan Kay, formerly of Xerox, once remarked, "The future was predictable, but hardly anyone predicted it".

It's not easy being different

Of the 10,000 or so grape varieties in the world today (Robinson et al. 2012), it is estimated that a clear majority of the world's wine exports would comprise less than 20 different varieties. There is some irony in those numbers; until approximately the late 1950s, hardly any wine in the world was sold under a varietal description. As the thirst for wine, wine knowledge and diversity expanded in the New World, the choice of varietals diminished, not in availability, but in market uptake. This presents just one outstanding opportunity for producers to continue to explore ways to differentiate. It is not easy to be different, but if done with conviction and commitment, success can be achieved. My former employer Yalumba showed that – by becoming the world's most influential producer of Viognier during a 25-year period of overnight success.

The traditional differentiators in wine have been variety, place of origin and style. The most difficult to copy is place of origin and that continues to provide the best opportunity for value creation through differentiation. Generally, but not exclusively, the highest value wines in the world are single vineyard wines, followed by wines of finite appellation. It is strongly recommended, therefore, that winemakers from the New World should not attempt to emulate Old World benchmarks in their wines, but build on what is unique in their environment and celebrate its differentness. Seek inspiration, not imitation. Ultimately, one's place and intellect will be the value creator.

Innovate, differentiate, recruit, educate and create an experience

If "Innovation is the fuel of economic growth..." (Wall St Journal) then we must use our imagination to create differentiated products and positions and set about recruiting our customers. Many of the sustained success stories of wine over time were not particularly popular at inception. Most Australians know that Penfolds Grange was a secretive project, an 'ugly duckling', and an unpopular wine at inception, before ultimately carving out an eminent position in the global wine scene like no other Australian wine. This may well have been a great challenge, but it seems to have been worth the effort. Celebrated wine author and Decanter contributor Andrew Jefford (pers. comm. 2013) cites Barolo and Sherry among many others as examples of wine styles that were not necessarily appealing or consumer-friendly wines from the start, but which we eventually came to appreciate, enjoy and eventually laud. Again, serious value has been created. Just as with food, we have all heard similar stories in wine where many of us have had to be taught to enjoy a product in the first instance, before becoming enthusiastic evangelists.

Great wine starts in the brain. Start with an idea, add your thumbprint, define your house style, and celebrate what's different about what you do. If you do that well, engage with your customers and tell the story, you will be making wines that consumers want to drink, something of value to you and your customers. "The best way to predict the future is to invent it." (The X-Files).

Conclusion

The first wine industry priority is to ensure that consumers want to drink wine as an alcoholic beverage of choice. That is, to make wine desirable. This presents an opportunity to be part of a growth industry and help create a better society. Then, producers have a choice between:

- making wines that consumers want to drink, i.e. give them what they want; or
- making consumers want to drink wines that they make, i.e. teach them what they want.

All producers must establish a value proposition for their particular offering(s) and recruit consumers that want to drink their wine.

Making everyday wines that cater to novice or non-wine drinkers is a worthwhile cause, particularly in growing the wine market, but one which has the potential to make future enterprise value difficult to maintain due to the challenge of differentiating the offer. There is a strong case to be made for the majority of winemakers to intelligently stick to the traditional wine industry approach of crafting wine, particularly but not exclusively fine wine, that suits their philosophy, geography and climate – then set about 'teaching' their consumers to appreciate and value that wine. To again quote Andrew Jefford, "... that each place should make the best wine which nature and well-adapted varieties for that place can provide – and if it is a 'distinguished site' or globally interesting place to make wine, then it will endure and flourish, even if consumers take a little while to come to an understanding of that wine." (pers. comm. 2013).

The opportunity is to discover or create your point of difference, to find or create niche markets and to lead in your area of speciality. To create and capture maximum value, you must make your wine an object of desire rather than only an object of convenience. Most value is created by increasing net sale price – and that will only be

sustainable if the consumer understands and accepts the benefits. All winemakers should be prudent and rigorous in managing costs and productivity – it is not solely the task of high-volume convenience winemakers. Innovation in thought and action will be important to achieve both your point of difference and your business case.

A cohesive approach to integrating production, marketing, sales and financial disciplines is mandatory even if you are a one person operation. Terms such as 'production-driven', 'sales-driven', 'marketing-driven', and 'finance-driven' should be outlawed. Only an integrated approach will work in the long run. The offering should be authentic in its differentiation and it may not be immediately lauded by all, but if your wine and the accompanying story are real, then one is presented with the opportunity of capturing long-term brand value and (occasionally) loyal customers. Remember, our engaged drinkers are wine polygamists, not monogamists. You'll be capturing value and giving consumers wines they want to drink – even if they don't know it yet!

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Price vs value: consumer perception of value

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Abstract

Does wine have intrinsic value? Is it an aesthetic object, or can its consumption be considered an aesthetic experience (Charters and Pettigrew 2005; Fretter 1971)? And, more importantly, how can winemakers and marketers enhance the perceived value of their product offerings amongst their target consumers? Given the frequent mismatch between the results of blind and sighted tasting studies, the question that has to be asked is where exactly does the value in wine reside and how, as a wine professional, can one increase it in the mind of the consumer? In this article, I will take a closer look at the results of a number of studies of blind wine tasting. The marked differences in the results of sighted versus blind tasting (no matter what the product being evaluated) support the view that the brand, price, label, logotype, and perhaps even the weight of the wine bottle can all modulate the perceived value of a wine. Clearly the intrinsic sensory attributes/quality of the wine itself cannot be ignored (especially should the wine happen to contain some faults). However, in order to really understand the drivers underlying the consumer's perception of value, and the relative importance of product intrinsic versus product extrinsic cues, one needs to be aware of the complex relationship that exists between price and perceived quality. While the available evidence suggests that you can't simply taste the price of a wine (e.g. as highlighted by the results of many a study of blind wine tasting), if you know the price then you most certainly can (see Spence 2010, for a review)! For those readers wanting a resolution to this riddle, read on...

An introduction to the blind versus sighted tasting of wine In his fascinating book, *Wine Scandal*, Fritz Hallgarten describes an occasion on which he gave a group of young wine consultants ten sparkling wines to taste blind. The consultants were instructed to pick the best-tasting wine, as well as to try and identify which of their glasses contained the champagne (of which there was only one). Apparently, no one was able to identify the champagne correctly. In many cases, the wine consultants rated sparkling wines from places such as Israel and Luxembourg as tasting better! Crucially, though, and this speaks to the prominent role that branding plays in contributing to people's evaluation of the value of a wine, the consultants thought that whichever sparkling wine tasted best to them was the champagne (Hallgarten 1987, pp. 116–117)!

Elsewhere, in an episode of Heston Blumenthal's TV series, Heston's 80s Feast, that aired a couple of years ago (and which was watched by many millions of television viewers), the celebrity chef and proprietor of The Fat Duck restaurant, located in Bray in the UK, tested the preferences of people whom he was shown accosting on the streets of London. Heston asked people which of two sparkling wines they preferred, one a glass of champagne, the other a glass of Blue Nun wine that had been carbonated using a Sodastream.¹ If the results of the television footage are to believed (and believe me, that is a very big 'if'), Heston's on-street testing appeared to show that most of the punters he tested either preferred the carbonated Blue Nun, or else expressed no preference, when given the choice between that and genuine champagne in what can be considered an informal sip test!² Meanwhile, the results of another blind taste test demonstrated that a Domaine Ste. Michelle Cuvée Brut, a sparkling wine from Washington (retailing at approximately \$12 a bottle) was preferred by the majority of those tested to a \$150 a bottle Dom Perignon (see http://www. freakonomics.com/2008/07/24/keep-the-cheap-wine-flowing/).

Now, these three examples can all be criticised on the grounds that none of them constitute well-controlled laboratory experiments. However, the key point to note here is that all of the available scientific research has essentially come to the same conclusion: the majority of normal wine drinkers are simply unable to discriminate between champagnes or to pick out the most expensive sparkling wine when a number are tasted blind. Take, for example, the following wellcontrolled experimental study conducted in Dijon, France, in which a group of social drinkers were given five brut non-vintage champagnes to taste blind (see Lange et al. 2002). The bottles in this study varied in price between 11 and 23 Euros; they included a bottle of the cheapest champagne that the researchers could lay their hands on, together with three bottles from a selection of the best-known houses of the former 'syndicat des Grandes Marques'. The social drinkers tested in this study gave the five sparkling wines the same hedonic rating. That said, significant differences in the participants' preferences did appear just as soon as the experimenter unveiled the labels.

Once the brand information had been disclosed, the social drinkers tested in Lange et al.'s (2002) study reported that they would pay significantly more for the three champagnes from the top brands as well as for the mid-priced bottle, but would pay less for the unknown brand (than they said they would have done in the blind tasting condition). What is more, the social drinkers also gave the champagnes a higher hedonic rating when the brand information was made available. That is, they actually reported enjoying the champagne more. Such a pattern of results can be taken to suggest that the value of sparkling wine, at least amongst social drinkers lies very much in the product extrinsic cues, such as are provided by branding and other marketing communications.

Of course, showing that social drinkers do not enjoy expensive champagne any more than cheap sparkling wines under blind testing conditions is one thing, but surely on the basis of what one reads you'd have to predict that the wine experts would gain more pleasure from (and/or give a higher hedonic rating to) more expensive champagnes than to cheaper wines even under conditions of blind tasting? However, as Hallgarten (1987) might well have anticipated, the answer appears to be no. Harrar et al. (2013) recently conducted a blind tasting in London with a group of participants that included four champagne experts, six tasters with an intermediate level of experience with champagne, and five social drinkers. Everyone who took part in the main experiment sampled a range of seven sparkling wines (including six champagnes) that varied in price from £18 all the way up to £400 per bottle. In this particular study, the wines also varied in the proportion of red and white grapes that had been used to make them: going all the way from a Blanc de Blancs (Perrier-Jouët Belle Epoque Blanc de Blancs) made entirely from Chardonnay grapes through to a Blanc de Noirs (from Mumm de Verzenay)

¹Blue Nun, for anyone who is unfamiliar with the brand, is a sweet German wine that rose to prominence in the 1970s when the population of the UK were first starting to acquire a taste for wine (http://en.wikipedia.org/wiki/Blue_Nun).

²The last time I checked, the clip was still available for viewing. Click on Episode 6 of Heston's Feasts Series 2, at http://www.channel4.com/programmes/hestons-feasts/ episode-guide/series-2. The show was originally broadcast in the UK on Channel 4 on 11 May 2010.

made entirely from Pinot Noir grapes. The results showed that not only were these tasters hopeless when it came to trying to judge the relative percentage of white versus red grapes in the wines, but there was absolutely no correlation between their hedonic ratings of the sparkling wines and their retail price (Figure 1). Even when the data from the experts was analysed separately, there was still nothing more than a minor trend towards the expert tasters being able to appreciate the more expensive champagnes more than the cheaper alternatives. That said, it should be noted that Harrar et al. 2013 were only able to test a relatively small number of experts (n = 4), and hence it would certainly be worthwhile to repeat this study while testing a substantially larger sample of wine experts.

What do the results of taste tests show?

What is true of sparkling wines when tasted blind turns out to be equally true of a whole host of non-alcoholic drinks: that is, consumers will normally swear blind that they would be able to pick out their preferred brand in a blind taste test. Most of the time, however, the results clearly demonstrate that this is simply not the case. The average consumer tested in many such studies may well express a preference for one product over the others. What is more, they will be sure that the product that they prefer in the blind taste test is their preferred brand. However, most of the time they will have ended up picking another brand instead. One other finding to have emerged from a large number of blind taste tests conducted across a range of non-alcoholic beverage and food products is that as soon as the consumer is informed that a particular product is branded (assuming the brand is a reasonably good and/or well recognised one) then their ratings of the product will immediately go up (Lange et al. 2002). This general pattern of results has been documented over the last half a century in studies that have involved the blind tasting of everything from coffee (Martin 1990) to cola (Sheen and Drayton 1988; Kühn and Gallinat 2013; McClure et al. 2004), beer (Allison and Uhl 1964)³ and water (e.g. Nevid 1981; Wells 2005).

What do the results of blind wine tasting experiments really show?

Robert Goldstein, a prominent food and wine critic from the USA conducted a meta-analysis of more than 6,000 observations from 17 different blind wine tastings organised during 2007 and 2008. He documented a slight negative correlation between the price of a wine and its overall rating by non-experts (see Goldstein et al. 2008). To be absolutely clear, this means that social drinkers actually enjoy cheap

³According to rumour, the inability of consumers to pick their preferred brand in blind taste tests is part of the reason why Stella Artois went with the slogan "Reassuringly expensive" – apparently there was nothing else that they could say.



Figure 1. Results of a study by Harrar et al. (2013) highlighting the absence of any correlation between the retail price of a selection of seven sparkling wines (including six champagnes) and the hedonic ratings of a group of consumers (including a number of experts, together with social drinkers, and some individuals having an intermediate level of experience with champagne). Figure copyright Harrar et al. (2013)

wine more than more expensive wine! By contrast, for those with some degree of wine training, for example, those who had taken a course to become a sommelier, there was at least a hint (but nothing more)⁴ of a positive relationship between price and enjoyment.

One might argue that the absolute prices of the wines, not to mention the range of values, that were tested in Goldstein et al.'s (2008) blind tastings would have had some effect on the pattern of results obtained. However, while the actual wines in Goldstein et al.'s blind tastings varied in price from \$1.65 to \$150, essentially the same results were obtained when wines in the \$6 to \$15 price range⁵ were assessed.

In 2012, George Taber led a blind tasting that was billed as a repeat of the 1976 'Judgement of Paris' (see Cowen 2012). In this case, though, French wines priced up to USD \$650 a bottle, including famous name vineyards such as Château Haut Brion and Château Mouton Rothschild, were pitted against some of the cheapest wines from New Jersey, USA (not quite 'Two Buck Chuck', but close enough). The French wines won - the top white was a Beaune Clos de Mouches Drouhin 2009, while the 2004 Mouton-Rothschild was the top red (see Report 161 on http://www.liquidasset.com/, for a detailed breakdown of the results). That said, three of the top whites were from New Jersey, as was the third placed red, despite the American wines costing only one-twentieth of some of the French bottles. Moreover, subsequent statistical analysis of the results revealed that the differences between the tasters' ratings of the wines were so small as to be statistically meaningless (meaning that the ordering would most likely change should the study be repeated).

Roman Weil (2005) has taken a slightly different approach to the question of whether people really do get value for money when it comes to paying for wine. In his experiments, Weil, an economist by training, normally selects two bottles of wine and decants them out into four identical containers. Next, samples of wine are poured from three of those containers into wine glasses. Those whom he tests then have to try and pick the odd one out from the three glasses (this is known as a triangle test). Weil's tasters consisted of MBA students at the Graduate School of Business in Chicago, together with alumni from the University of Chicago and their companions. These individuals described themselves as enthusiastic wine drinkers, but were by no means experts. In one of his studies, Weil had his participants try to distinguish between a reserve and a regular bottling, from the same producer and year. So, for example, tasters might unknowingly be given two wines from Chateau Latour; the regular bottling was the second wine from Latour - the Les Forts de Latour (at the time retailing for \$56 per bottle), while the reserve bottling was the famed first growth Chateau Latour weighing in at a hefty \$200 per bottle.

Given the price differential, you would certainly have hoped that Weil's participants would have been able to discriminate between these wines. However, contrary to such expectations – though in line with everything that we have seen so far in this paper – those tested only managed to correctly pick the odd one out of the three wine glasses 40% of the time. Not so impressive when you consider that, by chance, the taster should get one in three right (that is, 33% correct). What is more, among those tasters who correctly identified the odd one out of the three, only half actually preferred the reserve bottling! Not much of a benefit given that, on average, the wines differed in price by an order of magnitude. More specifically, the reserve wine typically came in at anywhere between 40% and 300% more expensive. The same results were obtained no matter whether red wine, white wine, or champagne was being tasted.

⁴Note that the trend for a positive correlation in the experts was only borderline-significant. It was no longer significant when rigorous statistical criteria were used. ⁵At the time Goldstein published this research, the majority of US wine sales would

 $^{^{\}rm 5}\!At$ the time Goldstein published this research, the majority of US wine sales would have fallen squarely within this price bracket.

These results therefore apparently add further weight to the claim that social drinkers should not expect to enjoy wine that they have paid more for any more than a wine that costs far less. Weil himself was led to the conclusion that: "If you serve the reserve wine in its first decade or two of life, be sure to show your guests the label because the chances are four to one against any one person's being impressed by the taste. (Any warm feelings the guest forms of your generosity will likely come from visual, not olfactory and taste, stimuli.)" (Weil 2005). Sage words if ever I heard them.

Of course, it is worth remembering that part of what one might be paying for with a reserve bottling is its ageing potential, and hence testing a reverse bottling in its first few years might not really provide a fair test of a wine's true value, or quality. Therefore, in order to be absolutely sure that it isn't worth paying for the reserve bottling, one would need to repeat Weil's study with some much older wines as well, for comparison.⁶ However, that said, if one industry expert's aside to me at a recent wine conference in Canada is anything to go on, perhaps the reserve bottling will never win out over the regular bottling, no matter how long one waits. For, according to this expert, reserve bottlings often represent nothing more than a cynical marketing ploy by certain producers to push their wine out of its regular price bracket (and perhaps to try some unconventional/ experimental winemaking practices at the same time).

Interim summary

Goldstein et al. (2008) captured the conclusion that many writers (and scientists) working in this area have come to over the years when he suggested that the social wine drinker should not expect to enjoy a wine any more simply because they have paid more for it. Such words might well be expected to put the fear of God into many a wine marketer. However, I think that there are two important points to make here. First, the fact that consumers cannot pick out their favourite brand in a blind taste test hasn't eliminated the price gradient one sees for many other branded drinks products. Just think about bottled water! Or, for that matter, vodka.⁷ Instead, practitioners working in the fields of sensory science and marketing have rather started to go on the offensive and question just what the results of blind taste tests really tell you. As John Geoghegan put it a few years back: "A taste test, on its own, is absolutely meaningless, because taste is only 1 part of what a soft drink is all about" (cited in Davis 1987).

Second, I would dare to suggest that Goldstein et al.'s (2008) main conclusion is simply invalid. It certainly doesn't follow, at least as far as I can tell, that just because there is no correlation between preference and price in a blind taste test that more expensive wine won't taste better. As I have argued at length elsewhere (see Spence 2010), the more you (or someone else) pays for a bottle of wine (provided that the drinker is aware of the price that has been paid, or the current value of the wine) then the better it will taste (see also Almenberg and Dreber 2009, on this point). The reason being that while the same wine tasted under blind and sighted conditions obviously cannot change its physical characteristics, the experience of the wine taster very definitely does change. Here, I would like to suggest that one should really consider whether the blind and sighted tasting of a given wine do not represent two completely different experiences for the taster. Remember here that our experience of the sensory qualities of a wine depends on what is going on in our brain when we are tasting (or drinking), as much as what happens to be in the glass at the time (Shepherd 2012).

The crucial point to note here, then, is that a wine really can taste better when the drinker knows how much has been paid for a bottle, or when a host of other kinds of wine-relevant information are provided instead. Consequently, one might be tempted to wonder whether the blind tasting of wine should be seen only as a means of the assessing the faults and basic sensory qualities in the wine, rather than necessarily as a particularly effective way to assess the quality (or value) of wine – which, anyway, may be as much a matter of personal preference as anything else.⁸

Finally, before moving on, it is worth pausing to reflect on the question of whether the internationally renowned wine writer would be able to extract any more meaning, or perhaps pleasure, from the experience of drinking great wines blind. However, from what I have read to date this really does not appear to be the case. Take the following from the late great French oenologist Emile Peynaud (1987): "Blind tasting of great wines is always disappointing"; or the following from the prolific British wine writer Hugh Johnson (2009, p. 12): "Blind tasting is a humiliating snare." Perhaps this also helps to explain why other famous wine writers, for example, Robert Parker do not appear to relish the prospect of public blind wine tastings (McCoy 2006). It is perhaps also worth noting here that the wine writer appears to be just as (if not more) likely to be misled if, for whatever reason (fraud or experimental purposes), a given wine is presented in an inappropriately labelled bottle (see Wallace 2009, 2012). A good description of this follows:

One point to bear in mind here, though, is that, in a very real sense, a wine expert's perception and enjoyment of a wine comes from the associations that it will have acquired over the years. As such, one might question just what the results of a blind tasting really demonstrate, especially when a cheap, relatively new, or unknown wine gains a higher score than a very expensive famous wine. It could be argued that while the blind tastings of flights of anonymous wines provide a scientifically rigorous means of evaluating a wine's relative sensory qualities (albeit favouring the blockbuster, which has the oomph to stand out from the rest), it misses out on a large part of what genuine wine appreciation is all about: everything that is associated with a wine's identity, and its ability to take the connoisseur back to where it was made or where he or she first tasted the wine. (Spence 2010, p. 120).

Price on the brain

Many researchers have worried that if people change their rating of a beverage or food product following the revelation of price, brand, or other information then that doesn't necessarily mean that their experience of the taste of the wine itself has changed. After all, how could it have? Rather, the suspicion has always been that any change in a person's ratings (e.g. seen under sighted as compared to blind tasting conditions) may reflect nothing more than a response bias. Lee et al. (2006) describe the underlying concern thus: "...it remains unclear in most taste-test studies whether brand identity is just another input to respondents' overall evaluation (a valued attribute in its own right, like temperature or sweetness) or whether it modifies the actual gustatory experience (by affecting the tongue's chemoreceptors or the part of the brain that interprets the gustatory signal)." In other words, the idea amongst most researchers has always been that the provision of product extrinsic cues does not change the taste of the wine,

⁶Indeed, writers such as Michael Steinberger (2010) have made a very similar point about the 1976 'Judgement of Paris' in which some Californian wines came out on top of French wines in a blind tasting that was held in, you guessed it, Paris.

⁷Vodka is a product whose definition in the USA explicitly states that it must be odourless and tasteless!! According to the regulations: "Vodka is neutral spirits so distilled, or so treated after distillation with charcoal or other materials, as to be without distinctive character, aroma, taste, or color." (http://www.greatvodka.com/vodkaHistory.htm).

⁸Remember also that typicity is an important factor when evaluating a wine. However, it is obviously going to be much harder to judge how 'true to type' a wine is in a blind tasting where one is given absolutely no information about the wine at hand. Perhaps here the single blind tasting (e.g. when one has a flight of wines that one knows all come from a given region, or producer, say) may be much more useful. (Though, as the philosopher Jonathan Cohen (2011) has noted, just because a taster does not have any information about the wines that they are drinking blind does not mean that they do not have a number of more or less concrete hypotheses about what the wine that they are tasting might be.)

only the response that a person decides to give when asked about that wine. However, this traditional view has been overturned by a host of recent neuroimaging studies that have now unequivocally demonstrated that a variety of product extrinsic sources of information can change the brain's response to whatever a participant happens to be tasting in some of the earliest (perceptual) regions of the brain. Such results therefore help to buttress the position that the experience of a wine tasted under blind and sighted conditions can really be very different perceptually (regardless of what a taster may feel inclined to say about those experiences).

So, for example, Hilke Plassman and her colleagues at the California Institute of Technology investigated what happened in the brain of wine drinkers when they were given different information about the price of a selection of five different Cabernet Sauvignon wines (Plassman et al. 2008). The twenty students who took part in this study were informed that they would be drinking five different wines. The \$5 wine was either correctly described as such or else mislabelled as a \$45 wine. Another bottle actually cost \$90 and was either presented as a \$10 wine or as a \$90 wine. That is, the misleading prices were either 900% higher or lower than the actual retail price for the wine. Subtle, these marketing manipulations most certainly were not. The third wine was correctly referred to as costing \$35 a bottle. The price was flashed up on a screen whenever a sample was squirted into the participant's mouth. Each and every one of the participants tasted each of the wines 16 times. On some trials, they had to rate the intensity of the wine's taste using a 6-point scale, while, on other trials, they had to rate its pleasantness instead. Sometimes, the participants were instructed to make no behavioural response at all.

Perhaps unsurprisingly, the expensive wines were liked more than the cheap wine. Interestingly, though, price information did not affect the participants' ratings of the intensity of the taste. Analysis of the participants' brain scans revealed increases in the flow of blood to the medial orbitofrontal cortex. This part of the brain is located just behind the eyes, and is known to code for the pleasantness and reward value of stimuli (i.e. how much you like and appreciate the wine). By contrast, no such blood flow changes were observed in the primary taste cortex. The latter part of the brain is more interested in deciphering the sensory-discriminative attributes of a wine's taste, e.g. how sweet, sour, etc. it is. Plassman et al.'s results also suggested that providing inappropriate pricing information had a larger effect on brain activation (i.e. elicited a larger change in blood flow) for the cheaper wine than for the more expensive one. Interestingly, when the same wines were presented eight weeks later, now without any indication as to their price, and this time away from the environment of the scanner, no significant differences in pleasantness were reported. This result once again fits with many of those that we have seen already in this article.

While Plassman et al.'s study was focused on the influence of providing price information on people's perception, researchers have now shown that providing many other forms of information, such as concerning the brand (Kühn and Gallinat 2013; McClure et al. 2004) or the likely taste profile of a drink (see Spence and Piqueras-Fiszman, in press, for a review), can also influence how the brain processes the sensory information that is associated with tasting, and that these effects can occur in some of the earliest neural sites where sensory information is processed on its way from the nose and tongue to the higher centres of the human brain. As such, what a person is told (or believes) about the wine that they are tasting really can change the way in which it is perceived (and not just how it is rated).

... the brain is literally tasting price and region before it even begins to consider the merits of the wine itself. (Priilaid 2006, p. 30)

There are a couple of final points worth noting here, though. First, when I last spoke to Hilke Plassman a few years ago, she suggested that her neuroimaging study may have worked so well because it had been conducted in North America, more specifically, California. Her intuition, though at the time it was nothing more than an intuition, was that people tend to be more price-conscious there than in many other parts of the wine world. In other words, she thought it possible that she might have obtained a somewhat different pattern of results had the study been conducted in Bordeaux, say, or at least with French wine experts.

Second, it is important to bear in mind when trying to interpret/ extrapolate from the results of pretty much any neuroimaging study involving the administration of a product (and 'administration' rather than 'tasting' would seem like the most appropriate term to use here) just how unnatural the experimental situation in which participants find themselves really is. Just imagine yourself lying flat on your back, mechanically inserted several feet down a claustrophobically narrow tube (this is the brain scanner). You have your head clamped still in order to minimise any motion artefacts (that can make it difficult to analyse the neuroimaging data). You are instructed to clench a tube between your front teeth, and await tiny amounts (1 ml doses) of wine to be squirted (or perhaps dribbled) periodically into your oral cavity. You have to hold the wine there for a few seconds in order to try and evaluate its taste, without swallowing. Finally, you have your mouth washed out with artificial saliva (though typically the experimenter will pick a euphemistic term for it), before the whole process starts all over again. Lovely, I'm sure! Given such conditions, it is certainly very difficult to imagine that the participants could actually have found tasting any of the wines particularly pleasant.

Product extrinsic cues and the value of wine

Given the marked discrepancy between the results of blind and sighted tastings, Priilaid (2006, p. 19) was led to conclude that: "All too often it seems that sighted and blind tasting scores seem so disparate as to suggest that either the wine pairing has been mixed up or that one of the two tasting panels was bribed. From this apparent lack of correspondence, it is tempting to conclude that for visual judgements – extrinsic cues appear to be over-riding or masking the true intrinsic merit of the wine." I, for one, certainly believe that Priilaid is right to focus on the importance of product extrinsic cues when it comes to trying to understand the experience of wine for the consumer. I would argue that the difference that one nearly always sees between blind and sighted tasting tells you all you need to know about where the value of a wine really resides: specifically, in the absence of any obvious faults, the value of a wine lies as much in all the product's extrinsic factors as in the wine itself.

There simply isn't space to go into all of the experimental details here, but researchers have demonstrated how the provision of a whole host of different sorts of product extrinsic information can individually exert a significant influence on a drinker's (or taster's) perception of a wine: everything from the stated region of origin (Wansink et al. 2007) through to the number of points that Robert Parker awarded the wine (Siegrist and Cousin 2009), and from the tasting notes (Gonzalez et al. 2006) through to the suggested vintage (Wallace 2009). One would presume that all those medals one finds pasted on the front of so many bottles of wine these days must also exert some influence, though I am not aware that anyone has formally studied this as yet.

... nothing is as important to a brand's identity as its label. That's because, as consumers, we can't help but link our feelings about what is in the bottle to what is on the bottle. In today's highly competitive world market, the wine label (and the entire package) is more crucial than ever. (Cutler 2006)

In closing, it is worth remembering that a host of other factors can also influence how much we enjoy a glass (or bottle) of wine: everything from the quality (or perceived quality) of the glass from which we drink (see Spence 2011, for a review) through to the weight of the bottle from which the wine happens to be poured (Piqueras-Fiszman and Spence 2012)⁹, and from the colour of the lighting (Oberfeld et al. 2009) through to any music that may happen to be playing in the background (North 2012; Spence and Deroy 2013). Of course, that the product extrinsic cues should have such a profound influence on our perception of the value of a wine should come as little surprise to all those of us who have experienced the joys - and disappointments - of the Provençal rosé paradox (Smith 2009). The paradox refers to the fact that rosé wine always seems to taste better while sunning oneself on holiday in the Mediterranean with a loved one than alone on a cold dark winter's night back at home in England¹⁰ At this point, I will let my colleague Prof. Barry Smith, a London-based philosopher of wine, take up the story:

The experience is familiar to many. There you are sitting in the sun, au bord de la mer on the Cote d'Azur, eating delicious seafood with a loved one, and drinking Provençal rosé. The glass frosted with condensation contains a wine of pale salmon colour; the bottle rests in the ice bucket. The experience is intensely pleasurable and at that moment you can come to believe that this is one of the most enjoyable wines you have ever had. Later you buy a case of the wine and when you open in it back home on a cold grey day, it has lost all its savour. This is not an exceptional wine. It is not even that enjoyable. What has brought about this decline in the value of the wine from Provence? Is it that it doesn't travel? We know that winemaking techniques and preservation have dramatically increased and there is no reason to suppose - if the wine was properly transported and stored that the wine has suffered any more than any wine that comes from foreign shores. Its fate cannot be due to a dramatic change in the wine. So what explanation can we give of this paradox of Provençal rosé? (Smith 2009)

I would argue, in the context of the present article, that the very ubiquity of the experience captured by the above description highlights another of the key factors modulating the value of wine for the consumer, namely the place in which they drink it. Not in the sense of the dramatically different mark-ups that one sees as a function of the restaurant that one happens to be dining in (Chung 2008)¹¹, but rather in terms of the context, be that the atmosphere, or the mood that we happen to be in, often as a result of the company that we happen to keep (Spence and Piqueras-Fiszman, in press). All-in-all, then, given the profound effect that a variety of product extrinsic factors has on the enjoyment of wine, both for the social drinker and for the wine expert, one is left wondering just what is the value of the blind taste test.

Acknowledging the fact that the value lies in the experience and the 'everything else' (that is, everything other than the product's intrinsic attributes) is something that the world of spirits has recently done. They have been forced into this partly as a result of the homogenisation of taste (with home brand and cheap commoditised versions of branded products becoming increasingly similar in terms of the taste

and flavour profiles), and the resulting barrage of newspaper organised taste tests showing that the cheaper alternatives will very often win under conditions of blind tasting. Rather than continuing to worry about how to top the blind test, many brands are now shifting the dialogue with their consumers toward thinking about the value of the overall drinking experience. One wonders whether it is not the appropriate time for the makers and marketers of wine to take their lead from the marketing of spirits.

Conclusions

While it is certainly possible that a very small subset of professional winemakers, sommeliers and/or wine judges may be able to perform reasonably well (that is, reliably) in the double-blind tasting of wine on different occasions (see Smith 2007, on the variability of wine expertise; and see Gawel and Godden 2008; Hodgson 2008, 2009a, b, for the low levels of reliability of even many professional judges' ratings in wine competitions), the majority of consumers, and many wine experts (not to mention a surprisingly large number of wine writers) appear unable to pick out the more expensive wines in a blind tasting (see Derbyshire 2013; Goldstein et al. 2008; Harrar et al. 2013; Lange et al. 2002; Sample 2011; Weil 2005). In this regard, then, the blind tasting of wine is very much like the blind tasting of pretty much any other food or beverage product (e.g. see Allison and Uhl 1964; Martin 1990; Nevid 1981; Sheen and Drayton 1988; Wells 2005).¹²

Now, of course, here I have focused solely on assessing the value of a wine in terms of its sensory-discriminative and hedonic qualities. However, it is undoubtedly the case that the purchase and conspicuous consumption of an especially expensive bottle of wine may obviously serve as a kind of Veblen good¹³ (see Spence 2010, for discussion). Furthermore, for many collectors and wine investors, the value of a bottle (or more likely a case) of wine lies not in its taste, but rather in its potential to grow in price as it ages.¹⁴ However, in both of the above situations, the actual taste of the product (assuming that the wine is not corked) and any differences in flavour profile from that of competitor wines plays only a secondary role in terms of ascribing a value to the product. Once again, it is the 'everything else' that turns out to be key to determining the value of the wine.

In summary, the value of wine undoubtedly represents a complex and multi-faceted concept. The key point to note, though, is that very little of the actual value of a fault-free wine resides in the immediate sensory properties of the wine itself. Correctly determining where the true value lies, and at the same time questioning the utility of the blind taste test, until now a cornerstone of the wine industry, when assessing value will, I believe, help to ensure that, in the years to come, wine producers can deliver a consistent product offering that offers genuine value for money for the consumer. This conclusion is likely to hold true no matter whether one is marketing wine to the consumer living in one of the well-established (though in many cases declining) wine markets (think Old World), or else one of the far more exciting and rapidly emerging markets (think China).

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⁹As Goldstein and Herschkowitsch (2010) put it when describing the wines from one particular producer: "These Bogle bottles are hefty, and their weight is a nice feature – one that often tricks people into thinking the wine is more expensive than it really is."

¹⁰For any Australians reading this piece, please feel free to insert your own sunny holiday destination here.

¹¹Chung highlights the fact that one and the same bottle of wine, e.g. take a bottle of 1999 Dom Pérignon Champagne, may retail at anywhere between \$155 (at Legal Sea Foods in Washington) and an eye-watering \$595 (at Per Se in New York). In the latter case, the argument is presumably that the price reflects the highly professional wine service bestowed on the diners by the sommelier that one would expect to receive at such a famous restaurant. Given what we have seen in this article, the wine likely tastes significantly better at the latter restaurant as well.

Allison, R.I.; Uhl, K.P. (1964) Influence of beer brand identification on taste perception. J. Market. Res.1: 36–39.

¹²In fact, the blind testing of many different products, even violins made by Stradivarius turns out to be much harder than most experts would have us believe. Well, put more bluntly, it is impossible to tell the sound of a Stradivarius apart from the sound made by other high quality violins in a blind listening test (Fritz et al. 2012).

¹³A Veblen good is a commodity that has an increased demand as its price increases (http://www.investorwords.com/16863/veblen_good.html)

¹⁴Note here that estimated annual returns on investment grade wines of as much as 10% are not uncommon (Masset and Weisskopf 2010; Sanning et al. 2007).

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Poster Summaries

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CANOPY MANAGEMENT

1. Influence of proactive and reactive canopy management techniques on wine quality in Shiraz (Vitis vinifera L.)

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The ratio of vegetative vine growth to yield (vine balance) is of central importance to optimising fruit composition and wine quality. To achieve optimal vine balance, a range of canopy and yield management techniques can be imposed, depending on vineyard, variety and end-use specifications. Adopting one or more management techniques is often necessary in order to achieve vine balance. The aim of canopy management in Treasury Wine Estate vineyards is to achieve a balanced leaf area to crop load, which supports even flowering, fruit set and veraison, to decrease intra-vineyard variability and promote even ripening.

An experiment was conducted on medium to high vigour Shiraz (*Vitis vinifera* L.) blocks at six sites, to evaluate the application of various proactive and reactive canopy management techniques on canopy development and microclimate, yield, fruit and wine quality. Trial sites were located in the Barossa Valley, McLaren Vale, Padthaway and Coonawarra wine regions of South Australia (Table 1). At each site, a randomised replicated experiment comprised eight different canopy management techniques (Table 2). These eight treatment combinations were applied to six replicate plots consisting of six rows of fifteen vines per replicate. The effects of canopy management were assessed by measures of yield and yield components, colour and tannin. Canopy temperature per treatment was monitored hourly using tiny tag temperature data loggers placed at cordon height.

The results showed that all treatment yields were driven primarily by bunch weight rather than bunch number. Treatments with four kicker canes (T3, T4) had lower yield per vine and bunch weights relative to the control (Figure 1a, b). A strong correlation was observed between harvest berry colour and phenolics (Figure 2a). The shoot

	Table	1.	Canopy	management	trial	site	details
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Region	Latitude	Longitude	Clone	Rootstock	Year Established
Barossa Valley 1	34°24′32″S	139°01′45″E	1654	140 Ruggeri	1999
Barossa Valley 2	34°29′48″S	138°53'42"E	1654	140 Ruggeri	2000
McLaren Vale 1	35°11′01″S	138°33'23"E	Unknown	Own roots	1998
McLaren Vale 2	35°14′48″S	138°33′57″E	BVRC12	Own roots	1999
Padthaway	37°37′17″S	140°30′45″E	BVRC12	1103 Paulsen	2004
Coonawarra	37°18′52″S	140°49′56″E	BVRC30	140 Ruggeri	2002

 Table 2. Canopy management treatment details

Treatment number	Canopy management technique type	Treatment description
T1	reactive	Control
T2	proactive	Kicker (sacrificial) canes – 2 per vine
Т3	proactive	Kicker (sacrificial) canes – 4 per vine removed E-L 35
Τ4	proactive	Kicker (sacrificial) canes – 4 per vine removed E-L 32
Т5	reactive	Shoot thinning E-L 12
T6	reactive	Leaf plucking eastern and western sides E-L 31
Τ7	reactive	Leaf plucking eastern side only E-L 31
Т8	reactive	Trimming E-L 19

thinning treatment (T5) showed significantly (p<0.05) higher colour at harvest (Figure 2b) when compared to all other treatments. A similar trend was observed for phenolics (data not shown). No significant differences were observed between the treatments in term of harvest tannin (epicatechin) levels or canopy temperature at cordon height (Figure 3).

Overall this study has shown that both proactive (T2, T3, T4) and reactive canopy management techniques (T5, T6, T7, T8) affected yield components, vine growth, yield composition and quality parameters. Proactive rather than reactive techniques appeared more effective for decreasing bunch weight; however, this was more evident for treatments with four kicker canes (T3 and T4). Although the shoot thinning treatment (T5) showed higher colour and phenolics, it is unclear whether this was driven by the effect of season or severity of this practice at each site.

Over time, this study will evaluate the long-, characteristics and cost effectiveness term implications of applying these canopy management techniques to achieve desired wine quality. Trial findings are expected to significantly impact our future management of Shiraz.















Figure 3. Effect of treatment on total tannin (epicatechin) and cordon-height temperature pre-veraison. Vertical bars are standard errors.

CLARIFICATION AND MATURATION

2. An evaluation of commercial bentonite in terms of performance, characteristics and cost-effectiveness

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Bentonite is comprised of the clay mineral montmorillonite and is primarily added to white wines or juice to remove unstable proteins and to improve clarification. There is a range of oenological bentonites available on the market, and all differ in terms of physical performance, product characteristics and overall cost-effectiveness. Bentonites differ primarily due to variations in the inter-laminar cationic matrix, with the main cations found being sodium and calcium, leading to two major bentonite categories. Products in each category display broadly common characteristics, although some variations occur due to the differing raw materials. Sodium bentonites typically have poor lees compaction but high ion exchange capacity, whereas calcium bentonites usually have better lees compaction but less ion exchange capacity, leading to higher addition rates. In addition to these two main bentonite categories, some products are formulated from mixtures of the two, or undergo partial cation exchange, and offer mixed characteristics accordingly.

Eight different commercial bentonites were evaluated according to several key parameters, notably lees compaction, settling kinetics, and the extent of cationic transfer into the wine as a part of the ion exchange process. Sodium bentonites were seen to suffer poor lees compaction although addition rates were lower, whilst calcium bentonites generally had similar or better lees compaction at higher addition rates.

Transfer of Ca²⁺ was found to vary but generally increased with dosage rate. Interestingly, even sodium bentonites potentially elevated Ca²⁺ levels slightly, perhaps through cationic metathesis rather than proteinaceous ion exchange.

A cost-efficiency model was developed that clearly indicated one bentonite to be superior, a calcium bentonite with partial sodium cationic exchange that had exceptional lees compaction. This bentonite also displayed rapid settling kinetics, sufficient for it to be used in a different manner to all other bentonites tested to minimise water additions to wine. In spite of requiring the highest addition rate, the strong lees compaction offered by this product meant that significant savings could be made through wine recovery compared with all other bentonites.

3. An evaluation of filtration media in terms of colour adsorption and filtration performance

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Filtration media have remained virtually unchanged for some decades now, with few genuine advances in performance being made in this time. Typically, depth media are composed of cellulose, diatomaceous earth and/or perlite, and resins to bind these components together, whilst membranes (0.45 μm) and membrane pre-filters (0.65 μm) are usually fabricated from nylon. Both of these media types have inherent problems pertaining to their respective compositions, most notably in areas such as physical strength (especially depth media), efficiency of flow and colour adsorption. This represents a particular problem for wine filtration due to the importance placed by the consumer on product colour.

Recently this situation has changed, however, with the development of 100% cellulose depth media and polyethersulfone (PES) membrane materials, and these are rapidly being accepted in the marketplace for wine filtration due to their unique properties relative to older-style depth and membrane materials. Both the cellulose depth medium and PES membranes adsorb significantly less colour than the older media, which translates into improved filtration and production performances.

The new depth medium was shown to absorb approximately 30% of the colour adsorbed by the standard medium. Nylon membrane discs likewise adsorbed significantly more colour than PES membranes. When combined into a cellar and bottling filtration model for a red table wine the media packages removed 11.0% of total colour (cellulose depth/PES membrane) and 17.5% (standard depth/nylon membrane). When this model was transposed onto lightly coloured rosé, the cellulose depth/PES membrane train removed 21.8% of total colour whilst the standard depth/nylon membrane train removed 46.0% of colour. The nylon membranes removed significant levels of colour despite their thin cross-section, and this was shown to be adsorption rather than coloured particulate removal since in a sequence of 0.45 μ m discs both appeared the same and removed similar amounts of pigmentation.

4. Turbidity versus filterability as a means of evaluating wine impact on filtration media

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Many bottling facilities use the measurement of wine turbidity, typically expressed in nephelometric turbidity units (NTU), as a means of determining a wine's suitability for bottling in terms of its likely impact on wine filtration media. Bottling trains are usually designed to be multi-stage, most commonly a depth stage followed by membrane prefilters (0.65 μ m) and then a final membrane (0.45 μ m). The purpose of these filtration stages is to spread the filtration load, enabling longer media life. This is especially important to maximise the usable life and cost-effectiveness of the final membranes that provide a defined microbial barrier, which are the most expensive component of the train. NTU measurements are based on the extent of light scattering in a sample, and so results can vary depending on the reflectivity of a wine cannot be inferred from an NTU measurement since colloids do not necessarily reflect light.

An alternative means of evaluating wine condition is a filterability index (FI), which is based on an index generated using a final membrane disc. This technique is simple to use and provides definitive results, as both colloidal and particulate wine components provide the membrane challenge that generates the index.

NTU was demonstrated to have no correlation with FI. FI can provide much more valuable information pertaining to wine impact on filtration media, which can save costs for both the winemaker and the bottler. A section of an extensive database illustrated the lack of correlation (r^2 =0.045) between NTU and FI, and presented some wines that passed on FI but failed by NTU. Best practice would appear to require the use of both measurements, NTU for ease of use and approximate wine loading, and FI for definitive measurement of wine condition.

5. OPTIOAK[™]: optimising oak aromas through near real-time analysis

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This research is focused on harnessing technological advancements in mass spectrometry to provide oak wood chemistry data in (near) real time. Innovation and development of mass spectrometry have placed this technology at the forefront of cutting edge science (Yates III 2011). Aroma is a well established and significant determinant of wine quality; however, complex interactions of odorants with nonvolatile components highlight the benefits of a holistic approach to flavour chemistry analysis (Polášková et al. 2008). The goal of this research is to develop a rapid analytical procedure that can be integrated into cooperage production processes providing comprehensive chemistry data to facilitate objective classification of oak according to wine flavour impact.

To optimise any system the parameters affecting key variables must be known (Dooley et al. 2012; Williams 2013). Natural variation in oak wood chemical composition is recognised as the key challenge in producing maturation products with predictable properties (Prida and Puech 2008). Consequently, the prerequisite for 'optimising oak' is provision of comprehensive flavour chemistry data. Current oak chemistry evaluation methods require samples to be prepared and shipped to specialised laboratories for analysis. Accordingly, provision of oak chemistry data currently involves time-consuming, expensive and destructive sampling procedures. The absence of comprehensive (and timely) oak chemistry data limits our control and understanding of wood-wine interactions and resultant wine quality.

Winemakers are forced to rely on qualitative descriptions of oak quality, inherently difficult to relate to wine flavour impact, and further complicated by descriptions that are not standardised across suppliers (cooperages). This research seeks to address these challenges by creating a new paradigm for controlling oak impact and wine quality through rapid, comprehensive and objective oak chemistry analysis.

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6. Use CMC in white, red and rosé wines and maintain the high quality of your wine!

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Despite its efficacy, cold stabilisation is a long and expensive process that, if badly managed, can be detrimental for wine sensory quality, causing loss of aroma and structure. Tartrate stabilisation with protector colloids offers an alternative more respectful of wine quality.

Among protector colloids, carboxymethylcellulose (CMC) delivers a highly effective treatment option with long-lasting results. Its effectiveness depends on its high negative charge that makes it able to interfere with the growth of potassium bitartrate crystals. Because of the negative charge, it can also interact with wine proteins and colour, causing haze and precipitation in wines that are not stable. This fact combined with its negative impact on wine filterability can represent an obstacle to industrial CMC use.

A study was carried out to find the best way of using CMC in order to get only the positive effect on tartrate stability and to avoid any associated negative consequences. Preliminary laboratory tests were conducted on industrial wines already clarified, filtered and ready for tartrate stabilisation. For white and rosé wines, turbidity, protein stability and tartrate stability were measured with increasing CMC dosage additions. With red wines, turbidity, colour stability and tartrate stability were measured with increasing CMC dosage additions. Wines that according to the preliminary tests could be stabilised with CMC, were treated on industrial scale volume. CMC was added either before microfiltration or after microfiltration by means of a dosing pump.

According to our experience, mandatory conditions for a successful application of CMC in white and rosé wines are: protein stability; two to five days interval between CMC addition and bottling; temperature higher than 10°C; turbidity lower than 1 NTU. In these conditions, CMC can be added before microfiltration.

With red wines, besides assuring the same conditions of temperature and clarity as per white and rosé wines, it is crucial to remove unstable colour and use CMC in combination with gum Arabic in order to avoid colour precipitation that may occur when wine is exposed to low temperatures (Figure 1). The impact of both CMC and gum Arabic on wine filterability implies that in-line addition after microfiltration is the easiest way of using these protector colloids for red wine stabilisation.



Figure 1. The combination of CMC with a high molecular weight Verek gum Arabic prevents colour precipitation caused by interaction among CMC, colour compounds and exposure to low temperature

7. Microwaves aid in accelerating yeast autolysis

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Methods for accelerating yeast autolysis are being widely studied in order to find ways to shorten the ageing period (usually 6–24 months) in order to reduce the costs of winemaking and to minimise the risks of potential wine spoilage. Microwaves have been employed as a modern extraction technique and effective bacterial inactivation as well. Thus, the possibility that microwaves may be an effective means for accelerating yeast autolysis with minimal side effects has been explored.

The effectiveness of microwaves as a possible means to accelerate yeast autolysis during wine ageing has been studied by examining the levels of certain chemical metabolites coupled with a descriptive sensory analysis. An optimised treatment temperature of 85°C at 300 W was found. Thermal treatment to 85°C was adopted as control. Sensory effects on a commercial dry unwooded Chardonnay wine were examined by an 11-member descriptive analysis panel. Microwaved, untreated or thermally treated lees (85°C), which were freshly harvested from a Chardonnay fermentation were washed in milliQ H₂O and back added into a commercial base wine at reconstitution levels of 1%, 2% and 3% (v/v, of lees stock solution, concentration of 0.3912 ± 0.0019 g/mL). The wines were left on lees for 24 hours and then centrifuged to remove the lees and bottled under CO₂. Three commercially available beta-glucanase products were also evaluated for comparison with microwave samples (at 35°C). Glucidic colloids released were examined as an indicator of accelerated autolysis.

It was found that glucidic colloids, total soluble protein levels and antioxidant capacities all increased compared with untreated lees (Figure 1). Increases in the observed levels of glucidic colloids and soluble proteins were: microwave > heated > untreated; and both the heated and microwave treatments resulted in elevated antioxidant abilities (DPPH and FRAP), though differences between microwave and untreated trials were not substantial. Microwave and beta-glucanase did not have synergistic effects on accelerating yeast autolysis when evaluating total glucidic colloids released (Figure 2). The effects of microwave treatment were observed up to three days after treatments. On the other hand, Transmission Electron Microscopy (TEM) images of yeasts after microwave or thermal treatments are different from those of yeasts after natural autolysis in wine for



Figure 1. Soluble protein, glucidic colloids and free radical scavenging abilities of yeast autolysates after different treatments. Glucidic colloids in base wine: 1162.7 ± 180.0 mg/L. All results based on two parallel treatments, except for untreated (one sample), and each treatment was tested in triplicate. All data were significantly different between treatments by Student-Newman-Keuls one-way ANOVA analysis (p<0.5).

up to two years (Figure 3). Yeasts after two years of natural autolysis show thinner and amorphous cell walls, with only the fibrous part observed (e-f), plasmolyse space between cell wall and membrane appeared after microwave treatments (c-d) while the untreated (g-h) were still intact, which indicated the accelerated release of cytoplasmic contents happened during microwaving. Misshaping and even breakage of cell walls happened to the yeasts after thermal treatments up to 85°C (a-b).



Figure 2. Co-effect of microwave and enzymes on release of glucidic colloids from lees. B:blank, untreated lees; MW: microwave treated; MW-L: microwave with enzyme L (LALLZYME® MMX, Lallmand, Canada) treated; L: enzyme L treated only; MW-N: microwave with enzyme N (Vino Taste Pro®, Novozyme, Denmark) treated; N:enzyme N treated only; MW-O: microwave with enzyme O (Optivin elevage®, Enzyme solutions, Australia); O: enzyme O treated only.



Figure 3. TEM imagines of ultrathin sections of Saccharomyces cerevisiae lees after treatments. (a-b) thermal treatment at 85°C; (c-d) microwave treatment at 85°C; (e-f) natural autolysis at 15°C in bottled Chardonnay wine for two years; (g-h) yeasts after wash with MilliQ H_{2} O and before treatments.



Figure 4. Attributes among different treatments and addition levels

Sensory assessment of treated wines showed decreased intensity of savoury aroma and bitterness, but elevated pome fruit flavour. However, the levels of ethyl hexanoate, hexyl acetate and ethyl decanoate, compounds associated with fruity aromas were reduced (Figure 4).

Microwave treatment is an effective way to accelerate yeast autolysis in terms of yeast metabolites released. The mechanism of microwave acceleration of yeast autolysis is different from natural autolysis which may be the reason the accelerated yeast autolysis introduced more intense fruity flavours which usually decrease during natural lees ageing. Thus a new wine style could be developed if further understanding of accelerated yeast autolysis is developed.

8. A review of CMCs – carboxymethylcellulose as a cold stabilisation aid

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Cold stabilisation of wine aims to prevent the formation of potassium and calcium tartrate crystals. A wine is deemed cold stable when no observable tartrate crystals can be seen after chilling a sub-sample of wine at -4°C for 72 hours. To achieve cold stabilisation, traditionally the wine may or may not be seeded with potassium hydrogen tartrate to induce crystal formation and is then stored at 0°C for an extended period of time. This method however may affect the acidity and requires extensive refrigeration time to achieve stabilisation.

A more recent method to cold stabilise white wines is the addition of sodium carboxymethylcellulose, more commonly known as CMCs. CMCs are applied to 'bottle ready' wine and are thought to provide long-term stability. The interaction of CMCs with tartrates is largely unknown; however, evidence suggests CMCs achieve cold stabilisation by binding to the active crystal forming binding sites of tartrates. In late 2011, CMCs were approved for use in Australia as a cold stabilisation wine additive. Even though CMCs have been applied in Europe since 2006, little is known regarding their impact on colour, phenolics and turbidity amongst other things. CMCs are not recommended for red wines since they are known to interact with colour compounds and strip colour from wines. While CMCs have historically been applied as food thickeners, it remains unclear whether the application of CMCs influences viscosity of wines and thus, filterability downstream of production. This poster is a summary of current findings regarding the interaction of CMCs in wine and aspects to consider prior to its application.

9. Fibres from processing wastes as novel fining agents for wine tannin

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Concerns over the health and labelling implications of using animalderived proteins as fining agents in wine have led to research into the development of plant-derived sources. Recent work has shown the capacity of grape-derived insoluble fibres to adsorb grape and wine tannins (Bindon and Smith 2013), which has led to its consideration for application as an alternative fining agent.

Grape and apple pomace fibres were isolated, and applied in model fining experiments to a) red wine, and b) isolated wine tannin. Apple fibre had a far higher binding capacity for wine tannin than grape fibres by dose. A treatment of commercial casein was also applied for comparison purposes. Both fibre and casein application in wines reduced anthocyanins, total phenolics, and wine colour density, but maintained hue (Table 1). Fibres significantly decreased Fe, Al, Mn, Zn, S and K concentrations in wine, and the effect was more significant than for proteins. Selectivity of fining agents for wine tannins was analysed in model experiments with a purified wine tannin isolate. The dose of fining agent was varied, and the tannin concentration kept constant at 3 g/L. The application of commercial proteins and fibre extracts generally reduced tannin molecular mass compared with the control, as can be seen from a shift in the cumulative molecular mass distribution toward a lower average (Figure 1). The reduction in tannin molecular mass was greatest when fining with apple fibre. For some fining agents, for example Cabernet Sauvignon pomace, tannin molecular mass was decreased following fining, the proportion of epigallocatechin (skin tannin) subunits remaining in the wine tannins was also reduced.

This work has provided a comparison between commercially available proteins and fibres as fining agents for wine tannins. In general, the removal of tannin was greater per unit protein addition than for fibres. While some differences in the selectivity of the applied fining agents for tannins based on their subunit composition and molecular mass was demonstrated, this was within the variability reported in current literature (Cosme et al. 2009). Plant-derived fibres may therefore provide a useful alternative to traditional protein-based fining agents.

 Table 1. Changes in tannin, anthocyanin and wine colour measure following fining with grape and apple fibres (applied at 5 mg/mL) and commercial casein (applied at 0.30 mg/mL), expressed as a % change from the control

	Tannin	Antho- cyanin	Wine colour density	Non- bleachable pigments	Wine hue
Grape pomace fibre A	-16.9	-13.1	-19.1	-20.4	No change
Grape pomace fibre V	-21.8	-13.2	-19.9	-22.1	No change
Apple pomace fibre	-37.1	-22.3	-36.5	-35.0	No change
Postassium caseinate	-19.9	-6.8	-15.4	-14.4	No change



Figure 1. Cumulative molecular mass distribution of wine tannin before (control) and after fining determined by gel permeation chromatography (20% w/w of tannin was removed by each fining treatment). The molecular mass at 50% elution represents the sample average

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CLIMATE CHANGE

10. Delayed pruning of grapevines: a tool to manage the effects of climate change on fruit quality and harvest compression

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Between 1993 and 2013, maturity of grapevines in Australia advanced 0.5 to 3 days per year across a range of regions. Warmer temperatures and an advancement in maturity potentially impact on wine style, causing 'unbalanced fruit' where high sugar levels are reached before optimum colour (and potentially flavour) development has been achieved. Associated with the advancement in maturity there has also been a compression of vintage, with different varieties grown in the same region reaching optimal maturity at similar dates and the peak period over which a variety matures becoming narrower.

Delayed pruning offers the potential to delay the initiation of vine growth and shift phenology back into a more familiar time frame, potentially improving fruit and wine quality by allowing optimum flavours to be reached at a more appropriate sugar level. Spreading the harvest period will allow better utilisation of equipment and help avoid compromises in quality where fruit is harvested before or more often after optimal maturity due to constraints in processing capacity.

In the Barossa Valley the maturation of Shiraz was successfully delayed by three weeks and Cabernet Sauvignon by two weeks in field trials during the 2012 vintage. The spread in phenology between vines pruned during dormancy and up to five weeks post-budburst reduced as the season progressed. Vine growth and berry weights were also reduced by the delayed pruning which may have also improved fruit quality.

Delayed pruning offers a tool for the Australian wine industry to counteract some effects of climate change.

11. Impacts of global warming on grape phenology and vine growth

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The latest predictions concerning the future climate indicate a 2°C rise for the Murray Valley by 2050 (IPCC 2007). The region accounts for approximately 60% of the Australian grape crush. There is uncertainty as to whether the predicted temperature increase will allow growers to maintain current quality standards. Modelling of climatic impacts on the growth habits of grapevines have indicated a number of issues which could impact on wine quality (Petrie and Sadras 2007; Webb et al. 2011). It is therefore important to assess and anticipate potential impacts of expected climate scenarios in the vineyard.

A project conducted in Mildura in NW Victoria simulated aspects of the current climate change predictions for the Murray Valley region in Australia. The field experiment included three varieties: Chardonnay, Cabernet Sauvignon and Shiraz. Active heating of the air space in large Open Top Chambers (OTC) by 2°C above the ambient temperature was used to simulate the future climate scenario in the vineyard. The effect of elevated vineyard temperature year round was measured for two seasons. Stomatal conductance, leaf temperature, vine phenology and leaf area index were recorded throughout the season. Berries were sampled at different growth stages and their composition was analysed.

Heating substantially advanced the phenology of Chardonnay, Cabernet Sauvignon and Shiraz. A rise in the average temperature by 2°C accelerated budburst by 3–12 days, cap fall by 5–10 days and veraison by 5–12 days. The temperature rise accelerated leaf area index but delayed leaf fall in all varieties but especially in Chardonnay. Heating had no influence on important leaf physiological indicators like stomatal conductance or leaf temperature, independent of variety.

The changes in phenology with a relatively small change in average temperature confirm modelling predictions. Earlier budburst can pose additional frost risks and earlier harvest dates will compound the effect of elevated temperatures by bringing harvest into a period with a greater probability of high temperature extremes. A lack of apparent stress due to heating suggests that vines readily adapt to a moderate temperature increase provided their water requirement is met regularly so they don't suffer from water stress.

Results suggest that under the imposed climate change scenario the growing of wine-grapes in the Murray Valley region of Victoria will remain a viable option for growers provided other economic factors are favourable.

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FERMENTATION

12. New Schizosaccharomyces spp. uses in modern oenology

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The yeasts of the genus *Schizosaccharomyces* have traditionally been described as wine spoilage organisms owing to their production of compounds with negative sensorial impacts, such as acetaldehyde, H_2S and volatile acids. However, the industrial use of *Schizosaccharomyces* has been described in the fermentation of cane sugar in rum-making and the production of palm wine (Benito et al. 2012a, b). The genus has also been studied at the laboratory and semi-industrial scales in the winemaking industry, given the notable capacity of some of its members to deacidify wines via the ability to metabolise malic acid with the production of ethanol.

One of the new applications of *Schizosaccharomyces* is ageing over lees, made possible by these yeasts' strong autolytic release of cell wall polysaccharides. Further, certain *Schizosaccharomyces* mutants may be able to reduce the gluconic acid contents of spoiled musts. The urease activity of *Schizosaccharomyces* spp. is also of interest with respect to food safety; its production could reduce high wine ethyl carbamate contents by reducing urea concentrations (a precursor of ethyl carbamate) (Suárez-Lepe et al. 2012).

To further our knowledge of the fermentative activity of *Schizos-accharomyces*, the present work examined the fermentations of four strains of *Schizosaccharomyces pombe* and two strains of *Saccharomyces*, along with the consumption of glucose + fructose and the production of acetic acid, pyruvic acid and urea.

Table 1 shows fermentations final results. Saccharomyces cerevisiae 7VA and S. uvarum S6U finished fermentation on days 4 and 11, respectively, although S6U left some residual sugar. Schizosaccharomyces pombe 935, 936, 938 and 2139 required 15 days to complete fermentation, leaving very little residual sugar. Schizosaccharomyces pombe 936, 938 and 2139 consumed all the malic acid present, while strain 935 reduced its concentration by 50%. Differences in acetic acid production were seen among the yeast species, as well as among Schizosaccharomyces strains. Saccharomyces cerevisiae 7VA and S. uvarum S6U produced mean acetic acid concentrations of 0.23 and 0.36 g/L, respectively. The S. pombe strains, however, produced concentrations of 0.86-1.01 g/L, rendering them unsuitable for use on their own in winemaking. Saccharomyces cerevisiae 7 VA and S. uvarum S6U showed maximum pyruvic acid production at four days, reaching 0.061 and 0.045 g/L, respectively. The Schizosaccharomyces strains produced more, however, within the same time frame and with significant differences between most of the member strains. Strain 938 reached a maximum of 0.386 g/L while 2139, 936 and 935

reached maxima of 0.292, 0.207 and 0.199 g/L, respectively. Pyruvic acid-based selection studies on *S. cerevisiae* returned maximum values of 60–132 mg/L after four days of fermentation (Benito et al. 2012a); values for the present *S. pombe* strains are shown in Table 1.

The metabolic properties of *S. pombe*, that is, the breakdown of malic acid, production of pyruvic acid and the breakdown of ethyl carbamate precursors, are of great interest in modern winemaking. However, its major drawback is its strong acetic acid production at least for the unselected strains commonly used in wine research. The selection of *Schizosaccharomyces* strains with low production of acetic acid could bring a new oenological tool for unbalanced musts (Benito et al. 2013).

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Investigation of the genetic basis of high nitrogen efficiency (HNE) in wine yeast

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Insufficient yeast assimilable nitrogen (YAN) in grape juice could cause failure of alcoholic fermentation (Ingledew and Kunkee 1985; Alexandre and Charpentier 1998). Instead of the common YAN addition method, employment of high nitrogen efficient (HNE) wine yeast provides a quick and sustainable option to conquer low YAN issues of grapes. A high nitrogen efficiency wine yeast is a yeast that can catabolise all sugars (generally ~200 g/L) with limited nitrogen (~100 mg/L N). Our initial efforts using transposon mutagenesis and high-throughput analysis yielded some HNE wine yeast mutants for characterisation and the associated genes were identified. To understand the HNE phenotype from a genetic basis, three HNE deletants were generated in a wine yeast genome. These three mutants are C911D Δ ecm33, C911D Δ pst1, and C911D Δ slt2, and C911D Δ psr1.

Deletants were studied by examination of fermentation performance under low nitrogen conditions (55 mg/L N). Triplicated 100 mL fermentations were conducted using chemically defined grape juice medium (CDGJM) containing 200 g/L sugars (Figure 1). The experiments show that mutant Δ ecm33 fermented much faster than

Poster 12 Table 1. Analytical results for the wines produced in the different fermentations involving the use of Schizosaccharomyces pombe and Saccharomyces strains (all performed at 25°C with an initial sugar concentration of 224 g/L and initial malic acid content of 2 g/L)

Yeast strain	Glucose+Fructose (mg/L)	Malic Acid (g/L)	Acetic Acid (g/L)	Pyruvic Acid (g/L) (day 4)	Urea (mg/L)
S. cerevisiae (7VA)	0.68 ± 0.24a	1.69 ± 0.18d	0.21 ± 0.02a	0.06 ± 0.01e	3.16 ± 0.28a
S. uvarum (S6U)	6.22 ± 0.32b	1.32 ± 0.12c	0.28 ± 0.01b	0.09 ± 0.01d	2.62 ± 0.32a
S. pombe (935)	0,72 ± 0.32a	1,08 ± 0.21b	0.82 ± 0.02b	0.21 ± 0.01c	0.38 ± 0.18b
S. pombe (936)	0.43 ± 0.48a	0.02 ± 0.01a	1.06 ± 0.02d	0.22 ± 0.02c	0.36 ± 0.24b
S. pombe (938)	0.56 ± 0.29a	0.01 ± 0.01a	0.97 ± 0.01cd	0.45 ± 0.01a	0.44 ± 0.31b
S. pombe (2139)	0.76 ± 0.22a	0.02 ± 0.02a	1.01 ± 0.01cd	0.29 ± 0.03b	0.32 ± 0.21b

Results represent mean ± SD for three replicates. Means in the same column with the same letter are not significantly different (p<0.05)

other strains, with fermentation duration only 70% of that of the control (C911D). Further fermentations were performed using various nitrogen conditions (60–450 mg/L N). An enhanced fermentation phenotype was still observed in mutant Δ ecm33, with a reduction in duration of approximately 15 to 30% of total fermentation time (data not shown).



Figure 1. Sugar catabolism by HNE candidates in CDGJM during fermentation under low YAN conditions. Data points are the mean values from triplicate fermentations \pm standard deviation (SD)

To determine changes in cell morphology by deletion of ECM33, growth sensitivity plate assays were used. Cells were spotted in a 10-fold dilution series on YPD (Yeast Extract Peptone Dextrose) agar plates containing calcofluor white (CFW, 5–250 μ g/L). The hypersensitivity of the mutant to CFW indicates that Δ ecm33 has increased chitin content (Figure 2). This may suggest that the basis for the greater tolerance of Δ ecm33 to the harsh fermentation environment is an increased chitin content of the cell.



Figure 2. Growth phenotypes of the wild type C911D and mutant $\Delta ecm33$ on calcofluor white (CFW) and YPD plates

To investigate the HNE mechanism of mutant Δ ecm33, quantitative real-time polymerase chain reaction (PCR) was performed to determine the gene expression levels during fermentation. Two stages of the fermentation were analysed that were representative of when the culture reached the middle and end stages of fermentation, (~100 and <4 g/L, respectively). The expression levels of genes of interest were normalised with three housekeeping genes. Results showed that two genes were upregulated in mutant Δ ecm33 during fermentation (Figure 3): SLT2 and HOG1, which are involved in the cell wall integrity pathway and the high osmolarity pathway, respectively.

In conclusion, the improved fermentation performance of mutant Δ ecm33 appears to be due to increased cell wall resilience under high osmolarity and/or nitrogen starvation. Knowledge from this study will be applied to enhance industrial yeast strain improvement and optimisation of fermentation management strategies.



Figure 3. Determination of gene expression in mutant Δ ecm33 and wild type strain C911D; data points are the mean values from six replicate fermentations ± standard deviation (SD); NREL; Normalised relative expression level. t-test; * P <0.05; ** P <0.01; **** P <0.001

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14. Vacuolar acidification may play a key role in the ability of yeast to successfully complete industrial fermentation

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In winemaking, yeast's ability to grow and ferment is affected by the many stressors present during grape juice fermentation. Typically these juices contain initially high concentrations of sugars (200-270 g/L), which is a very common yeast stressor in industrial fermentations. Previous work in this laboratory identified 93 genes that were essential for the completion of fermentation by the laboratory yeast BY4743 in a high sugar medium (Fermentation Essential Genes; FEGs, Walker et al. 2013). A Gene Ontology (GO) analysis of these genes revealed that vacuolar acidification (VA), amongst other GO terms, was significantly enriched. In fact, 20 of the 26 genes annotated to VA are FEGs. Yeast vacuoles are well known to be involved in the regulation of ionic and chemical homeostasis, related to many biological pathways and are required to be acidified for appropriate function (Cyert and Philpott 2013). We hypothesise that fermentation, particularly in high sugar juices requires maintenance of intracellular acidification, carried out at least in part by VA.

To determine whether other FEGs, not previously associated with VA are also involved, we analysed vacuole acidification of FEG deletants during fermentation with the use of a pH-sensitive fluorescent dye, 6-carboxyfluorescein diacetate (6-CFDA) (Preston et al. 1989). Cells were harvested, labelled with 6-CFDA and observed by both microscopy and fluorescence-activated cell sorting (FACS) (Figure 1). Dual labelling with propidium iodide (PI) allowed for measurement of yeast viability.

The fluorescence intensity (and thus extent of VA) of each FEG mutant was measured and reported as the mean value of peak intensity (Figure 1C). The relative fluorescence intensity of each deletant

was then calculated by comparison to the parent. Of the 93 FEG deletants, 33 had increased fluorescence, indicating non-acidified vacuoles. Importantly, 19 of these genes have not previously been associated with vacuolar acidification.

We further examined these mutants on solid media with varying pH values and found that, similar to the VMA (vacuolar membrane) gene family, which are well characterised as components of the vacuolar ATPase (the mechanism by which vacuolar acidification is maintained) most of these 33 FEG mutants were slow or failed to grow on neutral media.

In summary, the ability of yeast to maintain appropriate vacuolar acidification is a key for successful high sugar fermentations. Further understanding of this process will contribute to ongoing efforts to improve yeast and their use in an industrial context.

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15. Immobilised yeast as strategy to control the ethanol level in wine

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Nowadays, low alcohol wines present in the market have been produced by dealcoholisation or alcohol elimination using reverse osmosis, vacuum distillation and evaporation technologies. These have been effective and legal technologies in Europe since 2009, but the high cost and sensory changes after the process make them disadvantageous. Dealcoholised wines have about 0.5% alcohol. However, according to the international legislation (OIV), any beverage has to be at least 8.5 to 9.0% to be called wine.

This work studies the immobilisation of yeasts on different supports with the aim of manipulating the fermentation residence time of the yeasts in the must and so achieving the desired alcohol level. Natural (grape wastes) and synthetic (calcium alginate pellets) supports have been tested for this purpose. During fermentation the yeast count, density, sugars and ethanol were monitored. In addition sensory quality parameters were evaluated. Preliminary results have demonstrated that it is possible to produce wine with reduced ethanol content. A protocol of yeast immobilisation was developed and implemented. Normal, coated, and dehydrated encapsulated yeasts were tested. In addition, results of laboratory fermentations showed similar behaviours of fermentations using soluble and immobilised yeasts. However the coating of alginate droplets with an outer layer must be evaluated in order to avoid the yeast leaking into the liquid medium and the consequent conversion of the free sugar into alcohol.



Poster 14 Figure 1. Phase contrast and fluorescence microscopy (A) and flow cytometry analysis (B and C) of yeast cells labelled with 6-CFDA and/or PI after 24 hours of growth in chemically defined grape juice medium with 200 g/L sugars. Each histogram represents a measurement of 10,000 events

16. Monitoring the indigenous yeast microbiota of Chilean Carmenere grapes during spontaneous fermentation

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Changes in indigenous yeast microbiota of Chilean Carmenere grapes were monitored during the spontaneous fermentation of the grape juice. Whole grapes were blended to a homogeneous juice and aliquots were incubated at 25°C under aerobic conditions for ten days. Cell counts were characterised in selective yeast agar. Distinct cell morphologies were isolated at different points during the fermentation and identified based on their biochemical profile. Thirteen non-Saccharomyces species were isolated. Among them Candida sake, Candida pulcherrima and Kloeckera apis/apiculata were the species most commonly present throughout the fermentation period. Therefore, the three yeasts were further characterised based on substrate utilisation and product formation. For this purpose filter-sterilised grape juice was inoculated with each yeast culture and fermented for seven days under the same conditions described above. Changes in pH, sugar and alcohol content, and cell counts were monitored. For all treatments must pH decreased as fermentation proceeded to a final pH of 3.4-3.5. Decrease in pH was correlated with sugar utilisation and product formation. After seven days of experimentation about 50% of sugars were utilised by each culture, however alcohol content only reached half of the expected value as compared with the Saccharomyces cerevisiae-inoculated control. C. sake presented the most accelerated growth followed by K. Apis/apiculata and finally C. pulcherrima presented the slowest growth. Fermented must sensorial characteristics were found not to be different compared to control samples. Results suggest that these isolates present a low alcoholproducing profile and could potentially be used for the production of reduced alcohol wines.

17. Enhanced winemaking efficiency: evolution of a superior lactic acid bacteria

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Malolactic fermentation (MLF), also known as secondary fermentation, involves the enzymatic conversion of L-malic acid to L-lactic acid by the lactic acid bacterium *Oenococcus oeni*. This conversion improves the organoleptic properties of wine and also decreases the risk of microbial spoilage. *O. oeni* is a notoriously fastidious microbe prone to slow growth, especially in the harsh physiochemical environment of wine: high ethanol, presence of sulfur dioxide, low pH and low temperature. Each of these factors influences the growth rate and metabolism (including MLF) of this organism.

This research aims to generate improved strain(s) of *O. oeni* with the ability to withstand the environmental pressures of wine using directed evolution (DE). This work summarises a successful effort to generate a strain of *O. oeni* that is more tolerant to high ethanol concentration.

Directed evolution is a non-recombinant method of generating improved strains. The process involves an organism mutating spontaneously, and potentially adapting to a high stress environment, in this case a high ethanol concentration, over several hundred generations. This method has been used successfully to generate improved strains of other lactic acid bacteria and its efficacy as a method for the production of bacterial strains for the wine industry is detailed here.

A continuous culture of *O. oeni* was established in media containing low amounts of ethanol, which were increased over a period of many months and generations. Samples of this culture were screened for malic acid consumption (MLF) compared to the original parent. Figure 1 shows that the evolved population completed fermentation 70 hours faster than the parent.



Figure 1. A mixed population from the evolving directed evolution experiment screened in MRSAJ media at 15% (v/v) ethanol

With proof of concept achieved, individual clones of bacteria were isolated from this culture in order to demonstrate the ethanol tolerant phenotype. A screening was performed in MRSAJ media in 15% (v/v) ethanol, firstly in micro-scale ferments, then at 10 mL and 50 mL volumes, for individual isolates that showed the improved ethanol tolerance. As shown in Figure 2, four strains were selected.

This work is the first known use of directed evolution for *O. oeni* strain improvement and has confirmed directed evolution can be successfully used as a technique for developing new strains. Further characterisation is now required in order to assess efficacy in wine fermentation and suitability for industry.



Figure 2. Four individual isolates were selected based on their ability to complete fermentation faster than the parent

18. Identifying genes of oenological importance in commercial winemaking yeast

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Deciphering the genetic basis of complex fermentation traits of the yeast *Saccharomyces cerevisiae* remains a challenge. For this project, two commercial winemaking yeasts (Enoferm M2 and Zymaflore F15) were crossed and 96 recombinant F_2 progeny were dissected from the F_1 generation. All strains were sequenced using various next-generation sequencing platforms. 8,200 high-quality sequence variants were identified between the two parental strains. The 96 F_2 progeny were genotyped at these loci and a genetic map of the cross was generated.

The 96 F_2 progeny were used to ferment Marlborough Sauvignon Blanc (SB) juice. Lag phase, fermentation rate and efficiency were modelled using weight loss data. Aroma compounds in finished wines were quantified using solid phase micro-extraction gas chromatography mass spectrometry. Other traits of oenological relevance were measured in additional experiments.

One and two-dimensional genome scans revealed quantitative trait loci (QTL) linked to many of the studied traits, including glucose/ fructose utilisation, hydrogen sulfide release and the production of volatile aroma compounds. These loci point to candidate genes with mutations between the parents. The relative contribution of a QTL to a trait and its interaction with other QTL were measured and may be useful for breeding purposes. The approach used for this project has proven to be powerful and accurate for finding genes related to winemaking. The potential of this yeast cross has not yet been fully realised.

19. Improving alternate nitrogen utilisation during wine fermentation

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A deficiency of assimilable nitrogen for *Saccharomyces cerevisiae* can cause stuck or sluggish fermentations, which are a common problem faced by the global wine industry. Proline is typically the most abundant amino acid present in grape juice and wine, however, only a small amount can be utilised during fermentation. Proline uptake is limited since its specific permease, Put4p, is repressed and inactivated when other preferred nitrogen sources exist. Once these nitrogen sources have been exhausted and proline uptake is possible, catabo-
lism cannot occur because fermentations have become anaerobic and the first catabolic enzyme, proline oxidase, has a strict requirement for oxygen.

Generation of constitutive proline-utilising strains was achieved via ethyl methanesulfonate (EMS) mutagenesis and selection techniques. Desired strains were identified by their ability to grow on proline in the presence of the ammonium analogue, methylamine, under aerobic and anaerobic conditions. Methylamine as an ammonium analogue can be assimilated by *Saccharomyces cerevisiae* but not serve as a nitrogen source (Roon et al. 1975). Its uptake mainly depends on pH (6.0–6.5) and temperature (<35°C). In theory, proline consumption should be repressed by the presence of methylamine. In this study, a significant amount of proline was assimilated by the EMS-treated isolates.

Aerobic fermentations with two isolates of QA23 (Q3 and Q7) were conducted in Yeast Nitrogen Base (YNB) medium initially containing 100 g/L sugar, 4.8 g/L methylamine and 2.5 g/L proline. Sampling was performed at several time points and proline consumption was analysed. The two isolates showed higher fermentation rates compared with the wild type strain QA23 (Figure 1). Proline was removed completely by Q7 and more than 1.3 g was removed by Q3 (Figure 2). Q7 had significantly different growth kinetics and proline consumption from QA23 (Figure 2). The research is ongoing and will characterise the constitutive proline-utilising mutants.



Figure 1. Sugar consumption during fermentation of Q3, Q7 (isolates of QA23 treated with EMS) and QA23. Fermentations were conducted in YNB medium initially containing glucose at 100 g/L, 2500 mg/L of proline and 4.8 g/L of methylamine. pH was adjusted to 6.2 with 5M sodium hydroxide. Proline content was determined using the isatin method. Results are the means of triplicate cultures



Figure 2. Proline consumption and yeast growth estimated by OD600 of Q3, Q7 and QA23 during fermentation. Results are the means of triplicate cultures conducted as described in Figure 1

Reference

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20. Unravelling the efficient fermentation phenotype of an evolved wine yeast

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Directed evolution is the process by which a biological system (in this case yeast) evolves and therefore adapts under various environmental conditions (Elena and Lenski 2003). This method offers a versatile model for the development of optimised wine yeast. The robust and efficient fermentation of sugars under oenological conditions by an adaptively evolved wine yeast strain, isolated by this laboratory, has been previously reported (McBryde et al. 2006). Through multiple laboratory and industrial trials we have shown that this evolved strain performs equal to or better than other commercially available, 'gold standard' efficient wine yeast strains.

We have shown that the efficient fermentation phenotype of this evolved strain is stable and since it was not produced using GM techniques, it can be used directly in industrial winemaking.

Complex phenotypes such as fermentation efficiency are most likely due to multiple pathways working in concert and as such are difficult to characterise. In this study we use a systems biology approach to investigate how this evolved strain can catabolise all sugars in a shorter time frame than its parent. We report that the genome sequence of this evolved strain differs from its parent, including via SNPs (single nucleotide polymorphisms) in genes of multiple biological pathways, some known to influence fermentation efficiency. However, even with a known genome, relation of any genomic changes to a phenotypic outcome is challenging. For this reason we are also examining the metabolomic profiles under various conditions, in particular those relevant to industrial winemaking.

An in-depth examination of fermentation efficient strains such as these will result in a better understanding of the basic process of fermentation as well as identification of the basis for fermentation efficiency. A thorough understanding of the impacts of such changes and, in turn, how such strains enable more reliable fermentation will allow a more specific, targeted approach in further yeast strain development. A better understanding of some of the main contributing metabolic pathways influencing fermentation dynamics, particularly in an industrial setting such as winemaking will also result.

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21. The structure and dynamics of the wine's fermentation microbiome

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Winemaking is a historical food transformation process which entirely relies upon a complex fermentation achieved by several microorganisms acting synergistically. Indeed, microbial diversity, grape quality and variety and wine fermentation conditions are critical for wine flavour and bouquet, and hence its identity. *Saccharomyces cerevisiae* is the main yeast responsible for complete wine fermentation, though non-*Saccharomyces* indigenous yeasts and several bacteria also have an impact on the development and incorporation of flavour and bouquet into wine.

In this study, we characterised the microbiome of wine fermentations from eight wine appellations using massive parallel DNA sequencing and unveiled its high complexity. We have analysed wine must samples from both vineyards and wine cellars at the beginning and end of fermentations, to monitor the dynamics of microbial populations. Interestingly, we observed 25 eukaryotic genera/prokaryotic families common to all samples, namely eukaryotes from the genera Aspergillus, Botryotinia/Botrytis, Cladosporium, Cryptococcus, Metschnikowia, Penicillium, Rhodosporidium and Rhodotorula, as well as prokaryotes from the Acetobacteraceae, Comamonadaceae, Enterobacteriaceae, Kineosporiaceae, Methylobacteriaceae, Microbacteriaceae, Micrococcaceae, Nocardioidaceae, Pseudomonadaceae, Sphingomonadaceae and Xanthomonadaceae families. Furthermore, we isolated the most abundant yeast, whose metabolic and phenotypic properties we are currently exploiting.

Our work gives new insights on the complex biochemical reactions that take place during the production of wine, opening new horizons for the development of indigenous wine fermentation agents, capable of enhancing the flavour and bouquet of wine.

22. Genome screening as an approach to understand the cellular mechanisms behind yeast adaptation during fermentation to allow for successful completion

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We have looked at the genes and related mechanisms which allow yeast to successfully complete industrial fermentations. Wine fermentation, typically of high sugar content and low pH juices, is conducted by *Saccharomyces cerevisiae* yeast, and results in the production of ethanol and secondary fermentation products. The cellular mechanisms that allow yeast to grow in and respond to such a harsh environment and successfully adapt to changing chemical stresses incurred during fermentation are largely unclear. A genome screening approach utilising collections of yeast mutants with individual known gene deletions, is one paradigm being used to address this gap.

Our research seeks to identify genes that are required for fermentation and which can modulate fermentation outcome. Such genes are representative of what we term the 'fermentome'. As part of this research, we have evaluated a collection of diploid laboratory yeast clones possessing homozygous single gene deletions to identify those deletions that result in protracted or stuck fermentation. A total of 93 genes were identified (i.e. Fermentation Essential Genes) and compared with the Fermentation Relevant Yeast Gene database (compiled from data sets annotated to fermentation-relevant phenotype terms). Of the FEG data set, 83 occur in the FRYG database, with 10 genes unique to our fermentation screen. Through gene ontology (GO) analysis, we were able to identify the biological processes and genes which may play a role in the cellular mechanisms behind yeast adaptation during wine fermentation. Validation is proceeding in order to allow exploitation of this knowledge to enable better management of wine microbiology and fermentation.

23. Second generation yeast with reduced hydrogen sulfide and sulfur dioxide production

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Hydrogen sulfide (H_2S) and one of its precursors, sulfur dioxide (SO_2), are intermediates of yeast sulfur metabolism, produced via assimilation of inorganic sulfur (from sulfate) into methionine and cysteine. Some 10% of wines are affected by H_2S formation at some time, typically in nutritionally-deficient musts. Excess H_2S in wine has a noxious odour and may be complexed into similarly undesirable mercaptans and disulfides. SO_2 inhibits malolactic fermentation, is subject to legal limits (as part of total sulfites) and affects sensitive consumers. Current remedies do not fully address this widespread issue and some, for example 'low H_2S strains' produced through disruption of sulfite reductase (last step in sulfide formation), can also over-produce SO_2 . To date, demand still exists for new yeast strains that produce little H_2S under any condition without the complication of excessive SO_2 .

Sulfate is the most abundant inorganic sulfur compound in musts, ranging from 160-380 mg/L (González Hernández et al. 1997) to as high as 700 mg/L (Amerine et al. 1980). In this study, two strains were mutated using ethyl methyl sulfonate to produce mutants defective in sulfate uptake, with the aim of modulating sulfate metabolism to minimise both H₂S and SO₂ liberation during yeast sulfur and nitrogen assimilation. Mutants defective in the two sulfate transporters, Sul1p and Sul2p were selected using toxic analogues of sulfate. Genetic heterogeneity was also exploited (Bradbury et al. 2006) through sporulation (meiosis) allowing the mixing and segregation of genetic material within the rediploidised 'selfed' progeny. Candidate strains were evaluated against the parent strains in laboratory scale fermentations for H₂S and SO₂ (and glutathione) production. These new wine yeasts ferment as well as EC1118 or PDM, but produce only limited or no H₂S and reduced SO₂ in low nitrogen juice. We would like to evaluate these strains in larger (50L-200L) scale fermentations.

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24. Chemical and sensory differentiation in red and white wines made by 'wild' yeast fermentation

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The use of selected cultures has increasingly dominated the wine industry due to better control of fermentation speed, completion and flavour production leading to more reproducible winemaking. Winemakers who are wary of using spontaneous ('wild') fermentations, due to the perceived deleterious outcomes, such as off-flavours and stuck ferments, may forgo different flavour and chemical profiles that could differentiate their wines (Pretorius et al. 1999).

Investigations were conducted to explore the differences in chemistry, microbiology and sensory attributes that may occur through the use of 'wild' fermentations in one red (Shiraz) and two white wines (Sauvignon Blanc and Viognier) in 2011 to 2013. Standard practices (but no use of sulfites) were used to prepare replicate 800 L juice batches of each variety which were then fermented using either *Saccharomyces cerevisiae* yeast or allowed to undergo spontaneous fermentation (Figure 1). Each pair of resulting wines was analysed for volatile aroma compounds and basic wine chemistry and underwent sensory difference testing.



Figure 1. Wine fermentation scheme

Chemical differences were significant (p<0.05) between some 'wild' and inoculated wines in some years (Table 1). The largest number of differences appeared in white wine fermentations. All fermentations completed successfully and produced no off-flavours such as acetic acid (Table 1). H_2S levels were typically low in all of the wines.

 $\mbox{Table 1}.$ Wine chemistry analysis. Viognier, Shiraz and Sauvignon Blanc 2011–2013. Significant differences (p< 0.05) are highlighted in red

	2011			2012				2013				
Analysis	Sauvignon Blanc		Shiraz		Viognier		Shiraz		Viognier		Shiraz	
	wild	inoculated	wild	inoculated	wild	inoculated	wid	inoculated	wid	inoculated	wild	inoculated
alcohol %	10,5	10.3	13.4	13.1	14.9	14.8	15.0	14.8	13.3	13.4	15.1	14.9
malic acid g/L	0.84	4.80	3.12	3.13	1.13	2.38	3.61	3.76	2.07	2.81	1.84	2.12
pН	3.36	3.34	3.66	3.66	3.50	3.40	3.76	3.75	3.67	3.63	3.89	3,95
TAg/L	5.7	7.3	7.1	7.1	5.4	6.2	6.1	6.2	5.4	5.3	7.1	6.9
acetic acid g/L	0.06	0.09	0.13	0,14	0.09	0.20	0.30	0.24	0.19	0.11	0.33	0.19
colour density (au)	-	-	9.3	7.6	-	-	15.8	17.9	-	-	-	-
hue	-		0.72	0.78		-	0.89	0.87	-	-	-	-
total phenolics (au)	0.3	0.8	36.5	32.3	0.7	0.4	54.0	58.5	1	1.6	-	4
total anthocyanins (mg/L)			313	255	-	-	383	414	-		-	

The quantitative gas chromatography-mass spectrometry data of Shiraz and Viognier from 2012 have shown many fruity esters are significantly increased in 'wild' wines above reported sensory thresholds.

Sensory difference testing by duo-trio indicates that 'wild' and inoculated Shiraz (2011 and 2012) wines are not discernable in flavour and aroma and that the only apparent differences are colour for Shiraz 2011, supporting the spectrophotometric data (Table 1). Colour differences were not apparent in every year studied. For Viognier, (2012) duo-trio analysis indicated the ability of a sensory panel to differentiate the 'wild' from inoculated wines, however, the Sauvignon Blanc (2011) wines were not considered significantly different.

The analysis results reflect the variability of 'wild' ferments on chemical parameters and the resulting sensory determinations. There do appear to be discernable differences in Viognier wines, but lack of sensory differences in Shiraz wines are likely to be the combination of small differences in wine chemistry and a small number of volatile compound differences.

Overall however, the 'wild' wines appear to have few detrimental outcomes when compared to inoculated wines and do not suffer offflavours, stuck or sluggish fermentation. These 'wild' wines may hold some sensory or chemical differences that may provide a positive benefit for the winemaker.



Figure 3. Wine volatile differences in 2012 Viognier (inoculated QA23 wine values were standardised to 100%)

Reference

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25. Unravelling citrate metabolism in Oenococcus oeni under different wine conditions

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The most important and best adapted lactic acid bacteria (LAB) associated with wine is Oenococcus oeni. This species is primarily responsible for metabolising malic acid in wine via malolactic fermentation (MLF). O. oeni is also able to metabolise other organic acids in wine such as citric acid. The metabolism of citrate by LAB results in the production of important flavour and aroma compounds, such as diacetyl, acetoin and 2,3-butanediol. Citrate metabolism also provides a way for LAB to produce energy and regulate intracellular pH. Citrate permease, citrate lyase, oxalolactate decarboxylase, diacetyl and acetoin reductase are some of the enzymes involved in citrate utilisation. However, very little is known about the regulation and expression of these genes under different wine conditions and the concomitant effect on the patterns of end products. Detailed studies are thus needed to gain knowledge on how certain conditions impact the pathway and how this can be used to control and manipulate the final aromatic profile.

The aim of this work is to study the effect of different wine parameters (malic and citric acid concentration, ethanol content, pH and temperature) on the concentration of end products from the citrate pathway, the transcriptional response of the citrate pathway genes and the relationship between malic and citric acid utilisation. Fermentations were carried out in synthetic wine media with an *O. oeni* strain inoculated at 1×10^7 CFU/mL. The experiment started off with a constant malic acid concentration, ethanol content and temperature, whereas the citric acid (0.0 g/L, 0.3 g/L, 0.8 g/L) and pH (3.2, 3.6) parameters were altered. Sampling occurred regularly until citric acid was completely degraded. The viable cell numbers and organic acid (citric, L-(-)-malic, L and D-(-)-lactic, acetic and pyruvic acid) concentrations were measured. Samples were also taken for the analysis of carbonyl compounds (diacetyl and acetoin) and ribonucleic acid (RNA) extractions for gene expression analysis.

The organic acid results showed that pH mostly had no effect, but if it showed an effect on organic acid degradation and production, the result was not consistent. Malic acid utilisation was delayed when no citric acid was present in the medium. Treatments with a higher citric acid concentration took a few days longer to completely consume malic acid, even though the initial degradation rate was similar to the other treatments. It has been reported that citrate metabolism in wine was delayed when compared to malic acid utilisation (Nielsen and Richelieu 1999), but our results show that citrate and malate metabolism occur simultaneously. In the treatments with 0.3 g/L citric acid, malic and citric acid were depleted on the same day. However, in the treatments with higher citric acid concentrations (0.8 g/L), citric acid metabolism stopped at 0.36 g/L once malic acid was completely consumed. More D-(-)-lactic acid was produced in the treatments with 0.0 and 0.3 g/L citric acid compared to the 0.8 g/L citric acid treatments, while the presence of citric acid compared to no citric acid in the medium resulted in the production of more acetic acid. Carbonyl compounds and expression analysis have not been finalised.

The current results show that different parameters can indeed influence the by-products of citrate metabolism and it would be interesting to see if these data are in agreement with the transcriptional results. For future studies, the influence of various ethanol and malic acid concentrations should definitely be investigated.

Reference

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26. Identification of bacteria associated with 'wild' or uninoculated malolactic fermentations in red wine

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Spontaneous or 'wild' malolactic fermentation (MLF) can facilitate many observable changes in the concentration of flavour and aroma compounds during winemaking (Izquierdo Cañas et al. 2008). Different species and strains of lactic acid bacteria can therefore influence wine composition (Pozo-Bayón et al. 2005). Excellent winemaking outcomes and commercial success can occur for wines produced via 'wild' MLF. However, limited research has been undertaken regarding the nature and contribution of the bacteria populations involved.

Three vintages of 'wild' and inoculated MLF for Shiraz and one vintage for Grenache wines were undertaken (Figure 1). Samples of 10 mL were collected for bacterial identification analysis every second or third day during MLF. At the same time, because there was an initiation of MLF in Grenache wines which contained 17%(v/v) alco-

hol, samples from these wines were diluted and plated on MRS plates (with cycloheximide and apple juice) and single colonies were chosen to screen for strains with superior performance. The technique of terminal restriction fragment length polymorphism (TRFLP) was used to analyse the bacterial populations during fermentation. Gramstain, catalase test, species-specific PCR and 16S rRNA sequence were used to identify bacteria strains isolated.



Figure 1. The fermentation procedure for Shiraz and Grenache wines. A1, A2, A3 were inoculated with commercial wine yeasts; A4, A5, A6 were 'wild' alcoholic fermentation M1, M3, M5, M7, M9, M11 were inoculated with commercial *Oenococcus oeni*. M2, M4, M6, M8, M10, M12 were 'wild' MLF. There was approximately one tonne of wine in each AF tank, and 200 litres of wine in each MLF tank.

We established a TRFLP database of 25 potential wine bacterial isolates and using web-based bioinformatics tools, restriction enzymes were selected to undertake digestion. Further, the appropriate reaction conditions were ascertained to complete the TRFLP analysis. The TRFLP analysis of the Grenache wine samples showed that there were several bacteria species in wine after alcoholic fermentation. Once MLF started, *Oenococcus oeni* gradually became the most important species, and after the mid stage of MLF, *Oenococcus oeni* was the only species that could be detected by TRFLP.

Gram positive and catalase negative strains were selected. A total of 108 bacteria strains were isolated from the Grenache wines during malolactic fermentation. 16S rRNA sequencing showed that *O. oeni* represented 96% of the isolates. Other bacteria identified include *Lactobacillus hilgardii* and *Staphylococcus pasteuri* (Figure 2). However, some of the bacteria detected were not present in the TRFLP database. Therefore alternative methods, such as a clone library, will be employed to identify these bacteria. The genotype of the isolated bacteria will be determined using amplified fragment length polymorphism (AFLP). Malolactic activity and stress tolerance (e.g. alcohol) analysis of these isolates will be investigated to determine if these strains have superior MLF performance under a range of oenological conditions.



Figure 2. Phylogenetic relationships of bacteria species isolated from Grenache wines; neighbour-joining tree based on 16S rRNA gene sequences

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27. Restarting stuck wine fermentations using an evolved wine yeast

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Stuck or sluggish fermentations represent one of the major risks during the production of dry wines. In fact, residual sugar from incomplete wine yeast catabolism can represent a substrate for the growth of undesirable microorganisms and/or add unwanted sweetness to the wine. If fermentations are not promptly restarted, the quality of the wine may be compromised, resulting in considerable loss for the producer. To limit the risks of stuck or sluggish fermentations, much effort has been directed to the isolation of more robust strains with increased fermentation capabilities. Amongst such strains are those that can be used to restart stuck fermentations. In our laboratory, we have generated an evolved yeast strain, by Directed Evolution (DE), which exhibits faster fermentation kinetics when used to initiate fermentations. We report here on the preliminary evaluation of this evolved strain as a rescue yeast to restart stuck or sluggish fermentations. Wines from naturally arrested or slow fermentations sourced from local wineries were used and inoculated with either the evolved strain or reference industrial strains. The beneficial attributes of the evolved strain are described.

28. Can non-conventional yeast be used for the production of wines with lower alcohol concentration?

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Over recent decades average ethanol concentration in wine has increased, reflecting consumer acceptance for wine styles associated with increased grape maturity. High alcohol concentration can affect wine sensory properties, reducing the complexity of flavours and aromas. In addition, for reasons associated with health and economics, the wine sector is actively seeking technologies that facilitate the production of wines with lower alcohol content.

Non-conventional yeast, in particular non-*Saccharomyces* yeast, have shown potential for producing wines with lower alcohol concentration. These yeast species live on grapes and are usually present in the first stages of fermentation, but are not able to complete alcoholic fermentation unaided. We evaluated 50 different non-*Saccharomyces* isolates, belonging to 19 different genera, for their capacity produce wine with lower ethanol concentration when used in sequential inoculation with an *S. cerevisiae* wine strain AWRI1631.

Our results showed that the non-*Saccharomyces* isolate AWRI1149 yielded wine with 1% v/v lower ethanol concentration than wine made with AWRI1631 alone. AWRI1149+AWRI1631 produced at least 20% more volatile compounds, such as esters and higher alcohols, than AWRI1631. Most of these compounds showed concentrations below their respective sensory thresholds indicating a minimal impact on wine flavour profile. In conclusion, it is possible to obtain wine with lower ethanol concentration using non-conventional yeasts while minimising negative effects on wine flavour.

29. The 'dynamic' crusher: a new technological concept for extraction of harvested grapes in oenology

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The technological process of crushing is the bursting of grape berries without altering the seeds, pulp or any plant debris (leaves, stalks, etc.), which, if crushed, could release or diffuse substances that are undesirable for the quality of the wine (e.g. galloylated procyanidins of the seeds). The following study is presented with the aim of comparing traditional roll crusher methods and the new crushing method called 'dynamic'.

The basic principle of the traditional crusher is a hopper that receives the grapes and then transfers them through two finely serrated rollers which rotate and burst the grape berries. The spacing between the cylinders is variable, making it possible to adapt the crusher to the berry size. The new crusher concept developed by Pellenc aims to make it possible to open the berries passing through it by providing each berry with kinetic energy and a convergent movement toward a fixed bursting wall. This new concept means it is no longer necessary to adjust the gap settings and enables high throughput rates. The appearance of the grapes after crushing, in identical conditions, is very different depending on the process. In fact, the berries appear completely open with the dynamic crusher, and simply crushed with the other crushers. This opening of the berries means that seeds are not compromised and are easily released from the fruit, minimising the risk of green taint. This means that crushing is based on maturity rather than size.

The extraction performance by maceration during fermentation shows that the dynamic crusher leads to faster kinetics of extraction of red pigments at wine pH. After bleaching of the anthocyanins by sulfites (SO_2), the pigments analysed are those resulting from the reaction of anthocyanins with other compounds, including anthocyanintannin complexes (Figure 1). These derived pigments are much more stable over time. Therefore, generation of such pigment derivatives is much faster in the case of the use of the dynamic crusher compared







Figure 2. Development of the Total Polyphenol Index (TPI): a) for the 10 days of maceration, b) after alcoholic fermentation and bottling. Carignan grapes, 2010 harvest

to other crushers. It shows that the dynamic crusher allows greater extraction of tannins (Figure 2), making the genesis of higher anthocyanin-tannin complexes possible after the end of alcoholic fermentation, thereby increasing colour intensity of the wine after bottling. Sensory analysis based on visual criteria shows that the wine made with the dynamic crusher differs from the other by its darker, more purple tones. On an olfactory level, the dynamic crusher method is characterised by its notes of cream/butter, while that of the noncrushed method tends to have leather notes. The wine from grapes crushed using tapered micro-toothed rollers presents rather vegetable notes. On a taste level, few differences were observed between the crushing methods.

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30. Understanding the genetic basis of tolerance and sensitivity to low pH in wine yeast

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Background: There are many stresses encountered by yeast upon inoculation into grape juice. Through examination of grape juice composition and subsequent analysis of the contribution of individual elements to fermentation performance of different yeast strains, we identified pH as a key determinant of strain dependent fermentation performance (Schmidt 2011). In the current work we aimed to identify genes that contribute to tolerance of low pH conditions in the context of wine fermentation.

Methods: We have used a wine yeast gene deletion collection comprising 2,300 variants of a wine yeast strain, each with a different gene deleted. These 2,300 gene deletion knockouts were pooled and used to ferment a continuous Chardonnay fermentation in which less fit strains would be washed out. The relative fitness of mutants within mixed populations was assessed using a DNA sequencing-based strategy.

Results: Out of 2,300 gene deletion mutants screened, 23 were identified as contributing significantly to fitness at pH 3.0. Individual fermentations of those 23 mutants verified one deletion that fermented less well in grape juice at pH 3.0 compared to fermentation at pH 3.5. This deletion mutant exhibited significantly lower biomass formation and slower fermentation rates than the parent strain at pH 3.0 but not at pH 3.5. Using this competitive fitness approach we have been able to map the contributions of different genes to yeast strain robustness and to better understand how pH can influence yeast strain fitness, potentially a target for development of novel strains with increased stress tolerance.

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31. Introducing a new breed of wine yeast: interspecific hybrids between *Saccharomyces cerevisiae* and *Saccharomyces mikatae*

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Corresponding author's email: jenny.bellon@awri.com.au Interspecific hybrids are commonplace in agriculture and horticulture with examples in grains and fruits routine in our marketplace. We have generated a new breed of wine yeast by interspecific hybridisation between a robust Saccharomyces cerevisiae wine yeast strain and Saccharomyces mikatae, a species hitherto not associated with industrial fermentation environs and isolated only from soil and decaying leaf litter. Although different species of Saccharomyces are considered to be closely related, DNA sequence variation between Saccharomyces cerevisiae and Saccharomyces mikatae corresponds roughly to that between a human and a mouse. While commercially available wine yeast strains provide consistent and reliable fermentations, many winemakers consider that un-inoculated spontaneous fermentations build a more complex palate structure with greater diversity of flavour profiles. We have attempted to reap the benefits of spontaneous fermentations by hybridising the genomes of two different species to generate an interspecific hybrid yeast. The hybrid inherits fermentation properties necessary for its role in winemaking from the robust S. cerevisiae wine yeast parent whilst delivering novel, and wider ranging, yeast-derived flavour-active metabolites from the

S. mikatae parent. Chemical analysis of Chardonnay wines made by hybrids showed that, relative to the *S. cerevisiae* wine yeast parent, the hybrids produced wines with different concentrations of volatile metabolites that are known to contribute to wine flavour and aroma, including flavour compounds associated with non-*Saccharomyces* species. The new *S. cerevisiae* × *S. mikatae* hybrids have the potential to produce complex wines akin to products of spontaneous fermentation while giving winemakers the safeguard of an inoculated ferment.

32. Systems Biology: a new approach to industrial yeast strain development

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The ability to interrogate genome-wide biological data sets as part of a Systems Biology framework is poised to revolutionise the development of industrial microorganisms such as the yeast S. cerevisiae. Over recent years, laboratory strains of S. cerevisiae have been applied at the cutting edge of Systems Biology research. However, relative to laboratory strains, industrial S. cerevisiae strains, such as those used in baking, brewing, winemaking and biofuel production, display very distinct phenotypes, such as increased stress tolerance and the production of key secondary metabolites, that are critical for industrial applications. Consistent with this phenotypic diversity there is considerable genomic variation that separates industrial and laboratory strains of S. cerevisiae, including both single nucleotide polymorphisms and clusters of strain-specific ORFs (open reading frames). Given the intellectual and economic benefits that fundamental understanding of industrial yeasts will provide, we have undertaken a collaborative Systems Biology investigation of industrial wine yeast fermentation. Comparative genomic, transcriptomic (RNAseq), proteomic (2D-gels and iTRAQ) and metabolomic (targeted and

non-targeted metabolomic profiling and flux balance analysis) data have been collected for wine yeast under model winemaking conditions. These data are being analysed with the aim of modelling an industrial fermentation for the development of improved strains for industrial application. Our first task is to modify wine yeast metabolism to increase glycerol production without negatively affecting wine sensory properties.

33. Assessing the compatibility of the MLF starter culture 'Anchor Co-inoculant' with different wine yeasts and nutrients

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Malolactic fermentation (MLF) is the secondary fermentation that occurs after alcoholic fermentation or co-inoculated with the yeast. It is a de-acidification process carried out by lactic acid bacteria, usually *Oenococcus oeni*, but nowadays *Lactobacillus plantarum* is being used more frequently and even combined as a mixed culture, for example 'Anchor Co-Inoculant'.

Besides de-acidification, MLF is usually performed to improve aroma and flavour. The first aim of this study was to assess the compatibility of different wine yeasts. Small-scale trials over two vintages were performed for red wines using co-inoculation. Fermentation kinetics were determined during the fermentations and aroma production was measured at the end of MLF using gas chromatography with flame ionisation detector (GC-FID) and gas chromatography-mass spectrometry (GC-MS). Fourteen different commercial wine yeasts were co-inoculated with the Anchor Co-inoculant starter culture in 2011 and results showed that the MLF had no impact on alcoholic fermentation, but that the yeast impacted on the MLF rate. The yeasts could be categorised into two groups, namely neutral or stimulatory towards MLF (Figure 1).



Figure 1. Malic acid degradation (g/L) observed for different yeast strain/Co-Inoculant combinations in Merlot. Graphs indicate example yeast strains that represent the longer lag phase, neutral and stimulatory MLF categories, respectively, from top to bottom

Co-inoculated MLF showed positive aroma changes in red wines with a general increase in total esters (associated with fruity characters in wine) especially diethyl succinate and ethyl lactate that also contribute to wine mouth-feel. Production of esters, volatile fatty acids and higher alcohols seemed to depend on the yeast and LAB strain used. The Anchor Co-Inoculant contributed to the monoterpenes produced and MLF led to increased concentrations of diacetyl and acetoin, which are associated with buttery characters in wine. All treatments showed an increase in diacetyl and acetoin when co-inoculated with the Anchor Co-inoculant, but the monoterpenes results varied amongst the yeasts.

The second aim of this study was to evaluate the impact of wine additives (used during co-inoculation) such as yeast and bacterial nutrients, clarifying and detoxifying agents on the ability of the Anchor Co-Inoculant to conduct MLF and to assess their impact on the aroma compound production in the final wine. No negative or positive impact on the malic acid degradation of the Anchor Co-Inoculant or the resulting aroma compound production was observed for the different wine additives used in this study.

The results generated from this study showed that the selection of yeast strains is important as it will influence both the fermentation duration and final wine aroma.

34. Malolactic fermentation starter culture for high pH red wines – combining Oenococcus oeni and Lactobacillus plantarum

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Lactic acid bacteria (LAB) are responsible for malolactic fermentation (MLF), a secondary fermentation process that results in a decrease in acidity due to the conversion of L-malic acid to L-lactic acid, modifications in the wine aroma profile and increased microbial stability (Lerm et al. 2010). Commercial MLF starter cultures are readily available, most of which consist of *Oenococcus oeni* as the single bacterial culture. Recent research however, has shifted towards the use of *Lactobacillus plantarum* for possible use in commercial starter cultures. In addition, recently the co-inoculation of MLF cultures together with (or 24 hours after) the yeast culture has proven to be most advantageous, with benefits such as reduced overall fermentation duration and positive aroma modifications (du Toit et al. 2010).

The initial characterisation of the O. oeni or L. plantarum strains showed that L. plantarum strains tend to have a more complex enzymatic profile compared to that of the O. oeni strains, specifically with regard to the presence of the β -glucosidase gene (Lerm et al. 2011). Three strains each of O. oeni and L. plantarum were selected to evaluate as mixed MLF starter cultures in Pinotage, Cabernet Sauvignon and Shiraz and three mixed cultures were selected for further evaluation. This led to the commercialisation of a mixed MLF starter culture by Anchor Yeast/Oenobrands called 'NT 202 Co-Inoculant'. It was found that the NT 202 Co-Inoculant starter culture produced significantly higher concentrations of total esters during co-inoculation, compared to sequential inoculation. Having an L. plantarum strain in the Co-Inoculant resulted in more complex wine aromas (Lerm et al. 2012) especially due to the liberation of grape-derived aroma compounds via β-glucosidase enzymatic activity such as terpenols and norisoprenoids, as well as total monoterpene production (Figure 1).

This study showed that co-inoculation and using *L. plantarum* and *O. oeni* as a mixed MLF starter culture can produce diverse wine

aroma compounds, implicating the use of MLF as a tool to define a specific wine style.



Figure 1. A comparison of the monoterpene production of Anchor NT202 Co-Inoculant, the individual *O. oeni* strain and commercial cultures during co-inoculation in Shiraz in 2011

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35. Inactive dry yeast preparations: effect on glutathione levels during alcoholic fermentation

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Glutathione (GSH) is an important antioxidant in white wine, which can reduce the formation of Grape Reaction Product and browning in juice, while protecting volatile thiols and certain terpenes in wine (Kritzinger et al. 2013). We have found in a previous study that inactive dry yeast preparations (DYP) may increase the extracellular GSH concentrations of white wines (Kritzinger et al. 2012). How these additions in combination with different initial juice GSH levels influence the evolution of both intracellular and extracellular GSH levels during alcoholic fermentation as well as the sensory characteristics of the final wine is not well known.

The main aims of this study were to investigate the evolution of intracellular and extracellular GSH during alcoholic fermentations with different additions of GSH and DYP as well as any sensory impact. Sauvignon Blanc juice (clarified by flotation at a commercial cellar) containing 3 mg/L GSH was used in this experiment to which DYP was added (just after yeast inoculation with QA23) at a level that would theoretically increase GSH levels to 5.5 mg/L. Other treatments included GSH additions and are summarised in Table 1. Ultra-high performance liquid chromatography–mass spectrometry was used to measure intracellular and extracellular GSH levels during fermentation (Kritzinger 2012; Kritzinger et al. 2012). These measurements were performed on samples taken just before and just after

Table 1. Juice treatments applied

Treatment	Code
Control (no addition)	С
80 mg/L GSH added	80 GSH
glutathione enriched inactive dry yeast preparations added	DYP
5.5 g/L GSH added	5.5 GSH
80 mg/L GSH and glutathione enriched inactive dry yeast preparations added	DYP+80 GSH

the additions of the products for extracellular GSH determinations, while intracellular GSH and extracellular GSH were also determined on samples taken after 25, 50, 75 and 100% completion of alcoholic fermentation. Another aim was also to assess the sensory characteristics of these wines with descriptive analyses using a trained panel.

Extracellular and intracellular GSH levels varied during alcoholic fermentation, with extracellular GSH levels increasing from the middle to end of fermentation. In previous studies the addition of DYPs led to an increase in extracellular GSH in the final wines (Kritzinger et al. 2012), which was not observed in this study. However, an increase in the final extracellular GSH concentrations was observed where GSH additions were made to the juice irrespective of the addition of DYP. Intracellular GSH concentrations also differed between some treatments at the end of fermentation (Figure 1) which should be further investigated. The addition of DYP to wines led to significantly higher overall and canned tropical, ripe guava, banana and canned pineapple aromas, while the other treatments had significantly higher fresh tropical and pineapple aromas (Figure 2).



Figure 1. Intracellular GSH concentrations (mg/g wet weight) during fermentation. Vertical bars denote 0.95 confidence intervals.



Figure 2. Sensory effects of the different treatments on Sauvignon Blanc wines

Increased juice GSH levels at the beginning of fermentation will thus probably lead to higher extracellular GSH levels in the wine. The addition of DYPs does not always lead to increased wine GSH levels, but the intracellular GSH levels should be further investigated. However, the addition of DYP seems to influence the sensory characteristics of wine more than that of GSH which also need further attention.

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36. Novel wine yeasts with mutations in the regulatory gene YAP1 that produce less volatile acidity during fermentation

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Acetic acid, a by-product formed during yeast alcoholic fermentation, is the main component of volatile acidity (VA). When present in high concentrations in wine, acetic acid imparts an undesirable 'vinegar' character that results in a significant reduction in quality and sales. Therefore, the control of acetic acid production during winemaking is of key importance. Previously, it has been shown that saké yeast strains resistant to the antifungal cerulenin produce significantly lower levels of VA. In this study, we used a classical mutagenesis method to isolate a series of cerulenin-resistant strains, derived from a commercial diploid wine yeast. Four of the selected strains showed a consistent low-VA production phenotype after small-scale fermentation of different white and red grape musts. A pilot-scale trial conducted in a collaborating winery provided further confirmation that one of these strains (DC49) produced less volatile acidity during fermentation of Chardonnay.

Specific mutations in YAP1, a gene encoding a transcription factor required for oxidative stress tolerance, were found in three of the four low-VA strains. When integrated into a haploid wine strain, the mutated YAP1 alleles partially reproduced the low-VA production phenotype of the diploid cerulenin-resistant strains, suggesting that YAP1 might play a role in regulating acetic acid production during fermentation. This study offers prospects for the development of low-VA wine yeast starter strains that could assist winemakers in their effort to consistently produce wine to definable quality specifications.

37. Effects of organic and inorganic nutrition on yeast – a metabolomic study of Chardonnay fermentation

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Yeast assimilable nitrogen (YAN) concentration in grape must is a key parameter affecting wine fermentation outcomes, from both efficiency and quality perspectives, particularly when YAN is in the suboptimal range. Under these circumstances, inorganic nitrogen salts such as diammonium phosphate (DAP) are widely used to enhance fermentation rate and minimise formation of hydrogen sulfide. Recent studies have emphasised the broad effects of DAP supplementation on formation of volatile aroma compounds during fermentation, and shown that if the same amount of nitrogen is instead provided in an organic form (amino acids) the resultant wines differ in sensory properties. Such results pave the way for nutritional modulation of wine style.

Aside from changes to vineyard practices, winemakers seeking to shift the balance of organic and inorganic nitrogen available to yeast have limited options. One of these is the addition of complex yeast-derived organic nutritional supplements, either at rehydration or during fermentation. We sought to better understand the impact of complex nutrition on yeast in wine fermentation, in terms of fermentation performance and volatile aroma compound production. Rather than focus solely on known yeast metabolites, a metabolomic screening method was also used to generate 'fingerprints' of wines made with different yeasts subjected to a range of nutrient treatments. Results will be presented that reinforce the impact of nutrition on volatile aroma compound production by yeast.

38. Automating fermentation control with computer simulation

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Current fermentation management places huge demands on winery resources, with process efficiency further impacted by stuck fermentation. Now after extensive testing with commercial wine producers over several vintages, the AWRI has developed a breakthrough fermentation simulator. This novel tool gives winemakers the ability to test and evaluate alternative ferment management strategies, monitor refrigeration and electricity demand and predict problem ferment behaviour so that early corrective action can be taken exactly when it's needed.

How does it work?

The AWRI Ferment Simulator applies biochemical equations to model fermentation performance. Unlike other models in the scientific literature, the AWRI Ferment Simulator incorporates new innovations to address heat transfer and hydrodynamics that are important in commercial winemaking. Particle Swarm Analysis is used to adapt the simulation to changing commercial ferment conditions such as temperature, yeast, wine type, nutrient levels, agitation regime and tank size.

What is the performance? What are the features?

During industry evaluation, ferment completion times predicted after 2 to 3 days of available data were found to deviate from actual times by 1 to 1.5 days or less in most cases.

Capability has been included to allow wine producers to follow multiple concurrent ferments across a tank farm, with a visual 'trafficlight' style display of fermentation status for each active ferment.

Winemakers can also follow refrigeration load profiles by tank or across all active ferments based on fermentation progress and ambient weather patterns. Warnings are given when total refrigeration capacity is exceeded.

'What if?' analysis capability allows winemakers to assess the impact of strategies such as temperature adjustment, yeast nutrient addition and tank agitation. Process changes can be simulated before being implemented, to ensure the optimal strategy is chosen.

What are the benefits?

Problem fermentation behaviour can be predicted earlier and controlled more effectively through computer simulation, giving winemakers advanced warning on pending issues before they occur. 'What if?' analysis provides winemakers with the ability to simulate, evaluate and fine-tune alternative ferment management strategies. By calculating refrigeration load profiles and peak electricity demand, wine producers will also be better informed to manage site electricity use on hot days and minimise punitive electricity demand tariffs.

This tool provides a unique and powerful resource for continuous quality improvement and product consistency from ferment to ferment.

39. Influence of malolactic fermentation on red wine fruity properties

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Malolactic fermentation (MLF) is an integral step in red winemaking which, in addition to deacidifying wine, can also influence the composition of volatile fermentation-derived compounds with concomitant effects on wine sensory properties. In particular, lactic acid bacteria strains responsible for conducting MLF are capable of changing the wine ester profile as well as other flavour components which can potentially affect red wine 'fruity' sensory properties. Since the 'fruity' profile is a central parameter of red wine quality, objective assessment of the influence of MLF on wine 'fruity' properties and the factors affecting this metabolism is therefore required.

Chemical analysis of wine components following MLF supports the view that MLF-driven impacts on intrinsic wine volatiles, including 'fruity' esters, is a key driver to associated changes in red wine 'fruity' aroma. Studies conducted over several vintages have demonstrated that MLF can have significant effects on 'fruity' sensory properties of Cabernet Sauvignon and other red wine varieties. The extent of such MLF-induced effects on the wine 'fruity' profile was highly dependent upon a range of factors including choice of bacterial strain, wine matrix composition (pH and ethanol content), grape variety and region. Further investigations are required to gain greater control of MLF-induced changes to the 'fruity' and broader sensory properties of wine.

40. The AWRI wine microorganism culture collection – a valuable resource for the Australian wine industry

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Culture collections play a vital role in preserving and conserving microbial biodiversity. They are an essential part of biological science infrastructure. The prime role of the AWRI Culture Collection is to collect and store wine yeast and bacterial isolates to ensure microbial genetic diversity of the Australian wine industry is not lost. An essential aspect of the maintenance and operation of a culture collection is quality assurance. The AWRI Culture Collection follows OECD international guidelines in managing microbial strains, thus providing assurance to winemakers and wine researchers of the identity of yeast and bacteria sourced from the Collection.

The AWRI Culture Collection contains over 2,800 yeast and bacterial strains. These microorganisms include reference strains, winery isolates, research strains and experimental isolates. Strains are not only available for research projects, but can also be obtained for winemaking purposes.

One of the numerous services provided to wine companies by the AWRI Culture Collection is the provision to preserve and store winery isolates of yeast and bacteria which can then be accessed for future use. The Culture Collection can offer to you the opportunity to deposit and store your yeast and bacterial strains. The advantages of this include: reducing the expense of maintaining and storing your microorganisms, deposited strains will be maintained by staff with specialised expertise in the appropriate storage conditions and ongoing access to your strains is free.

41. The Oenococcus oeni genome is more diverse than originally thought – what does this mean for the development of improved MLF bacteria?

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Malolactic fermentation (MLF) in red, white and sparkling base wines is performed almost exclusively by *Oenococcus oeni*. Whilst this is the best organism available to winemakers for MLF it is far from perfect; it is fastidious and can be very slow to complete its task. Most winemakers will have had experiences of dealing with problem MLFs. *O. oeni* is also very difficult for microbiologists to work on: it is slow-growing, temperamental and not amenable to the application of modern microbial genetics techniques. Thus it has proven almost impossible to develop novel, improved strains of this bacterium. Things, however, are about to change.

It is now possible to rapidly sequence the genomes (the full complement of genetic material – DNA – of an organism) of bacteria and this has led scientists at the AWRI to compare the genomes of a number of *O. oeni* strains. One amazing discovery in this work is that there is an enormous amount (up to 30%) of genetic diversity across this species. The variation in gene coding potential was shown to potentially impact on several traits, including cell wall exopolysaccharides composition, sugar transport, and utilisation and synthesis of amino acids; all of which, in a wine context, are important. Strain-specific regions of the genome, presumably responsible for differences in winemaking phenotypes, are the focus of ongoing work. From this, genetic markers for important winemaking traits will be identified and applied to the isolation of improved MLF bacteria that will take some of the pain out of deacidifying wine.

42. Characterisation of intra-specific genomic diversity in industrial yeasts by whole-genome sequencing

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Industrial yeasts, such as those of the genus *Saccharomyces* that are involved in the winemaking, brewing and pharmaceutical industries, represent a diverse collection of species and strains that have been selected for their ability to perform specific biochemical transformations despite exposure to osmotic, nutrient and ethanol stress. However, in addition to these beneficial yeast species, there are common industrial spoilage yeasts, such as the *Dekkera bruxellensis*, that also thrive under the stressful conditions of an industrial fermentation while producing metabolites with detrimental effects on the industrial fermentation process.

In many cases, the phenotype of industrial microbes is highly variable across strains of the same species, with individual strains displaying a broad range of desirable and undesirable characteristics. By understanding the genetic basis of these phenotypic differences, it will be possible to maximise the desirable characteristics within a strain while minimising potential undesirable characters. We have therefore applied next-generation genome sequencing and comparative genomics to catalogue the variation present across several strains of *D. bruxellensis*. Significant levels of genetic variation, including large insertions and deletions of genetic material, separated individual strains. Furthermore, these differences are suggested to have important phenotypic consequences regarding the ability of this spoilage organism to grow in winery conditions.

43. Development of a micro-scale microbiological screen for compatibility of yeast and bacterial strains in MLF

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Screening large numbers of combinations of yeast and bacterial strains for malolactic fermentation (MLF) efficiency can quickly escalate to unmanageable numbers of samples, if performed in flasks or tubes. We have developed a micro-scale (200 μ L) fermentation system that can be used to rapidly screen a large number of combinations of yeast and bacteria, under various fermentation conditions. The fermentation platform utilises microtitre plates and a robotic liquid handling workstation, and the method was validated by comparing results from this platform with standard laboratory 5 mL and 40 mL scale MLFs.

This method was then used to evaluate the MLF performance of 19 bacterial strains (13 *Oenococcus oeni* and 6 *Lactobacillus* strains) in Cabernet Sauvignon wines prepared from the same grapes and fermented with 14 different *Saccharomyces cerevisiae* strains. To mimic winemaking practices as closely as possible, wines used in the MLF screening were not adjusted post-alcoholic fermentation.

Most yeast strains were found to support MLF, with the exception of one strain which is known to produce high concentrations of SO₂. Bacterial strains responded in various ways: MLF was supported in the majority, some or few of the wines, and *Lactobacillus* strains performed better in wines with higher pH. Future work will focus on yeast and bacteria combinations in a range of wines made from different grape varieties.

44. Screening of Australian *Lactobacillus* strains for wine stress tolerance and MLF performance

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Malolactic fermentation (MLF) is an important vinification process in red, white and sparkling winemaking, predominantly for wine deacidification, but also increasingly for enhancing wine flavour. Because of its high tolerance to stressful wine conditions and its low spoilage potential, *Oenococcus oeni* is the main species of bacterium used for MLF. However, there has been interest in using *Lactobacillus* sp. as a new generation of MLF starter cultures. One commercial *Lactobacillus plantarum* strain has recently been released for winemaking, in particular for use with high pH red wines. Using a recently developed micro-scale screening method, 35 *Lactobacillus* strains were screened in a synthetic wine matrix for tolerance to pH, ethanol and SO_2 , and ability to grow at a range of temperatures. Bacterial growth was monitored by optical density. The most important limiting factor for growth of *Lactobacillus* strains was found to be pH. Seven interesting *Lactobacillus* strains which exhibited a wider spectrum of wine stress tolerances were selected for testing MLF performance in red wine. All strains were able to complete MLF in a timely manner. In addition, none of the *Lactobacillus* strains were found to carry genes for biogenic amines histamine (*hdc*) or putrescine (*odc*); one strain (of the 35) has the potential to produce tyramine (*tdc*). Future work will involve trialling these *Lactobacillus* isolates in larger-scale red and white wines and analysing wine composition and sensory properties.

45. Management of fermentation performance in low pH juices – can fermentation nutrient additives help?

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Background: Yeast encounter many stresses upon inoculation into grape juice. Through examination of grape juice composition and the contribution of individual elements to fermentation performance of different yeast strains, we identified pH as a key determinant of strain-dependent fermentation performance (Schmidt et al. 2011). In this work we sought to understand whether commercially available rehydration fermentation nutrients/additives could be used to alleviate the negative impact of low juice pH on fermentation by pH-sensitive wine yeast.

Method: Rehydration and fermentation additives from three manufacturers were evaluated. Active dry yeast (strain Lalvin 71B), was rehydrated with or without rehydration nutrients according to manufacturer's instructions. Rehydrated yeast was inoculated into pH 3.0 and pH 3.5 filter clarified juices at 4×10^6 cells/mL. Fermentation additives were added to the fermenting must according to manufacturer's instructions, at approximately 30% of fermentation progress. Fermentation progress and yeast growth rate were monitored daily.

Results: Inoculation of Lalvin 71B into low pH juice often results in delayed initiation of fermentation due to a reduction in cell viability. The use of rehydration nutrients did not reduce this pH-associated lag time, relative to a 'no rehydration nutrient' control. Fermentation nutrient addition, on the other hand, did result in a reduction in fermentation times but the effect was general; the performance improvement was the same in juices of either pH. No additional benefit of combining fermentation nutrient additives with rehydration nutrients was observed in moderately ripe (22°Brix) juices with adequate nitrogen and potassium concentrations.

Reference

Schmidt, S.A.; Dillon, S.; Kolouchova, R.; Henschke, P.A.; Chambers, P.J. (2011) Impacts of variations in elemental nutrient concentration of Chardonnay musts on *Saccharomyces cerevisiae* fermentation kinetics and wine composition. Appl. Microbiol. Biotechnol. 91: 365–375.

46. DAP – a powerful wine aroma and style tool: case study with Shiraz

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Vine development can be constrained by nitrogen availability, which restricts berry amino nitrogen accumulation and leads to suboptimal fermentation performance. Consequently, diammonium phosphate (DAP) has become a widely used fermentation stimulant, especially when grape musts are nitrogen deficient. Despite its wide application, the impact of DAP on wine flavour is poorly understood. This question has been explored in Shiraz wines.

Low YAN Shiraz musts (100 mg N/L) were supplemented with DAP to produce musts in the range 100–400 mg N/L, and fermented by maceration on skins. DAP supplementation increased esters and decreased higher alcohols. Light volatile sulfur compounds, especially thioacetates and dimethyl sulfide (DMS), increased in response to DAP supplementation. DAP delayed onset and production of H_2S in the headspace whereas wine-residual H_2S was dependent on yeast strain x nitrogen interaction. Few changes were found in grape-derived aroma and flavour compounds whereas monomeric pigments but not tannins increased.

Unsupplemented, low YAN wines had pronounced, complex aroma descriptors of 'cheese/sweat', 'earth', 'yeast' and 'savoury', which were associated with higher alcohols and branched-chain fatty acids and their esters. DAP supplementation increased 'red fruit', 'dark fruit' and 'confectionary' descriptors, which were associated with sulfides, thioacetates, acetates and ethyl esters. The 'reduced' attribute was associated with H₂S, methanethiol and augmented by higher alcohols.

These studies reveal complex interactions between DAP and yeast strain in Shiraz. As for white wines, DAP modulates aroma profile to produce wines having a complex or 'fruity-floral' style but the 'reduced' character depends on nitrogen x yeast interaction.

47. DAP – a powerful wine aroma and style tool: case studies with Albariño and Chardonnay

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Vine development can be constrained by nitrogen availability, which restricts berry amino nitrogen accumulation and leads to suboptimal fermentation performance. Consequently, DAP has become a widely used fermentation stimulant, especially when grape musts are nitrogen deficient. Despite its wide application, the impact that DAP has on wine flavour is poorly understood. This question has been explored in Albariño and Chardonnay wines.

Albariño is an aromatic variety, which requires fermentation to reveal its varietal potential. The control juice (250 mg/L YAN), sourced from Galicia, Spain, was supplemented with 0.5 and 1 g/L DAP to produce juices with 350 and 450 mg/L YAN. Moderate DAP addition produced the highest content of varietal compounds, including free monoterpenes and norisoprenoids, as well as most yeastderived fermentation products. Analysis of odour activities suggests that moderate DAP supplementation produced the highest aromatic impact, whereas high addition reduced potential aromatic impact.

Unsupplemented, low YAN (160 mg/L) Chardonnay produced a complex aroma profile with less desirable descriptors, such as 'stale beer', 'cheese' and 'artificial grape'. Moderate supplementation (320 mg/L) produced cleaner and more intense 'fruity-floral' wines, due to increased ester and reduced higher alcohols formation. High organic nitrogen (480 mg/L; amino acids added to simulate high vineyard N) gave greatest intensity of 'fruitiness' whereas high inorganic-N produced 'volatile', 'solvent' off-odours, due to excessive ethyl acetate.

These studies reveal complex interactions between nitrogen, yeast and wine flavour production, which can, however, be exploited to modulate aroma profile to produce wines with a complex or 'fruityfloral' style.

48. Bioprocess monitoring and trend identification in wine fermentations with FT-IR spectroscopy and chemometric modelling

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Wine fermentation is characterised by successive microbial-mediated reactions that are accompanied by continuous and often rapid changes in the chemical composition of the ferment. The time courses for alcoholic and malolactic fermentation are seldom predictable in absolute terms, and significant batch-to-batch variation is characteristic of wine production (Cozzolino et al. 2006). Effective management of wine fermentations therefore requires real-time and cost-effective monitoring strategies, with easily interpretable graphical displays, to assess the process stage and to identify problematic fermentations. The strategy of choice for this task is infrared spectroscopy coupled with chemometric modelling, based on the information richness of the spectra, the low analysis cost, graphical display of the processes and speed of measurement.

In this work we used both quantitative and qualitative data obtained with infrared spectroscopy and various chemometric modelling techniques to follow the trends of alcoholic and malolactic fermentation and to identify the stages of completion of these processes. Off-line mid-infrared (MIR, 929 - 5,011 cm⁻¹) and near-infrared (NIR, 800 -2,500 nm) spectroscopy was used to monitor 11 Shiraz batch fermentations that were elaborated with Saccharomyces cerevisiae NT 202 for alcoholic fermentation and different Oenococcus oeni and Lactobacillus plantarum strains, in both co-inoculation and sequential inoculation strategies, for malolactic fermentation. Spectra, taken at regular time intervals during the fermentations, were modelled by chemometric techniques, including Principal Component Analysis (PCA) and Partial Least Squares (PLS), as well as statistical techniques, including response curves and spectral conformity tests (Figures 1 and 2). PLS calibration models based on infrared spectra were established to predict the concentrations of ethanol, glucose, fructose and malic acid.

In the particular fermentations reported here, the co-inoculated fermentations proceeded significantly faster than the sequential

fermentations. The predicted concentrations of sugars, ethanol and malic acid over the duration of the fermentation time, were modelled by non-linear response curves and reflected the fermentation kinetics in an easily interpretable graphic display. This trend could also be modelled by a conformity test of IR spectra alone, thereby bypassing the need to generate quantitative data. This approach considerably reduces the cost and time needed for fermentation monitoring. PCA analysis confirmed this time course trend, and the main variation in the fermentations was dominated by the conversion of sugar to ethanol.



Figure 1. PCA score plot of FT-MIR spectra (PC 1 and 2) showing the complete fermentation time



Figure 2. PCA score plot of FT-NIR spectra (PC 1 and 2) showing the complete fermentation time

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GRAPE AND WINE AROMA, FLAVOUR AND COLOUR

49. Evolution of oak lactone from glycoconjugate precursors during toasting and maturation

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Oak maturation plays an important role in the production of high quality wine, enhancing both physical attributes (colour and stability) and sensory properties (aroma, flavour and astringency). Of the 200 oak-derived volatile compounds identified in oak-aged wine and spirits to date, the most important are considered to be the *cis*- and *trans*-isomers of oak lactone, which contribute 'woody', 'vanilla' and 'coconut' aromas. Oak lactone is a natural component of oak wood, but it also exists in glycoconjugate precursor forms. This study investigated the role of glycoconjugates of 3-methyl-4-hydroxyoctanoic acid (a galloylglucoside, glucoside and rutinoside) in the evolution of oak lactone during the toasting process of cooperage and wine maturation.

Ten samples of oak wood shavings were sourced from forests in different regions of France. The samples were powdered and their glycoconjugate profiles determined by high performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS) analysis. Maturation trials were then conducted to investigate:

- · the evolution of oak lactone
- the hydrolysis of glycoconjugates.

Samples were also heated at 100 or 200°C for 5 or 30 minutes to investigate the influence of toasting conditions, that is the temperature and duration of toasting, on the glycoconjugate content of oak wood.

The glycoconjugate content of powdered oak wood varied considerably, but in each case, the galloylglucoside was the predominant precursor (Table 1). Following 12 months' maturation, between 2and 11-fold higher concentrations of the glucoside were observed, indicating hydrolysis of the galloylglucoside to the glucoside (Table 1). Both *cis*- and *trans*-oak lactone were released from their glycoconjugate precursors during maturation (data not shown). Oak lactone precursors were also thermally degraded during toasting, but only after heating at 200°C for 30 minutes (Table 2).
 Table 2. Concentrations of galloylglucoside, glucoside and rutinoside precursors to oak lactone in toasted oak wood

Toosting	Concentration in oak (µg/g)								
conditions	galloyl glucoside	glucoside	rutinoside						
5 min at 100°C	139.4	7.9	2.5						
30 min at 100°C	133.4	8.4	2.3						
5 min at 200°C	130.3	8.7	2.3						
30 min at 200°C	100.6	8.2	0.7						

Further reading

Wilkinson, K.L.; Prida, A.; Hayasaka, Y. (2013) Role of glycoconjugates of 3-methyl-4-hydroxyoctanoic acid in the evolution of oak lactone in wine during oak maturation. J. Agric. Food Chem. 61: 4411–16.

50. What is the flavour potential of oak battens made from decommissioned barrels?

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During barrel maturation, the volatile compounds extracted from oak wood can contribute to a wine's overall aroma and flavour, enhancing its character and complexity (Rodríguez-Rodríguez and Gómez-Plaza 2011). However, oak maturation increases the cost of wine production, in terms of both capital investment in inventory (i.e. oak barrels) and the labour associated with cellar management (Wine Australia 2007). Barrels have a finite pool of extractable material and so the amounts of oak-derived volatile compounds available for extraction diminish over time (Pérez-Prieto et al. 2002). As a consequence, barrels are typically decommissioned after five to six years. This study investigated whether or not decommissioned barrels can be 'reclaimed' and used as a previously untapped source of high quality oak for wine maturation.

Oak battens were prepared from the unused portion of oak wood recovered from decommissioned French and American oak barrels. Barrels were disassembled and the wine-affected portion of staves was discarded. The remaining oak was split laterally and planed to expose fresh wood, and the resulting battens toasted using far infrared heat. The composition of toasted reclaimed oak was then compared with that of toasted new oak, to determine flavour potential.

Poster 49 Table 1. Concentrations of galloylglucoside, glucoside and rutinoside precursors to oak lactone in powdered oak wood and in model wine following 12 months' maturation with powdered oak

Oak samples		Cond	centration in oak (µ	lg/g)	Cone	Concentration in wine (µg/L)				
stack no.	department	galloyl glucoside	glucoside	rutinoside	galloyl glucoside	glucoside	rutinoside			
504549	Orne	7	1	0.2	2	12	2			
175170	Maine-et-Loire	154	8	5	1234	1388	83			
503544	Yvelines	305	26	9	1172	3835	175			
175171	Maine-et-Loire	138	13	4	100	1517	34			
503543	Yvelines	110	7	3	71	1140	43			
180093	Haute-Marne	196	20	5	3	1175	51			
505502	Maine-et-Loire	210	26	9	4	1010	140			
175595	Maine-et-Loire	290	23	20	41	4160	314			
175575	Maine-et-Loire	354	24	19	278	5209	355			
175168	Maine-et-Loire	245	21	15	1153	2616	233			

Poster 50 Table 1. Concentration of oak volatiles in new and reclaimed samples of toasted oak

Och Constan	Concentration (µg/g)									
Oak Samples	<i>cis</i> -oak lactone	trans-oak lactone	guaiacol	4-methylguaiacol	eugenol	vanillin				
new French oakª	nd–11.4	nd-6.8	2.3–18.5	1.3–10.2	0.7–2.3	53–190				
reclaimed French oak ^b	nd–33.4	nd–73.1	1.5–11.6	0.8–4.9	2.7–7.7	58–115				
new American oakª	12.3–47.9	3.3–5.3	4.2–13.5	0.9–7.9	4.2-6.1	42–140				
reclaimed American oak ^c	nd–65.5	nd–9.1	0.8–12.3	0.6–5.6	2.3–6.2	70–137				

nd = not detected

^aData reported in Alañón et al. 2012, Fernández de Simón et al. 2010 and Campbell et al. 2005. ^bValues are means from 24 replicates. ^cValues are means from 22 replicates.

Comparable levels of important oak-derived volatile compounds were observed in: (i) reclaimed French oak battens and new French oak; and (ii) reclaimed American oak battens and new American oak (Table 1); albeit the concentration of oak volatiles differed between French and American oak battens, in agreement with previous studies (Pérez-Prieto et al. 2002; Alañón et al. 2012; Campbell et al. 2005). These results demonstrate the flavour potential of reclaimed oak, and thus, its suitability as a raw material for the preparation of alternative oak products for wine maturation. The temperatures achieved during far infrared toasting, between 200°C (inside the batten) and 250°C (on the surface of the batten) are not only sufficient to generate oak volatile compounds, but should also reduce microbial load, thereby preventing carry over of spoilage yeast and/or bacteria. It costs \$150 to reclaim a barrel, with approximately 8 m² of oak battens produced from each decommissioned barrel.

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51. The impact of light, temperature, acidity, sulfur dioxide and caffeic acid on the production of glyoxylic acid in a tartratebuffered model wine system containing iron

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Glyoxylic acid may contribute to the spoilage of wine by inducing the polymerisation of flavan-3-ols to form pigments (Es-Safi et al. 2000) and was recently identified as a product of the photochemical oxidation of tartaric acid in model wine solutions containing iron(II) (Clark et al. 2011). A Box-Behnken experimental design and response surface methodology were used in this study to assess the effect of UV-visible light (darkness or light exposure), temperature (15, 30, 45°C), acidity (pH 2.8, 3.4, 4.0), SO₂ (0, 20, 40 mg/L) and caffeic acid (0, 100 mg/L) on the production of glyoxylic acid in a model wine system (12% v/v ethanol, 2.7 g/L tartaric acid) containing iron(II) (5 mg/L). Samples were exposed to light (> 300 nm) using a xenon arc lamp in combination with a heat-absorbing filter or stored in darkness for 30 min, and then analysed using high-performance liquid chromatography with photo-diode array detection at 210 nm, before and after a treatment step developed to release glyoxylic acid from its SO₂ addition product, to determine the free and total amount of glyoxylic acid. The coefficients of the equations for predicting the free and total amount of glyoxylic acid in different samples stored in different conditions were calculated using a coded design matrix in which the value of each of the variables is represented by -1, 0 or +1. This enabled the influence of factors with different physical scales to be directly compared. The significance of each coefficient was determined from the measured and predicted glyoxylic acid concentrations using a two-tailed t test (p < 0.05).

Glyoxylic acid was not detected in the samples stored in darkness, and the presence of caffeic acid did not significantly affect the production of the aldehyde in the samples exposed to light. The equations for predicting the free and total glyoxylic acid concentrations of samples exposed to light both have the form $y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$ where $x_1 = pH$, $x_2 = SO_2$, $x_3 = T$ and the coefficients are shown in Figure 1.



Figure 1. Coefficients of the equations for predicting the free and total amount of glyoxylic acid in model wine samples exposed to light

The SO₂ coefficients (b_2) of both equations are significant (p < 0.05) and negative, and the effect of SO₂ on the total amount of glyoxylic acid is shown in Figures 2a and b. The pH and temperature interaction term coefficients (b_{13}) of both equations are also significant (p < 0.05) and the combined effect of these factors on glyoxylic acid production in the absence of SO₂ is shown in Figure 2c. The equations predict that a maximum amount of glyoxylic acid will be formed in samples exposed to light with 0 mg/L SO₂ and either pH 4 at 45°C or pH 2.8 at 15°C, though relatively high amounts will be formed in the absence of SO₂ at the intermediate pH and temperature values (Figure 2c) and a minimum amount will be formed in samples with 40 mg/L SO₂ and either pH 4 at 15°C or pH 2.8 at 45°C.

This study showed that light exposure had a greater impact on the production of glyoxylic acid than the other factors assessed and that the presence of caffeic acid did not significantly affect its formation in samples exposed to light. The results suggest that SO_2 slows the production of glyoxylic acid in bottled wine exposed to light, and that the production of the aldehyde in these conditions also depends on the wine pH and storage temperature.



Figure 2. Response surface graphs showing the effect of temperature, pH and SO_2 concentration on the predicted amount of glyoxylic acid formed in model wine samples exposed to light

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52. Aroma modifications from ascorbic acid and glutathione additions to Sauvignon Blanc at harvest as supplements for sulfur dioxide

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We have previously shown that Sauvignon Blanc juices advanced in oxidative terms tend to produce wines with lower concentrations of the varietal thiols 3MH and 3MHA (Allen et al. 2011). This trend can be somewhat reversed through large sulfite additions shortly after mechanical harvesting of the fruit (Makhotkina et al. 2013).

To assess whether excessive sulfite additions can be avoided, the effects on wine aroma compounds of ascorbic acid and glutathione additions to Sauvignon Blanc grapes and juice in the field were studied. Juices were sourced from three sites in the Marlborough region of New Zealand, and were subjected to three different treatments: 30 mg/kg of sulfur dioxide alone, 30 mg/kg of sulfur dioxide plus 100 mg/L of ascorbic acid and 30 mg/kg of sulfur dioxide plus 100 mg/L of glutathione.



Figure 1. Relative wine aroma compound levels related to harvest antioxidant additions

After pressing and fermentation, the concentrations of the varietal thiols (3MH, 3MHA and 4MMP) and other aroma compounds were measured in the resulting wines. With each of the wines, higher 3MH and 3MHA concentrations appeared from the juices that had received additional antioxidant protection from the inclusion of ascorbic acid and glutathione at harvest. The results obtained for the varietal thiol

4MMP were different, in that no change in 4MMP concentration was seen with the addition of ascorbic acid, while the concentration doubled as a result of the glutathione addition. Many of the remaining esters and higher alcohols were present at similar concentrations across the different treatments.

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53. Characterisation of intracellular esterases from Oenococcus oeni and Lactobacillus hillgardii and their potential for application in wine

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Oenococcus oeni is the lactic acid bacterium (LAB) most typically used in winemaking to carry out malolactic fermentation (MLF). Alongside this, LAB can metabolise precursors present in wine during the MLF and as a consequence alter its chemical composition and quality. Aroma compounds such as esters and the quantities in which they occur can play a particularly important role in determining wine quality (Sumby et al. 2010). Esters are primarily formed during fermentation by yeast after which LAB are capable of modifying ester concentration during MLF. Ester hydrolysis and synthesis can be catalysed by esterases, which have greatest specificity for water-soluble short-chain esters.

With a view towards understanding and enhancing the role of LAB in ester profile modifications during MLF, we report the cloning, heterologous expression, partial purification, and biochemical characterisation of EstA2, EstB28, and EstCOo8 esterases from O. oeni and EstC34 esterase from Lactobacillus hillgardii. Enzyme function under the harsh physicochemical conditions frequently encountered in wine was examined to evaluate their potential applicability in this context. The influence of pH (3.0 to 8.0), temperature (10 to 60°C) and ethanol (2 to 22% (v/v)) on esterase activity was determined. All esterases tested retained at least partial activity under wine -ike pH, temperature and ethanol conditions (Sumby et al. 2009, 2012, 2013b). Substrate specificity trials were conducted with eight different pNPlinked ester substrates. This activity was also confirmed using natural substrates (Sumby et al. 2013a). Substrate specificity of the enzymes was shown to vary, thereby suggesting possible applications in wine for targeted ester removal (Figure 1).

Having established that EstA2 and EstB28 should retain at least partial activity in wine, they were assayed for activity in two separate wines by using solid phase micro-extraction gas chromatographymass spectrometry to monitor the appearance or disappearance of esters. EstB28 and EstA2 demonstrated duel hydrolysis and synthesis activity in wine and are the first LAB esterases demonstrated to retain activity in wine (Table 1). Once the esterase enzymes were characterised, the basis for previously observed strain-specific differences in ester hydrolysis by whole cells was investigated through wine MLF trials. Ester concentration changes in wine were dependent on the strain conducting the MLF. Further investigations will allow a more informed choice of MLF strain.



Figure 1. Relative activity of EstA2 and EstB28 on natural substrates, measured by solid phase micro-extraction gas chromatography-mass spectrometry (SPME-GC-MS). A: Hydrolysis of esters by EstA2. B: Hydrolysis of esters by EstB28. C: Synthesis of esters by EstA2. D: Synthesis of esters by EstB28. Activity against ethyl acetate (EA), ethyl butanoate (EB), ethyl hexanoate (EH), ethyl octanoate (EO), ethanol and acetic acid (AA), ethanol and butanoic acid (BA), ethanol and hexanoic acid (HA)

Table 1. Summarised activity of esterases in wine



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54. Contributions of grape berry compounds to wine aroma

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Aroma compounds have major influences on consumer preferences for wine. This has led to interest in understanding the development of wine aroma compounds and variables affecting the final volatile composition of wines. Understanding the origin of important wine aroma compounds could allow interventions in grapegrowing and wine production that improve characteristics that are desired by wine consumers.

Grapes contribute to the composition of final wine, not only through varietal 'impact' compounds such as terpenes and methoxypyrazines, but also through non-varietal aroma compounds, such as C_6 -alcohols and some esters of higher alcohols. A recent study in our group showed that many aroma compounds increased in model ferments as the proportion of Riesling or Cabernet Sauvignon grape juices increased.

This study seeks to isolate compounds from grapes that can be implicated in altering volatile content of wine produced from them. The strategy consists of chromatographic steps to produce fractions and mock assays to assess fractions for their capacity to change volatile concentrations. Those fractions which result in high levels of volatile compounds of interest in the mock assay are further fractionated and assayed until the contributing compounds can be structurally identified.

Organic extracts of grapes were stripped of sugars, salts and yeastassimilable nitrogen (YAN) by cyclic loading on a reversed-phase resin. The retained compounds were fractionated by eluting with solvent of increasing organic content. The fractions were dried and sub-samples analysed by adding to model grape juice/must and conducting micro-fermentations, followed by volatile analysis by headspace solid phase micro-extraction gas chromatography-mass spectrometry (HS-SPME-GC-MS).

Wines made from different fractions differed in their volatile profiles. Wines made from early fractions contained high concentrations of terpenoids. Wines made from late fractions contained high concentrations of C6-compounds. There were differences in the concentrations of fermentation-derived volatile compounds, such as fatty acid ethyl esters. Subsequently, fractions have been selected for further investigation. Further fractionation and identification of the compounds in these fractions is ongoing.

55. The impacts of copper and iron on the reductive characteristics of a bottled Chardonnay

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It is well known that transition metal ions such as copper and iron play important roles in the oxidation processes that occur in wine both during production and post-packaging. The role of these metal ions in the more reductive environments typically found during long-term tank storage or post-packaging, however, is much less well characterised. Wine often has chemically significant amounts of both copper and iron post-bottling and the levels of these elements have the potential to strongly influence the amount of volatile sulfur compounds (VSCs) that may be produced after packaging. These compounds are usually associated with what are known as reduced sensory characteristics and have been shown to have a negative influence on consumer preference. In this study, samples of a Chardonnay wine were packaged with differing levels of copper addition and monitored for six months to determine the impact on the formation of VSCs. The results showed not only that higher copper levels can lead to increased levels of VSCs such as hydrogen sulfide but that the effect is strongly dependent on the relative ratios of copper to iron present in the wine.

56. The impacts of oak chip and dust additions during red wine fermentation on colour and phenolic profile

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The use of oak in winemaking has a long history and is integral to the production of many wine styles. In recent times there has been increasing promotion of using oak products such as chips and dust in red ferments to improve long-term colour outcomes and phenolic profiles. However, there is very little information in the literature about the veracity of this approach or the best methods of implementation. A small scale study was undertaken to determine if the use of oak chips or oak dust at various rates during a red fermentation had any short- to medium-term impact on the development of colour and phenolic profile. Samples of oak chips which had been de-aerated were also trialled to investigate whether the effects observed were in any way associated with the oxygen entrained in the oak products. While the results after six months' storage showed a high degree of variability between replicates, they did indicate that colour and phenolics profiles were influenced by the different oak treatments applied. The trends observed between fermentation and six months' storage also suggested that the differences observed would have longterm consequences for wine colour and phenolic profile.

57. Attitudes, drivers of consumption and taste preferences: a focus on Chardonnay

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Chardonnay is an important variety to the Australian wine industry and in recent years its popularity amongst consumers has been questioned. Anecdotal explanations for the decline abound, yet little research has been conducted. Using a multi-disciplinary approach, we used qualitative and quantitative methods to determine the reason for any decline in perception. Sensory descriptive analysis confirmed a wide range of flavour styles available in Australia (see Figure 1). Preference mapping confirmed that several of the styles were highly liked by consumers, especially the fruit-driven and balanced styles; further, all styles had some segments of the market that were 'followers', though for the oak-driven style the segment was quite small. While focus groups did point to some negative perceptions about Chardonnay, further experimental and quantitative and qualitative survey work did not. We interpreted the broad range of results from multiple methods as indicating that there was not a negative perception of Chardonnay per se, but that within a peer group situation such as found in focus groups, it had become popular to say negative things about Chardonnay. Our results show that it is time for the industry to start talking positively about the prospects of Chardonnay, especially since the negative perception of Chardonnay reported in focus groups was largely echoed from anecdotal claims found in the popular press. There have been oversupply issues, alongside increased competition from other varieties which need to be taken into account, but our results show a positive future for Australian Chardonnay if flavour styles and size of market segments are taken into account.





58. Microbial and chemical characterisation of indigenous versus inoculated wine fermentations: the role of bacteria

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In recent years there has been a significant increase in research investigating the sensory effects of various lactic acid bacteria (LAB) involved in the malolactic fermentation (MLF) of wine. However, currently there is little research published which compares differences between the final bottled products of 'wild' and inoculated MLF treatments. Many questions remain about the impact of indigenous bacteria during these fermentations in terms of reliability and specific chemical modifications. Thus the feasibility and desirability of controlled inoculations of selected indigenous strains warrant investigation – the goal being to achieve some of the perceived benefits of 'wild' fermentations in a reliable manner.

Winery scale fermentations of Shiraz (both 'wild' and inoculated alcoholic fermentations) have been conducted at Yalumba Winery (Angaston, South Australia) over three consecutive years. After alcoholic fermentation (AF) the 1200 L fermentations were split into two 200 L stainless steel barrels for both 'wild' and inoculated MLF (PN4 strain). Samples were taken approximately every second day for plating onto MRS + apple juice + cycloheximide (MRSA +C) agar to isolate bacteria populations present. Further, samples were centrifuged and the pellet and supernatant retained for subsequent non-culture-dependent analysis. After MLF, the wine was bottled to commercial standards to be used for various chemical analyses, including: aroma, flavour and colour properties such as volatile analysis via gas chromatography-mass spectroscopy (GC-MS).

Qualitative GC-MS analysis has shown significant differences (P<0.05) in the levels of a number of aroma compounds between wines subject to 'wild' or inoculated MLF. For instance, the 2011 'wild' MLF wines had three times as much 2-methylbutyl acetate as the inoculated MLF wines (Figure 1). Also, several other acetate esters and fatty acid ethyl esters were present at approximately twice the levels in the 'wild' MLF wines compared to the inoculated MLF wines (Figure 1). Other as-yet-unknown compounds are present in the 'wild' MLF wines at significantly different levels. All of these differences occur in MLF wines produced from 'wild' alcoholic fermentations (AF), while differences were not significant in MLF wines produced from inoculated AF wines. Quantitative GC-MS analysis is

still ongoing but significant differences have been found among fatty acid ethyl esters such as ethyl octanoate and ethyl decanoate. Again, these differences only occur in MLF wines derived from 'wild' AF.





In this study, various chemical analyses have been conducted over three consecutive vintages in order to discover sensorial differences between 'wild' and inoculated malolactic fermentations. Significant differences between 'wild' and inoculated MLF treatments with regards to wine compounds such as acetate esters and fatty acid ethyl esters have been shown but further analysis needs to be conducted in order to investigate the role of the alcoholic fermentation. GC-MS is currently being undertaken on pre-MLF bottled wines.

59. Clonal impacts on rotundone concentration throughout ripening in *Vitis vinifera* L. Syrah

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New Zealand Syrah is becoming increasingly popular as a high quality and in some cases iconic wine, largely due to an elevated, pungent black pepper aroma that contributes to the profile of the wine and creates a point of difference. Rotundone is an oxygenated bicyclic sesquiterpene recently identified as the black pepper aroma compound in grapes and wine. Thus far, research has found widely varying concentrations of rotundone in fruit and wine, adding to anecdotal evidence of differences experienced in wines. Previous research has shown differences on the basis of some management techniques in addition to regional differences throughout Australia. Currently, little is known about the impact of different vegetative clones of Syrah on the concentration of rotundone in fruit for winemaking. The importance of using a variety of clonal material has been widely investigated and is current practice for a multitude of reasons from vineyard through to final blending. In several areas such as colour and primary constituents, different clones of the same cultivar perform differently in the field and winery year by year. This results in the need for field selections and blending options. However, to date no research has explained what impacts this blending has on rotundone.

This study focused on three commonly used vegetative clones of *Vitis vinifera* L. Syrah, chosen for the initial work at the beginning of the annual growing cycle each year: 'Chave'; 'Dijon 470'; and 'Mass Select (MS)'. These were chosen due to their popularity in New Zealand, and the availability of large commercial plantings in the same area on the same rootstock. The vines were managed uniformly throughout the growing season as part of the regime onsite. Fruit-zone leaf removal occurred before veraison and clusters were lightly thinned at this time. Vines were arranged in a randomised design

modified to ensure suitable uniformity, and monitored throughout the season. Replicated samples of ~300 g fruit were taken at three intervals between veraison and harvest from all areas and immediately frozen with liquid nitrogen and stored until analysis of rotundone.

The vegetative clones were indeed found to impact upon the concentration of rotundone in Syrah fruit. We found that the Mass Selection had the lowest concentration of rotundone at all stages and all years: between 13 and 119 ng/kg. The Chave clone, anecdotally considered the more peppery clone, yielded 65 to 165 ng/kg, and Dijon 470 was shown to have between 150 and 185 ng/kg rotundone in the berries. Considering that the sensory perception threshold for rotundone in red wine is 16 ng/kg, it is clear that the selection of clones in this research may have had a strong influence on the pepperiness of final wines.

Further it was shown that the rotundone concentration increased at different rates among the clones. Fruit from Dijon 470 had higher concentrations of rotundone at harvest than Chave or MS clones. These results indicate that common clone selection practices for quality wine production impact upon rotundone concentration, and may be used to manage rotundone levels as desired in finished wines.

60. Manipulation of wine volatile aroma profiles in white wine through the use of oxygen during grape processing and fermentation

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Background: The role of oxygen in the stimulation of fermentation rates has been well described (Salmon 2006). The most effective way to stimulate fermentation performance with the use of oxygen is by adding a single dose at the end of exponential growth, 36 to 48 hours into fermentation (Sablayrolles et al. 1996). While attempts to increase fermentation efficiency have been key drivers of much work on oxygen use during fermentation, the effects on wine chemistry resulting from oxygen exposure during winemaking have had considerably less attention. In this work we explore the impact on volatile aroma compounds of controlled oxygen use during grape pressing and fermentation.

Method: Eden Valley Riesling grapes were whole bunch pressed using an inert press. The resulting juice was either exposed or unexposed to air, clarified by cold settling, and then inoculated with commercial yeast strain D254. Oxygen treatments were then applied to half of the ferments with all treatments performed in triplicate. The resultant wines were analysed three months after fermentation.

Results: Increased levels of ethyl esters were observed as a result of oxidative juice handling but reduced through the use of oxygen during fermentation. Conversely the levels of branch chain volatile acids were increased by both inert juice treatment and oxygen use during fermentation. The levels of aroma-active volatile compounds detected suggest oxidative handling of juices prior to fermentation can interact with the use of oxygen during fermentation management to have a sensory impact on resultant wines.

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61. Origin and effects of matter other than grapes (MOG) on eucalyptol concentration in red wine

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The aroma compound 1,8-cineole, commonly known as eucalyptol, has been reported to contribute 'eucalyptus', 'mint', 'fresh', 'cool', 'medicinal' and 'camphorous' aroma qualities to wine. Our previous investigations revealed it was present in significant quantities (i.e. above its aroma detection threshold of 1.1 μ g/L), in red (but not white) wines. Prior to our recent research, eucalyptol in wine was thought to be present because of aerial transfer from Eucalyptus trees to grape berries, or, as proposed by another research group, formed from grape-derived terpene compounds acting as precursors.

Given the industry interest in this characteristic aroma compound, we conducted thorough investigations in vineyards and wineries to clarify the source of eucalyptol in red grapes and wine. Both vineyard position and winemaking conditions can significantly alter eucalyptol concentration in red wine but precursor hydrolysis as previously thought is not an important source.

Results demonstrating the effects of MOG, notably Eucalyptus leaves, in the winemaking process on the concentration of eucalyptol in wine will be presented, along with some recent Cabernet Sauvignon and Pinot Noir data.

62. The effects of metals on the evolution of volatile sulfur compounds during wine maturation

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Reduced aromas caused by volatile sulfur compounds (VSCs) can impact negatively on the aroma of wine. 'Boiled or rotten egg', 'sewage' and 'rubber' are descriptors associated with these VSCs. The pool of potential precursors to VSCs in wine is extensive, and

many sulfur-containing molecules are present in mg/L concentrations, while VSCs start to become problematic at μ g/L concentrations. This makes it important to not only understand the formation of VSCs from precursors but also the mechanisms, or switches, driving the release of VSCs from various precursor molecules. Investigating the role of metal ions as catalysts in the formation of VSCs is crucial to gain a full understanding of the chemical processes governing the formation of post-bottling 'reductive' aromas.

In this study we have investigated the formation of VSCs during wine maturation, as catalysed by five transition metals (Al, Cu, Fe, Mn and Zn) normally present in wine and that are known for their catalytic ability (Larcher and Nicolini 2008). Wines were stored under anaerobic conditions and analysed at five time points over a 12-month period. The results showed that the evolution of hydrogen sulfide (H_2S), methanethiol (MeSH) and dimethyl sulfide (DMS) were directly influenced by different metals, and in some instances a combination of metals was responsible for the largest increase in VSC concentration. The effect of available oxygen on the formation of VSCs in wine was also important. At the start of the experiment, when high concentrations of oxygen were available some metals significantly reduced the concentration of the VSCs. During wine maturation, the oxygen concentration decreased to 0 ppb in the control samples and the effects of some metals were reversed with their presence now being associated with significant increases in VSC concentrations.

A series of notched boxplots is displayed in Figure 1 that indicates the distribution of the MeSH concentrations (μ g/L) in Shiraz samples (n = 96) with or without added Cu. The notched boxplots graphically display differences between MeSH concentration in the samples, the median (white line), the mean (star) with the red area depicting the 95% confidence interval for the mean, as well as outliers (black dots). At Day 1 (Figure 1a) no MeSH is present in samples with or without added Cu, but after one month of storage the interaction between Cu and MeSH can be observed in the significantly reduced MeSH concentration in all samples with added Cu (Figure 1b). However, after four months of storage, the MeSH concentration slowly increases to nearly the same levels in both samples with or without added Cu (Month 4, Figure 1c). After 6 to 12 months of anaerobic storage and after depletion of available oxygen, the MeSH concentration has significantly increased in all samples with added Cu to levels above MeSH's odour threshold value of 1.8 µg/L (Siebert et al. 2010) (Figure 1d, e).

From these results it is clear that the formation of VSCs from their precursors in wine is significantly affected by the presence of metals. Furthermore, the wine conditions had an impact on the type of reactions that the metals were involved in. Copper concentration in wine is particularly influenced by vineyard and winery practices and as such its use should be considered in light of its potential effects on VSCs.

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Figure 1. Notched boxplots indicating the distribution of MeSH concentrations (μ g/L) in Shiraz samples, showing a significant decrease (b) and significant increases ((d) and (e)) due to Cu addition. The lines parallel to the x-axis in (c), (d) and (e) indicate the odour threshold value for MeSH of 1.8 μ g/L

63. Flavour and aftertaste of smoke-affected wines: the role of glycoside precursors

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The volatile phenols guaiacol, 4-methylguaiacol, syringol, 4-methylsyringol, and o-, m- and p-cresol, as well as their glycoconjugates, were shown to be increased in smoke tainted wine, a taint that has caused significant problems to the Australian wine industry in the last years.

Glycosidically-bound volatile compounds are abundant in grapes and are important flavour precursors as they can be released from their bound form during winemaking and ageing. Recently it was shown that glucosides of volatile phenols can be hydrolysed in-mouth, which means that glycosides may release flavour during tasting and have a direct impact on sensory attributes.

Reconstitution experiments were used to mimic the smoke taint in red wines via addition of free volatiles in combination with their glycosidically-bound forms. It was shown that the addition of different volatile phenols together with their glycosidically-bound forms had the closest similarity to the smoke taint flavour. The direct sensory impact of different glycosidically-bound flavour compounds were further analysed by volatile release experiments. Results suggest that enzymes present in human saliva are able to release the volatiles from their glycoconjugates and therefore may play an important role in the flavour and aftertaste of wine.

64. The effect of grapevine rootstock on the sensory properties of Chardonnay and Shiraz

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Understanding the role of salt in the sensory properties of wines is important for a number of reasons. Salty taste in wines is regarded unfavourably and there are upper limits set for the concentration of chloride in Australia and in a number of countries to which Australia exports wine. There is also an upper limit on sodium in some other countries. Irrigation of vines using water with higher salt concentrations can potentially result in differences in wine composition and in wine sensory properties. In this study, Chardonnay and Shiraz grapes have been grown on a variety of rootstocks in vineyards where salt uptake from vineyard water sources could affect vine performance, grape and wine composition and potentially wine sensory properties. This has provided an opportunity to better understand the impact of salt, and more particularly chloride, on composition and sensory properties and how these effects may be modulated by different rootstocks.

We discuss the sensory impacts and their relationship to wine chemistry for Chardonnay wines produced from vines on six rootstocks in 2011 and Shiraz wines produced from vines on eight rootstocks in 2012. In both cases, there were some relationships between wine chemistry, particularly ion concentrations, and wine sensory properties, with differences between rootstocks.

65. Descriptive analysis and napping: understanding wine style using traditional and rapid methods

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Wines can be assessed in many ways, but as with any product which is a complex mixture, both chemically and sensorially, it can be difficult to get an objective picture of the overall differences and similarities between wines, particularly when the wines display subtle differences. Descriptive sensory analysis rates the presence and intensity of relevant attributes to generate quantitative information about individual attributes and using multivariate analyses, the overall similarities and differences between wines. This method is very sensitive, however, it requires specific, ongoing training, is time-consuming, and expensive.

'Napping' or projective mapping, is a more rapid method which can be used to provide information about the overall similarities and differences between wines in a group, which can be difficult to articulate in other ways. It requires assessors who are familiar with the method and are experienced tasters. Assessors evaluate, then group or separate the wines by their sensory properties, based on their own criteria. Assessors can also provide information about the characteristics of the wines which define a wine or group of wines. This information can be used to understand common attributes which are important in grouping or separating wines. This method has the advantage of reduced panel training time and sensory assessment time, thus reduced costs. However, it is not as sensitive as descriptive sensory analysis and statistical analysis of the data is more complex. We show how both methods can be used to analyse a group of wines, showing the benefits of both methods in different situations.

66. Monitoring the impact of pectolytic enzymes on autolysis characters in sparkling wine during bottle ageing

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Sparkling wine is an important, growing, and highly-profitable sector of the Australian wine industry. However, limited research has been conducted into the production of this wine type and the mechanisms by which secondary fermentation and ageing on lees contribute to the final sensory characteristics of the wine. A number of commercial pectolytic enzymes are purported to increase the speed of the ageing process and generate desirable autolysis characters in a shorter time frame, allowing quicker market access and reducing storage and management resources.

In conjunction with Yalumba Wines, the impact of two commercial pectolytic enzymes (at different dose levels) on the development of autolysis characters was investigated in a commercial Pinot Chardonnay sparkling wine. Several spectroscopic techniques were employed to monitor wine development in bottle, including UV-visible and mid-infrared spectroscopy, as well as non-destructive analysis (visible-near infrared spectroscopy) using the BevScanTM analyser. Spectral monitoring of Yalumba's sparkling wines over a ninemonth period has shown noticeable differences between the wines as they develop over time. UV spectra have been shown to provide the most insight into enzyme activity, with differences due to the two enzyme types and dose level applied being apparent.

Sensory assessment of the wines and subsequent chemometric analysis have revealed that the aroma and flavour attributes of the wines are impacted by enzyme type and dose level, including 'fresh', 'fruity'/'citrus', 'honey', 'aldehyde', 'creamy'/'viscous' and 'acidity' attributes.

67. From grape to consumer: relationships between grape maturity, wine composition and wine sensory properties in Cabernet Sauvignon

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The grape ripening process produces a systematic transition in the sensory profile of resulting wines (Heymann et al. 2013) whereby an earlier harvest results in more 'acidic' and 'vegetative' attributes, and later harvests result in 'hotter', 'bitter' wines with 'dark fruit' attributes. The aim of the study presented was to determine whether changes in wine composition associated with grape ripeness confer specific changes in wine sensory properties. Since delaying harvest can result in undesirable increases in wine alcohol, a further consideration was whether a 'sweet spot' in terms of consumer preference exists.

Grape samples were obtained from a commercial vineyard at five stages of ripeness, and produced wine alcohol contents ranging between 12.0% v/v and 15.5% v/v. Detailed compositional (Bindon et al. 2013) and sensory analysis was performed on the wines. A consumer test was carried out in Sydney, Australia with 104 red wine consumers. Sensory and chemistry data for the wines were modelled using partial least squares (PLS) regression.



Figure 1. X and Y loadings plot from PLS regression for appearance and aroma terms using selected chemistry data where X loadings (chemistry) are shown in blue, Y loadings (sensory) are shown in red. The distribution of overlaid scores for wines from the five harvest dates (H1-H5) is indicated by different colours

The wines from early harvest dates were strongly associated with descriptors such as 'red fruit' (aroma and palate), 'red colour' and 'fresh green' (aroma and palate). Later harvest dates were associated with attributes such as 'hotness', 'pungent', 'opacity', 'dark fruit' (aroma and palate), 'overall fruit' (aroma and palate) and to a lesser degree 'astringency', 'bitter' and 'earthy' attributes. The appearance and aroma terms were modelled separately from the palate terms and are shown in Figure 1 (appearance and aroma) and Figure 2 (palate).



Figure 2. X and Y loadings plot from PLS regression for palate terms using selected chemistry data where X loadings (chemistry) are shown in blue, Y loadings (sensory) are shown in red. The distribution of overlaid scores for wines from the five harvest dates (H1-H5) is indicated by different colours

'Opacity', 'purple colour' and 'astringency' were strongly associated with higher total anthocyanin, wine colour density and SO_2 -resistant pigment, tannin concentration, mean degree of polymerisation and % skin-derived tannin. For 'dark fruit' aroma and flavour there was a strong influence of multiple esters, dimethyl sulfide and a strong negative relationship with isobutyl methoxypyrazine (IBMP). 'Red fruit' aroma and palate were negatively correlated with the 'dark fruit' attribute. The 'fresh green' attribute was not significantly correlated with IBMP or C_6 volatiles in the aroma model, but was significant in the palate model. 'Pungent' and 'hotness' were correlated with higher alcohol and ethyl acetate. 'Viscosity' was positively associated with alcohol and glycerol, as well as yeast-derived mannoprotein.

The results of the consumer study showed a clear trend in which the wines at 12 to 13% alcohol were the least preferred. Thereafter, liking scores reached a plateau at 13.6% alcohol, after which no further increases were observed with wines from later harvest dates, up to 15.5% alcohol at the final harvest. The results show that delaying harvest to optimise wine attributes may not achieve a higher wine quality target in terms of consumer preference.

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68. The effect of polysaccharides, phenolics, pH and alcohol on the mouth-feel and flavour of white wine

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Polysaccharides are the most abundant macromolecules in white wine. As they originate from both the grape and yeast, their total concentration and profile can potentially be influenced by a number of winemaking processes including juice extraction, fermentation, and lees management. We investigated the effect of the presence of low, medium and high molecular weight polysaccharides and aspects of the wine matrix - pH, alcohol and phenolic concentration - on the taste and mouth-feel of model and white wine. Higher total polysaccharide concentration reduced palate hotness of both low and high phenolic white wines, while flavour intensity, perceived viscosity and perceived acidity were not significantly affected. Alcohol hotness of the model wine was reduced when medium molecular weight polysaccharides were present. Both the medium and high molecular weight polysaccharides contributed to perceived viscosity but only when the model wine was low in alcohol. Importantly, variations in pH and alcohol concentration also strongly affected the perception of many of the tastes and textures. Specifically, higher pH wines were perceived to be more bitter and viscous, but less astringent, flavoursome and acidic while higher alcohol wines were significantly more bitter, astringent and hot. These results suggest that the use of winemaking practices that increase the concentration of medium molecular weight polysaccharides could result in wines that display reduced palate hotness of white wine, and that pH and alcohol level also significantly influence the taste and mouth-feel of model and white wine.

GRAPEVINE PHYSIOLOGY

69. The influence of vineyard and fruit exposure on the accumulation of methoxypyrazines in Marlborough Sauvignon Blanc grapes

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Methoxypyrazines (MPs) are now recognised as some of the key aroma/flavour compounds responsible for the distinctive flavour of Marlborough Sauvignon Blanc wine, imparting 'green' flavour and altering the balance of 'green' and 'fruity' flavours and hence the perceptible uniqueness of these wines (Parr et al. 2007). Despite their importance in wine, relatively little is known about how and when MPs are formed and accumulated in grape berries under the viticultural and climatic conditions experienced in Marlborough. To address this void of local knowledge, we investigated two factors thought to be important influences on MPs - vineyard site and fruit exposure.

Two contrasting vineyards in Marlborough were chosen for the experiment, one vineyard at Seaview in the lower Awatere valley and the other at Brancott (Booker) in the Southern valleys region. The vines growing in these two vineyards were of similar age and plant densities, same clone and rootstock, and managed to a four cane vertical shoot position (VSP) canopy. The influence of fruit exposure at both vineyards was examined by sampling berries from naturally exposed and shaded bunches from post-fruit-set through to harvest.

Accumulation of MPs appeared to occur independently of veraison, with production commencing as early as five weeks before veraison (Figure 1). Maximum MP concentration occurred two weeks before veraison at both vineyards (results not shown), but maximum MP content per berry either peaked just before veraison or near harvest, depending on vineyard location (Figure 1).



Figure 1. The effect of vineyard site and berry exposure on Sauvignon Blanc berry iso-butyl methoxypyrazine (IBMP) content from post-fruit-set to harvest 2009. Vertical dashed lines = veraison window = 0 to 100% berry softening. SV = Seaview vineyard; BK = Booker vineyard. Exp = exposed, Shd = shaded. Error bars = LSD (0.05)

The Seaview vineyard showed a greater propensity to accumulate MPs than the Booker vineyard by harvest time in the 2009 season (Figure 1). This measured result is consistent with previous unpublished studies and anecdotal industry opinion. Over time, grapegrowers and winemakers have observed that vineyards in the lower reaches of Awatere Valley in Marlborough, in particular, produce 'greener' fruit and wines with measurably higher concentrations of MPs than many wines produced in other sub-regions of Marlborough. The particular aspects of the Seaview vineyard that contribute to the greater production and accumulation of MPs remain unclear, but temperature, wind run and water availability, in particular, may be more important than other factors, because Seaview has an annual wind run almost double that of Booker and 30% lower annual rainfall, and thus needs more irrigation to offset lower rainfall, higher evaporation and higher canopy transpiration losses caused by the wind run.

In addition to the vineyard effect, fruit exposure had significant and consistent impact across both vineyards. Naturally exposed fruit (in the absence of the confounding effect of canopy leaf removal) had a reduced capacity to accumulate MPs compared with shaded fruit in the same canopy, by 50% or more (Figure 1). Although fruit exposure implied the berries were receiving more sunlight, it also meant they were more exposed to the elements, including for example, warming by the sun, rainfall and chemical spray coverage. Thus the observed reduced capacity for MP production may not be solely attributable to light exposure.

This research suggests that the distinctive 'green' MP flavours of Marlborough Sauvignon Blanc are highly sensitive to factors like vineyard site and fruit exposure. Thus grapegrowers and winemakers should consider the implications of both direct and indirect influences of vineyard site and management practices on berry exposure, and hence berry MPs, and resulting wine style. Understanding the mechanisms controlling berry MP production is the focus of future research.

Acknowledgements

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70. Predicting grape berry ripeness – the analysis of peduncle evolution

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Harvesting grapes at their optimal ripeness is the first step in making a quality wine. Traditional berry ripeness indicators such as pH, TA and Brix do not always reflect the flavour and phenolic maturity of grapes; and it is time-consuming and costly to do these tests routinely. In many varieties, stems change colour from green to brown upon ripeness and it has been mentioned that this stem colour change is in parallel with berry ripening (Bisson 2001; Watson 2003). However, no research has been done on grape stems during ripening. The grape stem is composed of the peduncle, rachis and pedicels. In this study, grape peduncle and rachis were studied from veraison to harvest, with emphasis on their colour and chemical changes and whether these correlate with those occuring in the berries.

During the 2012 and 2013 vintage, eight patches of Shiraz grapes were sampled from veraison to harvest and 24 peduncles and rachises from each patch were scanned into digital images. Peduncle area, length and colour (RGB and CIELab) were measured by Matlab software. Then the peduncles and rachises were freeze-dried and ground into a fine powder for extraction and chemical analysis, including chlorophyll, carotenoid, total phenolics and antioxidant activity. All



Figure 1. 2013 peduncle colour a value (CIELab) change during ripening (a<0 represents green while a>0 represents red)

data were subject to Principal Component Analysis (PCA) to examine the correlation between berry ripeness and peduncle change.

Image analysis of the peduncles showed that there was no significant change in peduncle size while the peduncle colour changed from green to red during ripening (Figure 1). Chemical analysis revealed that peduncle total chlorophyll and carotenoid levels decreased toward harvest, while total phenolics concentration and antioxidant activity increased slightly. It was also found that the rachises contained significantly higher amounts of the chemical metabolites mentioned above than the peduncles.

Importantly, PCA plots indicated that peduncle colour correlates with berry Brix, pH and TA. Furthermore, a Harvest Index (Hi) calculated by peduncle RGB values was subject to regression with number of days after flowering. The regression formula developed after five samplings efficiently predicted the harvest dates for the 2013 vintage when it was two weeks before the actual harvest date (Figure 2).



Figure 2. 2013 Harvest Index of Redness (HiR) and HiR/Greenness (HiR/G) calculated five weeks after veraison predicted the harvest dates would be 111 and 113 days after flowering, which were very close to the actual harvest dates – 109, 114 and 117 days after flowering.

Overall, this is the first time that grape peduncles and rachises were studied from veraison to harvest, with many new findings on stem colour and chemical composition made. This study indicates that monitoring grape peduncle colour evolution can be a new, nondestructive and effective way to evaluate berry ripeness and therefore predict harvest date.

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71. The effect of water stress on the reproductive performance of Shiraz grafted to rootstocks

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An experiment was conducted in the Barossa Valley, South Australia to examine the effects of rootstock on reproductive performance of Shiraz (*Vitis vinifera* L.) in the absence of irrigation. Irrigation applied

to control treatments was between 0.6 ML/ha and 1.3 ML/ha across three seasons. The absence of irrigation strongly influenced vine growth and performance. Yields were reduced in unirrigated treatments due to a reduction in bunch number, bunch weight and berry weight rather than fruit set. Unirrigated Ramsey was the only rootstock able to maintain a comparable yield to irrigated rootstocks. In contrast, unirrigated own roots performed well in

the first season but not in the second and third seasons when water stress caused a negative effect on yield.

Introduction

Increased climate variability is likely to result in grapegrowing regions being forced to operate with reduced water availability. Early and late season water deficits have been shown to be detrimental to the development of both the current and the following season's crop. Early season water deficits can interfere with pollination and fertilisation and can cause poor fruit set and/or abscission of inflorescences (Alexander 1965; Keller 2005) and result in fewer berries per cluster (Rogiers et al. 2004). Rootstocks may help alleviate the effects of water stress during flowering and berry development.

An experiment was conducted in the Barossa Valley, South Australia (Figure 1) to examine the effects of rootstock on reproductive performance of Shiraz (*Vitis vinifera* L.) in the absence of irrigation (Table 1).



Figure 1. Trial site at Nuriootpa in Barossa Valley, South Australia

Table 1. Rootstocks names and parentage used at Nuriootpa

Rootstock	Parentage
Shiraz (clone BVRC30)	V. vinifera
110 Richter	V. berlandieri x V. rupestris
1103 Paulsen	V. berlandieri x V. rupestris
140 Ruggeri	V. berlandieri x V. rupestris
99 Richter	V. berlandieri x V. rupestris
Ramsey	V. champinii

Materials and methods

The study was established at Nuriootpa, South Australia, Australia (34.48° S, 139.01° E). The vineyard was planted in 2001 at 3 m × 2.25 m row and vine spacing. Vines were unirrigated or irrigation applied was between 0.6 ML/ha and 1.3 ML/ha across three seasons, based on measures of pre-dawn leaf water potential (Ψ_{pd}). Vegetative and reproductive parameters were measured by assessing the following:

- Pruning weights
- Bud fruitfulness
- Flower number
- Coulure Index (CI)
- Millerandage Index (MI)
- · Bunch weight
- · Berry weight
- Fruit yield per metre of cordon.
- Fruit set indices were calculated according to formulae in Collins and Dry (2009) (Figure 2).



Figure 2a. Diagram of fruit set indices and visual identification of seeded berries, seedless berries and live green ovaries (LGOs) Figure 2b. Calculation of fruit set indices adapted from Collins and Dry (2009)

Results and discussion

Shiraz exhibited an anisohydric response as $\Psi_{\rm pd}$ declined with decreased soil water potential. Water stress ($\Psi_{\rm pd}$ >0.8 MPa) was exhibited in the unirrigated vines from veraison onwards (Figure 3). The warmer growing season for 2009/2010 contributed to the lower $\Psi_{\rm pd}$ values while the higher rainfall at flowering and pre-harvest in 2010/2011 contributed to the higher $\Psi_{\rm pd}$ values for all treatments. In addition, unirrigated treatments were lower (more negative) than irrigated treatments at both veraison and pre-harvest.

Yields were reduced due to a reduction in bunch number, bunch weight and berry weight rather than any effect on fruit set and berry number. In each of the three seasons, zero irrigation reduced pruning weights, cane weights and cane numbers (Table 2).

Zero irrigation reduced yield by 25% in 2008/2009, 22% in 2009/2010 and 23% in 2010/2011 (Figure 4).

There was no significant effect of zero irrigation on fruit set in any of the three years. However, a strong inverse relationship between fruit set and CI was observed (Figure 5). This appears to be a good indicator of disruption to reproductive development for Shiraz.

A cumulative effect of zero irrigation was most notable in Shiraz than in rootstock treatments (Table 3). The cumulative effect of drought of season one and two severely affected yield and yield components for unirrigated Shiraz. In contrast, unirrigated Ramsey was able to maintain comparable yields with irrigated Ramsey in seasons two and three. 1103 Paulsen unirrigated in every season was associated with the lowest yields (Table 3). Although rootstock type appeared to have some effect on reproductive performance, this was inconsistent and season had a greater influence than either rootstock type or irrigation.



Figure 3. An example of the effect of irrigation treatment on pre-dawn leaf water

Table 2. The effect of zero irrigation on pruning weight across three seasons in Barossa Valley, South Australia

Pruning weight					Ti	reatment					
(kg/ metre <u>cordon)</u>	Treatment	Control (SHI)	110 Richter	1103 Paulsen	140 Ruggeri	99 Richter	Ramsey	Schwarz- mann	Treatment mean	P value	LSD (5%)
2008/2009	Control	0.97	0.41	0.98	0.56	0.45	0.37	0.44	0.60	<.001(R)	0.164
	Zero	0.90	0.29	0.62	0.44	0.37	0.34	0.41	0.49	0.009 (I)	0.083
	Rootstock	0.93	0.35	0.80	0.50	0.41	0.36	0.43		0.370 (R*I)	n.s
2009/2010	Control	0.97	0.41	0.98	0.56	0.45	0.37	0.44	0.60	<.001(R)	0.164
	Zero	0.90	0.29	0.62	0.44	0.37	0.34	0.41	0.49	0.009 (I)	0.083
	Rootstock	0.93	0.35	0.80	0.50	0.41	0.36	0.43		0.370 (R*I)	n.s
2010/2011	Control	2.2	1.1	1.4	1.2	1.1	0.9	1.2	1.3	<001(R)	0.008
	Zero	2.1	1.0	1.3	1.23	0.9	1.0	1.1	1.2	0.042(I)	0.052
	Rootstock	2.1	1.0	1.3	1.2	1	0.9	1.2		0.063(R*I)	n.s

Table 3. The cumulative effect of zero irrigation on yield across the three seasons of analysis in Barossa Valley, South Australia

	Treatment											
Yield kg/m	Treatment	Control (SHI)	110 Richter	1103 Paulsen	140 Ruggeri	99 Richter	Ramsey	Schwarz- mann	Treatment mean	P value	LSD (5%)	
2008/2009	Control	4.17 ^f	3.04 ^e	1.99 ^d	2.75°	1.79 ^{bcd}	1.64 ^{bcd}	1.71 ^{bcd}	2.44	<.001(R)	0.34	
2008/2009	Zero	3.83 ^f	1.87 ^{cd}	1.35ªb	1.60 ^{bcd}	1.1ª	1.5 ^{abc}	1.47 ^{abc}	1.82	<.001(l)	0.16	
2000/2010	Control	3.6 ^f	3.2 ^{de}	2.3 ^b	2.7°	3.3 ^{def}	3.2 ^{de}	3.6 ^f	3.1	<001(R)	0.236	
2009/2010	Zero	3.0 ^d	2.6 ^{bc}	1.7ª	1.7ª	2.3 ^b	3.4 ^{ef}	2.4 ^{bc}	2.4	<001(l)	0.113	
2010/2011	Control	3.5°	3.3 ^{de}	3.3 ^{de}	4.0 ^g	3.5 ^e	4.2 ^f	3.3 ^{cde}	3.7	<001(R)	0.316	
	Zero	2.9 ^{bc}	3.1 ^{cde}	2.4ªb	3.2 ^{cde}	3.0 ^{cd}	3.5°	2.0ª	2.9	<001(l)	0.178	

potential at flowering (a) veraison (b) and pre-harvest (c). Error bars represent the standard error of the mean (n=15).



Figure 4. An example of the effect of irrigation treatment and rootstock genotype on yield (kg/m) for the 2010 seasons at Nuriootpa, South Australia. Error bars represent the standard error of the mean (n=21)



Figure 5. The inverse relationship between fruit set (%) and Coulure Index: an abnormal condition of fruit set that results when flowers either shed excessively or fail to develop into a berry or LGO (n= 620)

Conclusion

This study examined the reproductive performance of Shiraz grafted to rootstocks in the absence of irrigation for three consecutive seasons. The absence of irrigation reduced both vegetative and reproductive parameters. Yields were reduced due to a reduction in cluster number, cluster weight and berry weight rather than any effect on fruit set and berry number. A cumulative effect of prolonged zero irrigation was most notable in Shiraz than in rootstock treatments. The cumulative effect of drought of season one and two severely affected unirrigated Shiraz, even when season three was wetter than average.

In contrast, unirrigated Ramsey was able to maintain comparable yields with irrigated Ramsey in seasons two and three. 1103 Paulsen unirrigated in every season was associated with the lowest yields.

These findings may have significant consequences for rootstock choice in grapegrowing regions faced with future drought and water allocation issues.

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72. Rootstocks and water use efficiency I: the role of conferred vigour in determining crop water use index

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Increasing pressure on fresh water supplies from rising populations, environmental requirements and climate change means that the availability of water for irrigation is only likely to decrease in the future. The vast majority of Australian vineyards are irrigated and during the recent drought irrigation allocations reached as little as 20% of normal. Consequently, improving water use efficiency of vineyards, whilst maintaining profitability, is essential for the future success of the industry.

Rootstocks can be used to impart specific traits upon the scion; in particular, they can be used to produce a wide range of scion vigour. As canopy size is a primary determinant of vine water use, rootstocks that minimise canopy size whilst maximising yield are likely to improve the water use efficiency of wine-grape production.

We have used a fully replicated field trial of more than 20-year-old Shiraz vines grafted to a range of rootstocks, including the low-moderate vigour Merbein series recently released by CSIRO, to establish the role of rootstock-conferred vigour in determining crop water use efficiency. Whole vine transpiration was monitored and canopy growth determined in seven rootstocks, the latter measurement demonstrating a twofold range in canopy size. The relationship between yield and water use, when determined for each rootstock, demonstrated a higher crop water use index (yield/water transpired) in the lower vigour rootstocks. Furthermore, the lower vigour rootstocks also had reduced inter-seasonal variability in yield and wine quality.

73. Shiraz berry development responds to rootzone temperature

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Soil warming following winter dormancy activates root metabolism and encourages root starch mobilisation (Field et al. 2009). These carbohydrates provide the energy to drive budburst and early canopy development (Rogiers et al. 2011; Rogiers and Clarke 2013). Flower and berry development are particularly responsive to both vine carbohydrate status and current photoassimilation; consequently rootzone temperature may play a role in these developmental processes through altered carbon partitioning. Aside from air temperature, seasonal variability in rootzone temperature may thus be an additional abiotic factor driving seasonal heterogeneity in fruit yield and composition.

We exposed potted Shiraz grapevines to cool, ambient and warm rootzone temperatures for two months in spring using a heat exchange system comprised of heated or cooled water recirculating through tubing embedded in the soil. The three rootzone temperatures consisted of ambient, 5°C below or 5°C above ambient levels and were applied from budburst to fruit set. Carbohydrate mobilisation, vegetative growth and reproductive development were monitored. A portable photosynthesis system was used to measure leaf gas exchange at weekly intervals.

Warm rootzone temperatures after budburst stimulated carbohydrate mobilisation and root growth. This was accompanied by hastened leaf development and shoot elongation. Elevated rootzone temperature also resulted in higher daytime stomatal conductance, transpiration and net assimilation rates. Likewise, we found that night-time stomatal conductance and transpiration rates were greater for plants grown in warm rootzones. Anthesis, fruit set, berry enlargement and the onset of veraison also occurred earlier in those vines exposed to this treatment. At maturity, berry fresh and dry weights were greater but titratable acidity was lower. Total soluble solids and anthocyanin concentrations were higher on a berry basis however the concentrations were not different among the treatments.

In summary, warm rootzones during spring hastened the phenological development of the canopy, flowers and berries with carryon effects on berry size and composition at harvest. These results indicate that seasonal variability in temperatures prior to fruit set may contribute to seasonal heterogeneity in berry composition at maturity. Accordingly, models predicting yield and berry composition must consider rootzone temperature, especially in light of global increases in air and soil temperatures.

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74. The effects of warming on metabolism of organic acids in berries of field-grown vines

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Grape berry malic acid accumulates during fruit development and is degraded during ripening. The loss of malic acid during ripening is accelerated by heat (Kliewer 1971) and can affect organoleptic properties of the fruit and wine, as well as winemaking strategies that are dependent on pH for maintaining yeast viability and reducing microbial spoilage. This study investigated effects of elevated vineyard temperature on malic acid level at particular developmental stages, with the aim of identifying key enzymes responsible for the accelerated malic acid loss.

Elevated temperature experiments employed 'open-top chambers', 'closed-top chambers' and 'bunch-heaters' to simulate heat events of varying duration and intensity with Vitis vinifera (cv. Shiraz) vines in the field. Berries were collected throughout development and used for fresh weight, °Brix determination and organic acid quantification via high performance liquid chromatography (HPLC) and enzyme-linked assays. Selected samples were also tested for activities of enzymes involved in malic acid metabolism in plants, using nicotinamide adenine dinucleotide phosphate (NAD(P)H)-dependent spectrophotometric assays.

Elevated day temperature had little effect on organic acid levels during early berry development, but resulted in accelerated loss of berry malic acid when vines were treated during veraison and ripening stages. Elevated night temperature increased berry malic acid levels when vines were treated during early berry development, but had little effect during berry ripening. A combination of day and night heating at veraison showed the characteristic loss of malic acid when fruit was exposed to elevated day temperatures however this effect was reduced when night temperature was also elevated. A similar pattern was observed in activity of the malic acid synthetic enzyme, phosphoenolpyruvate carboxylase (PEPC), suggesting a possible link between decreased malic acid level and decreased malic acid synthesis during elevated temperature events.



Figure 1. Effect of elevated day and/or night temperatures at veraison on (a) malic acid content and (b) PEPC enzyme activity. (n=4, mean \pm standard error of the mean)

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75. Effects of elevated temperature on vine phenology, physiology and berry composition

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We established three factorial experiments combining two thermal regimes (control, elevated temperature using open-top chambers) with (a) four varieties (Cabernet Franc, Shiraz, Semillon, Chardonnay), (b) two source:sink ratios (control, 0.5-0.6 bunches removed) and (c) two irrigation regimes (fully irrigated, water deficit). Elevated temperature caused:

i) A non-linear effect on phenology. Phenological trajectories of heated and control vines diverged during stages dominated by temperature-driven processes (e.g. flowering) and converged during phases dominated by resource-driven processes (e.g. berry growth). Increased source:sink ratio that relaxed resource constraints enhanced thermal effects on phenology. The thermal effect was largest in Semillon and smallest in Shiraz. Actual shifts in maturity were smaller than expected from time series.

ii) An asymmetric effect on fruit yield and fruit/pruning weight ratio: yield response to elevated temperature varied from 46% reduction to 177% increase in relation to controls, and the response of fruit/ pruning weight ratio varied from 56% reduction to 145% increase.

iii) An increase in phenotypic plasticity of stomatal conductance and photosynthesis; this was partially related to larger stomata under heat. Increased source:sink ratio reduced the plasticity of stomatal conductance; the effects of source:sink ratio and temperature were additive.

iv) The decoupling of anthocyanins and sugars in Cabernet Franc and Shiraz. Water deficit favoured a higher anthocyanin-to-sugar ratio.

INFORMATION AND TECHNOLOGY TRANSFER

76. Economic evaluation of selective harvesting of variable vigour vineyard blocks: case study of a Cabernet Sauvignon block from Western Australia

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Vine vigour is thought to influence berry composition and, therefore, price. Within a block differing vigour zones can exist (e.g. due to topographical or soil variations), producing fruit of varying chemical composition. Understanding these inherent differences and treating them as separate units is the basis of differential management (precision viticulture), however it is unclear whether site-specific or uniform management generates a greater financial return. This work aims to understand the economic implications of differential vs uniform management.

For this research, a Cabernet Sauvignon block in Western Australia was used. Plant cell density imagery was used to divide the block into high and low vigour sections, and costs were traced throughout the growing season. A week before commercial harvest, berry chemistry (pH, TA, Brix) was analysed on berries from 110 sample vines representative of the block. The vineyard was differentially harvested, and yield data were collected from 680 sample vines, divided proportionally among each zone. Economic analysis was performed at the commodity level.

The results show that:

1. The vineyard block had a significant variation in plant cell density (PCD). Based on commercial operational considerations and the range of variation in PCD, the block was delineated into two management zones – high and low PCD (Figure 1).

2. Overall berry chemistry differed between the high and low vigour zones. On average the low vigour zone had a higher pH, lower total acidity, and higher Brix values. Not surprisingly, the high vigour zone showed opposite results with lower pH, higher total acidity, and lower Brix values (Figure 2 A, B and C).

3. Yield was similarly correlated, as the low vigour zone yielded on average 30% less per vine than the high vigour zone (Figure 2 D).

4. Although revenue and net profit for the high vigour zone were about 10% higher than the low vigour zone (due to increased yields), net profit for both the low and high vigour zones were distinctly greater than that achieved through uniform management (Figure 3).



Figure 1. Plant cell density imagery, captured at veraison, displaying the two zones (high and low vigour)



Figure 2. (A), (B) and (C) – Berry chemistry maps generated from fruit analysed one week prior to commercial harvest. Berry chemistry clearly demonstrates a significant relationship with PCD. (D) – Yield map collected during commercial harvest is similarly correlated to PCD and berry chemistry findings



Figure 3. Revenue, cost, and profit incurred during the 2012–2013 growing season. Note: the numbers presented do not include financials for the business as a whole and therefore do not include liability, asset, or equity figures as would pertain to the company's balance sheet and financial records

The conclusions drawn show that up to 12% higher profit margins are realised through differential management as opposed to uniform management, therefore, site-specific management is the more economically viable approach for this block.

77. Tocal College – recognising your skills and helping to build wine industry capacity through the National Wine and Grape Industry Centre in New South Wales. Your opportunity to get LinkedIn[®] to wine industry vocational education and training (VET) and help raise the 'skills' bar in Australia

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The New South Wales Department of Primary Industries has a Registered Training Organisation (RTO) trading as Tocal College. Tocal has an education officer-viticulture based at the National Wine and Grape Industry Centre (NWGIC) in Wagga Wagga NSW.

Over the last three years Tocal has been engaged by many individuals in order to have long-standing skills and knowledge formally recognised through its skills recognition program. Several graduates have gained Diplomas and/or Advanced Diplomas in Production Horticulture by gathering evidence of their skills and experience and participating in interviews with College staff.

Trainers have also been involved in the presentation of several workshops aimed at filling industry skills shortages focusing on the safe operation of all terrain vehicles, safe chemical applications, trunk disease management and irrigation scheduling.

The College was invited to represent registered training organisations on the National Wine Extension and Innovation Network (NWEIN) and as a result would like to better represent other vocational education and training (VET) organisations nationally.

Tocal invites industry, RTOs and VET professionals to network via LinkedIn^{*} and assist each other in meeting the information needs of the Australian industry. The endorsement of a nationally recognised Diploma in Viticulture will provide an excellent opportunity for member organisations and industry representatives to validate training and assessment across Australia. In future, individuals will continue to enjoy the benefits of skills recognition programs and the network will help identify, supply and review industry training needs as part of the larger information and technology transfer system.

78. Vintage operations in real time – leading edge systems to inform and optimise the supply chain

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Vintage intake operations rely on the ability to synchronise vineyard, transport and winery activities and personnel. A whole communication web involving multiple phone calls and conversations supports these activities. Often these communications are not visible to all the key stakeholders in the supply chain and this can result in inefficiencies in the vintage process. This has the potential to impact on both grape and wine quality and cost of doing business.

In 2012/2013, Treasury Wine Estates (TWE), in partnership with the Herbert Resource Information Centre (a sugar industry service organisation based in Queensland) initiated a pilot study in the McLaren Vale winegrowing region in South Australia. The pilot involved the construction of a customised online wine industry platform to visualise and monitor vintage activities in real time - including harvest, transport and receival activity at the winery. Spatial data layers visualised on a map in combination with multiple dashboards enable key stakeholders in the supply chain to monitor the status of grape harvest and delivery in real time.

By understanding real-time events and making vintage information easily accessible to all stakeholders through this online platform, TWE envisages that it will be able to improve efficiencies in its supply chain. Ongoing analysis of the benefits is occurring in 2013, with a view to rolling out the use of the platform more widely for vintage 2014.

79. The Australian sparkling wine market: a snapshot

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Sparkling wine has accounted for almost 10% of Australian domestic wine sales since the late 1980s. Australian sparkling wine production, which reached 37 ML in 2012 (Wine Australia), represents a small, but significant proportion of the Australian wine industry's total production. Furthermore, the local market is diverse, comprising Moscato and white, rosé and red sparkling wine styles, as mono-varietals and blends, at various price points.

A study was undertaken to (i) determine the importance of wine styles via analysis of sales data; and (ii) gain an insight into sparkling wine consumers and their purchasing behaviour via in-store observational studies. Data for sparkling wine sales in Australia were purchased from marketing firm AC Nielsen. Three hundred sparkling wine consumer purchases were observed, either pre- or post-Christmas (Dec 2012 or Feb 2013); comprising 30 consumers in each of 10 liquor stores around metropolitan Adelaide, South Australia. The information gathered included the wine purchaser's age (under or over 35 years), gender, the time taken to make a selection, whether wine selections were pre-determined, whether chilled sparkling wines were purchased, whether staff were asked for advice, whether wine back labels were inspected, and whether other beverages were also purchased.

The distribution of sparkling wine sales in Australia for 2005 and 2012 is illustrated in Table 1. Most notably, champagne sales increased from 8% (2005) of total sparkling wine sales to 19% (2012), representing an increase in sales from 34.4 to 102 million dollars (AC Nielsen). While the overall sales represented by sparkling white wines has reduced to 54%, the monetary sales value for this, and most other sparkling wine styles, remained relatively constant during this time. In regards to Moscato, no individual sales data were available in 2005. It is possible that sales of Moscato in 2005 may have been captured under the 'other' category.

Table 1. Distribution of sparkling wine sales in Australia for various wine styles based on percentage of overall sales values of 444M in 2005 and 545M in 2012 (AC Nielsen)

Wine Style	% of overall sales					
while Style	2005	2012				
Champagne	8	19				
Sparkling White	64	54				
Sparkling Rosé	9	7				
Sparkling Red	4	3				
Moscato	-	8				
Other	15	9				

The 300 in-store observations performed for sparkling wine purchases revealed that the Australian sparkling wine purchaser was biased towards females over 35 years of age, who did not seek advice from staff or read the wine label, but had a predetermined choice and took less than one minute to make their selection. Of the 300 transactions for sparkling wine, 55% were for one bottle, while a further 21% were for two bottles. Of all bottles sold, 75% were Australian sparkling and 20% were French champagne. These results were similar for that captured by AC Nielsen sparkling wine sales data in Australia for 2012.

In conclusion, the popularity of champagne has greatly increased in recent years with little growth in sales of Australian sparkling wine. Studies are now being undertaken to investigate sparkling wine consumers' preferences for French champagne versus Australian sparkling wine.

80. Online information from The Australian Wine Research Institute

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Relevant and valuable information is compiled, packaged and made available online for the convenience of grape and wine producers through the AWRI website. The range of communication platforms are designed to meet the information needs of winemakers, viticulturists, grapegrowers, industry bodies, exporters and consumers.

Website of the AWRI (www.awri.com.au)

The AWRI website brings together extensive technical information with current and practical advice. Users can access the agrochemicals 'Dog Book' (available to download as smart phone app or online search), winemaking calculators, fact sheets, current research topics and a calendar of events outlining dates and locations for upcoming roadshows, seminars and webinars. Online databases to search and order winemaking supplies, library resources and AWRI staff publications are also available.

News services (stay up to date)

When 'hot' topics arise, the AWRI responds rapidly via email with the release of an eBulletin. This eBulletin is uploaded to the AWRI website which becomes an online service that provides alerts and practical solutions. The AWRI also sends out via email a bi-monthly electronic newsletter (eNews), which is also made available via the AWRI website.

Webinars

The AWRI webinar program covers a range of winemaking, winery operations and viticulture topics and offers participants the opportunity to 'sit-in' on live and interactive seminars from their workplace.

Technical Review

Technical Review is a bi-monthly, online and print publication. A 'current literature' section provides a valuable summary of abstracts of recent literature in oenology, viticulture and wine and health. Also included are updates on AWRI research.

82. Library and information services for the Australian grape and wine industry

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Access to the latest published research and technical information is central to understanding and adopting research innovations. Maintaining a collection of grape and wine technical literature and making it easy to access supports producers to learn how new technologies and processes can be implemented to build capacities and capabilities in wineries and vineyards – underpinning the sustainability of the Australian wine industry.

Since 1969, the John Fornachon Memorial Library has supported the industry through strategic sourcing and dissemination of relevant and useful digital and print resources covering vines to wines. The collection comprises over 73,000 journal articles, books, conference proceedings and standards on viticulture and wine production.

Online library catalogue

You don't have to visit the library to access the resources! All resources are catalogued and the catalogue is available for access 24/7 via the AWRI's website (http://www.awri.com.au/information_services/library-services-to-levy-payers/). Journal articles, books, conference proceedings and other resources can be ordered online.

Article and book requests

Looking for the latest journal articles on grape and wine production? The online library catalogue is the first place to start. The catalogue contains over 50,000 records of the latest articles from technical and trade journals. The online ordering system is a convenient way to order the articles you need.

Specialised library databases

In addition to the library catalogue, the AWRI website also hosts a range of specialised library databases including AWRI publications, environment, and smoke taint.

MICROBIAL SPOILAGE

83. Abduction of ethylphenol precursors in wine via the formation of pyranoanthocyanins by selected yeasts

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The genera *Brettanomyces/Dekkera* are to blame for the appearance of phenolic and 'animal' odours. These result from the formation of ethylphenols from hydroxycinnamic acids, a consequence of these microorganisms' hydroxycinnamate decarboxylase (HCDC) and vinylphenol reductase (VPhR) activities. The aim of the present work was to facilitate the formation of vinylphenolic pyranoanthocyanins using HCDC+ strains of *Saccharomyces*, in order to reduce the hydroxycinnamic acid content of wine during fermentation and thus prevent the formation of ethylphenols by *Brettanomyces/Dekkera* (Benito et al. 2009, 2011).

Real musts were fermented with two yeasts 7VA (HCDC+) and S6U (HCDC-). These assays were performed in triplicate and it showed an average content of 0.47 ± 0.07 mg/L for 4-ethylphenol in the wine fermented by 7VA. This concentration was obtained 31 days after the inoculation of *Dekkera bruxellensis* D37. This value was below the preference threshold for 4-ethylphenol of 0.620 mg/L (Benito et al. 2009). Moreover, the must fermented by S6U (HCDC-) manifested strong 'Brett' character with a final concentration of 1.10 ± 0.06 mg/L of 4-ethylphenol (and 0.46 ± 0.08 mg/L of 4-ethylguaiacol), see Table 1.

High malvidin-3-O-glucoside-4-vinylphenol formation was verified in the musts fermented with 7VA, see Table 1. This pigment was not found in the musts fermented by S6U. The formation of 0.8 mg/L of malvidin-3-O-glucoside-4-vinylphenol and 0.3 mg/L of malvidin-3-O-glucoside-4-vinylguaiacol in the musts fermented by 7VA reduced the production of 4-ethylphenol by more than 50% and reduced the production of 4-ethylguaiacol by more than 75% compared with the S6U fermentations after inoculation with Dekkera D37.

In the controls withouth *Dekkera* inoculations, concentrations of 0.8 mg/L of malvidin-3-O-glucoside-4-vinylphenol and 0.3 mg/L of malvidin-3-O-glucoside-4-vinylguaiacol were detected after fermentation by 7VA and not detected in the S6U fermentations. In both controls, 4-ethylphenol and 4-vinylphenol were not detected after 31 days.

The HCDC activity of the fermentative strains significantly increased the formation of vinylphenolic pyranoanthocyanins and reduced the final concentration of 4-ethylphenol and 4-ethylguaiacol generated by the vinylreductase activity (VPhR) of *D. bruxellensis*. The use of *Saccharomyces* strains with strong HCDC activity reduces the final formation of 4-ethylphenol in wines.

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84. Comparative genomics of the spoilage yeast Dekkera (Brettanomyces) bruxellensis

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The yeast species *Dekkera bruxellensis* shows up in many fermentation processes, playing a strong role in shaping the style of beverages such as wine, beer and cider; and impacting on the efficiency of biofuel production. In wine, growth of *D. bruxellensis* post-alcoholic fermentation is associated with production of volatile phenols that impart 'medicinal' and 'barnyard' aromas. These aromas are known colloquially by the industry as 'Brett' character, and 'Brett' is generally regarded as a negative. To further our understanding of this species, we sequenced and *de-novo* assembled the genome of the predominant spoilage strain in Australia, finding a complex and highly heterozygous triploid genome enriched in membrane transport proteins and oxidoreductase enzymes. Subsequent re-sequencing and transcriptomic studies have been undertaken to gain insight into evolution of the species, and the adaptations that enable its growth and survival for long periods in wine.

Poster 83 Table 1. Fermentation by Saccharomyces 7VA (HCDC+) and S6U (HCDC-) and post-fermentative inoculation of Dekkera D37 in Tempranillo musts. The must had a pH of 3.5 and 220 g/L of sugars

		After f	ermentation		31 days after Dekkera bruxellensis D37 inoculation						
Yeast	TA	M3G	M3GVPh	M3GVG	TA	M3G	M3GVPh	M3GVG	4EP	4EG	
	mg/L						n	ng/L			
must									nd	nd	
7VA	172.4±18.6	58.2±1.0	0.81±0.02	0.32±0.01	75.9±11.9	23.3±8.6	0.54±0.01	0.24±0.01	0.47±0.07ª	0.105±0.02ª	
S6U	142.2±19.5	54.6±2.5	nd	nd	74.5±8.8	24.9±3.8	nd	nd	1.10±0.06 ^b	0.463±0.08 ^b	
7VA*	168.2±22.8	60.3±1.3	0.83±0.01	0.34±0.03	83.7±23.5	26.6±13.7	0.79±0.02	0.27±0.01	nd	nd	
S6U*	135.5±17.5	52.7±1.5	nd	nd	68.6±4.0	22.8±1.1	nd	nd	nd	nd	

Values are means±SD of three fermentations. Nd: non detected. * control without *Dekkera* inoculation. TA: Total Anthocyanins. 4EP: 4-ethylphenol. 4EG: 4-ethylguaiacol. M3G: malvidin-3-O-glucoside. M3GVPh: malvidin-3-O-glucoside-4-vinylphenol. M3GVG: malvidin-3-O-glucoside-4-vinylphenol. M3GVG: malvidin-3-O-glucoside-4-vinylphenol. M3GVG: malvidin-3-O-glucoside-4-vinylphenol.

NEW VINEYARD TECHNOLOGIES

85. Making sense of the vineyard environment

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There is a plethora of information about how to manage grapevines. Extension outputs usually provide general strategies applicable to a grapegrowing region. Individual growers need to make sense of this information for their particular vineyard characteristics and conditions. What if decision-making, based on each grower's local accumulated experience and knowledge, could be complemented with sensed and measured vineyard-specific information? What if it were then possible to link vineyard conditions directly to the internet to get real-time situation awareness for each vineyard? This would enhance each grower's specific decision-making. While such information can be obtained from on-site weather stations and other forms of environmental monitoring, these solutions are limited because they are purpose-built - measuring one thing. With an increasing number of such systems coming online, it becomes difficult to integrate information sources into an easy-to-interpret decision support system. Additionally, multiple systems increase the time and resourcing to individually support and maintain.

The Sense-T Program (www.sense-t.org.au) is building core infrastructure to facilitate integration of environmental sensor data. This infrastructure will enable inter-operability and allow data to be re-used and/or re-purposed for different applications. The infrastructure will ensure that sensor data are properly described so that the data can be used with confidence in different analytical tools/systems. Sensor networks are being established in four Tasmanian vineyards to help build and demonstrate the Sense-T infrastructure and to facilitate development of new applications and regional research and development. Each sensor network comprises an automatic weather station and up to three lower-cost environmental monitoring stations recording temperature, relative humidity and surface-wetness duration.

The first applications will provide tailored alerts for *Botrytis* bunch rot and frost risk. Applications for *Botrytis* risk will employ knowledge generated by Evans et al. (2010) and be guided by the experience of the New Zealand Winegrowers in implementing *Botrytis* Decision Support (Beresford et al. 2012). The project team is also working with the technical committee of Wine Tasmania, participating vineyard managers and service providers to design a fit-for-purpose system, engage the wider industry, and develop the business model for service delivery.

The current two-year project (2013–2014) will focus on research and development to address questions such as the sensitivity of risk models to changes in environmental conditions and sensor proximity. Information and communication technology research will focus on the use of knowledge to discover appropriate third-party sensor data, as well as end-user requirements for usability and usefulness. In the longer term, the minimum number of sensors needed to capture spatial variation in vineyard environmental conditions needs to be determined.

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PESTS AND DISEASE

86. Parasitic wasps that attack light brown apple moth: why do some species occur in vineyards and not others?

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Light brown apple moth, *Epiphyas postvittana* (Walker) is the most destructive insect pest in Australian vineyards. Control of *E. postvittana* by using natural enemies is an environmentally friendly method. There are 25 species of parasitic wasps that are associated with *E. postvittana* (Paull and Austin 2006), some of which are potential biological control agents to supress this pest. However the range of parasitic wasps that attack *E. postvittana* in vineyards is limited compared to their known diversity. One species, *Dolichogenidea tasmanica* (Cameron) (Hymenoptera: Braconidae), has been reported as the dominant parasitic wasp attacking *E. postvittana* in Australian vineyards.

In this study, we investigated:

1) whether the parasitic wasps that attack larval stages of *E. postvittana* in vineyards are related to those occur in adjacent vegetation in the Adelaide Hills region; and

2) factors that could influence the diversity and distribution of parasitic wasps that attack *E. postvittana*.

We suspected that parasitism would be higher in native vegetation than in adjacent vineyards because wasps are adapted to their native environment. Also, parasitism should vary among sites with different landscape characteristics and surrounding vegetation. We tested our hypotheses in replicated studies in the Adelaide Hills region in 2011 and 2012. Newly hatched E. postvittana were inoculated on potted plants of grape and plantain in 2011 but only grape plants were used in 2012. Potted plants with pest larvae were placed at each experimental site for two weeks. The larvae were then recovered and reared in the laboratory to record parasitism. Parasitic wasps' diversity and rate of parasitism of early larval E. postvittana were assessed at six vineyards at three locations: within vineyard, vineyard border and within adjacent native vegetation in 2011. Two vineyards were added to the 2012 study, and data were collected from within the vineyard and within adjacent native vegetation. Both experiments were repeated twice.

Split-split-plot analysis of data from the 2011 and 2012 studies revealed several patterns (Figure 1). The location of *E. postvittana* (vineyard, vineyard border, native vegetation) significantly influenced the level of parasitism by *Therophilus unimaculatus* (p<0.01). Host plant had a significant effect on parasitism by *D. tasmanica* (p<0.05) and overall parasitism (p<0.01). In 2012, only the location of *E. postvittana* significantly affected the overall parasitism (p<0.05), parasitism by *D. tasmanica* (p<0.05), and parasitism by *Therophilus unimaculatus* (p<0.01).

Parasitism in vineyards is not closely linked to nearby native vegetation (Figure 1); the parasitic wasp *Therophilus unimaculatus* was dominant in the native vegetation but parasitised very few *E. postvittana* inside vineyards. In contrast to *Therophilus unimaculatus*, *D. tasmanica* parasitised the most larvae in vineyards and was not active in the native vegetation.



Figure 1. Mean parasitism ± standard error by all parasitic wasps, *Dolichogenidea* tasmanica and *Therophilus unimaculatus* at different locations in six vineyards (2011), and eight vineyards (2012)

The conclusion that *Therophilus unimaculatus* and *D. tasmanica* differ in their use of habitat could be due to the several factors and additional research is needed to investigate these hypotheses:

1) Host leaf roller preference. *Therophilus unimaculatus* and *D. tasmanica* may attack a different range of other leaf roller species. They are not specific to *E. postvittana*.

2) Host plant effects. The parasitic wasps may vary in their preference of *E. postvittana* feeding on different host plants.

3) Historical effects. Parasitoids such as *D. tasmanica* may have established breeding populations in some vineyards which could partly explain their abundance at these locations.

4) Competition. Observations indicate a negative relationship in parasitism rates between *D. tasmanica* and *Therophilus unimaculatus* in different habitats, which suggests competition between the two species.

5) Abiotic factors such as temperature could be another reason for the difference in use of habitat of different parasitic wasps. *Therophilus unimaculatus* may prefer lower temperatures in the shade of woody vegetation. At the experiment sites, the woody native vegetation surrounding the vineyards had more shading area and the temperature was lower than that in the vineyard.

Overall, the study has shown that the level of parasitism in vineyards is lower than that in adjacent vegetation, and some parasitic wasps are not reaching their full potential as control agents. A change in vineyard management practices may enhance the activity of parasitic insects. *Therophilus unimaculatus* is dominant in native vegetation but less active in vineyards. This species has potential to be managed to enhance biological control of *E. postvittana*.

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88. Effect of brown marmorated stink bug on wine – impact on Pinot Noir quality and threshold determination of taint compound trans-2-decenal

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The brown marmorated stink bug (BMSB) is an invasive pest that originated from East Asia. In the United States it was first observed in Allentown, Pennsylvania in 1996 and is currently found in 38 states. This insect does not only impact grapes but has been found to affect a broad range of horticultural crops. Specifically, BMSB appears to infect crops by migrating from surrounding areas, causing an increase in population in the vineyard. BMSB is a problem for the wine industry as it produces damage to the grapes and can impact wine by being introduced to wine processing through contaminated grape clusters.

The impact of BMSB on wine quality was first evaluated by incorporating BMSB during wine processing. The insects were added to the grapes prior to destemming. Treatments included a control with 0 bugs per cluster, T1 with 1 bug per 4 clusters and T2 with 1 bug per 2 clusters. Standard Pinot Noir winemaking procedures were used. Impact of BMSB on the finished wine was determined using difference testing (triangle tests). Multidimensional gas chromatography (MDGC) was used to determine the taint compounds in the insects and in the finished wine. The detection threshold (DT) of trans-2-decenal was measured using triangle tests and the consumer rejection threshold (CRT) was measured using a paired preference test, both combined with ascending forced choice method of limits. In total 72 panellists (41 females, 31 males) participated in the study. The base wine was a 2010 commercial Pinot Noir. DT and CRT levels ranged from 0.049 - 30 µg/L. Samples were presented in increasing concentration with randomised order.



Figure 1. Gas chromatogram of volatile compounds produced from the brown marmorated stink $\ensuremath{\mathsf{bug}}$

Results show that wines produced by incorporating BMSB (T1 and T2) during processing were significantly different from the control. Therefore the presence of BMSB during wine processing will also have an impact on wine quality. MDGC analysis showed that while BMSB excretes four volatile compounds (trans-2-decenal, trans-2-octenal, dodecane and tetradecane) only trans-2-decenal, dodecane and tetradecane were present in the finished wine. Trans-2-decenal was the only compound with a strong aroma and therefore the main taint compound associated with this insect. The detection threshold for trans-2-decenal in Pinot Noir was found to be 4.95 µg/L and

consumer rejection threshold was found to be 15.5 μ g/L. The wines with trans-2-decenal were described as 'cilantro' and 'green' which is consistent with previous work on this taint. These threshold levels can be useful to wineries and other regulating bodies for establishing control levels for BMSB taint in the vineyard and winery.

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89. Susceptibility of grapevine inflorescences to *Greeneria uvicola* and *Colletotrichum acutatum:* management of bitter rot and ripe rot of grapes with fungicide sprays at flowering

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Bunch rot diseases of grapes can be caused by a range of filamentous fungi. Two such organisms that frequently occur in vineyards prone to warm and wet conditions close to harvest are *Greeneria uvicola* and *Colletotrichum acutatum*, which cause bitter rot and ripe rot respectively. Although these fungi are associated with fruit rots at harvest, previous studies (Steel et al. 2013) indicated that grapevine flowers are also susceptible to infection. The aim of the current study was to confirm this using a combination of light and scanning electron microscopy. A further aim was to investigate potential fungicide sprays that could be used at flowering to limit subsequent bunch rots at berry maturity.

Examination of artificially-inoculated flowers using electron microscopy and by culturing infected material onto artificial media revealed that flowers were infected within 2 and 12 hours post-inoculation for *C. acutatum* and *G. uvicola*, respectively.

A series of fungicides (azoxystrobin, boscalid, captan, chlorothalonil, iprodione, pyraclostrobin, pyrimethanil and trifluoxystrobin) registered for the management of other diseases of grapevines were screened for their ability to inhibit the growth of *C. acutatum* and *G. uvicola* on fungicide-amended agar plates. Pyraclostorbin was found to be the most effective fungicide in this experiment (Figure 1).



Figure 1. Inhibition of *Colletotrichum acutatum* (Ca) and *Greeneria uvicola* (Gu) growth on PDA plates supplemented with different concentrations of Cabrio (active ingredient: pyraclostrobin)

Cabrio (active ingredient: pyraclostrobin) was applied to field grown flowers at mid-flowering (F) and/or at veraison (V) in field trials conducted over three growing seasons. Five days after the fungicide was applied, inflorescences were inoculated with either *G. uvicola* or *C. acutatum*. Subsets of these inflorescences were harvested 24 hours after inoculation and a further subset harvested at veraison and at harvest and the incidence of *G. uvicola* or *C. acutatum* examined. Cabrio applied at flowering and veraison, independently and in combination, significantly reduced the severity of bitter rot and ripe rot over several growing seasons (Figure 2) with the exception of 2011–12 (Figure 2c). Due to climatic conditions there was a higher than normal disease pressure in the 2011–12 growing season which may explain this lower efficacy.



Figure 2. Effect of Cabrio on (a) ripe rot (2009–12), (b) bitter rot (2009–11) and (c) bitter rot (2011–12) severity. Results are presented as the mean values over the term of the project with the exception of the data for bitter rot in the 2011/12 season. F = flowering, V = veraison

Management of bunch rot diseases of grapes relies on a combination of chemical sprays and vineyard management practices to limit disease incidence. One limiting factor in the use of fungicide sprays is limited availability of chemicals that can be applied to wine-grapes destined for the export market. Our studies demonstrate that an application of Cabrio at flowering has the potential to limit ripe rot and bitter rot of grapes at harvest.

Reference

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90. Population dynamics of grape berry microflora during different stages of berry development

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The microbial ecosystem on the surface of grape berries is complex and consists of yeasts, filamentous fungi and bacteria (Setati et al. 2012). These microorganisms play a pivotal role in pre- and postharvest grape quality and contribute significantly to the final aromatic properties of the wine. The stage of grape berry development has great influence on the population dynamics of each microbial species (Barata et al. 2011). Microbial populations peak at harvest when the berry surface available for adhesion is largest and no agrochemical treatments have been applied for some weeks (Renouf et al. 2005).

This study was conducted to evaluate the population dynamics of filamentous fungi, yeasts, acetic acid bacteria (AAB), lactic acid bacteria (LAB) and miscellaneous bacteria during different stages of berry development. Two Chardonnay vineyards (vineyard 1 and vineyard 2) were selected in Tumbarumba (NSW) and berries were collected when immature, at pre-veraison and at maturity during the 2011–2012 vintage to evaluate the berry microflora. Filamentous fungi, yeasts and bacteria were isolated using non-destructive berry washings.

Among the filamentous fungi, *Alternaria, Aspergillus, Cladosporium, Epicoccum* spp. and *Botrytis cinerea* were predominant. Vineyard 2 had greater populations of *Aureobasidium* and *Epicoccum* and lower *B. cinerea* incidence (Figure 1). The lower *B. cinerea* incidence may be due to the presence of higher populations of *Epicoccum* and *Aureobasidium*, two organisms with potential biocontrol properties. There was a significant difference between the yeast populations on pre-veraison berries (P = <0.05) for the two vineyards although this difference was not apparent at harvest. The total number of yeast isolated increased from the immature berry stage to harvest. There was no significant difference in the total numbers of miscellaneous bacteria, lactic acid bacteria and acetic acid bacteria for the two vineyards.



Figure 1. Filamentous fungi isolated from Chardonnay at different stages of berry development. A: Alternaria spp.; B: Cladosporium spp.; C: Botrytis cinerea; D: Epicoccum spp.; E: Aureobasidium spp.

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91. Resistant rootstocks – making the right choice to protect against endemic strains of grapevine phylloxera

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Introduction

In Australia, grapevine phylloxera is currently restricted to phylloxera infested zones (PIZs) located in NSW and Victoria. Despite the relative success of quarantine protocols and boundaries, phylloxera remains a threat to an industry that is predominantly planted on susceptible ungrafted *Vitis vinifera* L. Recent phylloxera outbreaks in Victoria, outside existing PIZs, highlight that quarantine alone is not completely effective and rootstocks need to be selected which are effective against a range of endemic phylloxera strains. In Australia to-date 83 genetically different grapevine phylloxera strains have been identified (Powell 2008) which vary in their geospatial distribution on both ungrafted and grafted *V. vinifera*. Some strains such as G1 are relatively widely distributed and found in all PIZs while others (including G4, G7, G19, G20 and G30) have only been detected in a single PIZ.

Methods

An assessment of phylloxera development and root response to phylloxera feeding on ten *Vitis* rootstocks has been made under both laboratory and glasshouse conditions using six selected genetically diverse grape phylloxera strains (Powell 2012a). In replicated trials these strains were contained either in petri dishes on excised roots or in mesh enclosures around the roots of potted grapevines, which allowed an assessment of damage to mature lignified roots and quantification of individual life stages. Based on these assessments rootstocks were classed as resistant, tolerant or susceptible.

Results

In screening tests genetically different endemic phylloxera strains differed in population survival and development on both ungrafted V. vinifera and grafted rootstock hybrids. In addition root damage levels differed between phylloxera strains and rootstocks. A summary of 'genotype-specific' rootstock resistance ratings, based on laboratory and glasshouse screening conducted to date, for phylloxera resistance is presented. Results indicate that in some cases rootstock ratings based on in vitro (Table 1) and in planta (Table 2) screening are the same (e.g. in both trial types Schwarzmann, 5BB Kober and 3309C are resistant to G1 and G4 and only tolerant to G7, G19, G20 and G30; whilst Ramsey is only tolerant to all six phylloxera strains and tuberosity-like structures were observed on roots) whereas for other rootstocks there are some differences (e.g. Börner, 101-14). The rootstocks Ramsey, 140 Ruggeri, 103 Paulsen and 101-14 are predominantly used in Australia (Whiting 2012), yet their resistance/tolerance is dependent on phylloxera strain. This highlights the importance of using a two-tiered screening system in order to base resistance ratings on results obtained from a combination of the methods.

Conclusions

Although currently endemic strains of grape phylloxera in Australia are not widely distributed, the potential for a change in their geographic distribution as grapevine distribution changes due to climate change (particularly temperature changes) (Powell 2008) and the risk of rootstock breakdown is omnipresent (Powell 2012b). It is therefore very important to match the rootstock with the phylloxera strain. These results highlight the need for further studies focusing on the genetic basis for resistance using a genomic approach (Delmotte et al. 2011) whilst still continuing the screening of both conventional and novel rootstock hybrids against selected endemic phylloxera strains to ensure that the Australian viticulture industry is protected from this highly destructive insect pest.

 Table 1. Summary of overall rankings of ten rootstocks for resistance, tolerance and susceptibility based solely on *in vitro* excised root screening under laboratory conditions

Genotype	G1	G4	G7	G19	G20	G30
Vitis vinifera	S	S	S	S	S	S
Ramsey	т	т	т	т	т	т
Schwarzmann	R	R	т	т	т	т
Börner	R	R	т	R	R	т
110 Richter	т	т	т	т	т	т
1103 Paulsen	т	R	R	т	R	R
140 Ruggeri	т	т	R	R	R	R
5BB Kober	R	R	т	т	т	т
420A	R	R*	R	R*	R	R*
3309C	R*	R*	т	т	т	т
101–14	R	R*	т	R	R	R

S= susceptible, T = tolerant, R^* = partial resistance (insects survive up to eight weeks but do not produce eggs) and R = resistant; red = resistant, green = susceptible and yellow = tolerant.

Table 2. Summary of overall rankings of ten rootstocks for resistance, tolerance and susceptibility based solely on *in planta* screening under glasshouse conditions

Genotype	G1	G4	G7	G19	G20	G30
Vitis vinifera	S	S	S	S	S	S
Ramsey	т	т	т	т	т	т
Schwarzmann	R	R	т	т	т	т
Börner	R	R	R	R	R	R
110 Richter	т	т	R	R	т	R
1103 Paulsen	т	R	R	т	R	R
140 Ruggeri	R	т	R	R	R	R
5BB Kober	R	R	т	т	т	т
420A	т	R	R	т	т	R
3309C	R	R	т	т	т	т
101–14	R	R	R	R	т	R

S= susceptible, T = tolerant, and R = resistant; red = resistant, green = susceptible and yellow = tolerant.

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92. Bacterial inflorescence rot – a costly problem in some cool regions

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A recently identified bacterial pathogen, *Pseudomonas syringae* pv. syringae (Pss) causes grapevine inflorescences (young bunches) to rot and fall off early in the season. Pss has caused up to 80% crop loss in the Tumbarumba region. This pathogen prefers cool and moist conditions so it is mostly a problem in cool wine regions with moist humid springs. Many cool regions use overhead sprinklers to protect the vines from frost damage in spring, and this unintentionally creates microclimates in which Pss thrives. Phylogenetic studies show that the Tumbarumba Pss is more closely related to isolates from the Adelaide Hills from early 2000 than it is to isolates from apples in nearby Batlow, indicating that it may have been spread by the movement of diseased planting material. We are trialling control measures via root drench and trunk injection. Our preliminary results show that some treatments can decrease bunch loss.

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Whitelaw-Weckert, M.A.; Whitelaw, E.S.; Rogiers, S.Y.; Quirk, L.; Clark, A.C.; Huang, C.X. (2011) Bacterial inflorescence rot of grapevine caused by *Pseudomonas syringae* pv. syringae. Plant Pathol. 60: 325–357.

93. 'Bot' fungi (from rootstock source plants) and black-foot fungi (from nursery soil) can infect grapevines during propagation, causing young vine decline

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Decline of newly planted, grafted grapevines is a serious viticultural problem worldwide. A survey of Riverina grapegrowers showed that over 65% of vineyards were affected by young vine decline. We isolated black-foot disease fungi (*Ilyonectria macrodidyma* or *Ilyonectria liriodendri*) and 'Bot' fungi of the Botryosphaeriaceae family from rootstocks of 100% and 95% respectively of young diseased grapevines in 20 diseased Riverina vineyards. The Petri disease fungi (*Togninia minima* and *Phaeomoniella chlamydospora*) were less commonly isolated from the rootstocks of diseased plants, although they probably contribute to the decline of surviving grapevines as they age. All rootstock stems of grafted plants surveyed in one nursery were infected with both black-foot disease fungi and

'Bot' fungi. Black-foot disease fungi were isolated from the nursery soil and 'Bot' fungi were isolated from 25% of the Ramsey canes sampled from the rootstock source block. This study shows that 'Bot' fungi from rootstock cuttings and black-foot fungi from nursery soil causes decline of young, grafted grapevines in the Riverina. Grapevine rootstock source plants are particularly susceptible to 'Bot' infection because the shoots are usually pruned close to the trunk and so expose it to wound infection. Correctly applied hot water treatment of rootstock cuttings is known to control the 'Bot' fungi and fungicides may be used to control re-infection through trimming, disbudding and grafting wounds involved in subsequent propagation. However infection of young, grafted cuttings by black-foot fungi can only be prevented by use of non-contaminated nursery soil.

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94. Disinfest the pest! There are many ways to protect against the spread of grapevine phylloxera

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Introduction

Grapevine phylloxera, particularly root-feeding genetic strains, remains a constant threat to the viability of the Australian viticulture industry which predominantly uses phylloxera-susceptible *Vitis vinifera* L. In spring and summer when phylloxera is most active, phylloxera life-stages (particularly the 'crawler' or first instar lifestage) can be inadvertently spread on clothing, footwear, harvested grapes, planting material, grape products, soil, viticultural machinery and equipment (Korosi et al. 2009). Crawlers can also survive some post-harvesting procedures including crushing, destemming (Deretic et al. 2003) and cold storage. Because phylloxera is asexual, a single crawler can start a new infestation. Genetically different phylloxera strains are known to differ in their virulence levels under field conditions and the insects' survival is affected by temperature and humidity.

Methods

To protect uninfested vineyards from incursions of endemic phylloxera strains and reduce the risk of spread within infested vineyards, a variety of disinfestation protocols have been developed (NVHSC 2009). These protocols primarily focus on the use of heat, chemical and immersion treatments. Scientific validation procedures have been developed, including environmental (bioassay method 1) and immersion (bioassay method 2) chambers, and tested against some disinfestation protocols using selected phylloxera strains.

Results

Using bioassay method 1, the effect of dry heat and humidity has been tested against G1 and G4 phylloxera strains; differences in survival of the two strains were observed (Korosi et al. 2012). Using bioassay method 2, G4 phylloxera survival was assessed at low temperatures (2°C, 5°C and 10°C) and in a range of solutions including Chardonnay juice, sugar solution, acidic pH, dissolved sulfur and water. G4 phylloxera survival was affected by both temperature and liquid type (Powell 2012). In general, the lower the temperature, the shorter the survival. Phylloxera could survive immersed in water for a maximum of 21 days at 10°C compared with 9 days at \leq 5°C. Both

sugar concentration and white juice reduced survival compared to water. The presence of sulfur and acidic pH had minimal impact on survival (Powell 2012).

Conclusions

Bioassay methods have been developed to enable scientific validation of national disinfestation protocols, to reduce the risk of quarantine breakdown. Most protocols have not yet been tested against the key endemic strains present in Australia and it is essential to do this. Preliminary studies indicate that it is important to validate the protocols against a genetically diverse range of grape phylloxera strains to ensure their efficacy and also develop new disinfestation protocols where knowledge gaps may exist. Further scientific validation may be conducted as part of an ongoing research program on phylloxera management.

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95. Wine industry bio-protection: early detection of grape phylloxera (*Daktulosphaira vitifoliae* Fitch) infestation by LC-MS-based metabolomics methods

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Grape phylloxera is an invasive sap-sucking insect native to the north-eastern United States. Its incursion into most major viticultural centres in the world over the past 200 years has caused significant economic and physical damage to affected vineyards. Late detections of the insect cause significant economic damage to affected vineyards, with replanting onto phylloxera-resistant rootstocks costing AUD \$20,000 - \$25,000 per hectare.

Metabolomics offers a new and exciting approach for the early diagnosis of phylloxera infestation. Studies of leaf material obtained from field studies in the Yarra Valley, Victoria, indicated that there were metabolic differences between non-infested and infested vines. Analysis suggested that certain flavonols, as well as other, as yet unidentified, metabolites could be useful biomarkers of phylloxera infestation.

This liquid chromatography-mass spectrometry (LC-MS)-based study assessed the shifts in detectable metabolite profiles in grape phylloxera-infested grapevine leaves (Shiraz BVRC30) relative to uninfested controls. The experiment was conducted under glasshouse conditions over a ten-week period. Statistical analysis of the data set by principal component analysis (PCA) showed clear separation between treatments at six weeks post-inoculation with three compounds identified as down-regulated in infested grapevines. This provides further strong evidence supporting the continued development of biochemical detection methods in grape phylloxera research. Early detection of grape phylloxera is critical for the continued sustainability and profitability of the international viticultural industry.

96. Comparison of methods for quantification of *Botrytis* bunch rot in white wine-grape varieties

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Botrytis bunch rot (BBR), caused by the fungus Botrytis cinerea, is one of the most economically damaging diseases in wine-grapes in Australia and New Zealand. Although quantification of BBR is important for both grapegrowers and winemakers, the widely used visual estimation method for assessing BBR is time consuming and can be highly subjective. Various quantification methods were compared with the visual estimation method using naturally infected white wine-grape bunches. These methods included near-infrared spectroscopy (NIR), mid-infrared spectroscopy (MIR), quantitative PCR (qPCR) and image analysis software (RotBot). All quantification methods correlated well with visual estimation and each had advantages and disadvantages. The scanning of samples using NIR and MIR was quick and highly sensitive. Sample preparation for these methods was less labour intensive than the DNA extractions required for qPCR. Running the qPCR reaction also took longer than NIR and MIR scanning. One advantage of qPCR is that it quantifies B. cinerea DNA, which is directly related to fungal mass. It is unclear what NIR or MIR is quantifying and the relationship with BBR is purely empirical. The RotBot method required no sample preparation or expensive equipment and the software was able to batch-process images rapidly. However, this method only quantifies visible BBR symptoms. All methods tested were found to be reliable, accurate and objective alternatives to the visual estimation method. The choice of method would depend on the intended purpose and whether the additional time needed to achieve higher accuracy is justified.

97. Pathogenicity of Botryosphaeriaceous fungi isolated from grapevines in south-eastern Australia

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Botryosphaeria dieback of grapevines arises when Botryosphaeriaceous fungi infect vines via pruning and reworking wounds or other exposed surfaces. Symptoms include cankers, shoot and branch dieback, wedge shaped lesions in the trunks and cordons of infected vines, and a lack of vegetative growth (Pitt et al. 2010). In this study, the temperature-growth relationships and pathogenicity under field conditions of eight Botryosphaeriaceae species isolated from grapevines in south-eastern Australia were determined. Chardonnay grapevines were inoculated 30 cm below the crown with Botryosphaeriaceous fungi: *Botryosphaeria dothidea*, *Diplodia mutila*, *Diplodia seriata*, *Dothiorella iberica*, *Dothiorella viticola*, *Lasiodiplodia theobromae*, *Neofusicoccum australe* and *Neofusicoccum parvum*. Sterile potato dextrose agar (PDA) plugs acted as controls. Two years after inoculation, trunks were sectioned longitudinally in half through the point of inoculation. Lesion lengths were measured and compared among species via ANOVA and Tukey's test (P=0.05). Growth rates were also determined for each species at 5, 10, 15, 20, 25, 30, 35 and 40°C. Regression curves were fitted to values of daily growth rate (mm/day on PDA) versus temperature and optimum growth temperatures for each species were estimated based on a third order polynomial (Sanchez et al. 2003).

All eight Botryosphaeriaceae species were pathogenic to grapevines and produced lesions from which fungi were re-isolated. Lesion lengths ranged from 76 mm for *D. seriata* to 165 mm for *N. parvum* but differed depending on species (Figure 1).



Figure 1. Mean lesion lengths caused by Botryosphaeriaceous fungi on Chardonnay grapevines two years after inoculation. Means followed by the same letters are not significantly different according to Tukey's test (P=0.05). Bars represent the 95% confidence interval of the mean.

Botryosphaeriaceous fungi grew over a range of temperatures from 5 to 40°C (Figure 2). *Diplodia* and *Neofusicoccum* spp. grew optimally between 25 and 27°C, and were the most prevalent and widely distributed species isolated in surveys of south-eastern Australia. In contrast, *L. theobromae* and *B. dothidea* grew optimally at close to 30°C, and were isolated predominantly from grapevines grown in the hotter, dryer regions, while *Dothiorella* spp., with ideal temperatures between 22 and 24°C, were most commonly isolated from grapevines in cooler climates (Pitt et al. 2010).



Figure 2. Temperature–growth relationships and estimated optimal growth temperatures of Botryosphaeriaceous fungi used in pathogenicity studies

Management strategies for Botryosphaeria dieback currently rely on remedial surgery to remove infected wood and inoculum sources from the vineyard and the use of fungicides and paints to protect pruning wounds from infection (Urbez-Torres 2011). In addition to their pathogenicity, greater knowledge of the epidemiology of these fungi including their prevalence and distribution is likely to improve efforts to develop more effective control strategies.

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98. Isolation and identification of entomopathogenic fungi from vineyard soil

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Introduction

Biological control agents are natural enemies of agricultural pests and include invertebrates and entomopathogenic fungi. Around the world entomopathogenic fungi occur naturally as parasites of insects and arachnids. Fungal propagules can survive in soil and in some cases even within plants as endophytes. Entomopathogens are generalist pathogens, causing mortality to a broad range of insect hosts, making them suitable for extensive investigations as biological control agents of insect pests. In this preliminary study, the presence of two entomopathogenic fungi (*Metarhizium* spp. and *Beauveria* spp.) in an Australian vineyard was assessed.

Materials and methods

Thirty soil samples were collected from a 2.6 ha Cabernet Sauvignon block at the Charles Sturt University vineyard in Wagga Wagga, using an even distribution pattern to cover the whole block. The samples were taken at every 21st vine in every 8th row from under the nearest dripper adjacent to the selected vine. From each sampling point the top 5 cm of soil was discarded and approximately 300 g of soil between 5 and 10 cm depth was collected. The shovel was disinfested using 100% ethanol between each sampling point.

Fungi were isolated using a soil suspension on selective media method. One gram of soil was diluted in 10 mL of water, and then diluted in series from 10^{-1} to 10^{-5} . One millilitre of each of these suspensions was plated on selective Sabouraud Dextrose Agar media (SDA). After 4 days at 20°C the plates were inspected and if either *Metarhizium* spp. or *Beauveria* spp. were observed those colonies were re-plated on new SDA plates so that each plate would only contain a single fungus colony. The isolated fungi were visually identified as either *Metarhizium* spp. or *Beauveria* spp.

Results

In 3 of the 30 soil samples either *Metarhizium* spp. or *Beauveria* spp. were identified. Two samples only contained *Beauveria* spp. and one sample only *Metarhizium* spp.

Conclusion and future studies

Our targeted soil survey focused on two species of entomopathogenic fungi, namely *Metarhizium* spp. and *Beauveria* spp., the two most commonly used biological control agents of insect pests. We found both of these species in the first vineyard surveyed. In the future, additional vineyards will be surveyed and selected isolates will be tested to determine their efficacy against economically-important viticultural insect pests in Australia.

99. The effect of organic, biodynamic and conventional vineyard management inputs on growth and susceptibility of grapevines to powdery mildew

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Given favourable environmental conditions, powdery mildew can cause crop loss or taint wines. Consequently, there is a general reliance in the wine-grape industry on sulfur and synthetic fungicide sprays to control disease (Emmett et al. 1992; Crisp et al. 2006). Organic and biodynamic management systems offer alternatives to conventional practices (Steiner 1924; Proctor and Cole 1997). However, in the absence of clear scientific evidence, scepticism remains amongst many growers as to the potential benefits that the alternative inputs may offer. Although research on organic systems is being conducted and published, few papers report research on biodynamic viticulture, particularly disease management. To investigate the efficacy of biodynamic inputs, this study compared organic (OG), conventional (CV) and biodynamic (BD) management strategies with a water control (CON) for powdery mildew (PM).

An outdoor field trial on potted Chardonnay and Shiraz vines (*Vitis vinifera* L.) was established in 2010 at the Waite Campus. Appropriate fungicide spray regimes were based on industry standards and nutritional inputs suitable for each system were identified (Table 1). Eight treatments, two OG, two BD, three CV and one CON, were randomly allocated and applied in a split plot design, replicated in three blocks, on three vines per treatment, to both cultivars (Figure 1).

Table 1. Organic, biodynamic and conventional treatments

System	Code	Treatments	Nutrition Regimes
		Powdery mildew	Compost to all treatments
Control	CON	Water	Scotts Osmocote®
Conventional 1	CV1	Sulfur only	Complete D®
Conventional 2	CV2	Synthetic and Sulfur rotation	
Conventional 3	CV3	Sulfur only	
Organic 1	OG1	Potassium bicarbonate/ Botanical oil	Neutrog® Rapid Raiser'®
Organic 2	OG2	Full cream bovine milk/ Seaweed extract	
Biodynamic 1	BD1	Sulfur	BD compost preparations 502-507
		2 x 4 x 508 (Equisetum extract)	Manure concentrate ²
Biodynamic 2	BD2	2 x 4 x 508 (Equisetum extract)	Horn Manure: Preparation 500 Combined Soil Spray ¹

¹Horn Manure, barrel compost, winter horn clay, fermented equisetum 508 ²Cow manure' BD Preparations 502-507, rock basalt, eggshells

_		Panel	1	2	3	4	5	6	7	8
Block	Row	Cultivar				Treat	ments			
1	1	CHA	CV2	BD2	CON	OG1	C3	OG2	BD1	CV1
	2	SHI	CV2	BD2	CON	OG1	С3	OG2	BD1	CV1
2	3	CHA	BD2	CV3	OG1	CV1	OG2	CV2	CON	BD1
	4	SHI	BD2	CV3	OG1	CV1	OG2	CV2	CON	BD1
3	5	CHA	BD2	OG1	CV1	CV3	CV2	CON	OG2	BD1
	6	SHI	BD2	OG1	CV1	CV3	CV2	CON	OG2	BD1

 $\ensuremath{\mbox{Figure 1.}}$ Field trial, split plot design, replicated in three blocks, on three vines per treatment

Treatments were applied via individual spray packs in an isolation tent. PM incidence and severity were assessed over three seasons. Vegetative (two seasons) and reproductive (one season) measures were recorded to assess the effect of treatments on growth. Nutritional status was determined using petiole analysis.

In the wet and humid conditions of 2010/11, disease was severe across cultivars and treatments. Early in 2011/12, all treatments were effective in controlling disease (Figures 2, 3). From January onwards two treatments, OG1 and BD1, provided control of PM comparable with all CV treatments (Figures 2, 3). In the drier 2012/13 season, mean PM severity was low and there were no significant differences among treatments. In seasons 2011/12 and 2012/13, physiological measures of CV-grown vines were significantly different from those of OG and BD (Figure 4). In the 2012/13 season, yield parameters in CV treatments were significantly higher than OG and BD. Generally, BD and OG vines were significantly smaller and less productive than the CV vines.

While not always as effective as CV programs, some OG and BD materials used in this trial reduced PM as effectively as chemical treatments. BD materials may have potential for inclusion in disease management. Vine balance and productivity were affected by nutritional status resulting from the various treatments. There is a need for further experiments on mature vines in commercial vineyards to assess the effects of these treatments in industry.



Figure 2. Combined mean effect of treatments on powdery mildew on Shiraz leaves 2011/12. E-L: 31 Pea-size; 35 Veraison; 41 Post-harvest



Figure 3. Combined mean effect of treatments on powdery mildew on Chardonnay leaves 2011/12. E-L: 31 Pea-size, 35 Veraison, 41 Post-harvest



Figure 4. Combined mean effect of treatments on vegetative growth



Figure 5. Combined mean effect of treatments on pruning and harvest weights

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100. Consistency of fungicide deposition and stability concentration of the spray mix using a recycling vineyard sprayer

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The FMR SP2300R sprayer (otherwise known as FMR R-Series) has been designed to contribute to New Zealand's commitment to sustainable agriculture and environmental protection by recycling undeposited spray solution back into the tank during a spray application. Over the course of a spray run, the sprayer can cover a larger area before the tank needs to be refilled. The efficacy of the FMR R-Series at controlling *Botrytis* bunch rot is critical, as it is an important fungal disease from veraison to harvest that is detrimental to grape and wine quality. The aims of this study were:

- 1. To evaluate spray deposition concentrations on leaves in the fruit zone
- 2. To determine active ingredient concentrations of the botryticide in the tank during the course of a spray application
- 3. To monitor the incidence and severity of *Botrytis* bunch rot from veraison to harvest.

Using the FMR R-Series, 800 g/ha of Switch^{*} was applied at 80% flowering and pre-bunch-closure (PBC) to a block of mass selected Sauvignon Blanc on 3309 rootstock, in Marlborough, New Zealand.

During both applications, samples of the spray solution from the FMR R-Series' tank were taken during the course of a spray run at the end of specific rows, to analyse for cyprodinil and fludioxinil concentrations, the active ingredients in Switch*.

Before spraying, leaves were collected to obtain background concentrations of the active ingredients. After each spray application, leaves from targeted bays were collected to assay for amounts of deposited fungicide. Water sensitive papers (WSP) were used to assess spray deposition coverage.

Visual field assessments of the incidence and severity of *Botrytis* bunch rot were carried out from veraison to harvest using the Beresford et al. (2006) methodology (full methodology: Raw et al. 2012).



Figure 1. Leaf concentration of residues of two active ingredients in Switch[®] across a block of Sauvignon Blanc prior to and after 80% flowering and pre-bunch-closure spray applications by the FMR SP2300R sprayer

Before spraying, the leaves exhibited low concentrations of cyprodinil and fludioxinil. The sprayer targeted the fruit zone across the block, resulting in greater residues being detected on the leaves in that zone. Concentrations were greater after the PBC application, as the water rate was decreased from 400 L/ha at 80% flowering to 200 L/ha at PBC. Recycling the spray during application did not cause a dilution or a concentration effect of either fludioxinil or cyprodinil at either spray timing (Figure 1). The agrochemical residues remained at a constant concentration indicating that there was no change in the quantities of active ingredients reaching the target surface.

The use of WSP showed that there was 80% 'adequate to excellent' spray coverage both on the exterior and interior of the fruit zone.

At 80% flowering, no differences in concentrations in the samples from the sprayer tank were found, demonstrating that both active ingredients remained constant, close to the estimated targeted rates. At PBC, cyprodinil and fludioxinil expressed some variation across the rows. These amounts did not systemically diminish as the FMR R-Series moved across the rows (full results: Raw et al. 2012).

The visual assessments showed that there was effective control of *Botrytis* when Switch[®] was used in the FMR R-Series sprayer. The severity of *Botrytis* bunch rot reached a maximum of 0.81% at the final harvest assessment.

The application of Switch[®] using the FMR R-Series sprayer was effective in delivering a consistent amount of active ingredients to the target areas at both 80% flowering and PBC. The concentrations of active ingredients in the spray tank did not change as a result of the recycling process. *Botrytis* bunch rot was effectively controlled.

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PHENOLICS IN RED WINE

101. 'Cutting Edge Pinot' – reducing skin particle size early in fermentation is the key

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Pinot Noir is known to have thin skins and low concentrations of skin tannin relative to other red wine varieties. However the seeds compensate for this shortfall by having 50 times (w/w) higher tannin concentration than the skins. During winemaking the two tannin types compete for binding sites with the coloured pigments. However at high concentration, seed tannins tend to compromise both the taste and the colour stability of the wine.

In order to improve the quality of Pinot Noir we investigated how to extract more tannin from the skin to compete with the seed tannin. This was done by cutting the skins early in the fermentation, reducing the skin particle size to 10% of its original size and thereby allowing tannin and pigment to diffuse from the cut skin edges more rapidly. Using a micro-vinification technique (Smart et al. 2012) the procedure was imposed the day after inoculation, when the seeds were at their most robust and easily dispersed out of the way of the moving cutting blades. The phenolic composition of the wine was determined by spectral analysis at bottling and at six months' bottle age (Mercurio et al. 2007).



Figure 1. Phenolic characteristics of wine in which grape skins had been cut during fermentation. Wines (mean n=4) were analysed at bottling and six months' bottle age. (a) Total Tannin (P<0. 001); (b) Non-bleachable pigment (P=0.009); (c) Colour Density (P=0.002). D = days after inoculation

At bottling, there was a significant increase in total tannin, pigmented tannin and colour density of the treated wines. After six months in bottle, the total amount of tannin in 'Cutting Edge' Pinot Noir wines was 73% higher the control wines in which the skins were not cut. Pigmented tannin was 40% higher and the colour density was 31% higher relative to the control wines (Figure 1).

This procedure has beneficial implications for colour stability in lightly pigmented red wines. It may replace traditional methods such as cold-soaking of must before fermentation and extended maceration post-fermentation, thereby increasing winery throughput.

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102. Wine quality vs seediness: differential extraction of skin and seed tannins

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Exogenous tannins can be added to grape must to improve the structure and colour of wine. *Vitis vinifera* cv. Pinot Noir is an exceptional variety for which such additions may disturb the delicate balance between skin and seed tannins. Differentiating the tannin source is vital to the formation of stable colour and texture components in the wine. We report on the formation of non-bleachable pigments (pigment and pigmented-tannin complexes) in the presence or absence of excess seed tannin.

Three micro-vinification trials were conducted: the first trial compared wine made from a seeded clone with a seedless clone; the second compared the addition of fermented grape seeds with the addition of commercially available grape seed tannin; and the third examined the effect of removing seeds from the fermenting must.



Figure 1. Non-bleachable pigment content of Pinot Noir wines made from must with modified seed components. Wines (mean n=4) were analysed at bottling and six months' bottle age. (a) Seeded versus seedless clone (P<0. 001); (b) Additional source of seed tannin (P=0.009); (c) Seeds partially removed (P=0.27)

Wine made from a seedless clone of Pinot Noir was 2.4 times higher in non-bleachable pigments than the seeded clone. Wine made from ferments to which exogenous seed tannin was added had 30% less non-bleachable pigments than the control wine (Figure 1 b), while the effect of removing seeds was not significant. These results may be caused by competition between small seed tannin oligomers and larger skin tannin polymers to form pigmented tannin complexes with anthocyanin. The larger pigmented tannins are more stable than those derived from seed tannin, making them less prone to oxidation.

We conclude that the addition of exogenous sources of seed tannin to Pinot Noir ferments may be detrimental to the ageing potential of the wine.

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103. Waste not, want not: winery waste may be recycled to improve wine quality

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Pinot Noir is an exceptional variety with a dedicated following of enthusiastic consumers. The variety is one in which the ratio of seed to skin tannin is higher than other red wine varieties. This can compromise the quality and ageing potential of the wine. The tannin balance can be manipulated by the addition of exogenous tannins; in particular this report examines sources of skin tannin. While commercial skin tannin extracts are available, the pomace from white and sparkling wine production and fermented red grape marc each contain skin and seed tannin and are normally discarded by wineries. Might this material be recycled?

Using micro-vinification techniques, the phenolic composition of wines made from must to which either pomace or skins of Pinot Noir, Pinot Gris or Chardonnay grapes were added, was compared with that of musts to which Pinot Noir marc or fermented Pinot skins were added.



Figure 1. Non-bleachable pigment content and colour density of Pinot Noir wines made from must with pomace or skin additions. Wines (mean n=4) were analysed at bottling and 6 months' bottle age. (a) Pinot Noir (PN) with added grape pomace: PN, Pinot Gris (PG) or Chardonnay (CH); (b) PN with added grape skins: PN, PG or CH; (c) PN with added PN grape skins (fresh or fermented).

We found that the addition of skins alone was far more effective than the addition of pomace or marc containing seeds. At six months' bottle age the addition of 20% extra fresh skins of Pinot Noir or Pinot Gris, increased the stable non-bleachable pigment content of the wine by more than 15%. The addition of Pinot Noir skins from an extra 20% of fermented Pinot Noir berries increased the colour density by more than 12% and stable pigmented tannin content of the wine by more than 18%.

These preliminary research findings may open the way to further investigations on the use of winery waste to supplement the skin tannin content of Pinot Noir wines.

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104. Ever reliable Chardonnay?: co-fermentation of Pinot Noir must with Chardonnay pomace compromises colour stability

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The pomace from white grapes is usually discarded when the fruit is crushed. This pomace is a ready source of tannin. It may be used to supplement tannin shortfalls in other wines - even red wine - however, there are precautions. Using a micro-vinification technique we chose Chardonnay pomace as our additional source of tannin for Pinot Noir wines and co-fermented Chardonnay pomace 20% (w/w) with Pinot Noir must. The phenolic composition of the wine was determined by spectral analysis at bottling and at six months' bottle age.



Figure 1. Phenolic characteristics of wine from co-fermentation of Pinot Noir must with 20% Chardonnay pomace. Wines (mean n=4) were analysed at bottling and six months' bottle age. (a) Total tannin (P= 0.001); (b) Pigmented tannin (P<0.001); (c) Colour density (P<0.001)

At bottling we found that the 20% (w/w) addition of fresh, cool stored or frozen Chardonnay pomace to Pinot Noir must resulted in an average increase of 20% in total tannin content with no detriment to the colour density or the stable pigmented content of the wine. However at 6 months' bottle age, while the tannin content of the Pinot/Chardonnay co-fermented wine remained 14% higher than control Pinot Noir wines, the pigmented tannin content of the wine declined by 10–20%. The Chardonnay pomace which had been stored frozen and then thawed had the most severe effect on pigmented tannin and also reduced the colour density by 10%. This is most likely due to physical damage of berry tissues promoting tannin release.

We conclude that the addition of Chardonnay pomace to Pinot Noir ferments has short-term benefits but may be detrimental to the ageing potential of the wine.

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105. Addition of oenological tannins at the beginning of Pinot Noir maceration – impact on colour stabilisation

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When colour is a problem in the production of red wine, oenological tannins are an effective tool to help fix and stabilise colour. It is imperative to promote extraction of anthocyanins early in the alcoholic fermentation and there must be enough condensed tannins present to facilitate binding with the free anthocyanins. The earlier the bound anthocyanins are formed, the higher the colour intensity will be and a higher level of colour stability will be achieved.

All analyses conducted on this Pinot Noir Pommard clone sourced from River West vineyard unanimously demonstrate that of the commercial tannins investigated, 'trū/tan f²' tannins had the highest impact on colour fixation and stabilisation, even at lower dose rates. The percentage changes in free anthocyanins and bound anthocyanins and overall colour analysis showed that the most significant results can be achieved using this product. Therefore, we recommend the use of 'trū/tan f²' tannins at the beginning of alcoholic fermentation at a dose rate of 10 to 20 g/hL to promote the formation of bound anthocyanins that fix and stabilise red colour.

It is also relevant to note that untoasted French oak powder performed moderately well in this scenario and consequently continues to serve as a viable option. However, it will take longer to extract the tannins and must be applied at a high dose rate to have a significant impact. In this experiment, untoasted French oak powder was applied at 5 g/L with the goal of achieving a similar tannin impact to oenological tannins. Yet it is understood that any dosage exceeding 3 g/L will impart oak aromatics, including potential woody notes. If additional oak impact is not expected or desired, oenological tannins remain the ideal choice to contribute tannin without imparting oak aromatics.

As a final point, the experiment confirmed that adding condensed tannin (different from hydrolysable oak tannin) did not have a positive effect on colour stability. These results indicate there is already a sufficient amount of condensed tannin present in the grapes, and when extracted properly, enough condensed tannin is already available in solution to fix colour without additional input.

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106. Microwave maceration of Pinot Noir: phenolically equivalent, aromatically distinct

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Approximately 40% of Pinot Noir grape must is grape solids which are pressed off as marc, post-fermentation. Microwave maceration is a new method which has proven effective for rapid phenolic extraction (Carew et al. 2013). Rapid phenolic extraction by microwave maceration with press-off prior to alcoholic fermentation offers an alternative to alcoholic fermentation of Pinot Noir on pomace.

In this independently replicated trial, 1 kg lots of Pinot Noir grape must were microwave-macerated and one set of replicates was pressed off after approximately three hours' total contact time. Control (ctl), microwaved must with pomace (msk) and pressed off juice from microwave maceration must (mpr) were inoculated for alcoholic fermentation. All three treatments were fermented for seven days and wine phenolics were analysed by UV-visible spectrophotometry. Non-targeted profiling analysis of volatile aroma compounds in wines was carried out by gas chromatography-mass spectrometry (GC-MS).

Analysis of wines at 210 days post-harvest (six months' bottle age) showed that pressed-off microwave macerated wines (mpr) were equivalent to control wines for mean concentration of: total phenolics, total pigment, anthocyanin, total tannin, colour density and hue, and higher in mean pigmented tannin than control wines (0.46AU and 0.31AU, respectively). Microwave maceration wines fermented on skins (msk) were higher than control wines for all phenolic parameters apart from hue and anthocyanin.

Principal component analysis (PCA) of GC-MS response ratio for volatile aroma compounds at 320 days post-harvest (10 months' bottle age) showed that control (ctl) and microwave on skins (msk) wines were distinct from early press-off microwave wines (mpr). Eighty percent of the separation was explained by PC1. Loadings analysis indicated that separation on PC1 was driven by concentration of: 2&3-methylbutanol ('nail polish' aroma), 2-methylpropanol ('fusel', 'spiritous' aroma) and ethyl octanoate ('red cherry', 'raspberry' aroma).

We showed that microwave maceration may reduce constraints on winery capacity by eliminating pomace during fermentation, provide greater control over red wine phenolics and generate wines with distinct aroma qualities. Further research is required to determine the sensory impact of the full aroma compound array, as some compounds identified may be perceived as unpleasant (e.g. 'nail polish'), and others are highly sought after in Pinot Noir wine (e.g. 'red cherry', 'raspberry').

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107. 'Shining the light on wine shows' – rapid spectral wine analysis linked with show performance

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A study was carried out with the 2012 Hawke's Bay Regional Wine Show Syrah class to illustrate the trend that high quality wines have higher concentrations of both tannin and colour than lower quality wines. All Syrah wines in the 2012 Hawke's Bay Wine Show were sampled and analysed for tannin, pigment, total phenolics, pigmented tannin and free anthocyanins, using the AWRI Tannin Portal. Wines were judged blind by a panel of experienced wine judges and given scores using the standard Australasian 20 point scoring system, with gold medal (highest quality) wines scoring ≥ 18.5 , silver medal ≥ 17.0 , bronze medal \geq 15.5 and no award (lowest quality) < 15.5. The medal performance was compared with wine phenolic profiles. Standardised phenolic analysis data were reduced using Principal Component Analysis (PCA), performed with *The Unscrambler X* (Camo Norway). The PCA scores were used to perform discriminant analysis and predict medal ratings from the analytical data. This was compared with the actual medal ratings the wines achieved and PCA loadings were used to highlight important analytes.

The Syrah class in the 2012 Hawke's Bay Regional Wine Show contained 42 wines from the 2009, 2010 and 2011 vintages. Judges awarded 5 gold, 10 silver, 9 bronze and 18 no award ratings to these wines. Principal Component 1 (PC1; 71% of the variance) was positively loaded for anthocyanins, pigment, phenolics, tannin and pigmented tannin. Principal component 2 (PC2; 23% of the variance) was positively loaded for anthocyanins and pigment, but negatively loaded for the other analytes. Different vintages formed clusters, with PC1 partly separating 2010 from 2009 and 2011, and PC2 separating 2011 from 2009. PCA loadings indicated that wines from the cooler 2010 vintage tended to be higher in tannin and colour. Gold medal wines formed a relatively tight cluster toward the top right quadrant with reference to PC1 and PC2. Silver medal wines tended to be spread more evenly along the upper halves of both PC1 and 2, while bronze and no award wines tended to be scattered.

Table 1. Medal discriminant a	analysis	confusion	matrix
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	No medal	Bronze	Silver	Gold
No medal	11	1	0	0
Bronze	4	6	2	0
Silver	1	1	8	0
Gold	2	1	0	5
% correct	61	67	80	100

Overall % correct = 71.4; Actual medals in columns, predicted in rows

Gold medal Syrah wines could be 100% discriminated and were high in all phenolic measures, but weighted slightly towards colour (free anthocyanins and total pigment). Silver medal wines could be 80% discriminated and were more loaded for colour, without necessarily high tannin. The scatter of bronze and no medal wines indicated another order of sensory discrimination, in addition to phenolics. Using the tannin portal data, vintage could also be discriminated, with 2010 vintage having a group of wines with highest values for all phenolic analytes.

This data illustrates vintage variation of wine phenolics and the importance of both tannin and colour to hedonic quality of Syrah red wine.

108. Microwave maceration for control of laccase and enhanced phenolic outcomes in Shiraz wine

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Microwave maceration is a novel process for red winemaking which has been demonstrated to offer several potential benefits for Pinot Noir including effective phenolic extraction, must sanitation and increased YAN (Carew et al. 2013). In some years, *Botrytis* heavily impacts red wine-grapes, particularly Hunter Valley Shiraz. During the 2013 vintage, microwave maceration was applied to Shiraz grape must from the Hunter Valley and shown to be effective for eliminating laccase from juice, and for rapid extraction of phenolic compounds for Shiraz winemaking.

Phenolics

In this replicated trial, four winemaking treatments were applied to Shiraz grape must:

- Control fermentation on skins for 7 days (ctl)
- Microwave maceration, 1 hr hold time, press-off prior to fermentation (mpr1)
- Microwave maceration, 3 hr hold time, press-off prior to fermentation (mpr3)
- Microwave maceration with fermentation on skins for 7 days (msk).

Micro-fermentors were used (200 g must/replicate) and fermentation was carried out under non-controlled conditions in a commercial winery. Wine phenolics were analysed by UV-visible spectrophotometry.

The longer hold time wine (mpr3) was equivalent to control wine (ctl) for mean concentration of: total phenolics, total pigment, free anthocyanin, total tannin, pigmented tannin and colour density. The shorter hold time wine was significantly lower than the control wine for total pigment, free anthocyanin and colour density, but equivalent for total phenolics, total tannin and pigmented tannin. Microwave maceration and fermentation on skins (msk) was associated with greater concentration of most phenolic indicators, compared with the control wine (ctl).

Laccase

In a separate trial, microwave maceration was applied to Shiraz musts made from 12 *Botrytis*-affected bunches, with infection levels ranging between 1 and 40% by visual inspection. Laccase concentration was measured using the Laffort 'Botrytest' kit.

Microwave maceration proved effective for reducing laccase in *Botrytis*-affected fruit across the range of infection levels trialled. Mean laccase concentration was 8.2 μ g/mL before microwave maceration and 0.9 μ g/mL after microwave maceration.

The findings reported here are based on a single small-scale trial but the opportunity to eliminate laccase and better manage phenolic outcomes in Shiraz wine could be of substantial benefit to industry. The research team is planning to pilot microwave maceration for red winemaking with industry in 2014.

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109. Microwave maceration for finished Pinot Noir wine in 37 days

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Because of its unique phenolic profile, Pinot Noir winemaking takes time, space and resources. A typical Pinot Noir alcoholic ferment (AF) may last eight days and cold soak or extended maceration may extend the AF period by four or more days (Haeger 2008). Malolactic fermentation (MLF) of Pinot Noir wine is commonly employed to moderate wine acidity but MLF can be difficult to initiate and is often slow to finish. The aim of this research was to generate 'proofof-concept' for ultra-rapid red winemaking from microwave maceration. Microwave maceration had previously proven effective for rapid extraction of phenolic compounds from Pinot Noir grape solids into juice (Carew et al. 2013).

Microwave maceration was applied to 1 kg lots of Pinot Noir must, which were pressed off after three hours total skin contact time. This reduced the volume of must in the fermentation vessel by approximately 40%. Due to the pasteurising effect of microwave maceration, SO₂ was omitted at crushing and this enabled immediate co-inoculation for simultaneous AF and MLF. The *Oenococcus oeni* strain PN4 (Lallemand) was applied for MLF, in conjunction with one of three yeast strain treatments: *Saccharomyces cerevisiae* RC212, *S.cerevisiae* EC1118 and *S.bayanus* AWRI1176 (Lallemand). Each of the yeast strains used proved compatible with PN4, and all replicates had completed AF and MLF within 17 days of inoculation. Wines from this trial were settled, stabilised and bottled by 37 days post-harvest.

The three yeast treatments applied delivered distinct phenolic outcomes in the finished Pinot Noir wines. At six months' bottle age, RC212 wines were significantly higher in mean concentration of free anthocyanin than AW1176 wines (255 AU and 222 AU, respectively) and RC212 wines were significantly lower in mean concentration of pigmented tannin than AW1176 wines (0.41 AU and 0.74 AU, respectively). Wines from the three yeast treatments were equivalent for mean tannin concentration.

Microwave maceration and early press-off were demonstrated to be effective for rapid red winemaking, and to warrant further investigation on a larger scale so that appropriate sensory evaluation might be undertaken to determine the industry potential of ultra-rapid winemaking by microwave maceration.

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110. The influence of delayed malolactic fermentation on Pinot Noir phenolic profiles

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Pinot Noir grapes have unusual phenolic profiles in comparison with other *vinifera* red varieties. They have low anthocyanin concentration and contain no acylated anthocyanins. They have high tannin concentrations, but have a lower skin to seed tannin ratio. These unusual phenolic profiles may explain why Pinot Noir winemaking has some mystique and methods are specialised, derived through empirical observation over the years.

An important winemaking process is the malolactic ferment; this study examines the effects on wine phenolic profiles by comparing wines which have had a malolactic ferment immediately after primary ferment with wines which have had delayed malolactic ferments. Delayed malolactic ferments may be more representative of more traditional methods where this step often occurs in the spring following the primary ferment.

A single batch of MV6 clone Pinot Noir fruit was divided into batches and distributed to five wineries to prepare wine and perform malolactic ferments, either naturally (with a delay) or after inoculation with commercial cultures (Lallemand PN4).

Wines were assayed with the Modified Somers and tannin assays (Mercurio et al. 2007; Dambergs et al. 2012) and were tasted by a large panel of winemakers at the Victorian Pinot Massif Workshop.

Delayed malolactic ferment had no effect on total tannin and total phenolics, but resulted in wines that had higher colour density and higher pigmented tannin (non-bleachable pigment). Free anthocyanin levels were reduced, representing conversion to stable forms. An unusual observation was that despite decreased anthocyanin content, the hue value decreased in response to delayed malolactic ferment, that is, the wines looked more purple. This may represent the formation of unusual pigmented polymers in the presence of lees and absence of sulfur dioxide. Although care must be taken to prevent microbiological spoilage in the absence of sulfur dioxide, delaying malolactic fermentation offers a method to manipulate Pinot Noir wine phenolic profiles and to enhance colour stability.

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111. Manipulation of Pinot Noir colour and tannin profiles during maceration

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Pinot Noir can be a challenging winemaking variety, partly due to its unusual phenolic profiles. Since Pinot's low-concentration anthocyanins are also less stable, it is all the more important that the pigment is efficiently extracted and stabilised during the maceration/fermentation process. Anthocyanins are easily extracted and as a result, they can be found in juice early during fermentation. Since anthocyanins are highly reactive, it is important that stable pigment formation is encouraged, and tannin plays a role in this. Although Pinot Noir grapes have high tannin concentrations, Pinot Noir wines tend to be low in tannin. This anomaly is most likely due to Pinot's low ratio of skin-to-seed tannin, when compared with other varieties. Seed tannin is more difficult to extract than skin tannin and tends to come out later during fermentation. Winemaking strategies need to take this into account, by enhancing extraction and stabilisation and using alternative tannin sources. Building on laboratory-scale maceration trials designed to address these problems, this study describes production-scale Pinot Noir maceration trials examining effects of yeast, alternative tannin sources, benchmarking of commonly used maceration methods and the use of novel maceration methods.

Tannin and stabilised pigment concentrations varied twofold between treatments and a surprising observation was that co-fermentation with white skins not only increased total wine tannin, but also stabilised pigment. Wines made with non-*Saccharomyces* and hybrid yeast were low in total tannin, but had a high ratio of pigmented forms, perhaps explaining their positive contribution to palate structure. This study clearly demonstrates that Pinot Noir wine styles can be strongly regulated by the maceration process.

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112. Sensory properties of wine tannin fractions: implications for in-mouth sensory properties

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Managing red wine texture requires knowledge of tannin concentration as well as composition. Current practices to reduce young wine astringency, including tannin additions, tannin fining and microoxidation (MOX) can be costly and therefore more efficient ways of managing wine texture are required. Grape tannin structure has been shown to influence the mouth-feel of model wines; however the impact of wine tannin structure on wine mouth-feel was unknown. The impact of wine age on tannin structure was also unknown.

The objective of this project was to compare the chemical structures of different isolated wine tannin fractions from different vintage wines with their sensory properties.

Tannin was isolated from a seven-year-old Cabernet Sauvignon (CAS) wine and a three-year-old CAS wine and separated into two fractions (F1 aged and F2 young, respectively). The sensory properties of each tannin fraction were measured (Figure 1) and compared with their chemical structures (Figure 2).







Figure 2. Impact of tannin structure on sensory properties

Larger, more water-soluble wine tannins were more astringent, while smaller, redder and more alcohol-soluble tannins were bitter with a hot aftertaste. The larger wine tannin fractions were also around three times more abundant by mass than the smaller fractions and are therefore likely to have more impact on the overall astringency of red wine. Aged wine tannins contained more pigmented polymers and were overall less grape-tannin-like (less susceptible to depolymerisation with acid due to more intramolecular bonding as a result of oxidation).

Controlling tannin structure during winemaking may be a more efficient way of managing the texture of young red wines and research is currently underway to discover how this can best be achieved.

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113. The French Paradox, reality or myth?

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The French diet involves eating more fatty food, smoking more and a high consumption of alcohol, yet the incidence of cardiovascular heart disease is the lowest in the Western world. This phenomenon has been linked to the polyphenolic content in wine and is known as the French Paradox. Resveratrol, a well-known hydroxylated stilbene found in red wine several decades ago, has been shown to prevent the oxidation of low density lipoproteins which play an important role in reducing the risk of cardiovascular disease. In recent years, a variety of resveratrol derivatives such as methylated resveratrol, hydroxlated resveratrol and resveratrol oligomers have been identified from various plant families including grapes. These analogues also exhibit similar pharmaceutical bioactivities to that of resveratrol such as antioxidant activity, anti-inflammatory properties and antiplatelet aggregation activity. However, there are numerous other resveratrol derivatives yet to be identified in wine. In this study, a range of new glycosilated resveratrol and related derivatives with potential health benefits have been synthesised and their presence in wine screened for by liquid chromatography-mass spectrometry (LC-MS). The synthesised standards include five resveratrol glycosides, one hydroxylated resveratrol (piceatannol), eight piceatannol glycosides and three resveratrol oligmers. LC-MS analysis has confirmed the reported presence of picead, piceatannol, astringin and the three resveratrol dimers in red wine. In addition, LC-MS analyses have tentatively identified four new resveratrol glycosides in wine for the first time. Although the identification of these compounds in wines and grapes needs to be further confirmed, the initial findings are encouraging. It should also be noted that these new resveratrol glycosides in red wine may undergo enzymatic hydrolysis in the human body after consumption and as such would lead to increased levels of resveratrol and therefore increased efficiency in the prevention of cardiovascular diseases. Such findings are aiding in unlocking the secrets of the French Paradox.

SOIL AND IRRIGATION MANAGEMENT

114. Organic soil amendments, including biochar, improve vineyard soil health by increasing populations of beneficial bacteria, fungi and nematodes

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This study investigated the effects of soil organic amendments (poultry litter biochar, composted cow manure, composted green waste and rice hulls) on two Riverina vineyards. One vineyard had no history of regular soil organic amendment application ('conventional') whereas the other had been regularly amended previously with composted cow manure under-vine ('sustainable'). Organic soil amendments increased soil moisture, root growth, and populations of bacteria, fungi and beneficial nematodes in the 'conventional' vineyard. However, there was little response to the amendments in the 'sustainable' vineyard, indicating that the compost-induced increases in microbial and beneficial nematodes had probably reached a plateau. The poultry litter biochar performed well in these trials, causing a large increase in soil moisture, soil fungi, beneficial nematodes and grapevine root mass. This is the first investigation comparing the impact of biochar and other organic soil amendments on vineyard soil microbes.

115. Setting benchmarks for soil quality in Australian viticulture

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Sharing expert knowledge with viticulturists about how to benchmark and manage soil quality by using key indicator tests of their soils is the basis of a current three-year project being conducted by Department of Primary Industries (DPI) Victoria in partnership with GWRDC, CSIRO and South Australian Research and Development Institute (SARDI). The project is setting the groundwork for a soil quality monitoring service that can be used by grapegrowers to assess the status of their soils in order to help them manage this resource. In order to develop such a monitoring system, the project team has identified the most appropriate set of biological, chemical and physical indicator tests to characterise soil quality, defined here as its fitness for the purpose of growing quality wine-grapes. The indicator tests have been chosen on the basis of both scientific merit and practicality. The intention is to use this set of tests as a standardised tool to build a database of regional soil attributes throughout the wine sector. The data sets will provide benchmark values for grapegrowers to compare their soil properties with the optimum ranges for their region, aiding decisions on management practices for maintenance and enhancement of soil condition and vine productivity. In Australia, a crossindustry system has been developed and hosted on the website: www.soilquality.org.au. To date, it has been predominantly targeted at the grains industry, but is now expanding to include viticulture through the outputs of this project.

116. Assessing the feasibility of recycling winery wastewater for vineyard irrigation – soil, grapevine and wine responses

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The wine industry makes an important contribution to the South African economy, particularly in the Western Cape. Unfortunately, the industry also produces large volumes of poor quality wastewaters that contain high levels of potassium (K) and sodium (Na) derived from cleaning agents. In this regard, a project was initiated and funded by the Water Research Commission of South Africa. The project is being co-funded by Winetech and the Agricultural Research Council. The aim of this study was to investigate the use of recycled wastewater for vineyard irrigation on soil, crop and product quality.

Cabernet Sauvignon/99R grapevines in a sandy, alluvial soil near Rawsonville in the Breede River Valley were irrigated using raw river water (T1) and wastewaters augmented to chemical oxygen demand (COD) levels of 100 mg/L (T2), 250 mg/L (T3), 500 mg/L (T4), 1000 mg/L (T5), 1500 mg/L (T6), 2000 mg/L (T7), 2500 mg/L (T8) and 3000 mg/L (T9), respectively. Pennisetum glaucum was cultivated in summer and removed before harvest to intercept excessive K and Na. Each treatment was replicated three times in a randomised block design, and repeated during the 2010/11, 2011/12 and 2012/13 seasons. Soil samples were taken at 30 cm depth increments from 0 to 180 cm in September and May. Vegetative growth was quantified by measuring cane mass at pruning. Bunches were picked, counted and weighed when total soluble solids (TSS) reached 24°Brix. Forty kilograms of grapes from each plot were micro-vinified at ARC Infruitec-Nietvoorbij winery. Wines were subjected to sensorial evaluation by a panel of 12 experienced wine tasters using a 100 mm unmarked line scale.

Six wastewater irrigations were applied per season at *ca.* 14 day intervals from mid-February to the end of April. Irrigation was applied only within the 60 cm rootzone in order to minimise leaching of elements into the deeper layers. In the case of less diluted wastewater, K (data not shown) and Na (Figure 1) increased in the topsoil during the irrigation season. These elements were leached from the soil during winter, as illustrated for K in Figure 2. The interception crop removed K to the extent that T1 to T6 required additional K fertilisation. The interception crop removed almost no Na.



Figure 1. Work row soil Na contents in May 2011 where grapevines were irrigated with raw water (T1) and winery wastewater augmented to 250 mg/L (T3), 1000 mg/L (T5), 2000 mg/L (T7) and 3000 mg/L (T9) COD, respectively



Figure 2. Seasonal variation in soil K contents (0–180 cm depth) in a sandy soil near Rawsonville in the Breede River Valley

Augmented wastewater irrigation did not affect vegetative growth or yield compared to raw water (Table 1). Wine sensorial characteristics were not affected by the augmented wastewater (Table 2). Furthermore, no off-odours or off-flavours were detected.

Table 1. Cane mass and yield components of Cabernet Sauvignon/99R irrigated with augmented winery wastewater. Data are means for 2010/11, 2011/12 and 2012/13 seasons. Values within a column followed by the same letter do not differ significantly ($p \le 0.05$).

Treatment number	Target COD (mg/L)	Cane mass (t/ha)	Bunches per vine	Bunch mass (g)	Yield (t/ha)
1	Raw	2.5 a	28 a	155.4 a	14.9 a
2	100	2.7 a	28 a	157.3 a	14.8 a
3	250	2.5 a	28 a	156.3 a	15.2 a
4	500	2.6 a	28 a	160.4 a	15.6 a
5	1000	2.4 a	29 a	154.4 a	15.5 a
6	1500	2.2 a	26 a	161.6 a	14.4 a
7	2000	2.2 a	26 a	146.2 a	13.3 a
8	2500	2.4 a	29 a	162.8 a	16.2 a
9	3000	2.5 a	27 a	146.1 a	14.1 a

Table 2. Wine sensorial characteristics of Cabernet Sauvignon/99R irrigated with augmented winery wastewater. Data are means for 2010/11 and 2011/12 seasons. Values within a column followed by the same letter do not differ significantly ($p \le 0.05$).

- 1						
Treatment number	Target COD (mg/L)	Colour (%)	Overall intensity (%)	Acidity (%)	Fullness (%)	Overall quality (%)
1	Raw	38.9 a	49.6 a	35.5 a	36.2 a	40.6 a
2	100	31.0 a	45.9 a	36.4 a	31.8 a	33.9 a
3	250	38.4 a	45.2 a	36.4 a	35.7 a	38.7 a
4	500	38.1 a	48.2 a	36.1 a	35.1 a	37.9 a
5	1000	46.3 a	50.8 a	36.5 a	39.3 a	42.0 a
6	1500	34.9 a	43.9 a	34.7 a	31.7 a	34.7 a
7	2000	44.6 a	45.1 a	36.8 a	35.4 a	39.8 a
8	2500	36.3 a	46.2 a	36.2 a	34.7 a	37.5 a
9	3000	45.0 a	50.3 a	36.9 a	38.0 a	40.9 a

Although irrigation with winery wastewater had almost no effect under the given conditions, negative effects might be more prominent in heavier soils or in regions with low winter rainfall. These aspects are being addressed in ongoing, parallel studies.

117. Irrigation strategies can change the allocation of chloride in Shiraz grapevines subjected to saline irrigation

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Within the Padthaway grapegrowing region in South Australia there is a trend of rising aquifer salinity due to the recycling of irrigation drainage water (Dept. of Water 2012). Since 2004 the region has experienced below average rainfall which has resulted in bore levels dropping by up to 1.5 m and salinity rising by up to 18 mg/L/year (Dept. of Water 2012). In 2008 a water allocation plan for the Padthaway region was implemented to restrict the overuse of water sourced from the unconfined aquifer and to reduce the rising salinity levels. Grapegrowers have had to adopt more efficient irrigation practices including deficit irrigation techniques to ensure they do not exceed their allocation on an annual basis. The aim of this project was to examine the effect of deficit irrigation on chloride (Cl⁻) partitioning and test the hypothesis that partial rootzone drying (PRD) reduces Cl⁻ movement to leaves and fruit.

Following on from a field trial conducted in Padthaway from 2009–2011, a pot trial was established to replicate the three irrigation treatments of control, reduced control (RC) and partial rootzone drying (PRD) on Shiraz and Grenache. In 2011 and 2012, saline water (2.3 and 2.7 dS/m, respectively) was applied to the point of run-off for the control treatment while RC and PRD received half the volume of the same salinity. Irrigation water was applied when soil tension reached 60 kPa (gypsum blocks). The soil surface in each pot was covered in plastic to minimise evaporative losses and to prevent rain infiltration. Measurements in 2011 and 2012 included midday leaf water potentials (LWP), stomatal conductance, and leaf Cl⁻ concentrations at various stages throughout the growing season. In 2012, fruit and root hydraulic conductance were measured at harvest followed by destructive sampling of plant parts for measurement of Cl⁻ concentrations.

The results indicated midday LWP was lowest with PRD, and stomatal conductance (g_s) was lowest with RC. There was no correlation between g_s or root hydraulic conductance and leaf Cl⁻. There was no significant difference in root Cl⁻ concentration between the treatments. Fruit and leaf Cl⁻ concentration were higher in the RC and PRD treatments compared to the control. The control treatment had the greatest dry weight for all vine components.

In conclusion, despite PRD receiving the same amount of water as RC, the PRD treatment had significantly higher total Cl⁻ present throughout the vine. There was also significantly more in the woody components of the PRD treatment. This suggests that irrigation strategy can affect Cl⁻ allocation to different vine components. Lower Cl⁻ levels evident in the control treatment of many of the vine components may be explained by a dilution effect and/or additional leaching of salts due to the application of more irrigation water.

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118. Deep ripping and mounding: an evaluation of site pre-planting soil management practices

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Worldwide in viticulture, deep ripping is performed to break impervious layers of rock and calcrete pre-planting to facilitate greater root penetration. For shallow-surfaced soils, topsoil is often mounded to increase suitable soil volume for root exploration. At Bordertown, South Australia, Australia (36°19′26″S, 140°41′26″E) the long-term effect of these two common pre-planting soil management practices on vine growth was evaluated after 20 seasons. Observations that have been taken from the deep ripping, no mounding technique:

- Deep ripping was performed to a depth of > 800 mm with no mounding of the topsoil
- Large boulders of limestone were brought to the surface and these were costly to remove
- No root exploration was seen below 400 mm A1 horizon, even though ripping went down to an average of 800 mm
- Vine roots were able to explore soil within the rip line, but the extent of this varied with depth to the limestone layer
- · Some vine root exploration has occurred into the mid-row
- Even infiltration of irrigation water into the soil can be seen with no uneven runoff or pooling
- Due to the nature of the flat soil surface under the vine, mulch has been applied at different times to enhance root volume
- The deep ripped soil has now resulted in the growth of wellbalanced grapevines.



Figure 1. Example of limestone boulders ripped up out of the ground when deep ripping



Figure 2. Root growth pattern in 23-year-old Merlot (Vitis vinifera L.) grapevines under deep ripping/no mounding situation

Observations that have been taken from the mounding, no ripping technique:

- The mounded soil has seen a high level of vine mortality over time with non-drought tolerant rootstocks such as Schwarzmann suffering greatly
- Mounds are now steep-sided, making them prone to erosion and unable to retain mulch on their surface or absorb applied soil moisture
- Irrigation water runs down the western side of the mound before it can infiltrate the soil. This water then pools in the wheel ruts amplifying soil compaction issues
- Root growth has followed this water runoff pattern; and is now more pronounced on the hot, western side of the mound. These roots are exposed to extreme afternoon heat in summer
- Vine roots have become bound within the remaining mound structure and have not penetrated the original soil surface below the mound or into the mid-row
- Scraping soil from the mid-row to create a mound, with no addition of ripping, is a much cheaper pre-planting technique compared to deep ripping.



Figure 3. Schematic diagram of current mound structure, 20 years after vineyard establishment



Figure 4. Restricted root distribution in mounded, non-ripped vineyard

Conclusions developed from these observations are as follows: The effect of pre-planting soil management practices on vine growth needs to be evaluated independently at each potential vineyard site, including for blocks within a planting site that may differ in soil characteristics. Extensive soil surveys are imperative to facilitate correct choices regarding not only soil preparation technique, but also use of rootstocks, irrigation design and further soil management. There is no one 'quick fix' for soil preparation. At this site, deep ripping appears to have been conducted too deeply and would have sufficed at a maximum depth of 500 mm. At this depth, vine roots would have been able to explore into the rip line to the limestone layer (as already seen), but minimal boulders would have been brought to the soil surface and the deep ripping costs may have been reduced. Due to the sub-surface limestone layer in this vineyard, it must be pointed out that shallow ripping will lead to a requirement for rock drilling to assist with post placement. Proposed redevelopment of the mounded vineyard involves planting of drought tolerant rootstocks and re-mounding using the structure in Figure 5 to encourage water and mulch retention on top of the mound.



Figure 5. Schematic diagram of proposed mound structure for redevelopment of current no rip/mounded site

Shallow ripping would also be advised to a maximum depth of 400 mm, using a floating tine to run over the top of large limestone structures, leaving them below the soil surface.

119. Can rainfall harvesting reduce soil salinity and increase the appeal of recycled wastewater for irrigation?

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In many of Australia's wine-producing regions, rainfall meets vine water needs in all but the driest months. Irrigation supplements rainfall through these dry periods. If the 'supplementary' irrigation water is saline, as can be the case with some groundwater and recycled wastewater sources, then salt will be imported into the soil. In 2010, SARDI commenced development of strategies to manage rootzone salinity. Through the 2011 and 2012 vintages, in a saline groundwater drip irrigated 'proof-of-concept' trial, SARDI demonstrated that redirecting rainfall from mid-row to under-vine soils reduced soil salinity and the expression of salt in the vine. Whilst treatments showed promise, they were not commercially viable. Furthermore, questions remained around the validity of rainfall redirection for different soils, irrigation regimes and water compositions. In vintage 2013, the rainfall redirection concept progressed to 'pilot study' stage at a vineyard drip irrigated with moderately saline recycled wastewater. Here, more commercially-acceptable treatments and different growing conditions were to be tested.

In vintages 2009 and 2010, toward the end of the 'millennia drought', some vineyards in the south-east of South Australia were suffering leaf damage and delayed ripening due to salinity. Excessive salts in the juice were beginning to reduce the marketability of wines made from these vineyards. In a survey of three of the salt-affected vineyards, Stevens et al. (2012) found concentrations of chloride (Cl⁻) and sodium (Na⁺) in leaves greater than those normally associated with leaf necrosis during berry ripening. At these same vineyards, the salinity of under-vine soil was high, indicating insufficient leaching, whereas that in the mid-row was low, indicating that mid-row leaching was in excess of the requirements for optimum vine performance.

SARDI researchers hypothesised that redirecting the rain falling on the mid-row to the soils immediately under-vine would increase the leaching of salts from the saline under-vine soil and thereby reduce salinity pressure on the vines.

A 'proof-of-concept' trial was established in a saline groundwater drip irrigated vineyard in 2010. Various changes to vineyard floor management were tested, with the primary treatment being the construction of a plastic covered earthen mound in the mid-row. Through vintages 2011 and 2012, redirecting rain from the midrow to under-vine soil reduced soil salinity by an average of 40% and reduced juice Na⁺, by 20%, and Cl⁻, by 40% across the same two year sampling period. Despite successfully reducing salt pressure, the proof-of-concept treatment was too expensive and impractical for commercial application.

Prior to vintage 2013, SARDI established more commerciallyviable treatments in a 'pilot study' at a second vineyard, this time irrigated with moderately saline recycled wastewater. Treatments included bare earthen mid-row mounds, mid-row mounds sealed with the periodic application of a spray applied crusting agent and buried impermeable layers.

In the first vintage of the pilot study, vintage 2013, less than 20 mm of rain fell between treatment construction and collection of yield and fruit maturity data. Vine performance not only reflected this low rainfall but also the vines' recovery phase post-treatment construction. In the first year of assessment, all treatments were equivalent in their yield, fruit maturity and vigour. This indicated that treatment construction had not adversely affected vine performance and that the pilot study was consistent with the proof-of-concept trial in that differences, or lack thereof, were linked to rain events. It is expected that treatment effects will become more apparent as rain and irrigation events accumulate. The authors anticipate recommending alternative salt management strategies, for users of variable water qualities by the mid-2015 project end.

Acknowledgements

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120. Grapevine response to long-term saline irrigation

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There have been no published studies to our knowledge on the effect of long-term (14 years) response to salinity of grapevines on their own roots compared with grapevines grafted to a range of rootstocks. Tregeagle et al. (2006) demonstrated a diminished capacity for chloride exclusion by some grapevine rootstocks over a nine-year period. For example, mean Shiraz grape juice chloride concentrations in 2002–03/2003–04 for rootstocks 1103 Paulsen, Ramsey and 140 Ruggeri were higher by 6.3, 3.7 and 2.9-fold, respectively, than in seasons 1995–96/1996–97, whereas Shiraz on own roots was only 1.3-fold higher. In pear trees that were subjected to eight years of saline irrigation, a progressive decline in tree yield and vigour was attributed to a cumulative effect of salinity that increased tissue salt concentrations and suppressed assimilation rates (Myers et al. 1995).

In this study, Chardonnay and Shiraz on own roots and on a range of rootstocks (Ramsey, 1103 Paulsen, 140 Ruggeri, Schwarzmann, 101–14, Rupestris St.George and 1202C), were subjected to 14 years of saline drip irrigation at Merbein, Victoria. The 12 seasons 1995–96 to 2006–07 involved irrigation with water of electrical conductivity (EC) of 2.1 dS/m and mean total water applied (1995–96 to 2006–07) of 7.2 ML/ha. The final two years, 2007–08 and 2008–09, were years of water restrictions in the Murray Valley, and involved irrigation with water of EC 1.65 dS/m, and mean seasonal application of 3.04 ML/ ha. Rootstock effects on tolerance of Chardonnay and Shiraz were compared between the initial two seasons (1995–96 and 1996–97) and final two seasons (2007–08 and 2008–09).

Between the initial and final (two) seasons, chloride concentrations in grape juice of Chardonnay on own roots increased 5.6-fold to 1096 mg/L, and that of Shiraz increased 1.8-fold to 668 mg/L. In comparison, chloride concentrations of Chardonnay on Ramsey and 1103 Paulsen rootstocks increased 28.0 and 16.7-fold to 504 and 233 mg/L, respectively, and that of Shiraz on Ramsey and 1103 Paulsen increased 3.7 and 12-fold to 336 and 588 mg/L, respectively. Rootstock 140 Ruggeri also showed diminished exclusion capacity, but final juice chloride concentrations (81 and 111 mg/L for Chardonnay and Shiraz, respectively) were significantly lower compared with own roots, Ramsey and 1103 Paulsen. Diminished capacity for sodium exclusion was also recorded, especially for Chardonnay on own roots and on Ramsey rootstock, and for Shiraz on own roots and on Ramsey, 1103 Paulsen, 101-14, Rupestris St. George and 1202C. Significant reductions in yield occurred for own rooted vines, and with some rootstocks, for example 101-14 with Shiraz as scion, whereas yield of vines on 140 Ruggeri was similar between initial and final years.

Shiraz vines were apparently less affected by prolonged exposure to salinity than Chardonnay vines. Ramsey sustained yields over the duration of the study with both scions. Own roots resulted in significant yield decline with Chardonnay, and own roots, 1103 Paulsen and 101–14 resulted in greatest yield decrease with Shiraz. Rootstocks 140 Rugerri, Schwarzmann and Rupestris St. George were best in terms of sustained chloride exclusion, and 140 Ruggeri was one of the better rootstocks for sodium exclusion.

Acknowledgements

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121. High potassium in winery wastewater can contribute to soil structure degradation

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Occurrence of significant amounts of potassium (K) in soils and irrigation waters such as winery wastewater has led to probing the long held opinion that only sodium (Na) is the central concern regarding soil structural stability problems in salt-affected soils. Neglect of potassium and simple appeal to sodium adsorption ratio (SAR) to infer soil structural stability can be misleading. We found that the dispersive effect of K was 0.56 times that of Na and the flocculating effect of magnesium (Mg) was about 0.6 times that of calcium (Ca).

Soil samples were saturated with cationic (Na, K, Mg or Ca) chlorides to prepare homo-ionic soils. After washing the soils free of electrolyte, dispersion (turbidity) and hydraulic conductivity tests were conducted and the particle size was measured using standard procedures. The results confirmed that K effects on soil structural degradation were less than those from Na and the protective effect of Ca on soil structural stability was higher than that of Mg.

We examined the efficiency of the newly developed (Rengasamy and Marchuk 2011) cation ratio of soil structural stability (CROSS) in a few soils containing varying levels of potassium and magnesium in addition to sodium and calcium. CROSS is better than SAR because it incorporates the differential effects of Na and K in dispersion and the difference in the flocculating efficiency of Mg and Ca. Our experimental results on a number of soils containing varying levels of Na, K, Mg and Ca showed that CROSS was superior to SAR in predicting clay dispersion from the soils (Figure 1). In soils containing low K and Mg, CROSS will be similar to SAR in relating to clay dispersion.





Figure 1. The relationships between turbidity (a measure of dispersion) and SAR or CROSS. The concentrations of cations are expressed as mmol/L

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122. Long-term impact of winery wastewater irrigation on soils

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A dramatic increase in wine production over the last two decades in Australia and other wine-producing countries has led to the need for sustainable management of winery wastewater to meet environmental concerns. Traditionally, application of potassium (K^+) to soils has been perceived as a benefit due to a large body of published research demonstrating the positive effects of K^+ on soil fertility and crop yield (Arienzo et al. 2008). However, K^+ can have the potential to cause clay swelling and dispersion as well as increasing overall soil salt levels, and hence degrade soil quality and land productivity (Rengasamy and Marchuk 2011). Thus, elevated K^+ concentrations in wastewaters could limit their disposal onto land. There are no field data cited in the literature that could be used to ascertain whether recycled winery wastewater is affecting soil structure. Information is required to ascertain the long-term effect of disposal of winery wastewater on soil structure.

Several trends emerged from the historical data analyses and soil surveys conducted:

- Higher organic carbon content of the winery wastewater resulted in increased total organic carbon content in the soils irrigated with winery wastewater
- Available potassium increased in the winery irrigated soils at a rate of 9.6 mg/kg per year at the depth of 20 cm
- Salinity, sodicity and available potassium in soils were noted to be elevated in the wastewater-treated plots, especially woodlot and pasture sites at certain wineries
- Wastewater irrigated soils had higher cation ratio of soil structural stability (CROSS) values which were related to the turbidity, a measure of clay dispersion.

The disposal of winery wastewater onto vines is becoming more widespread in the wine industry. This study highlighted some potential benefits such as the increase in soil organic matter. The lack of detailed knowledge of the effect of irrigating vines with winery wastewater should be of concern to winemakers. Currently, very little information exists on the loads of salts that different soil types can tolerate before ecological effects could be observed. Therefore, information on the tolerance of different soil types to winery wastewater in terms of adverse soil biological functions and/or soil chemistry parameters is urgently required.

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123. Beneficial crop options using winery wastewater

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Winery wastewaters contain nutrients and, with the right treatment, can be a safe, affordable and sustainable source of irrigation water. Many wineries are considering the use of treated wastewater or wastewater that has only undergone primary treatment, to produce a commercial benefit that does not lead to deterioration of soil or crop health. The aim of this study was to examine the ability of selected crops to utilise the winery wastewater applications and assess their capacity in handling high nutrient loads in winery wastewater.

Crops trialled included turnip, zucchini, cucumber, field pea and silver beet. We measured the effect of the sodium:potassium ratio (Na:K) in the winery wastewater (www) and its effect on Na and K availability to plants. Initially we conducted a series of germination tests, at different ratios of tap water (tw) and www (namely tw:www at 100:0; 50:50; 25:75; 0:100 and 75:25), for all of the selected crops. For a few of the crops we also applied wastewater for 90 days, with both turnip and field pea producing roots and pods (peas) respectively.

Germination of field peas, cucumber, zucchini and turnip seeds was not affected by 100% winery wastewater application. Silver beet germination was significantly affected at 100% www application. For turnip, 90 days of 100% www application resulted in an increase of turnip root weight of about 40% in comparison to both tap water and 50% www treatments. The application of 100% www did not affect field pea plant height but significantly reduced pod weight. Turnip root concentrations of Na decreased by about 30% from control to 100% www treatment, whereas K uptake increased by about 38%. K uptake in peas was relatively uniform across treatments. K concentration, in the roots and leaves, increased by a factor of about 1.7 from control to 100% www treatments. For field pea and zucchini there was a 2.3-fold increase in the biomass concentration of K. Potassium uptake by pea pods and turnip roots was significant in winery wastewater treatments.

These trials have shown that minimally treated wastewater can be used beneficially for the production of crops. The effect of the high salt load (Na and K) on soil physical properties, in particular when using 100% wastewater, is a potential limiting factor and requires further study.

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VINE NUTRITION

124. Assessing vine response to increasing compost application rates in high and low vigour zones

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Compost is commonly used in organic viticulture systems to improve soil health and nutrition; however the purchase or production of compost can be cost-prohibitive. Given that vineyards are inherently variable and soil and vine responses to compost are site-specific, differential application of banded compost applied under-vine presents an opportunity to maximise its cost effectiveness. A trial is being conducted at the organically certified Baileys of Glenrowan vineyard in Victoria, to assess the impact of four rates (1.2 t/ha, 2.5 t/ha, 5 t/ha and 10 t/ha) banded compost applied under-vine on relative vine vigour and yield across high and low vigour zones of a block in comparison to a control treatment with no compost.

The aim of this trial is to determine the optimum compost application rate to improve vigour uniformity by increasing vigour in low vigour sections of the vineyard, and to identify the minimum rate required to maintain soil health and vine nutrition in the remainder of the vineyard so differential application of compost can be employed in the future.

The trial is being carried out on a 4 ha block of Cabernet Sauvignon (G9V3 clone \times Schwarzmann rootstock), using a whole-of-block approach (Panten et al. 2010) with each treatment replicated three times across the block. Vine responses are being assessed by measures of yield and yield components, vigour and vine nutrition, while soil health is being measured using soil analysis of soil samples pooled from each treatment replicate. Two 70 metre length sections (one high vigour and one low vigour zone) have been identified across the treatment rows using historical plant cell density (PCD) maps, and are also being used to assess the impact of differential application rates on vines that are inherently high or low vigour.

Yield results after one season show that the control had significantly lower average bunch weight than the compost treatments applied at rates of 1.2 t/ha, 2.5 t/ha (p<0.10) and 10 t/ha (p<0.05), which was driven by significantly lower berry number per bunch (p<0.05). Conversely, bunch number at harvest was significantly higher in the control treatment compared to the compost treatments (p<0.05), despite there being no significant difference in bunch number at flowering between any of the treatments. There were no significant differences in yield per vine or berry weight between treatments (Table 1).

Table 1. Effect of increasing compost application rates on harvest yield components. $^{\rm a}$ and $^{\rm b}$ denote significant differences between treatments (p<0.10)

		-				
Treatment	Yield per vine (kg)	Bunch weight (g)	Bunch number flowering	Bunch number harvest	Berry number per bunch	Berry weight (g)
Control	7.49	100.64ª	64.67	74.44ª	105.73ª	0.96
1.2 t/ha	7.08	413.87 ^b	69.00	49.33 ^b	158.62 ^b	0.91
2.5 t/ha	6.99	142.77 ^b	62.78	50.11 ^b	140.18 ^b	1.01
5 t/ha	6.62	136.03ªb	58.33	48.33 ^b	142.49 ^b	0.96
10 t/ha	7.09	143.34 ^b	69.00	49.33 ^b	150.85⁵	0.95

PCD data shows a significant difference in the low vigour zone between the 2.5 t/ha compost rate and the control (p<0.10) and 5 t/ha rate (p<0.05) (Figure 1). There were no other significant differences between treatments in the low vigour, high vigour or full row length treatments, pruning weights, shoot number or average shoot weights.



Figure 1. Effect of increasing compost application rates on average plant cell density across full treatment rows and in high and low vigour zones. ^a and ^b denote significant differences between treatments (p<0.10)

Vine nutrition was largely unaffected by the application of compost in the first season, and is not linearly correlated with soil nutrient availability. Additions of compost have increased soil organic matter, electrical conductivity (EC), calcium, potassium and phosphorous and reduced magnesium, nitrogen, sodium, zinc and exchangeable sodium percentage (ESP) compared to the control.

First season results suggest that differentially banding compost at a rate of 2.5 t/ha in low vigour zones will increase vine vigour in low vigour zones, and 1.2 t/ha in high vigour zones is sufficient to maintain current vigour and yield. This result will affect our future management of variable blocks to ensure cost effective use of compost through differential applications across high and low vigour zones.

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VITICULTURE AND THE ENVIRONMENT

125. Effect of smoke exposure and leaf removal on the sensory properties of Chardonnay wines

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Smoke from bushfires or prescribed burns can affect the chemical composition and sensory properties of grapes and wine, in some cases leading to wines which exhibit undesirable 'smoky', 'ashy', 'burnt rubber' and 'medicinal' characters (Kennison et al. 2007). This study aimed to investigate leaf removal (or defoliation) as a method by which the sensory impact of grapevine exposure to smoke might be ameliorated, by removing leaves around bunches, either before or after grapevine exposure to smoke.

Field trials were conducted in 2010 in a vineyard located in Nuriootpa, in the Barossa Valley district of South Australia. Five different treatments were applied (each in triplicate) comprising:

- 1. 'control' i.e. no defoliation and no smoke exposure;
- 2. 'leaf removal' (LR) i.e. defoliation, but no smoke exposure;
- 3. 'smoke' i.e. no defoliation, but smoke exposure;
- 4. 'LR pre-smoke' i.e. defoliation before smoke application; and
- 5. 'LR post-smoke' i.e. defoliation after smoke application.

Defoliation and smoke treatments were imposed at approximately seven days post-veraison. Defoliation consisted of manual removal of all leaves directly above, opposite and below each bunch. Smoke treatments involved vines being enclosed in purpose-built smoke tents and exposed to straw-derived smoke for one hour. Wines were made (in triplicate) for each treatment. Descriptive sensory analysis was performed on wines using a trained panel.

Berry growth and sugar accumulation were not affected by either defoliation or smoke application (data not shown). Similar total leaf areas were observed for all treatments at harvest, indicating that grapevines subjected to leaf removal treatments grew replacement foliage. Descriptive sensory analysis (Figure 1) identified differences between experimental treatments which may be directly attributed to defoliation and/or smoke exposure:

- Defoliation enhanced the intensity of 'fruit' characters in wines from the 'LR' treatment, compared to the 'control' wines (i.e. no defoliation, no smoke).
- Defoliation prior to smoke exposure gave wines with intense 'smoky', 'ashy' and 'burnt rubber' characters. This practice also significantly decreased the perception of 'fruit' attributes compared with other treatments involving grapevine exposure to smoke.
- Defoliation after smoke treatment reduced the intensity of 'cold ash' and 'ashy aftertaste' attributes compared with other 'smoke' treatments. 'Fruit' characters were perceived to be as high as in the 'LR' treatment (i.e. defoliation, no smoke) indicating that enhancement of 'fruit' characters by defoliation could partially mask the perception of 'smoky' characters.

Conclusion

Leaf removal prior to smoke exposure is not considered to be a viticultural practice capable of mitigating smoke taint in wines, but defoliation after smoke exposure may reduce the perception of 'smoky' and 'ashy' characters in wines.



Figure 1. Mean ratings for sensory attributes of Chardonnay wines. (AT = aftertaste)

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126. Impact of smoke exposure on different grape varieties

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The exposure of grapevines to smoke from bushfires or prescribed burns in close proximity to vineyards can result in smoke tainted wines (AWRI 2003), with the intensity of smoke taint shown to be influenced by the timing and duration of smoke exposure (Kennison et al. 2009). The current study investigated the extent to which smoke taint developed in wines of different varieties following grapevine exposure to smoke.

Three white varieties, Chardonnay, Sauvignon Blanc and Pinot Gris, and four red varieties, Shiraz, Cabernet Sauvignon, Merlot and Pinot Noir, were included in this study. Field trials were conducted in 2010 in vineyards located in Adelaide and the Adelaide Hills, South Australia. Grapevines were enclosed in purpose-built smoke tents and exposed to smoke derived from the combustion of straw for one hour, at approximately seven days post-veraison. Fruit was harvested when total soluble solids levels were 18–20°Brix (for white varieties) and 22–24°Brix (for red varieties). Wines were made (in triplicate) from control (unsmoked) and smoke-affected grapes. Descriptive sensory analysis was subsequently performed using a trained sensory panel. The panel assessed the intensity of 'smoke', 'cold ash', 'earthy' and 'burnt rubber' aromas, and 'smoky', 'metallic' and 'ashy aftertaste' attributes on the palate. Wines were also rated for 'fruit' aroma and flavour, 'bitterness' and 'acidity'.

Descriptive sensory analysis readily differentiated wines made from control and smoke-affected grapes according to the intensity of various smoke-related sensory attributes (Figure 1). Smoke-affected wines of different grape variety were characterised as follows:

WHITE VARIETIES

Pinot Gris:	intense 'smoky', 'ashy' and 'metallic' attributes; weak 'fruit' aroma and flavour
Sauvignon Blanc:	intense 'smoky' and 'ashy' attributes, intense 'ashy aftertaste'; elevated 'fruit' aroma and bitterness, 'fruit' flavour not affected
Chardonnay:	intense 'smoky', 'ashy' and 'burnt rubber' characters; strong 'ashy aftertaste'; weak 'fruit' aroma; 'fruit' flavour not affected
	RED VARIETIES
Cabernet Sauvignon:	intense 'smoky', 'ashy' and 'metallic' attributes; intense 'ashy aftertaste', weak 'fruit' aroma and flavour
Pinot Noir:	intense 'smoky' and 'ashy' attributes, intense 'ashy aftertaste'; diminished 'fruit' aroma and flavour
Merlot:	'smoky' characters more intense than 'ashy' characters; intense 'ashy aftertaste', 'fruit' aroma and flavour not affected
Shiraz:	'smoky' characters more intense than 'ashy' characters, elevated 'burnt rubber'; fruit' aroma and flavour not affected
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Figure 1. Mean ratings for sensory attributes of white and red wines

Conclusion

The uptake of smoke by grapevines and subsequent development of smoke taint in wines was found to vary between the different grape varieties assessed. In the current study, smoke related sensory attributes were most apparent in Pinot Gris and Cabernet Sauvignon wines.

Acknowledgements

The authors gratefully acknowledge the vineyard owner and manager for participating in this project; Andrew Markides from Lallemand, for the provision of yeast and winemaking consumables; Margaux Vigy, Andrew Maronich and Jesse Graffam for technical assistance; and the sensory panellists. This research was funded under the Australian Research Council's *Linkage Projects* scheme and the financial contributions of industry partners are also acknowledged.

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127. Evaluating native insectary plant species to boost beneficial arthropod populations in vineyards

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Introduction

Insect pests cause economic damage in Australian vineyards each season. For example, light brown apple moth (LBAM) causes damage to flower clusters, resulting in yield losses and damage to berry skins. Damaged skins provide infection sites for moulds like *Botrytis cinerea*, which result in a reduction in fruit quality and yield losses. Annual losses from *Botrytis* and other bunch rots, and LBAM, were estimated to be \$52M and \$18M respectively, with a combined annual impact of \$70M (Scholefield and Morison 2010).

One of the key challenges faced by viticulture is that a diverse natural ecosystem is replaced by a monoculture of low diversity, which has a negative impact on biodiversity. Components of biodiversity include many species of predators and parasitoids, which are regarded as 'beneficials' and contribute to biological pest control in vineyards throughout the year.

However, it is possible to reverse this negative impact by restoring pre-European and remnant plant communities, and by revegetating with native plants that are well adapted for use in and around vineyards. Within a vineyard setting, existing vegetation, such as windbreaks, vegetation corridors, mid-row and under vine plants, and headland plantings, can be enhanced to provide resources for predators.

Insectary plant species planted near vineyards can provide <u>shelter</u>, <u>nectar</u>, <u>alternative prey</u>, and <u>pollen</u> (SNAP²) to nourish and enhance the capacity of predators to control pests. Native insectary plants that consistently provide season long benefits to beneficial predators will be identified in our research.

Aims

The aim of this research is to identify native insectary plants that enhance biological control of vineyard pests throughout the year, focusing on plants that provide food, shelter, and alternative prey, at key times, to boost populations of beneficial predators.

Where to from here?

- 1. Selected native plants will be surveyed to identify those that support beneficial predators each season.
- 2. Chemical markers will be used to track beneficial predators to determine how far they move from insectary plantings into vine-yards. These markers will include:
 - rubidium chloride (rare earth)
 - Rabbit, chicken egg whites (protein marking)
 - Resin-based dyes (visual assessment).
- 3. Quantifying the contribution that beneficial predators make to vineyard pest control.

Significance of the study

Specific links between native insectary plants and beneficial predators occurring in vineyards have not been identified before in Australia. At the end of this project, winegrowers will be provided with key information to help them produce grapes that are 'fit-for-purpose' with lower insecticide inputs. Key results will include:

 Which insectary species can meet the provisioning requirements of beneficials • How and where insectary plants can be used to maximise the abundance of beneficial predators in vineyards.

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129. Microbial communities in the vine: a dynamic study

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Vitis vinifera is naturally colonised by a wide variety of microorganisms, both beneficial and phytopathogenic, which interact with it and play a major role in its growth and vigour and will clearly influence the eventual wine quality. The natural microecosystem from grapevine is very dynamic and is mainly affected by spatial and temporal factors as well as by the application of plant protection products that are mostly based on a chemical control.

In this study we have extensively characterised the natural microbiome present on grapevine during the growth vegetative cycle using a metagenomic approach. The analysis revealed a surprising and complex microbiome associated with *V. vinifera* and a balance between the phytopathogenic and beneficial microorganisms was observed. This is of utmost importance for the grapevine phytossanitary status, vine performance and quality wines.

Furthermore, among the prokaryotic population the major microorganisms were represented by Proteobacteria, Actinobacteria and Firmicutes and on Eukaryotic population, *Ascomycota phylum* was the most abundant. Our samples were mainly characterised by the dominance of the *Aureobasidium pullulans* and the prokaryotic Enterobacteriaceae family which are considered as beneficial microorganisms. Despite the beneficial microorganisms identified, we have also detected phytopathogens such as *Botrytis, Phomopsis* or *Guignardia*.

Overall, the study of the global population from the vineyard revealed significant microbial biodiversity during the vegetative cycle of grapevine, showing interactions between plant-microbe communities and reflecting the impact of the co-habitation of beneficial and phytopathogenic microorganisms on vine performance and wine quality.

130. Does fruit maturity influence the intensity of smoke taint in wine?

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Smoke from bushfires or prescribed burns can affect the chemical composition and sensory properties of grapes and wine, in some cases leading to wines which exhibit undesirable 'smoky', 'ashy', 'burnt rubber' and 'medicinal' characters (Kennison et al. 2007); with the intensity of smoke taint influenced by the timing and duration of smoke exposure (Kennison et al. 2009). In this study, the extent to which fruit maturity (i.e. ripeness) influences the perception of smoke-related sensory attributes in wine was investigated.

Grapevines from two white grape varieties (Chardonnay and Sauvignon Blanc) and two red grape varieties (Shiraz and Merlot) were exposed to smoke under experimental conditions (for one hour) at approximately seven days post-veraison. Fruit was harvested at two levels of maturity: (i) Harvest A, when total soluble solids were 16–20°Brix, representing the fruit ripeness required for sparkling wine production; and (ii) Harvest B, when total soluble solids were 22–25°Brix, representing the fruit ripeness required for table wine production. Wines were made (in triplicate) for each variety and each treatment and descriptive sensory analysis performed to determine the intensity of smoke-related sensory attributes.



Figure 1. Mean ratings for sensory attributes of wines harvested for sparkling wine (A) and table wine (B)

The intensity of smoke taint in wines was found to be influenced by fruit maturity. The extent of tainting was also driven by grape variety (Figure 1). For white grape varieties, smoke-related sensory attributes were apparent in Sauvignon Blanc wine made from early-harvested fruit and in Chardonnay wine made from late-harvested fruit, only. Merlot and Shiraz wines exhibited smoke taint irrespective of fruit maturity. However, the intensity of 'smoke' and 'cold ash' aromas, 'smoky' flavour and 'ashy aftertaste' was rated higher in Merlot made from early-harvested fruit and in Shiraz wine made from lateharvested fruit. 'Fruit' aroma and 'fruit' flavour were rated lower in most of the smoked wines.

Acknowledgements

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131. Chloride and sodium concentrations in grape juice of Shiraz are influenced by seasonal rainfall and irrigation applied

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The Padthaway grapegrowing region in South Australia relies on supplementary irrigation to produce high quality fruit. The irrigation water is saline, ranging in concentration from 900–2000 mg/L. The last decade in Padthaway has seen five seasons experience below average rainfall (494 mm), which is winter dominant and is crucial to leach residual salts present in the soil profile. The influence of rainfall timing on the presence of sodium (Na⁺) and chloride (Cl⁻) within grapevines, particularly leaves and fruit, is largely unknown. As part of a larger PhD study investigating the effects of deficit irrigation on salt accumulation in vines, we discovered that seasonality of rainfall interacts strongly with applied irrigation in determining the pattern of Na⁺ and Cl⁻ concentrations in fruit.

A trial located at Padthaway that encompassed vintages 2009, 2010 and 2011 was used to assess seasonal rainfall and varying irrigation techniques. The experiment consisted of a block of 16-year-old ownrooted Shiraz vines separated into three irrigation treatments (using 2 dS/m irrigation water) – Control, Reduced Control (RC) and Partial Rootzone Drying (PRD). Each irrigation treatment had five separate sampling sites where grape juice was collected from berries throughout the ripening period. Rainfall data was sourced from the local Bureau of Meteorology site and then categorised into three separate timings – winter rainfall prior to growing season (EWRSB), growing season rainfall (EGSR) and annual rainfall (EAR). Only rainfall that totalled more than 5 mm was considered effective. Irrigation records were sourced to calculate amount of applied irrigation from September until the end of March in each year.



Figure 1. Principal component analysis (PCA) plot showing the relationship between rainfall timing (Effective Winter Rainfall season before – EWRSB, Effective Annual rainfall – EAR and Effective Growing season rainfall – EGSR) and Cl⁻ and Na⁺ in harvest grape juice

The results show that juice Na⁺ is highly influenced by rainfall and juice Cl⁻ is more influenced by applied irrigation (Figure 1). Figure 1 explains the large differences between seasons – 2009 (dry) and 2011 (wet) - and also shows the close proximity of the three irrigation treatments per season indicating no significant differences between Cl⁻ and Na⁺ juice concentrations at harvest.

In summary, rainfall is extremely important in determining the level of Na⁺ found in grape berries at harvest and applied irrigation water largely determines grape juice Cl⁻ concentrations. Growers should be aware of potential for high sodium and chloride in grapes when seasons are dry and should manage their irrigation accordingly.

132. Investigating mechanisms underlying poor fruit set of grapevine during salt stress

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Introduction

Salinity is an environmental constraint which poses a major threat to grapevine productivity and wine quality. Salinity reduces both vegetative and reproductive development of grapevine. Pollen tube growth is required for successful fertilisation and fruit set, and salinity reduces the fruit set (Bouquet and Danglot 1996; Mullins et al. 1992). Poor fruit set leads to poor yields and partially developed berries, which can decrease wine quality. In the present study we examine the mechanism by which salinity affects fertility in Shiraz; a variety that is moderately sensitive to salt stress, as well as contributing the major percentage of overall wine production in Australia. In recent years, the metabolite GABA (y-aminobutyric acid) was found to play a role in plant reproduction by guiding pollen tubes through maternal tissue at low concentrations but inhibiting growth at higher concentrations (Palanivelu et al. 2003). GABA concentrations also increase rapidly under salt stress (Kinnersley and Turano 2000). So we speculate that GABA may be a key regulator of fruit set in grapevine under salt stress.

Material and methods

In the present study an *in vitro* pollen germination assay experiment was performed according to Brewbaker and Kwack (1963). The effect of various GABA concentrations (1 mM, 2 mM, 5 mM, 10 mM, 20 mM and 40 mM) on Shiraz pollen tube growth (PTG) was measured in order to understand the role of GABA in plant reproduction during abiotic stresses.

Results

In the present study it was observed that there was a significant increase in PTG from 1 mM up to 10 mM, while the higher concentrations (20 and 40 mM) inhibited growth (Figure 1, 2). Our results are in accordance with the Palanivelu et al. (2003) who observed similar results in an *in vitro* pollen germination assay experiment in *Arabidopsis*. In these experiments a concentration gradient of GABA was reported to guide the pollen tubes from the stigmatic surface (20 μ M GABA) throughout the stylar region (60 μ M) up to the ovary walls (110 μ M). Our results further reinforce the role of GABA in plant reproduction up to a threshold level (Palanivelu et al. 2003) after which it starts inhibiting the PTG which is likely to lead to poor yield during abiotic stress. As abiotic stress can increase GABA levels more than 40-fold (Kinnersley and Turano 2000), the inhibitory concentrations we observed might suggest that GABA is a major determinant in fruit set percentage during stress conditions.



Figure 1. In vitro pollen germination assay experiment of grapevine pollen (Shiraz) on Brewbaker and Kwack (1963) media. (A) Shows the PTG on agar medium without GABA and (B) shows the PTG on agar medium with 10 mM GABA concentration. Scale bars represent 100 μ M (pollen tube length).



Figure 2. Effect of different GABA concentrations (1, 2, 5, 10, 20 and 40 mM) on PTG in *in vitro* pollen germination assay experiments in grapevine. This experiment was repeated three times and each treatment had five replicates. For each replicate 20 pollen tubes were measured. Error bars represent the mean \pm the standard error.

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133. Rootstocks and water use efficiency II: the role of hydraulic conductivity in determining conferred vigour

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Rootstocks are widely used to impart favourable characteristics on scions, particularly to reduce vegetative growth, improve disease resistance and abiotic stress tolerance in the scion. Decreasing vigour is particularly valued as it can improve fruit quality, increase bunch exposure, reduce disease pressure and increase ease of harvest. However, the mechanism whereby rootstocks generate differences in the growth of scions is still poorly understood. A role for hydraulic conductivity of the graft union, root system or trunk has been suggested, but the literature is limited, conflicting or inconclusive. Under well-watered conditions the relationship between hydraulic conductivity and vigour was investigated using Shiraz vines chip grafted onto four standard rootstocks (110 Richter, 140 Ruggeri, Ramsey and Schwarzmann) grown in glasshouse conditions. In young vines, both whole root and root length specific hydraulic conductivity (K_{root}) were highly correlated with total vine dry mass. A second experiment, investigating if differences in vine K_{root} were being driven by physical differences or differences in root aquaporin (PIP) activity, found that in four of five PIP genes examined, expression was significantly affected by rootstock. Unexpectedly, across the rootstocks aquaporin gene expression was negatively correlated with both K_{root} and plant dry weight. This suggests that differences in root hydraulic conductivity and, therefore, potentially vine vigour, are due to physical differences in xylem vessels. The up-regulation of PIP genes in vines with low root hydraulic conductivity supports the idea that the grafted plant is utilising aquaporins to overcome physical limitations in the movement of water. Hydraulic conductivity is intricately linked with rootstock conferred vigour in the scion. That the rootstock or graft union is a physical limitation on whole vine hydraulic conductivity is supported by the expression of PIP genes.

134. Biodynamic vs conventional viticulture in Australia: a comparison of costs and operations

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Around the world, many grapegrowers have converted their vineyards to organic and/or biodynamic systems (Zucca et al. 2009). Of the alternative farming system options, biodynamics (BD) has increasingly captured worldwide attention (Delmas and Grant 2008) as a farming system able to produce high quality grapes. The popularity of biodynamics among premium grapegrowers appears to be related to the perception that using BD practices could lead to a higher grape quality (Mushak and Piver 1992; Holzapfel et al. 2009) and therefore premium prices for the wine produced. High quality grapes do not often focus on high yields, unlike other fruit crops; therefore nutrient removal in vineyards is relatively low. Because of this, nutrient replacement in vineyards seems to be feasible through low input farming systems such as biodynamics.

The aim of this study was to assess and compare operations and costs of conventional and biodynamic vineyards. The novelty of the comparison is the assessment method, which considers vineyard size (and plant density), climate and operational/management efficiencies. The method was developed to determine variables that are influenced by management system choice and exclude operations that are not (e.g. pruning and harvesting).

In 2010, a survey was conducted with 24 biodynamic vineyards in Australia, representing approximately 20% of the estimated total commercial BD vineyards in Australia in that year. These vineyards were compared to 24 hypothetical conventional vineyards with similar size, soil and climate characteristics. The methodology took into consideration economies of scale, operational efficiency, climate and region, plant density and stage within biodynamics. The data collection from this study refers to the 2010 vintage.

Operations listed in Table 1 represent the main potential differences between the systems: pest and disease management, including weeds and nutrition. Table 2 shows typical conventional operations for the same year in wet and cool and dry and warm regions. These operations were used to create the conventional pairs to be compared to the survey participants.

The authors estimate that there were about 120 biodynamic commercial vineyards in Australia in 2010. There are no official statistics on the total BD vineyard area in Australia.

Table 1. Operation	ns performed b	oy respondents	during	growing	season	2009-
2010 (n=24)						

	1	2	3	4	ALL	
Operation	Certified and non-certified organic	Pre Certification	In-Conversion	Certified and non-certified fully BD	average	
501 spray	67%	all	all	79%	83%	
500 spray	all	all	all	93%	96%	
508 under vine	14	-	25%	• •	4%	
508 on canopy	33%	33%	25%	36%	33%	
Green trimming	67%		50%	64%	54%	
Leaf plucking	33%			14%	13%	
Shoot thinning	33%		75%	21%	29%	
Copper spray	67%		50%	57%	50%	
Sulphur spray	all	all	all	79%	88%	
Cultivation		33%		29%	21%	
Knifing or disking	33%	33%	50%	29%	33%	
Slashing midrow	67%	67%	all	93%	88%	
Slashing undervine	all	all	50%	43%	58%	
Sowing cover crops	33%	67%		43%	38%	
Steam weeder			25%	1.00	4%	
Grazing	÷		50%	43%	33%	
502-507		all	50%	57%	54%	
Mulch	33%	33%		43%	33%	
Compost	33%	all	50%	57%	58%	
Straw		33%	50%	21%	25%	

 Table 2. Conventional vineyards: assumptions for the number of operations performed during the Australian 2009-2010 growing season, by climate

Regional climate Amount of operations		Operation description
Wet and cool	Dry and Warm	y and Warm Under-vine management
		Under-vine management
3	1	Mid-row slashes
1	0	Selective broadleaf herbicide spray
3	2	Under-vine herbicide spray
		Canopy management
1	1	Vine trimming
8	5	Fungicide program (including full botrycide program)
1	1	Foliar fertilizer application
1	0	Shoot thinning

Table 3 shows a ranking of four levels of biodynamic development (or maturity) that was created as part of this study. The share of costs varies depending on which developmental stage the vineyard is in. The variation is related to a different set of operations performed in each stage.

 Table 3. Survey participants – biodynamic stages of development, from least to most biodynamic levels and canopy and under-vine management: percentage share of total costs

Biodynamic development stage	n=23*	Canopy	Under vine
1 Certified and non-certified organic	3	47%	53%
2 Pre-certification	3	12%	88%
3 In-conversion	5	33%	67%
4 Certified and non-certified fully BD	13	27%	73%

Figure 1 shows the shows a comparison of costs within the biodynamic development stages. Figure 2 compares all BD stages with the conventional system. The term 'costs' in this analysis refers exclusively to operations for managing the canopy and vineyard floor (undervine management). Total operational costs in this investigation refer to the sum of canopy and under vine costs.



Figure 1. Comparison of cost differences between the first BD stage (Certified and Non-certified organic) and subsequent BD stages (% change from the base to comparison) – ALL vineyards



Figure 2. Comparison of cost differences between Conventional and BD stages (% change from the base to comparison) – ALL vineyards

The total increase in operational costs between conventional and biodynamics vineyards was 11%, but this should be regarded with extreme caution, since results vary enormously depending on the chosen set used for the comparison, according to economies of scale or BD development stage. The percentage change in total costs between conventional and BD vineyards ranges from –13% (if only large/fully BD are considered) to 63% (medium/all BD stages). However, canopy management costs are always lower and under vine cost are always higher independent of the set. Biodynamic viticulture is a commercially feasible management system for high quality grapes.

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WINE AND GRAPE COMPOSITION AND ANALYSIS

135. Extraction of oak volatile and ellagitannin compounds and sensory profile of wine aged with French winewoods subjected to different toasting methods: behaviour during storage time

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At present, alternatives to oak barrels are being looked at to carry out the wine ageing process. This practice was recently approved and legislated by the European Community (CE 2165/2005 and CE 1507/2006). Factors such as piece size, amount of added wood and contact time between wood and wine affect both sensory and chemical wine characteristics (Frangipane et al. 2007; Chira and Teissedre 2013a, b). Until now, it has not seemed very logical to establish an ageing period between oak wood and wine through legislation. Hence, the question is: 'How do the oak wood extractable compounds develop once the oak wood is in contact with wine?'

A study of wine volatile and non-volatile composition along with a tasting assessment using winewood (oak wood with a surface of 0.24 m²) representing different toasting methods while being macerated in wine for 12 months was carried out. Different types of winewood (LT (Light Toast), MT (Medium Toast), MT+ (Medium Plus Toast), Noisette, Special) were added in separate stainless steel tanks with Merlot wine for 12 months (2 ww/hL and 0.24m²/ww). For MT, Noisette and Special the same toasting temperature is used. However in the case of Noisette, there is a prolongation of toasting time, whereas in the case of Special, 30 minutes before the end of the toasting process a watering process takes place. During the year of ageing in tanks with winewood, each red wine was sampled at 1, 2, 3, 6, 9 and 12 months, then the quantification of elagitannin and of aromatic compounds was performed by high performance liquid chromatography (Michel et al. 2011) and gas chromatography mass spectrometry analysis respectively (Barbe and Bertrand 1996). Sensory analysis of 'vanilla', 'spicy', 'overall woody', 'astringency', 'bitterness' and 'sweetness' descriptors was performed in parallel (Chira and Teissedre 2013a). A possible relationship between chemical composition and sensory assessment was investigated.

Overall, this study found different rates of extraction, depending mainly on winewood type and on contact time. The extraction differences were reflected by perceived sensory differences. In general, volatile phenols, such as eugenol, iso-eugenol, guaiacol and methyl guaiacol along with vanillin and lactones, showed increasing concentrations with increasing maceration time. The extraction rate of furanic compounds was maximum after 3 or 6 months of maceration; after 12 months these compounds were exhausted. Ellagitannins were extracted faster during the first 3 months; after 6 months an important decrease was observed. These decreases during maceration time can be attributed to the high reactivity of ellagitannins toward other wine constituents. Wines with winewood subjected to watering during the toasting process (Special) presented lower ellagitannin concentrations and demonstrated the greatest decrease during the maceration time. In the sensory evaluation, with the exception of wines with Special winewood, 'woody', 'vanilla' and 'spicy' flavours amplified linearly during the storage time. Moreover, wine storage with winewood had a sweetening effect and in parallel decreased the 'astringency' sensation and 'bitterness'. This reduction in astringency could be caused by ellagitannin loss during the contact time as well as by a chemical complex formation between wine tannins, polysac-charides and peptides brought out by oak wood.

Afterwards, each sensory descriptor was correlated with the chemical concentration of oak wood compounds of interest. Overall 'woody' character was positively correlated with guaiacol, eugenol, lactones and vanillin levels, which is reasonable since oak wood sensation is complex and influenced by the presence of various odour-active wood extractives. Perceived 'spicy' intensity was closely related to eugenol content, which is logical, since pure eugenol is described as 'clove-like'. 'Spicy' intensity was also linked positively to lactones and vanillin suggesting that in a complex medium such as wine these volatile compounds may influence spicy aroma by means of additive, or synergistic effects. 'Astringency' and 'bitterness' intensified significantly with ellagitannin concentration (R = 0.828, p = 0.001 for astringency and R = 0.607, p = 0.003 for bitterness). This correlation resulted in a useful tool applicable to wine development.

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136. The significance of pressing conditions on key aroma volatiles in Marlborough Sauvignon Blanc

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Differences in winery processing techniques such as the pressure at which juice is extracted can affect the mining of many volatile aroma compounds from the grape berry; thus resulting in numerous wine aroma profiles. Sauvignon Blanc varietal thiols 3-mercaptohexan-1-ol (3MH) and 3-mercaptohexyl acetate (3MHA) have been shown to decrease in wines made from pressed juices when compared to their free run alternatives (Patel et al. 2010). Since the separate fermentation of press fractions is a common practice within the wine industry this study aimed to evaluate the chemical and sensory profile of three Marlborough Sauvignon Blanc press fractions.

To gain an insight into the array of aroma compounds present within Sauvignon Blanc press fractions, two Marlborough vineyards were used for sample collection: one from the Wairau Valley and the other located in the Awatere Valley. Five juice sets (A, B, C, D and E) were collected and fermented in triplicate; each set contained free run (FR), light pressed (LP) and heavy pressed (HP) juice fractions. The pressed juices, LP and HP, were collected at 660 L/t and 760 L/t respectively, with the FR fraction consisting of juice obtained below 650L/t. After successful fermentation of all the press fractions, the wines were analysed using gas chromatography-mass spectrometry (GC-MS) for a selection of aroma compounds. These results were coupled with a sensory analysis of the wine, in which each was evaluated twice. The results showed that all five wine sets had significantly higher (p<0.05) amounts of both 3MH and 3MHA in wines made from the free run fractions compared to levels found in the pressed wines, confirming previous findings. Contrary to this the 'floral'/'rose' aroma compound of *cis/trans*-rose-oxide which is less studied in Sauvignon Blanc was found to increase in the HP wine fractions of all five wines. Many other compounds including benzaldehyde, hexanol, ethyl cinnamate (*trans*) and hexyl acetate were also seen to be significantly higher (p<0.05) in the HP fractions across all five wines.



Figure 1. Concentrations for *cis/trans*-rose-oxide between experimental wines made from different press fractions, dotted line denotes perception threshold (Ohloff 1978)

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137. Use of lateral flow devices for the estimation of *Botrytis* antigens in dessert wines

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The presence of *Botrytis cinerea* (noble rot) is desirable for the production of late harvest dessert wine. Quantifying the amount of *Botrytis* present and differentiating *Botrytis* from other fungi that are present on the surfaces of mature fruit is problematic. This study investigated two commercially available lateral flow devices (LFD) for the detection of *Botrytis* antigens in wines, one produced by EnviroLogix, Portland, ME, USA (EL) and the other by Forsite Pocket Diagnostics, York, UK (FPD). Both devices employ the same *Botrytis* monoclonal antibody, BC-12.CA4. The devices are read in their respective custom-made readers to give a Signal Intensity (SI) reading.

Twenty-seven dessert wines from Australia and France and one experimental Semillon table wine made from grapes infected with grey mould, or the ignoble form of *B. cinerea*, were examined in this study. Table wines were diluted 1:40 and dessert wines 1:500 in phosphate buffered saline plus Tween 20 (0.05% v/v).

When tested using the dessert wines, results from both types of devices were comparable although the SI values for the FPD were much higher than those from EL LFDs (Figure 1). Despite this, there was a good correlation between the results for the two devices with an R^2 value of 0.849.



Figure 1. Dessert wines tested for levels of *Botrytis* antigens by EnviroLogix (EL) and Forsite Pocket Diagnostics (FPD) Botrytis-Lateral Flow devices. Vintage year followed by 'F' indicates country of origin as France. All other wines originated from Australia

Relating the relative SI values with *B. cinerea* occurrence in the vineyard is difficult in the absence of accurate historical records. Despite this, the levels of *Botrytis* antigens in one set of wines made from grapes from one vineyard did correlate reasonably well with the winemakers' recollections of *Botrytis* incidence in a given year (data not shown).

The EL LFD was used to examine the levels of *Botrytis* antigen in apparently healthy and grey mould infected Semillon juice and wine samples in February 2011 (Figure 2). The 2010/11 season was wet and fungal disease pressures were high so the presence of *Botrytis* in juice and wine made from apparently healthy grapes is not surprising. Subsequent plating out of apparently healthy grapes on to artificial media confirmed the presence of *B. cinerea* in both apparently healthy and bunch rot affected grapes.



Figure 2. Botrytis antigen detection in Semillon juice and experimental wine in 2011. Results are the means of three replicate batches of juice/ferments.

Both LFDs are useful tools for rapidly determining levels of *Botrytis* antigens in grape juice and wines. They may be a useful tool that can be used to relate the amount of *Botrytis* antigens to the sensory properties of a given wine. Detection of the *Botrytis* antigen in juice from apparently healthy grapes demonstrates that the technique may also be used to detect latent *Botrytis* infections, and to detect *Botrytis* before disease outbreaks occur.

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138. An objective measure of sparkling wine quality?

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Australian sparkling wine is of high quality, particularly when fruit is sourced from cooler climates, such as in Tasmania. Producers often obtain fruit from a variety of vineyards, varieties and clones and an objective measure of sparkling wine quality would enable benchmarking of these sources against what the winemaker requires. Such a measure would also assist with blending decisions to achieve consistency of the product, particularly for non-vintage sparkling wines. Phenolic compounds are important for sparkling wine quality and a phenolic profile can easily be 'fingerprinted' by ultraviolet (UV) spectroscopy.

In the 2012 season, I10V1 Chardonnay and D5V12 Pinot Noir were harvested on the same day and whole bunch pressed into two press cuts. The first Chardonnay press cut was made at 350 L/t and during the second press cut an extra 150 L/t was extracted. For the Pinot Noir parcel of fruit, the press cuts were 400 L/t and 150 L/t. These press cuts were fermented separately using small scale (12 kg) standard protocol winemaking. Base wines were then UV 'fingerprinted' after dilution in 1M HCl. Principal component analysis (PCA) was performed on the UV spectra of the base wines to reveal clustering, and important wavelengths were identified with PCA loadings. Caffeic and ferulic acid UV spectra were also 'fingerprinted' for comparison.

There was clear separation between the first and second press cuts for both Chardonnay (Figure 1) and Pinot Noir. This separation was primarily driven by PC 1. Comparison with the fingerprints for caffeic and ferulic acid indicated that freely extractable hydroxycinnamates are most likely responsible for the differences between the press cuts.

In conclusion, a simple dilution of sparkling base wine, incubating for one hour and then a one minute analysis can provide an indication of phenolic profiles. Once the relationship between this profile and sensory attributes has been established, this information could be used as an objective measure of sparkling wine quality.



Figure 1. PCA scores (a) and PCA loadings (b) from Principal Component Analysis of UV spectra of Chardonnay base wines

139. Should we crop high or low for Pinot Noir sparkling base wines?

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Good quality sparkling wine-grapes command a premium price in Australia, in particular those from cooler climates, such as in Tasmania. It is generally accepted that Pinot Noir can be cropped higher for sparkling wine production than for table wine production, but the effect of this increased crop load on the base wine composition is relatively unknown.

The current trial was carried out over three seasons in a commercial vineyard in Northern Tasmania on own rooted, nine-year-old, clone 114 Pinot Noir vines. Varying crop load was achieved by altering winter pruning levels to leave 10, 40 or 60 nodes per vine by laying down 1, 4 or 6 arms per vine, with 10 nodes per arm. Fruit was harvested and small scale winemaking was carried out, using a standard protocol (12 kg ferments).

The significant increase in yield decreased total soluble solids (TSS) at the highest crop load. Other fruit composition parameters indicated that seasonal variability had a stronger effect than pruning level. Although TSS values were similar between seasons, varying levels of total anthocyanins and phenolics were recorded, with 2011 (quite a wet season) the lowest and 2012 (a mild and drier season) the highest. Low and high crop load treatments separated from each other on Principal Component Analysis (PCA) scores plots, with varying results for the medium crop load treatment according to vintage. The PCA loadings plots indicate that hydroxycinnamates are impacted upon by the variation of Pinot Noir crop load.

140. Does removing leaves improve sparkling base wine composition or does it just make us feel better?

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Increasing light exposure to grape bunches has long been shown to influence the amount of phenolics in the fruit at harvest for table wines and anecdotally, sparkling winemakers have expressed a desire for 'dappled' sunlight exposure of bunches. In cool climates, increasing exposure is a particularly common practice due to the added benefit of allowing better disease control. For sparkling wines, phenolic composition is as important as the quantity, however little is known about the effect of increased bunch exposure on the phenolic profiles of the juice and wine.

In this study, mature and lateral leaves were removed, up to and including the fourth node, at three different times in the 2011 and 2012 seasons (pre-flowering, pea-sized berries and 50% veraison) in Northern Tasmania with D5V12 Pinot Noir and I10V1 Chardonnay. Fruit composition parameters were measured and the phenolic profiles of base wines were analysed by ultraviolet (UV) spectral fingerprinting after dilution in 1M HCl. Base wines were produced using standard protocol small scale winemaking (12 kg ferments).

Very few yield composition effects were observed for either variety in either season. In the cooler and wetter season of 2011 (Table 1), pH and total phenolics of Chardonnay fruit were highest in the control fruit. In the warmer and drier season of 2012, total Pinot Noir grape phenolics were lower in the control fruit and when leaves were removed when berries were pea-sized.

Table 1. Seasonal	weather	conditions
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	GDD (Sep-Mar)	GST (Sep-Mar)	Rain (Sep-Mar)	MJT (°C)	MFT (°C)
2011	983.6	14.6	676.0	17.6	16.5
2012	1161.1	15.4	457.8	17.7	17.6

Principal Component Analysis (PCA) of Chardonnay base wines after dilution in 1M HCl showed a consistent separation in both seasons between the pre-flowering leaf removal treatment and the control along Principal Component (PC) 1. This PC's loadings showed strong loading minima and maxima at 260 and 330 nm with a shoulder at 310 nm (Figure 1). PCA of Pinot Noir base wines showed pre-flowering and control separation on PC 1 with similar loadings as for Chardonnay at 260 and 330 nm for base wines from the cooler and wetter 2011 season, however base wines from the warmer and drier 2012 did not show as strong separation, although PC loadings were similar.



230 244 258 272 286 300 314 328 342 356 370 384 398 412 426 440 X-variables (PC-2) (6%)

Figure 1. 2011 Northern Tasmania Chardonnay; (a) Principal component analysis (PCA) scores plot of UV spectra of base wines labelled by treatment (cont = control, pea = pea-sized berry leaf removal, ver = veraison leaf removal, pre-fl = pre-flowering leaf removal); (b) PC 1 loadings plot, x axis 230–450 nm; (c) PC 2 loadings plot, x axis 230–450 nm

Comparison with the 'fingerprint' of caffeic and ferulic acids showed similar loadings for these standards as was observed for the vineyard treatments. This indicates that treatment effects are most likely due to an impact on the readily extractable hydroxycinnamates (see Poster 138).

141. New measures of polyphenols and antioxidants in grape juice and wine using electrochemical sensors

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Several new rapid electrochemical measures have been developed for oxidisable compounds present in grape juice and wine, including polyphenols and antioxidant additives. This builds upon earlier approaches to characterise polyphenols in red and white wines using cyclic voltammetry with a glassy carbon electrode established at the University of Auckland. A more accurate measurement of total polyphenols was obtained by adding a small amount of acetaldehyde, which binds up the free SO₂ present (Makhotina and Kilmartin 2010). Conversely, a cyclic voltammetry scan before and after the addition of acetaldehyde provides a measure of the free SO₂ content in white wines.

The technique has now been applied to white grape juices (Makhotina and Kilmartin 2012). Information has been derived from the peaks obtained, including the concentration of caffeic acid derivatives plus catechin by the height of the first peak at 400 mV (versus a Ag/AgCl reference electrode); the concentration of flavonols, such as quercetin glycosides, is given by the second derivative of a second peak or shoulder at about 500 mV; and the area under the curve to 700 mV provides a total phenols measure comparable to the Folin-Cioculteau assay; a further peak at 900 mV is mainly due to nonphenolic species such as the amino acid tryptophan.



Figure 1. Typical cyclic voltammetry profile for a Sauvignon Blanc grape juice

By using a glassy carbon rod electrode to generate polyphenol quinones in a controlled manner, reactions of the active quinones with wine antioxidants, such as SO₂, ascorbic acid and glutathione, have been assessed for their ability to lessen wine browning and aroma losses (Makhotina and Kilmartin 2013).

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142. Discovering and characterising genes involved in tartaric and malic acid metabolism

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Grapes contain organic acids, which are important for the taste of wine and for providing the low pH needed to prevent oxidation and microbial spoilage during fermentation. Tartaric and malic acids are the two most abundant acids in the berry (Ruffner 1982). Malic acid is known to play a role in central metabolism and has been studied in a variety of fruits (Sweetman et al. 2009). In contrast, tartaric acid has no known role in metabolism. It is however the stronger of the two berry acids, playing the dominant role in pH control in juice and wine.

Global warming is predicted to increase the cost of addition of tartaric acid during winemaking, as malic acid breakdown is predicted to increase, leading to a higher pH of juice at harvest and increasing the amount of tartaric acid that is added to achieve a low pH. To counteract this issue, vines with higher acid levels at harvest need to be developed. However, before this occurs an understanding of the genetics behind acid metabolism needs to be established. To do this we are undertaking both a broad study of the genetics of acid variation with quantitative trait locus (QTL) analysis as well as measuring concentrations of malic and tartaric acid in new variety populations (Table 1) and studying candidate genes found in the literature (Figure 1).

Table 1. We are exploring the variation in tartaric and malic acid in new variety populations, using a liquid chromatography-tandem mass spectrometry (LC-MS/MS) approach to rapidly and accurately determine acid concentration in berries. Variation in malic (left) and tartaric (right) acid concentration in progeny populations from the 2011/2012 season. Listed are concentration range, the mean concentration and the concentrations of the parents for all populations

			Ma	alic						Tar	taric		
	Pre	-verai:	son	Po	st-verais	on		Pre	veraiso	m	Pos	t-verais	ion
cross	range mg/berry	mean mg/ berry	male parent mg/berry	range mg/ berry	mean mg/ berry	male parent mg/ berry	cross	range mg/berry	mean mg/ berry	male parent mg/ berry	range mg/ berry	mean mg/ berry	male parent mg/ berry
1	1,55-6,84	4.03	3,67	0.35-2.54	0.93	2.54	1	1.99-11.81	4.86	1.99	2.71-8.26	4.75	4.33
2	2,75-8,80	5.00	3,97	0.28-1,76	0.88	0.70	2	3.28-7.09	4.70	4.69	1.94-6.80	4.51	6.26
3	2.58-9.13	5.51	3.45	0.25-2.80	0.81	1.84	3	3.04-8.41	5.18	3.93	2.57-7.30	4.47	4.31
4	1.40-7.49	4.28	-	0.35-1.61	0.76	1.61	4	2.76-5.97	4.47		2.48-6.43	4.45	6.43
5	1.93-8.14	4.75	6,04	0.24-2.75	0.79	2.75	5	2.88-6.46	4.63	5.19	2.40-5.15	3.64	5.15
6	4.20-12.45	6,84	8,71	0,61-2,87	1.05	2.87	6	3.26-7.59	4,89	4.81	3,24-5.84	4,13	3.97
7	3.00-8.21	5.34	4.81	0.33-1.43	0.84	0.77	7	2.32-5.41	3.75	3.06	2.06-5.69	3.69	3.14
8	2.13-6.69	3.35	2.63	0.04-2.44	0.60	2.44	8	2.33-4.98	3.37	2.34	1.54-8.90	3.97	3.74
9	1,66-10.86	4.84	10.86	0.12-6.25	1.22	6.25	9	2.54-6.74	4.44	5,47	2.80-11.83	5,72	11.83
10	2,12-13.90	4.45	13.90	0.14-3.98	0.96	3.98	10	2.37-7.03	3.81	5.86	1.94-8.22	4.85	6.04



Chromosome 16

Figure 1. Pictorial representation of L-idonate dehydrogenase genes (L-IdnD) within the draft grapevine genome. L-IdnD 1 is known to participate in tartaric acid synthesis but L-IdnD 2 and 3 are yet to be characterised. All three genes are in tandem on chromosome 16. L-IdnD 1 and 3 are annotated in one direction and L-IdnD 2 is annotated in the opposite direction

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143. In-bottle analysis of sparkling wine tirage fermentation and maturation

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A critical step in the production of méthode traditionnelle sparkling wines is the tirage process, involving bottle fermentation and maturation. Spectral methods for wine analysis have become routine (Cozzolino and Dambergs 2009; Gishen et al. 2010), but for bottled wines, stock must be opened and sampled for analysis. When screening large numbers of a premium product, destroying stock represents a significant expense. Also when screening for faulty products e.g. 'flat' or oxidised sparkling wines, a non-destructive in-bottle analysis method is required so that good product can be returned to stock after analysis. In-bottle spectral scanning introduces problems with long path-lengths and the need to scan through flint glass. This rules out ultraviolet and long wavelength infrared regions of the spectrum, with visible and short near infrared wavelengths being ideal. This study describes a method for screening tiraged sparkling wines with a custom designed and built spectrophotometer that can scan through the bottle. Using spectral data and multivariate data analysis methods, discrimination of in-bottle fermentation, loss of carbon dioxide, maturation on yeast lees and oxidation have all been demonstrated.



Figure 1. Principal component analysis score plot of in-bottle UV-Vis scans of sparkling wines stored on tirage lees for 12 months, at either 4° C or 15° C

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144. Does cluster thinning improve Pinot Noir quality or just thin your profit?

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Crop yield is widely recognised as an important factor in the production of quality wine-grapes. The traditional belief that low-yielding vines are associated with higher quality wines is often used to place an upper limit on the yield in commercial vineyards. The practice of cluster thinning has been used in order to regulate yield, and to improve the chemical composition of the remaining berries through manipulation of the leaf to fruit ratio of the grapevine.

The aim of this study was to evaluate the effect of cluster thinning on the fruit quality of three Pinot Noir (*Vitis vinifera* L.) clones grown in southern Tasmania. Grapevines were submitted to three cluster thinning treatments carried out at different times during the season: flowering, pea-size and veraison, as well as a treatment where only the wing of the cluster was removed (this was imposed at veraison) and an untreated control.

In all three clones the thinning at flowering, pea-size and veraison treatments significantly reduced the total yield below the control and wing removal treatment. There were no significant differences in bunch weight, number of berries, or berry weight for clones D2V5 and MV6. However, in clone D5V12 bunch weight was significantly higher in the flowering, pea-size berries and veraison treatments than the control (P=0.037).

Despite thinning well below commercial yield (<4 t/ha), and regardless of the timing of treatment, there was no significant difference in pH, TA, or soluble solids, except for clone D5V12, where the total soluble solids (°Brix) was significantly lower in the control compared with the three cluster thinning treatments.

 Table 1. Did thinning clusters at flowering, pea-size and veraison result in a significant difference in yield or quality when compared with the control for three Pinot Noir clones?

	Yield Pa	arameters	Fruit Quality	Parameters
	Total Yield	Bunch Weight	Total phenolics, tannins, pH, TA, and anthocyanins	Total soluble solids
D2V5		Х	Х	Х
MV6	\checkmark	х	х	Х
D5V12		\checkmark	х	\checkmark

In conclusion, in a season which allows for a large crop to be ripened, cluster thinning means that growers are effectively reducing their return with no compensation in quality. The relationship needs to be tested in a season which presents lower temperatures and sunlight hours during ripening.

145. Isolation of tannin standards for the investigation of tannin structure and function

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Tannin is a major contributor to wine quality. Through their interactions with other compounds, tannins contribute to several organoleptic quality indicators in wine including astringency, bitterness, colour and colour stability and ageing potential as well as wine colloid formation. Understanding the function of tannin structure in these interactions is critical for guiding improvements in the vinification process to ensure continued enhancement of wine quality. Despite comprehensive information based on the gross compositional features of tannin, the knowledge of tannin structure-function relationships is limited by the lack of isolated and characterised individual tannin standards. To overcome this, methodology is being developed to facilitate the separation and isolation of a range of pure tannin standards, which can be made available for further research.

The methodology for the isolation of tannin standards uses a combination of several consecutive liquid chromatographic separation steps. Flash chromatography allows for initial crude separation of tannins from impurities and polymers with a high degree of polymerisation. Hydrophilic interaction chromatography (HILIC) on a preparative scale, utilising a diol column, is employed to separate tannins into fractions of similar molecular weight. Collected fractions are further separated over a preparative C18 column to isolate tannin polymers based on structural differences, such as subunit composition and stereochemistry.



Figure 1. Separation steps for the isolation of individual tannin standards. Step 1: Twelve fractions of grape seed tannin extract of increasing molecular weight separated over a diol preparative column. Step 2: Fraction 3, collected in step 1, is further separated over a preparative C18 column. Step 3: Peak A, collected in step 2, is subjected to C18 high performance liquid chromatography mass spectrometry (HPLC-MS) analysis to determine degree of polymerisation (DP) and subunit composition

This method has the ability to generate a range of structurally isolated tannin polymers including non-galloylated, mono- and di-galloylated tannin polymers and polymers containing epigallocatechin (trihydroxylated epicatechin) in mg quantities that can be made available to conduct further research.

146. What determines the amount of tannin extracted from grapes into wine?

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Wine tannin concentration plays an important role in wine quality. It is the primary determinant for the level of astringency in wine and is important for wine colour stability and ageing.

Being able to predict initial wine tannin concentration based on grape tannin concentration measured in the vineyard would greatly improve confidence for making informed winemaking and viticultural decisions. However, the amount of tannin extracted from grapes into wine cannot be determined by measuring the concentration of tannin in grapes. In the grape to wine continuum, there are different factors that tannin is influenced by (Figure 1). These include physical barriers and the reactions and interactions tannin undergoes as it is extracted from the grape berry and evolves into wine tannin.



Figure 1. Factors that influence the determination of wine tannin concentration in the grape to wine continuum

To predict the type and amount of tannin that ends up in wine and its potential concentration with wine ageing, each of these factors (Figure 1) need to be investigated to determine the extent to which tannin is influenced by each.

Here we describe factors that have recently been investigated to determine initial wine tannin concentration when fermentation conditions that influence tannin extraction are held constant.

Grape skin cell walls were investigated as a physical barrier to tannin extraction. It was found that increasing amounts of cell walls decreased tannin extraction into wine (Table 1). It is likely that cell wall structure including thickness and porosity have a greater impact on tannin extraction than polysaccharide composition and binding affinity by trapping large tannins. Variation in cell wall structure in grapes at harvest may have an impact on determining tannin concentration.

 Table 1. The effect of the amount of skin cell walls and their tannin binding affinity on initial grape and wine tannin concentration determined in Shiraz grapes from low, medium and high vigour canopy vines. Where the amount of skin cell wall material increased, the amount of tannin extracted into wine decreased

	Low vigour vines	Medium vigour vines	High vigour vines
Amount of grape skin tannin (mg/g skin)	3.0	4.2	4.4
Amount skin cell wall material (mg/g skin)	173	198	333
Tannin binding affinity of skin cell walls (μg/mg cell wall material)	3.87	3.69	3.40
Amount wine tannin extracted (mg/L)	243.9	229.0	148.7

To investigate reactions involved in determining wine tannin concentration, the influence of tannin structure on protein precipitation that might be involved in colloid formation and precipitation was investigated. It was found that not all tannin polymers have the same efficacy for precipitating protein (Table 2). Because there is a large range of tannin structures present in grape, the type that is extracted into wine will impact on the amount that form colloids and precipitate during winemaking.

 Table 2. The proportion of tannin precipitated by BSA protein when a known amount of tannin is added. The amount of tannin precipitated increases as the tannin polymer length increases

Tannin polymer length	Monomer	Dimer	Trimer	Tetramer	Pentamer	Hexamer	Heptamer	Octamer
% Tannin precipitated	0	0	12.4	23.9	36.8	32.7	67.3	93.4

Anthocyanin is thought to increase tannin solubility and was investigated to determine its impact on tannin extraction. It was found that wine made from grapes containing high levels of anthocyanin had high wine tannin levels regardless of the tannin concentration in the

grapes (Table 3). High levels of anthocyanin in grapes may increase wine tannin extraction for grapes with low tannin concentrations.

Table 3. Tannin and anthocyanin concentration in grapes and wine made from grapes with four different combinations of high and low grape tannin and anthocyanin concentrations. High grape values are highlighted in green and high values in wine are highlighted in red. Wines with high wine tannin concentration were made from grapes that had high anthocyanin concentration, but both high and low grape tannin concentration

	Tannin/Anthocyanin	Grape	Grape	Wine	Wine
	combination used in grapes for	Tannin	Anthocyanin	Tannin	Anthocyanin
	winemaking	(mg/g whole berry)	(mg/g whole berry)	(mg/L)	(mg/L)
Wine 1	Low Tannin/Low Anthocyanin	1.56	0.89	29	403
Wine 2	Low Tannin/High Anthocyanin	1.54	1.62	240	802
Wine 3	High Tannin/Low Anthocyanin	2.38	0.94	26	403
Wine 4	High Tannin/High Anthocyanin	2.29	1.67	239	831

In summary, each factor in the grape to wine continuum will influence the amount of tannin extracted, but to a different extent. By investigating each factor individually we have increased our understanding of how each has an impact on determining wine tannin concentration. Most significantly, cell walls trap and prevent large tannins from being extracted, but anthocyanin also plays a significant role in determining the solubility and stability of extracted tannin.

147. Nanosensors for wine quality analysis

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The wine industry is in need of rapid, low cost sensor technologies to provide vital feedback at critical points in the wine value chain. Electronic noses are a popular strategy for wine quality analysis, yet they are overwhelmed by the high ethanol and water content of wine. This leads to sample pre-processing and severely limits their effectiveness and use outside a strict laboratory setting.

Nanosensors exploit the unique properties of materials at the nanoscale and may be used for the direct analytical probing of wine. Our nanosensors are chemiresistors that comprise gold nanoparticles coated with chemically-sensitive molecules. These gold nanoparticle chemiresistor nanosensors require no sample pre-processing and offer robust operation in high ethanol, low pH and residual sugar levels.

Arrays of gold nanoparticle chemiresistor nanosensors were developed to provide a semi-selective approach to discrimination between different samples. The nanosensor arrays were repeatedly exposed to two specific wine samples derived from two different grape varieties (Botrytis Semillon and Sauvignon Blanc). Each nanosensor within the sensor array responded differently when exposed to each wine variety, producing a distinct pattern of responses (Figure 1a). Principal component analysis of the array responses also illustrated that the nanosensors can differentiate the two wines (Figure 1b).



Figure 1. (a) Nanosensor array responses when exposed to Botrytis Semillon and Sauvignon Blanc. (b) Principal component analysis plot of the nanosensor array response to the two wines

It has been shown that gold nanoparticle chemiresistor nanosensor arrays can withstand the chemical challenges presented by the wine matrix and can be used to directly probe a wine sample, with no sample pre-processing required. This sensor technology shows promise as a sensitive, portable, simple and cost-effective analytical tool for the in-field objective measure of wine throughout the wine value chain.

148. Influences of vine clone, yeast strain and canopy density on volatile thiols, their potential precursors and sensory attributes of Sauvignon Blanc wines

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Sauvignon Blanc wines are thought to have characteristics that are suggestive of tropical fruit aromas. Some of the key compounds that impart these characters are believed to be volatile thiols, which are released (from their cysteine and glutathione conjugates) or formed during fermentation. The expression of these characters in wines may be influenced by several factors including yeast strain, vine clone, and canopy density. While effects of yeast strain have been examined previously, only limited evidence exists on the effects of clone and canopy management. Here we report on results from a study that examined yeast strain, vine clone, canopy density and their interactive influences on volatile and conjugated thiols, monoterpenes, methoxypyrazines, and fermentation products as well as on sensorial characteristics of wines. The results show significant impacts of clone, canopy density and yeast on levels of conjugated and volatile thiols and some monoterpenes in finished wines. Regardless of clone or vigour, there was an order of magnitude variation between the levels of different forms of putative volatile thiol precursors in wines. While the levels of some of the precursors were similar in grapes and wine, the levels of other precursors in wine were only about 10% of the levels in grapes. Canopy density and clone also influenced levels of methoxypyrazines in wines but these were not affected by yeast strain. Levels of some of the fermentation products were also considerably influenced by clone, vigour and yeast strain. Sensory evaluation of wines by trained panels indicated distinct sensory differences that closely reflected the effects of the clone, vigour and yeast on the chemical components described above. More significantly, the results indicate that potential exists for modulation of levels of thiols and sensory characteristics towards a desired outcome.

149. Astringency: a physical approximation

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Astringency is one of the predominant factors that determine the quality of red wines; however, it cannot be predicted. The scientific community is discussing mechanisms that explain this phenomenon, since there are no conclusive results of wine parameters, which corre-

late with sensory astringency. This has led to the non-existence of direct methods to measure astringency, and while analytical methods are aimed at measuring homogenised grape tannins in grape skin and seeds, or wine, and there are few studies correlating these parameters with wine sensory astringency. Considering this, the present research is developing a physical method based on fluid rheology to predict sensory astringency.

The effect of commercial tannin extracts, extracted either from grape seeds or grape skins, on astringency was investigated in a model wine solution mixed with artificial saliva that mimics what happens to taste in the mouth. Commercial extracts of grape seed tannin (tseed) and skin tannin (tskin) were used in a ratio of 4:1 (w/w) (tseed:tskin) in concentrations of 0.05 to 1.0 g/100 ml of solution (Mitropoulou et al. 2011), with five treatments and three repetitions. Changes in astringency were studied using a coaxial cylinder viscometer and the rheological behaviour was determined.

The results showed a viscosity diminution with an increasing tannin levels (Figure 1). However, ANOVA showed significant differences between extreme samples (p < 0.05).



Figure 1. Relation between apparent viscosity [η] and shear rate [γ]. The T1 treatment corresponds to low doses of tannin and T2, T3, T4 and T5 to higher doses, respectively

The decrease of viscosity with high doses could be due to a major formation of aggregates that coalesce producing colloidal particles leading to precipitation of protein-tannin (Jöbstl et al. 2004). Although we must confirm that the decreased viscosity of tanninsaliva samples is related to sensory properties, both artificial saliva and tannins exhibited a similar behaviour to wine in-mouth at the moment of taste, with less viscosity (or more friction) perceived in more astringent wine. This makes it a potential quantitative method to determine sensory astringency.

On the other hand, the apparent non-Newtonian behaviour of saliva mixed with wine converted the fluid to being capable of being measured with instruments at non-constant shear rate. The fluid characterisation will be part of future investigations of this research group. This work will help to describe the fluid and thus understand astringency in physico-chemical terms.

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150. The Hunter Valley Semillon Project: links between soil types and phenolics

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Mirroring the general trend across other premium Australian grapegrowing regions, Hunter Valley winemakers are increasingly focusing on single vineyard wines and sub-regions to highlight the different styles available to consumers, as well as expressing the unique characteristics of the vineyard.

There is a common belief amongst Hunter winemakers that the four main soil types in the region produce fruit with different flavour, style and phenolic profiles. The Hunter Semillon project aims to determine whether soil type (and thus sub-region) plays a significant role in the phenolic profile of Semillon juices and what impact the winemaking process has on the resultant wines.

The first stages of the project have involved tasting 55 single vineyard wines from 2011 and 2012 in order to see if there is a consistent vocabulary being used to describe differences between wines originating from different soil types and sub-regions. The winemakers of these wines have also completed a survey as to their winemaking practices.

These wines were analysed via ultraviolet mid infrared (UV/MIR) spectroscopy and for basic wine chemistry to determine any significant trends. There were no noticeable trends according to the wine chemistry. The UV/MIR spectra showed an expected differentiation according to vintage but on closer examination the UV spectra also displayed an apparent separation between wines from sandy alluvial vs alluvial loam.

	Red	Sandy Alluvial	Pale Orange with Ironstone	Alluvial
Red	11	8	2	0
Sandy Alluvial	2	5	0	0
Pale Orange with Ironstone	7	2	10	2
Alluvial loam	1	6	0	6
% correct*	52	23	83	75
*chance event would be 20%				
Actual category				
Predicted category				
Correct classification				

Figure 1. Classification of soil types using analysis of juice absorbance values at 265, 280, 330 ${\rm nm}$

In the 2013 vintage, fruit samples were collected from over 20 different vineyards and the resultant juices assessed for phenolic profiles, using key UV-visible wavelengths (265, 280 and 330 nm). This initial data set indicates that there are correlations between soil types and phenolics and that hydroxycinnamates may be one class of compounds responsible for the differences seen between the wines.

Fruit from five of these vineyards was then processed using the same winemaking techniques at the same winery and the samples likewise are being reviewed for phenolic profiles using the full UV spectrum.

The soils from all of the vineyards sampled in 2013 as well as many of the single vineyards involved in the tasting have been sampled for both soil colour and texture. Samples are also being analysed for chemical composition. The implications from this initial work for Hunter Valley Semillon are important as one of the characteristics of hydroxycinnamates is that they are powerful antioxidants and would give white wines good ageing potential. This study has so far shown that soil type and subregional characteristics may have a role to play in the phenolic profile of the resultant wine.

151. Faster and better measurement of the potent flavour compound rotundone in grapes and wine

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Some important wine aroma compounds can have a strong contribution to wine flavour but only be present at trace concentrations, with extremely low aroma detection thresholds. Rotundone is such a compound, with a level of low ng/L being important to the sensory properties of wines. This compound is of particular interest to the Australian wine industry because it has been shown to be the key impact aroma compound responsible for the 'black pepper' characteristic in cool-climate Shiraz wines, with Shiraz accounting for approximately 25% of the wine-grapes grown in Australia.

To investigate the formation of this compound in the grape berry, and to study the viticultural factors that may affect the variability of rotundone levels in the grapes across the vineyard and from vintage to vintage, a suitable analytical method was needed to quantify the very low concentrations found in grapes and wine. Previously applied analytical methods require large sample volumes, substantial sample preparation and/or triple quadrupole mass spectrometry. A recently improved gas chromatography-mass spectrometry (GC-MS) method increases sample throughput by minimising sample handling, utilising membrane assisted solvent extraction (MASE) and large volume liquid injection. Interference from other compounds eluting around the same time was negated by using a multidimensional GC technique known as heart cutting. The method uses stable isotope dilution analysis with d5-rotundone as internal standard, and has been applied to both grape berry and wine samples.

152. What is the latest in the mechanism of protein haze formation in white wines?

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Protein haze is one of the key instabilities in white wine production and is due to the slow denaturation of proteins followed by their aggregation into insoluble particles that make the wine appear hazy. Haze from wine contains mainly chitinases, thaumatin-like proteins and non-proteinaceous compounds, and is the result of a complex interplay between a range of proteins and chemical and physical factors. Since hazy wines are not saleable, this instability is generally prevented via bentonite fining, a treatment effective in removing the grape proteins responsible for haze formation, but with drawbacks such as wine volume loss and disposal costs, as well as perceived effects on wine flavour and quality. Hence, alternatives are sought. So far, the search for alternatives to bentonite has not yet resulted in commercially viable solutions able to compete with bentonite's efficacy and low cost. It is believed that a better comprehension of the causes of haze is needed, because a thorough understanding of the mechanisms of protein haze formation has the potential to lead to the development of novel, efficient, and environmentally sustainable winemaking processes to prevent haze from forming. Here we present an overview of the recent advances on the study of protein instability of white wines, with particular attention to those obtained by our group. This will include: i) notions on the role of purified wine proteins, ii) explanation of the role of some non-proteinaceous wine components, iii) notions on the effect of different unfolding temperatures and unfolding/aggregation behaviour of grape proteins. A revisited mechanism of haze formation accounting for the several recent breakthroughs in the field will be presented.

153. Proctase – a viable alternative to bentonite for protein stabilisation of white wines

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White wines must be treated to remove proteins which could otherwise aggregate into light dispersing particles and cause unsightly haze. Bentonite is commonly used to remove the grape proteins responsible for haze formation, but is associated with significant processing and environmental costs. Proteases potentially represent an alternative to bentonite, but until now none has shown satisfactory activity under winemaking conditions. Proctase, a mixture of Aspergillopepsins I and II, is proposed as a viable bentonite alternative. It is food grade, well characterised and inexpensive, active at wine pH and at high temperatures (60-80°C). When added to clarified grape juice and combined with short-term heating (75°C for 1 min), Proctase has shown excellent results in removing haze-causing proteins (80-90% total protein reduction). Experiments have been conducted at laboratory, pilot and commercial scale across a range of juices. Sensory and chemical characteristics of wines made from Proctase-treated juice have not shown any significant differences when compared with bentonite-treated controls. In addition, the cost of Proctase treatment has been shown to compare favourably with traditional batch bentonite treatments.

154. The impact of vintage, environmental and viticultural factors on grape and wine composition

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Great wines can only be made from the highest quality fruit, yet a myriad of factors can affect the quality of the fruit that is produced in the vineyard, including environmental factors, geological aspects, viticultural techniques and the impact of the weather.

In order to understand the relative importance of some of these factors, the AWRI, in conjunction with Wynns Coonawarra Estate,

assessed the impact of vintage, soil type and clonal differences on the phenolic profiles of Cabernet Sauvignon grapes grown in the Coonawarra region of South Australia over four separate vintages from 2009 to 2012. 60 kg parcels of fruit were processed using identical winemaking techniques in order to compare the phenolic profiles of the resultant wines. Five Cabernet Sauvignon clones: CW44, G9V3, Reynella, LC10 and SA125, grown in one Coonawarra vineyard comprising two soil types (Terra Rossa and groundwater Rendzina), were utilised.

Results obtained have shown that the average temperature during the growing season was the most significant factor for tannin development in the grapes, with warmer vintages producing fruit with higher tannin levels. Neither clonal type nor soil type had a consistent impact on the accumulation of tannins or anthocyanins in the grapes across the four vintages. Wines produced from clone SA125 grown on Terra Rossa were consistently the most preferred from each vintage, with soil type appearing to influence wine sensory characteristics and resulting preference ratings. Grape tannin concentration at harvest was shown to be particularly important for the stabilisation and development of colour in the wines.

155. Post-bottling effects of early oxygen exposure during red winemaking

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Background: Red wine vinification in closed tanks, while preserving fruit characters, may lead to the development of sulfide-based off-odours. Even with nitrogen supplementation, wine may develop these odours during storage. Introducing oxygen into such ferments is practised by many winemakers whether by aerative pump-overs or introducing air/oxygen through sinters.

Method: To understand this practice, a vinification study was carried out using pilot-scale rotary fermenters with Shiraz grapes using 40% and 20% oxygen and 100% nitrogen introduced during fermentation through sinters and compared against a control with no gas injection.

Results: Evolution of H₂S was considerably decreased early on and was eliminated during fermentation using both oxygen treatments whereas no decrease was observed in nitrogen-sparged and control ferments. Analysis of volatile sulfur compounds periodically over 12 months indicated the continued absence of ethylmercaptan and ethylthioacetate in oxygen-treated wines and significantly decreased levels of methylthioacetate compared to the control. The belief that splashing involved in cellar operations may just be physically displacing H₂S has been disproved given little difference is observed between the control and nitrogen treatments. The oxygen-treated wines had significantly lower concentrations of Cu, Fe, Zn, total phenolics and total free anthocyanins but higher non-bleachable colour. Oxygen also brought about changes in the tannin structural composition commensurate with one to two years of ageing. Informal tasting six months after bottling indicated that the 40% O2-treated wine was still clear of sulfidic odours.

Conclusion: These data suggest that introducing oxygen into a closed red wine fermenter has a remarkable effect on the production of sulfidic off-odours.
156. Targeted and non-targeted analysis of grape and wine metabolites

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Wine composition, flavour and quality are the result of often unique combinations of hundreds of grape and yeast metabolites. Comprehensive, high-throughput profiling methods – both targeted and non-targeted – have been developed by Metabolomics Australia to further unravel the secrets behind wine quality and flavour.

A range of targeted methods are currently available for the quantification of organic acids, resveratrol and its metabolites, amino acids, and sulfur-containing compounds and their precursors. A targeted quantitative method for the high-throughput analysis of organic acids in grape and wine (including malic and tartaric) has been validated using ultra high performance liquid chromatography-tandem mass spectrometric (UHPLC-MS/MS). Using deuterated internal standards and with a run time of five minutes, this method provides an efficient and cost effective way to analyse approximately 250 samples per day.



Figure 1. Analysis of organic acids in grapes and wine by UHPLC-MS/MS



Figure 2. Grape metabolite profile and wine metabolite profile

The AWRI's Metabolomics group is combining cutting edge analytical chemistry techniques (such as high resolution tandem mass spectrometry) with bioinformatics tools for the untargeted, comprehensive profiling of yeast and grape metabolites and for the broad spectrum analysis of wine compounds. Metabolite profiling provides a comprehensive snapshot of wine composition. The information gained as a result of this includes the identification of relevant unknowns, increasing the chances of biomarker discovery and improving understanding of grape and wine quality.

The AWRI's Metabolomics group completed development of a range of robust and reliable profiling methods for sought-after polar and non-polar metabolites. In a recent study, non-polar metabolites were monitored from grapes to wine in three different varieties using HPLC-MS/MS. A total of 700 metabolites were detected in the grapes and wine, with 40 confirmed identifications to date. In general, the metabolite profile of the three grape varieties was different to the metabolite profile of the wines. Bioinformatics tools have identified important information from this data set including high quality peaks showing features that have a low relative standard deviation (RSD) between technical replicates; most intense peaks in the grapes and wine; metabolites unique and common to grapes and wine; and features that can be regulated from grapes to wine.

157. Chardonnay clonal variation – a comparative genomic and phenotypic evaluation

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Background: Chardonnay has an unusual genetic heritage, resulting from a cross, centuries ago in north-eastern France, between Pinot Noir and Gouais Blanc (Bowers et al. 1999). There are now many clones of this variety, some of which have only recently become available in Australia, exhibiting variation in a number of viticultural and oenological traits. Our aim is to assess the genetic variation within, and compare the variation among clones of Chardonnay available in Australia, and evaluate how this variation contributes to chemical and sensory variation in grapes and wines derived from the different clones.

Method: DNA from 15 Chardonnay clones was extracted from young leaves collected from vines in the Riverland (Oxford Landing), Barossa Valley (SARDI research station) and Okanagan Valley, Canada. Whole genome sequences were derived using hybrid assembly of HiSeq and MiSeq sequence from shotgun and mate pair libraries. Grapes were handpicked from 10 clones growing on a single block at Oxford Landing (Yalumba). Small lot wines (24 kg) were made in triplicate from each clone. Sensory evaluation of the wines and chemical evaluation of the grapes and wines was carried out to assign the clones an oenological phenotype.

Results: Sensory descriptors such as stone fruit, citrus and viscosity were important drivers of oenological variation, enabling a classification of clones into three groups. A similar degree of classification was evident from chemical profiling of the juices by hydrophilic interaction liquid chromatography liquid chromatography–electrospray ionization-mass spectrometry (HILIC LC-ESI-MS). Genome assembly and comparative genomic analyses are beginning to shed light on the relationship between clones and how genetic variation gives rise to phenotypic variation in a clonally propagated woody plant species.

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158. Intrabunch variability of rotundone concentration in *Vitis vinifera* cv. Shiraz wine-grapes at harvest

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Black pepper aroma is a desirable feature of high quality Shiraz wine. This unique characteristic is due to a grape-derived sesquiterpene, (-)-rotundone. Because of significant variability in rotundone concentration in grapes and wine from different vineyards, and from the same site in different vintages, research is being conducted to study the impacts of environmental and viticultural management practices on rotundone accumulation. Here, the distribution of rotundone within the grape bunch is reported, and found to be highest in the higher, more shaded part of the grape bunch. The concentration of rotundone in different parts of grape bunches has been observed, and may be due to exposure to ambient radiation and proximity to stems and leaves.

The study was conducted in 2012 in a commercial Shiraz vineyard located at Bayindeen, Victoria, Australia (Grampians). Prior to this study, the experimental block was separated into three vineyard zones based on the vine vigour (plant cell density maps), slope (digital elevation maps) and soil characteristics (EM38) (Scarlett et al. 2014). We selected five sampling points from each of three vineyard zones, and grape bunches were collected at the time of commercial harvest. Each bunch was divided into four parts: top front (TF), top back (TB), bottom front (BF) and bottom back (BB) dependent on position in the bunch and bunch orientation (Figure 1). Rotundone analysis was conducted for each group of collected samples as described by Siebert et al (2008).



Figure 1. Grape bunch separation: top front (TF) stands for the top 40% of the bunch directly exposed to sunlight; top back (TB) stands for the top 40% of the bunch that does not have direct sunlight; bottom front (BF) stands for the bottom 60% of the bunch exposed to sunlight; bottom back (BB) stands for the bottom 60% of the bunch with no exposure to sunlight



Figure 2. Rotundone concentration of berries from different parts of bunch (p<0.05). The coloured letters show differences within each vineyard zone, while the black letters show differences in each part of the bunch between zones

The top part of the grape bunch had relatively higher rotundone than the lower berries (TB>BB, TF>BF) in all three zones (Figure 2). This may be due to their shorter distance from the leaves and main stem which contain high concentrations of rotundone (Capone et al. 2012). Berries on the back of bunches have relatively higher rotundone than those in the front in both zones 1 and 2, except BB is slightly lower than BF in zone 2 (Figure 2). Berries on the back of bunches have relatively low level of solar exposure, and surface temperature. Zone 2 and zone 3 produced grape berries with significantly higher rotundone levels in all part of the bunch except that of the BB group, in which zone 3 has higher rotundone level than both zone 1 and zone 2.

Overall, solar exposure and grape surface temperature, and rotundone level in the vegetal part of vine are important factors that may affect rotundone concentration in grapes. In the 2013 field trial, berry maturity parameters, rotundone, temperature and sunlight will be investigated to understand the origin of rotundone in these vines.

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159. Factors affecting the levels of 3-isobutyl-2methoxypyrazine (IBMP) and C6 compounds in *Vitis vinifera* L. Merlot

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A study concerning seasonal and regional variability showed that fruit IBMP and C6 compounds at harvest are not necessarily higher in cooler climates, compared to warmer regions. Significantly higher levels of green aromas were observed in the warmest and driest of the seasons (2007) rather than the coolest and wettest (2010). Principal component analysis (PCA) identified the temperature during spring (growing degree days, GDD) as a key factor explaining these results, likely due to the direct effects of spring temperature on vine growth, and indirect effects of fruit shading.

A second study focused on irrigation and fertilisation practices, and showed again the significant effect of vine vigour on IBMP levels in fruit and wine. In contrast, C6 compounds were not responsive to these treatments.

Furthermore, a third study focused on winter rainfall, or lack thereof, a factor not previously considered in relation to fruit and wine 'green' aromas. Exclusion of winter rainfall had a very significant impact on IBMP fruit and wine levels, but again C6 compounds were found to be non-responsive to the experimental treatments. A severe imbalance between vegetative and reproductive growth was observed for vines under rainfall exclusion conditions. Significant effects were also recorded for vine yield components.

The studies conducted highlight the importance of conditions promoting vine growth as the main drivers of IBMP fruit and wine levels, mainly due to their negative effects on fruit exposure to light. Therefore, to achieve low IBMP levels at harvest, vineyard management practices that do not promote excessive growth during the spring are required. Otherwise, delayed harvest and decreased yield (due to berry dehydration) would be expected. This work has demonstrated that C6 compounds do not respond to vineyard management practices.

159a. Investigating copper(II) complexes in model wine solutions

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It is well known that metals such as copper and iron are found in both white and red wine. However, much less is known about the complexes that may form between these metals and a range of ligands that are commonly found in wine, such as organic acids and polyphenols. It has been suggested that the presence of such metal complexes could have implications in terms of: influencing the availability of metals to contribute to catalytic cycles, the metal complexes binding important sensory sulfur molecules, the metal complexes playing a role (direct or catalytic) in the release or formation of important sensory sulfur molecules from other molecules found in wine or metal-complexbound sulfur molecules being more susceptible to further chemical changes.

This study investigated copper(II) complexes of tartrate, malate, lactate and citrate, as these ligands are typically found in wines. The acid dissociation constants and binding constants for the ligands and copper complexes were determined in both aqueous and 12.5% ethanol solutions using potentiometric titrations in an attempt to further understand the speciation of copper in wine solutions. The acid dissociation constant of tartaric acid and binding constant of copper tartrate were also determined in 10 and 15% ethanol solutions. The speciation of the synthetic wine solutions was modelled using the acid/ligand and copper concentrations typically observed in wines (Rankine 1971).

It was found that both the pK_a values and copper-ligand binding constants for all the investigated acids increased in 12.5% ethanol solution compared to aqueous solution and that copper binding constants increased with increasing ethanol concentration. However, no difference was observed in the order of the binding constants, with citrate having the strongest binding constant followed by hydrogen citrate, malate, tartrate and finally lactate.



Figure 1. Speciation of copper complexes in 12.5% ethanol solution determined using the experimental pK_a and copper binding constant values and typical concentrations of the acids and copper found in wine

The speciation determined for aqueous and 12.5% ethanol solutions are similar with the data showing that copper tartrate should be the predominant copper complex present in wine as it is the predominating complex in the pH range of 3 to 4 (Figure 1).

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WINE AND HEALTH

160. Tooth structure erosion due to exposure to wine over an extended period: overcoming a significant OH&S risk for winemakers

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Enamel is the exposed surface of the tooth but with wear and gum recession, the softer supporting dentine can easily become uncovered. The major inorganic constituent of enamel and dentine is hydroxy-lapatite (HAP) (Ca₁₀(PO₄)₆(OH)₂) (García-Godoy and Hicks 2008; Hannig and Hannig 2010), arguably the hardest known bio-crystal-line substance.

HAP demineralisation (Figure 1) begins at about pH 5.5 (García-Godoy and Hicks 2008; Chikte et al. 2005; Ranjitkar et al. 2012). Wine pH is usually between pH 3 to 4; and *in vitro* studies confirm that white and sparkling wines (generally lower pH than reds) are more erosive than red wines on tooth structures (Mok et al. 2001; Willershausen et al. 2009).



Figure 1. Tooth structure erosion, HAP demineralisation, in an acidic environment (Hannig and Hannig 2010)

Winemakers are at a particularly high risk of damage given that they are continually bathing their teeth in an acidic solution; sometimes amounting to several hours over a 24-hour period. This major OH&S risk is not being fully addressed (or at best, is under-recognised) by the wine industry (Ranjitkar et al. 2012; Piekarz et al. 2008; Gray et al. 1998; Wiegand and Attin 2007).

With painful symptoms and accumulative long-term effects, wine-related damage can be irreversible and very expensive to repair (Ranjitkar et al. 2012).

Winemakers can significantly reduce their risk and HAP demineralisation can be reversed *if*: adequate time between acid exposures is allowed for remineralisation to occur; *and* suitable products are used; *and* practical measures are implemented (García-Godoy and Hicks 2008; Ranjitkar et al. 2012).

<u>Products</u> designed to help protect tooth structures and readily available for regular use:

• Tooth Mousse is a HAP remineralisation agent made from casein phosphopeptide with amorphous calcium phosphate nanocomplex (CPP-ACP) (García-Godoy and Hicks 2008; Hannig and

Hannig 2010; Ranjitkar et al. 2012; Piekarz et al. 2008) and ideally used with a **Night-guard** (Ranjitkar et al. 2012) – a lightweight, ultra-thin, fitted mouthguard which has the added benefit of reducing wear patterns due to overnight tooth grinding.

- Fluoride enriched toothpaste and mouth rinse can help strengthen tooth structures.
- Sugar-free chewing gum with CCP-ACP will raise mouth pH to neutral levels by stimulating saliva (the mouth's own buffer solution [García-Godoy and Hicks 2008; Chikte et al. 2005]) through the action of chewing while also helping HAP remineralisation (Hannig and Hannig 2010).
- **Soft bristle brush-heads** will help minimise gum recession around the tooth neck and avoid exposing the dentine that is more readily susceptible to erosion.

Practical measures to implement for common situations:

Day-to-day tastings - lengthy breaks between sessions (long-term damage risk)

- Rinse with water after each tasting session.
- Chew sugar-free chewing gum with CCP-ACP for 10-15 minutes.

Intensive tasting days – only short breaks between brackets (rapid damage risk)

- The night(s) before, use Tooth Mousse overnight in a Night-guard.
- In the morning, do NOT brush, instead use a fluoride mouth rinse. Plaque formed overnight provides a protective layer (Cheung et al. 2005) against acid in wine.
- During the day, rinse with water between tasting brackets.
- After completion, rinse with water and chew sugar-free gum with CCP-ACP.
- Do NOT brush your teeth for at least 2 hours afterwards. Acid in the wines tasted will have softened the exposed HAP, leaving it susceptible to abrasive damage (Mok et al. 2001).
- The night(s) after, use Tooth Mousse overnight to help HAP remineralisation.

Companies employing winemakers have a duty of care to support their staff, both in sustaining these practices and purchasing products. Consult your oral health professional to tailor a harm minimisation program to your individual requirements.

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161. The development of a novel and allergenfree biological fining agent for white wines

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The wine industry has developed and implemented sophisticated technologies for the clarification and stabilisation of red, rosé and white wines. Indeed, fining agents were developed to induce the flocculation and sedimentation of wine particles in suspension, allowing its clearing and stabilisation, and thus increasing the quality of wine.

The most commonly used fining agents are proteins of animal origin, namely egg albumin, casein and gelatine. Unfortunately, the use of such proteins raises important food safety concerns due to their association with allergies and food intolerances or to neurodegenerative diseases as Creutzfeldt-Jakob's disease. Still, their use in the production of premium and super-premium wines is unavoidable.

In this work, we have tackled such health concerns and developed a wine fining agent of yeast origin, which is endogenous in wine fermentations, and thus does not raise health concerns to the final consumer of wine. This biological fining agent has proved to have an effect on white wines similar to the application of bentonite, but with a smoother impact on the final sensorial properties of the wine. Indeed, it had a positive impact on the wine brilliance, on its stability and the final intensity of the yellow tonality, as evaluated using a tricolorimetric colour analysis.

Herein, we demonstrate the successful use of a unique biological fining agent of yeast origin, which does not require the use of any fining adjuvant, does not introduce exogenous aroma notes, nor raise food safety concerns.

WINE CONTAMINATION

162. Seeing through smoke: assessing the impact of smoke exposure in grapes and the resulting wine

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Wine produced from grapes exposed to smoke is often downgraded or unfit for sale, due to negative sensory characters known as 'smoke taint'. In response to the increasing incidence of bushfires in proximity to vineyards, the AWRI has concentrated its efforts on developing analytical strategies to detect smoke exposure in grapes and the resulting wine. This is important since it is currently not possible to prevent the uptake of smoke compounds in grapes and vines; it is also not possible to fully remove smoke-derived compounds from smokeaffected wines

Using gas chromatography-mass spectrometry and high performance liquid chromatography-tandem mass spectrometry, two new diagnostic assays were successfully developed and validated based on measurement of:

- volatile phenols that are present in significant concentrations in bushfire smoke
- numerous non-volatile grape metabolites of the volatile phenols (phenolic glycosides) that are present in grapes following smoke exposure.

The combination of the analytical methods together with comprehensive data about the natural abundance of smoke-related compounds allows identification of smoke exposure and assessment of its likely impact. In particular, on the basis of phenolic glycoside concentrations samples can be categorised where the concentration of volatile phenols is very low or where negative sensory characters are not obvious early in the winemaking process.



Figure 1. Guaiacol and total phenolic glycoside concentrations of grapes and wine samples suspected of smoke exposure

Phenolic glycoside analysis is a more reliable approach for assessing potential smoke exposure in grape and wine than guaiacol analysis alone. This is shown in Figure 1 which illustrates the guaiacol and total phenolic glycoside concentrations (sum of six selected glycosides) of grapes and wine samples suspected of smoke exposure. In grapes, according to their total phenolic glycoside concentration, 36 out of 136 samples were classified as smoke-affected. According to their guaiacol concentration, only 17 of the samples were correctly identified as affected. Of six samples containing total phenolic glycosides at concentrations exceeding 100 μ g/kg, all were incorrectly diagnosed as 'not smoke-affected' by guaiacol alone, indicating how important phenolic glycoside analysis is as a means for detection of smoke exposure. Meanwhile, 50 wines out of 150 samples were classified as smoke-affected according to their total phenolic glycoside concentration while only 13 were classified smoke-affected by the free guaiacol measurement.

163. Improved headspace GC-MS analysis of geosmin in grey mould affected wine

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Grey mould (*Botrytis cinerea*) of grapes is a widespread bunch rot disease that can cause a decrease in grape yield and leads to various off-flavours and aromas in finished wine. One of the compounds probably responsible for this loss of wine quality is geosmin, a volatile fungal metabolite, which causes earthy odours (Darriet et al. 2000).

This study reports on the optimisation and application of a robust and simple headspace solid phase micro-extraction gas chromatography-mass spectrometry (HS-SPME–GC–MS) method for determination of geosmin.

Different concentrations of geosmin with geosmin-D3 (methyl), deuterated isotopes of geosmin, 240 ng/L were prepared in wine base solutions and injected into an Agilent 7890A gas chromatograph with automated solid phase microextraction capability to design a standard curve for geosmin qualification.

Three batches of wine were made from Semillon grapes (February 2011) with three levels of grey mould infection as assessed by visual inspection: control (clean fruit that was apparently healthy), low level and high level of *Botrytis* infection. The geosmin levels in these three different wines were analysed by GC-MS and sensory descriptive analysis was later used to illustrate differences in final wine attributes.

Analytical sensitivity and reproducibility quantification was achieved using a calibration curve constructed for geosmin with a linear regression equation with a coefficient of determination $(r^2) = 0.99$ (Figure 1). Wine made from grapes with the highest level of grey mould had significantly more geosmin (Table 1). This result agreed with the sensory descriptive analysis of wine which indicated that the wine made with the higher level of grey mould had greater mouldy characters (Figure 2).



 $\ensuremath{\mbox{Figure 1.}}$ Standard curve for geosmin qualification. . Results are the means of three replicates

 $\label{eq:table_to_stable} \begin{array}{l} \textbf{Table 1}. \ \mbox{Geosmin levels in wine with different level of infection. Results are the means of three replicate batches of wine} \end{array}$

Wine with different level of infection

	Control	Low	High
Geosmin content	12.21 ± 1.4 ^a	8.44 ± 2.6 ^a	26.58 ± 5.6 ^b



Figure 2. Mean attribute intensity of wines for each treatment group (control, low and high level infection)

Since wine made from grapes with a high level of *Botrytis* contamination showed the most mouldy and oxidised characteristics and also had higher geosmin levels, it can be concluded that geosmin is one of the compounds that is responsible for undesirable aroma in wine made from grey mould affected grapes. Separate to this study the presence of *Botrytis* antigens was confirmed in both apparently healthy and grey mould affected grapes and wine (see Poster 137).

References

164. The effect of grape variety and smoking duration on the accumulation of smoke taint compounds in wine

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The risk of bushfires is on the rise due to global warming, and as a result prescribed burnings are also on the rise, to reduce the risk of bushfires. Research has established that wine-grapes exposed to smoke can lead to wines which exhibit undesirable characteristics known as 'smoke taint'. Repeated and long smoke exposure is often seen in bushfires, resulting in increased accumulation of smoke taint compounds in berries and subsequent wine, whilst different winegrape varieties can also exhibit different smoke-taint 'profiles.'

In this study controlled smoking experiments were performed on harvested berries of seven different wine-grape varieties. The aim of the experiment was to investigate whether volatile smoke taint compounds increase proportionally with time, using berries and wines made from grapes that were smoked for one hour compared to three hours. The relative effect of smoking duration on uptake of taint compounds for different varieties was also investigated. A modified industrial oven fitted with an extraction fan was used as the smoking chamber, and a purpose-built smoker was used to transfer smoke (derived from barley straw) into the chamber. Freshly-harvested berries from seven wine-grape varieties were smoked together in order to minimise variation and ensure each variety was exposed to the same intensity of smoke. Each variety was smoked for two time intervals, representing medium (one hour) and high (three hours) smoke exposure, in addition to unsmoked controls. The berries from each treatment were made into two duplicate wines using conventional small-scale winemaking practices, with red varieties fermented on skins and white varieties without skins. The berries and wines from each smoking treatment (plus unsmoked controls) were analysed for free smoke taint compounds by gas chromatography-mass spectrometry (GC-MS).

The total free phenols measured were higher across all varieties in wine-grapes exposed to smoke for three hours compared to one hour, in both berry (Figure 1) and wine (Figure 2) samples. Of these wines, Sauvignon Blanc showed the highest total free phenol concentrations within both the berries and wine samples for the three hour smoking, followed by Chardonnay, despite differences in winemaking.



Figure 1. Concentrations (mg/L) of total free forms of smoke taint phenols for berry samples for seven different wine-grape varieties smoked for one hour and three hours, along with unsmoked controls. Homogenised berry supernatant samples were used for analysis of Shiraz, Merlot, Cabernet Sauvignon, Pinot Noir and Pinot Gris; free run juice was used for Chardonnay and Sauvignon Blanc. All control samples showed total concentrations below 30 mg/L.



Figure 2. Concentrations (mg/L) of total free forms of smoke taint phenols for wine samples for seven different wine-grape varieties smoked for one hour and three hours, along with unsmoked controls. Results are average of two duplicate wines. All control samples showed total concentrations below 50 mg/L.

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The relative differences between one and three hours' smoking for individual compounds varied amongst varieties (Table 1), and were not consistent from berries through to subsequent wine. Results showed that Pinot Gris was least affected by smoke exposure and had the least increase in free phenols with extended smoke duration. Shiraz and Merlot berries showed the largest difference between one and three hours' smoking, although this difference was less in the wine.

Overall, this study has shown that an increase in the duration of smoke exposure increases the concentration of free phenols in grapes and wine, although this increase is not proportional to the increase in smoke duration. The effect of increased smoke exposure is also not consistent across varieties.

Table 1. Relative differences between one and three hours' experimental smoking for individual free smoke taint phenol concentrations for seven wine-grape varieties for both berry and wine samples. (Calculated by dividing concentration measured for each compound after three hours of smoking by concentration measured after one hour smoking, for each variety. Rounded to nearest whole number.) Homogenised berry supernatant samples were used for analysis of Shiraz, Merlot, Cabernet Sauvignon, Pinot Noir and Pinot Gris; free run juice was used for Chardonnay and Sauvignon Blanc.

		Phenol	o-cresol	p-cresol	m-cresol	4-ethylphenol	2,4-dimethylphenol	Guaiacol	4-methylguaiacol	4-ethylguaiacol	Syringol	Total Phenols
Shiraz	Berries	8	11	11	11	12	11	8	8	9	6	9
	Wine	3	3	3	3	3	3	2	2	2	2	2
Cabernet Sauvignon	Berries	4	5	5	5	7	6	3	4	5	3	4
	Wine	3	3	3	3	3	3	2	2	2	3	3
Pinot Noir	Berries	4	4	3	3	5	5	3	3	4	3	3
	Wine	2	3	2	2	2	3	2	2	2	2	2
Merlot	Berries	7	9	9	9	13	13	6	8	9	4	7
	Wine	2	3	3	3	3	3	2	3	2	2	2
Pinot Gris	Berries	1	3	2	2	3	4	2	2	3	2	2
	Wine	1	2	1	2	2	2	1	1	1	2	1
Chardonnay	Berries	2	2	2	2	2	3	2	2	2	1	2
	Wine	3	3	2	3	3	2	2	2	2	2	2
Sauvignon Blanc	Berries	4	5	4	4	5	5	3	4	4	3	4
	Wine	3	4	3	3	4	3	3	3	3	3	3

Poster PDFs



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Canopy management



1. Influence of proactive and reactive canopy management techniques on wine quality in Shiraz (*Vitis vinifera* L.)



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Clarification and maturation



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3. An evaluation of filtration media in terms of colour adsorption and filtration performance

- 4. Turbidity versus filterability as a means of evaluating wine impact on filtration media
- 5. OPTIOAK[™]: optimising oak aromas through near real-time analysis
- 6. Use CMC in white, red and rosé wines and maintain the high quality of your wine!
- 7. Microwaves aid in accelerating yeast autolysis
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Climate change



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11. Impacts of global warming on grape phenology and vine growth



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15. Immobilised yeast as strategy to control the ethanol level in wine

16. Monitoring the indigenous yeast microbiota of Chilean Carmenere grapes during spontaneous fermentation

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18. Identifying genes of oenological importance in commercial winemaking yeast

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21. The structure and dynamics of the wine's fermentation microbiome

22. Genome screening as an approach to understand the cellular mechanisms behind yeast adaptation during fermentation to allow for successful completion

23. Second generation yeast with reduced hydrogen sulfide and sulfur dioxide production

24. Chemical and sensory differentiation in red and white wines made by 'wild' yeast fermentation

25. Unravelling citrate metabolism in Oenococcus oeni under different wine conditions

26. Identification of bacteria associated with 'wild' or uninoculated malolactic fermentations in red wine

27. Restarting stuck wine fermentations using an evolved wine yeast

28. Can non-conventional yeast be used for the production of wines with lower alcohol concentration?



29. The 'dynamic' crusher: a new technological concept for extraction of harvested grapes in oenology

30. Understanding the genetic basis of tolerance and sensitivity to low pH in wine yeast

Fermentation



31. Introducing a new breed of wine yeast: interspecific hybrids between *Saccharomyces cerevisiae* and *Saccharomyces mikatae*

32. Systems Biology: a new approach to industrial yeast strain development

33. Assessing the compatibility of the MLF starter culture 'Anchor Co-inoculant' with different wine yeasts and nutrients

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Grape and wine aroma, flavour and colour



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Microbial spoilage



83. Abduction of ethylphenol precursors in wine via the formation of pyranoanthocyanins by selected yeasts

84. Comparative genomics of the spoilage yeast Dekkera (Brettanomyces) bruxellensis



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New vineyard technologies





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Pests and disease



86. Parasitic wasps that attack light brown apple moth: why do some species occur in vineyards and not others?

88. Effect of brown marmorated stink bug on wine – impact on Pinot Noir quality and threshold determination of taint compound trans-2-decenal

89. Susceptibility of grapevine inflorescences to *Greeneria uvicola* and *Colletotrichum acutatum*: management of bitter rot and ripe rot of grapes with fungicide sprays at flowering

90. Population dynamics of grape berry microflora during different stages of berry development

91. Resistant rootstocks – making the right choice to protect against endemic strains of grapevine phylloxera

92. Bacterial inflorescence rot – a costly problem in some cool regions

93. 'Bot' fungi (from rootstock source plants) and black-foot fungi (from nursery soil) can infect grapevines during propagation, causing young vine decline

94. Disinfest the pest! There are many ways to protect against the spread of grapevine phylloxera

95. Wine industry bio-protection: early detection of grape phylloxera (*Daktulosphaira vitifoliae* Fitch) infestation by LC-MS-based metabolomics methods

96. Comparison of methods for quantification of *Botrytis* bunch rot in white wine-grape varieties

97. Pathogenicity of Botryosphaeriaceous fungi isolated from grapevines in south-eastern Australia

98. Isolation and identification of entomopathogenic fungi from vineyard soil

99. The effect of organic, biodynamic and conventional vineyard management inputs on growth and susceptibility of grapevines to powdery mildew

100. Consistency of fungicide deposition and stability concentration of the spray mix using a recycling vineyard sprayer



Phenolics in red wine



101. 'Cutting Edge Pinot' - reducing skin particle size early in fermentation is the key

102. Wine quality vs seediness: differential extraction of skin and seed tannins

103. Waste not, want not: winery waste can be recycled to improve wine quality

104. Ever reliable Chardonnay?: co-fermentation of Pinot Noir must with Chardonnay pomace compromises colour stability

105. Addition of oenological tannins at the beginning of Pinot Noir maceration – impact on colour stabilisation

106. Microwave maceration of Pinot Noir: phenolically equivalent, aromatically distinct

107. 'Shining the light on wine shows' – rapid spectral wine analysis linked with show performance

108. Microwave maceration for control of laccase and enhanced phenolic outcomes in Shiraz wine

109. Microwave maceration for finished Pinot Noir wine in 37 days

110. The influence of delayed malolactic fermentation on Pinot Noir phenolic profiles

111. Manipulation of Pinot Noir colour and tannin profiles during maceration

112. Sensory properties of wine tannin fractions: implications for in-mouth sensory properties

113. The French Paradox, reality or myth?



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Soil and irrigation management



114. Organic soil amendments, including biochar, improve vineyard soil health by increasing populations of beneficial bacteria, fungi and nematodes

115. Setting benchmarks for soil quality in Australian viticulture

116. Assessing the feasibility of recycling winery wastewater for vineyard irrigation – soil, grapevine and wine responses

117. Irrigation strategies can change the allocation of chloride in Shiraz grapevines subjected to saline irrigation

118. Deep ripping and mounding: an evaluation of site pre-planting soil management practices

119. Can rainfall harvesting reduce soil salinity and increase the appeal of recycled wastewater for irrigation?

- **120.** Grapevine response to long term saline irrigation
- **121.** High potassium in winery wastewater can contribute to soil structure degradation

122. Long-term impact of winery wastewater irrigation on soils

123. Beneficial crop options using winery wastewater



Vine nutrition



124. Assessing vine response to increasing compost application rates in high and low vigour zones



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Viticulture and the environment



125. Effect of smoke exposure and leaf removal on the sensory properties of Chardonnay wines

126. Impact of smoke exposure on different grape varieties

127. Evaluating native insectary plant species to boost beneficial arthropod populations in vineyards

129. Microbial communities in the vine: a dynamic study

130. Does fruit maturity influence the intensity of smoke taint in wine?

131. Chloride and sodium concentrations in grape juice of Shiraz are influenced by seasonal rainfall and irrigation applied

132. Investigating mechanisms underlying poor fruit set of grapevine during salt stress

133. Rootstocks and water use efficiency II: the role of hydraulic conductivity in determining conferred vigour

134. Biodynamic vs conventional viticulture in Australia: a comparison of costs and operations



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Wine and grape composition and analysis



135. Extraction of oak volatiles and ellagitannins compounds and sensory profile of wine aged with French winewoods subjected to different toasting methods: behaviour during storage time

136. The significance of pressing conditions on key aroma volatiles of Marlborough Sauvignon Blanc

137. Use of lateral flow devices for the estimation of *Botrytis* antigens in dessert wines

138. An objective measure of sparkling wine quality?

139. Should we crop high or low for Pinot Noir sparkling base wines?

140. Does removing leaves improve sparkling base wine composition or does it just make us feel better?

141. New measures of polyphenols and antioxidants in grape juice and wine using electrochemical sensors

142. Discovering and characterising genes involved in tartaric and malic acid metabolism

143. In-bottle analysis of sparkling wine tirage fermentation and maturation

144. Does cluster thinning improve Pinot Noir quality or just thin your profit?

145. Isolation of tannin standards for the investigation of tannin structure and function

146. What determines the amount of tannin extracted from grapes into wine?

147. Nanosensors for wine quality analysis

148. Influences of vine clone, yeast strain and canopy density on volatile thiols, their potential precursors and sensory attributes of Sauvignon Blanc wines

149. Astringency: a physical approximation

150. The Hunter Valley Semillon project: links between soil type and phenolics



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Wine and grape composition and analysis



151. Faster and better measurement of the potent flavour compound rotundone in grapes and wine

152. What is the latest in the mechanism of protein haze formation in white wines?

153. Proctase – a viable alternative to bentonite for protein stabilisation of white wines

154. The impact of vintage, environmental and viticultural factors on grape and wine composition

155. Post-bottling effects of early oxygen exposure during red winemaking

156. Targeted and non-targeted analysis of grape and wine metabolites

157. Chardonnay clonal variation – a comparative genomic and phenotypic evaluation

158. Intrabunch variability of rotundone concentration in *Vitis vinifera* cv. Shiraz wine grapes at harvest

159. Factors affecting the levels of 3-isobutyl-2-methoxypyrazine and C6 compounds in *Vitis vinifera* L. Merlot

159a. Investigating copper (II) complexes in model wine soloutions



Wine and health



160. Tooth structure erosion due to exposure to wine over an extended period: overcoming a significant OH&S risk for winemakers

161. The development of a novel and allergen-free biological fining agent for white wines



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Wine contamination



162. Seeing through smoke: assessing the impact of smoke exposure in grapes and the resulting wine

163. Improved headspace GC-MS analysis of Geosmin in grey mould affected wine

164. The effect of grape variety and smoking duration on the accumulation of smoke taint compounds in wine



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