Techniques to achieve moderate alcohol levels in South African wine

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Abstract

The alcohol content of unfortified wines is increasing worldwide. Statistics from three winemaking regions are presented to demonstrate this trend.

Some commentators have suggested that the stylistic change has been overdone, and that winemakers now need to seriously consider limiting and even reducing alcohol levels in wine.

A basic mathematical model is presented for how yeasts convert sugar in grapes into alcohol. This model is compared with published linear approximations and practical experience.

The trend to higher alcohols and growing criticism of high alcohol wines raise the question of how to achieve moderate alcohol levels.

Techniques can be employed to achieve moderate alcohols during establishment of a vineyard as well as subsequent viticultural practices. These include choice of vineyard site, decisions during its establishment, canopy management, limiting bunch thinning and bud removal, virus infection, water management, dealing with methoxypyrazines, and harvest timing.

Further options are available in the winery to obtain moderate alcohol levels. Application of glucose oxidase enzyme, membrane treatments applied to the must and addition of water can be considered before fermentation. For fermentation, choice of yeasts, temperature, evaporative losses, and residual sugar can play a role. After fermentation, removal of alcohol and barrel maturation can both be used.

Although winemaking interventions are possible to reduce alcohol levels and even to cure excessive alcohol, viticultural intervention is likely to be more important overall.

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1. Introduction

Excessive alcohol levels in wine are raising concern in the wine trade. This document reviews techniques that can be applied in the production of wine to achieve moderate alcohol levels.

South African wine writer Michael Fridjhon recently lamented “the ever-increasing alcohol levels that have become a feature of ‘new-style’ South African red wines”. He went on to note that

> We all want our wines to deliver on taste, and we all wish to avoid the kick of the mule. (Fridjhon 2006)

Mat Garretson of Garretson Wine Company in Paso Robles, California says that high alcohol levels in his wines (for instance 15.9% for his 2003 Syrah) are becoming a problem because many potential clients pay attention to them. Therefore, at wine tastings he now only reveals alcohol levels after the wines have been tasted (Kakaviatos 2006).

Margaret Duckhorn of Duckhorn Wine Company, Napa Valley, California claims “it is what the consumer is used to drinking, thus those who are not used to tasting wines that have not achieved the full ripeness have a different expectation than those that are used to drinking fruity wines that have fully developed flavors” (Kakaviatos 2006).

1.1 Definitions

Alcohol Alcoholic drinks contain ethanol as well as higher alcohols such as 1-propanol, 2-methyl-1-propanol, 2-methyl-1-butanol, and 3-methyl-1-butanol (Boulton et al. 1996, p.150). In this document, alcohol will refer to ethanol.

Concentration Concentration of solutes in solutions can be expressed as a percentage by weight, a percentage by volume, as a ratio of weight of solute to volume of solution, or a ratio of volume of solute to weight of solution. The concentration of alcohol in an alcoholic drink is usually expressed as the notional percentage by volume of the drink that would be pure alcohol.

Wine In South Africa, unfortified wine is required to contain at least 6.5% and less than 16.5% alcohol by volume (South African Government 1990).

1.2 Scope and contribution

This document assumes a basic background in the theory of viticulture and oenology; familiarity with standard terminology is assumed.

The aim of this document is to outline those techniques, decisions and interventions that are relevant to achieving moderate alcohol in wine production in South Africa. Issues relevant in cooler climates are therefore not addressed. It is assumed that grapes can ripen reasonably fully, and that achieving moderate alcohol relates to reducing excessively high alcohol levels in the final product, or maintaining moderate alcohols currently obtained, as opposed to requiring addition of sugar to raise potential alcohol.

This document does not explicitly deal with techniques that aim to achieve zero alcohol or low-alcohol wines, although some of the techniques discussed can be used for this purpose. The aim is also to consider techniques that are or might become practical for producers. Treatments designed for laboratory or experimental use only are therefore not dealt with. Finally, some interventions are investigated that were previously outside the South African legal framework regulating wine, as well as some interventions that are legal in some winemaking regions but not South Africa. Interventions that could be useful in achieving moderate alcohols but which are illegal in all winemaking regions, such as addition of potentially harmful substances, are not discussed.

1.3 Overview of document

Alcohol concentration in wine and measures of must density are discussed in Chapter 2. The concept of moderate alcohol concentration in wine is presented, and several reasons are presented why achieving this is desirable. This provides a motivation for the topic of this document. However, there is a trend to increased alcohol levels in wine around the world, and evidence for this trend is presented.

Chapter 3 reviews how alcohol is produced during fermentation from sugar in grapes, and presents a mathematical framework to relate sugar concentration to final alcohol levels. The role of conversion factor is discussed and contrasted with practical experience. This provides a theoretical foundation for this document.

Chapter 4 is concerned with options that can help to achieve moderate alcohols during establishment of a vineyard and subsequent viticultural practices.

Chapter 5 then considers options available in the winery, before, during and after fermentation.

The main points are then reviewed in Chapter 6.

2. Background

Wine contains mostly water (usually over 80%), and alcohol is the second most important component (usually 8% to 16%). This chapter discusses alcohol in wine, what is meant by moderate alcohol, and why moderate alcohol is desirable. The underlying trend of increasing alcohols is then presented.

2.1 Alcohol

A unit of alcohol is 10ml. This is a measure most frequently used in the UK. Other countries use a concept of a “standard drink”, which varies widely, from 12ml of alcohol in Iceland to 25ml in Japan (Tapson 2006). Regardless of these different measures, a bottle of wine containing 16% alcohol by volume contains 33% more alcohol than a bottle containing a wine at 12%. At 12% alcohol, a 750ml bottle wine contains 90ml or 9 units of alcohol, while at 16% by volume, a 750ml bottle contains 12 units (Robinson 1988, p.103).

Peynaud (1987, p.172) defines a wine as *alcoholic* if “the taste of alcohol is clearly noticeable when tasting” the wine, and “the alcohol dominates the other elements to excess”.

2.1.1 Measures of must density

The main constituents of grapes are water, sugars, polysaccharides, and acids.

Brix or Balling is a measure of the weight of sugars in must, as a percentage of the total weight. It is expressed in symbols as °Brix, or °B, or in words as degrees Brix or degrees Balling, but the ”degrees” is often dropped in common usage. Brix and Balling are different, technically speaking, as Brix is calibrated at 20°C, while Balling uses 17.5°C as its reference temperature (Boulton et al. 1996, p.194). However, the difference between the two scales is small, about 0.18 degrees, so they are often regarded as identical for practical purposes. Balling is the usual term in South Africa, so in this document this term will mostly be used instead of Brix, which is used in the USA, Australia and Europe.

Two other density scales are frequently used in wine literature. Baumé is a measure of density that is approximately related to potential alcohol at sugar levels around 22°B, but only if the non-sugar content is ignored. It is mostly used in Europe, especially France. Öchsle (often written Oechsle) is a scale that is directly related to the specific gravity, by subtracting 1 and multiplying by 1000. This scale is often used in Germany (Boulton et al. 1996, p.194).

For ease of reference, Table 2.1 shows approximate conversions between the different must density measures. The table is calculated using

$$°\text{B} = 261.3(1 - 1/g)$$

and

$$\text{Baumé} = 145(1 - 1/g),$$

where g is the specific gravity of the liquid at 20°C. These are approximations obtained by nonlinear regression of published tables (Boulton et al. 1996, p.194).

2.1.2 Tools for measuring density

A refractometer or hydrometer measurement of juice is usually used to estimate the sugar content of grapes (Jackson 2000). These instruments actually measure the relative density of the must compared with water. In unripe grapes the readings from such instruments are dominated by the acids present, and will therefore overestimate the actual sugar present in the grapes. Above 18°B density measurements are regarded as reasonably accurate since at these ripeness levels the largest part of the total soluble solids in grapes consists of sugars, mostly glucose and fructose (Jackson 2000, p.236). However, there is still some inaccuracy involved, and up to 3.5°B of the measured density may be made up of substances other than sugar even in fully ripe grapes (Boulton et al. 1996, p.197).

2.2 Moderate alcohol

Moderate alcohol is a fluid concept.

Peynaud (1984, p.199) wrote that a "good wine ought to be between 11 and 12%. Below this the wine runs the risk of being weak and small, unless it is particularly rich in aroma. Above that it is hot and too heady, its higher alcoholic content making it difficult to drink in reasonable quantities."

During the April 2006 barrel tasting week covering the 2005 Bordeaux vintage, Paul Pontallier of Château Margaux stated that "[f]or the Margaux *terroir*, there would never be a truly great wine at 13.5% or above" and that "[f]or me, high alcohol is a real enemy of fine wine". Pontallier specifically mentioned that Merlot alcohol levels were up to 15.5% but that this was only used for their second wine. Jean-Claude Berrouet of Château Petrus stated "we seek fruit and freshness... The taste of prunes does not interest us", and explained that wines from all over the world

Öchsle	Baumé	°B/Brix	Öchsle	Baumé	°B/Brix
0.0	0.00	0.0	105.8	13.87	25.0
39.8	5.55	10.0	106.7	13.98	25.2
60.9	8.32	15.0	107.7	14.09	25.4
65.2	8.88	16.0	108.6	14.21	25.6
69.6	9.43	17.0	109.6	14.32	25.8
74.0	9.99	18.0	110.5	14.43	26.0
78.4	10.54	19.0	111.4	14.54	26.2
82.9	11.10	20.0	112.4	14.65	26.4
83.8	11.21	20.2	113.3	14.76	26.6
84.7	11.32	20.4	114.3	14.87	26.8
85.6	11.43	20.6	115.2	14.98	27.0
86.5	11.54	20.8	116.2	15.09	27.2
87.4	11.65	21.0	117.1	15.20	27.4
88.3	11.76	21.2	118.1	15.32	27.6
89.2	11.88	21.4	119.1	15.43	27.8
90.1	11.99	21.6	120.0	15.54	28.0
91.0	12.10	21.8	121.0	15.65	28.2
91.9	12.21	22.0	121.9	15.76	28.4
92.8	12.32	22.2	122.9	15.87	28.6
93.8	12.43	22.4	123.9	15.98	28.8
94.7	12.54	22.6	124.8	16.09	29.0
95.6	12.65	22.8	129.7	16.65	30.0
96.5	12.76	23.0	134.6	17.20	31.0
97.4	12.87	23.2	139.6	17.76	32.0
98.4	12.99	23.4	144.5	18.31	33.0
99.3	13.10	23.6	149.6	18.87	34.0
100.2	13.21	23.8	154.7	19.42	35.0
101.1	13.32	24.0	180.8	22.20	40.0
102.1	13.43	24.2	208.0	24.97	45.0
103.0	13.54	24.4	236.6	27.75	50.0
103.9	13.65	24.6	266.6	30.52	55.0
104.9	13.76	24.8	298.1	33.30	60.0

Table 2.1: Approximate conversion table between measures of must density.

now have excess alcohol, "because of warmer climates, but also because of later harvesting, greater leaf clearing and green harvests". (Kakaviatos 2006)

Even some who making a living from dealcoholising wine appear to believe things have gone too far. Clark Smith is the founder of Vinovation, a California company offering dealcoholisation services, and recently made the following observations.

> We convinced people that Brix had nothing to do with ripeness, but we should have taught them what ripeness was first. We've got a lot of Lulus out there who are letting the grapes hang until Christmas, and then they have no life or longevity, and they don't taste very good. That was a big mistake. We told them to throw away the refractometer, but we should have taught them to go out there and taste the fruit. (Cutler 2005)

This document does not attempt to clearly define what is meant by moderate alcohol. The aim is to survey techniques to achieve alcohols that are in the approximate range 8% to 13% alcohol by volume, with the lower range being characteristic of aromatic off-dry Rieslings from the Mosel-Saar-Ruwer region in Germany, and the upper end being typical of classed growth Bordeaux in a good vintage. It is left up to the reader to interpret the exact range.

2.3 Reasons for moderate alcohol

It can be argued that moderate alcohol is desirable in wines. Some of these reasons relate to health, legal limits on alcohol for drivers, food with which alcohol is paired, and stylistic aims of the wine producer. Each of these is now reviewed.

2.3.1 Alcohol and health

When alcohol is consumed, it is absorbed into the bloodstream. The concentration of alcohol in the blood of an individual consuming alcohol therefore rises. The alcohol is then metabolized by the liver, at a rate of one unit of alcohol per hour in men and somewhat less in women (Robinson 1988, p.109), although figures of 1.25 to 1.875 units per hour have also been suggested (McGee 2004, p.719). This means that over time the liver completely eliminates alcohol in the bloodstream.

Moderate consumption of alcohol is defined as 12.5 to 25ml alcohol per day for women and 12.5 to 44ml for men (Blackhurst and Marais 2006). Exceeding these consumption levels is associated with increased health risks.

If the alcohol content of wine increases from 12% to 16% (an increase of 33%), the amount of alcohol in a given measure of wine will also increase by 33%. The measures that people use to gauge how much they have had to drink (e.g. two glasses with a meal, three glasses with a leisurely meal) may therefore start to seriously underestimate the actual consumption.

A separate issue is that the total nutritive content of wine is largely determined by the concentration of sugar and alcohol. For those pursuing calorie-restricted diets, alcohol levels play an important role in determining which wines to consume (Dann and Burr 2006).

From a health perspective, the total quantity of alcohol consumed over the long term should not be excessive. The liver needs to process all the alcohol that is ingested, and excessive ongoing consumption of alcohol has been linked to cirrhosis. This is a condition where liver tissue is progressively replaced with scar tissue, leading to progressive loss of liver function (Robinson 1988, p.69).

Moreover, keeping the short term blood alcohol concentration moderate is also important. Different individuals will reach the same levels of blood alcohol concentration at different rates of consumption, with females and those of lower body mass tending to reach a given concentration sooner. Excessive levels of alcohol in the blood can be toxic and lead to death.

Since the liver metabolizes alcohol, if alcohol is consumed over several hours a lower blood alcohol concentration will be reached than if the same amount is consumed at once. It is therefore possible to consume a relatively large quantity of alcohol over several hours while maintaining a relatively low blood alcohol concentration level. On the other hand, it is also possible to reach a high blood concentration level by ingesting a relatively small amount of alcohol all at once (for instance, if it is injected directly into the bloodstream).

The level of blood alcohol concentration is not only relevant from a health perspective, but also has specific legal implications.

2.3.2 The law

Alcohol in the bloodstream results in slowed transmission of nerve signals, causing impaired judgement and slowed reactions (Robinson 1988, p.51). For this reason, legal limits exist in most countries for the acceptable concentration of alcohol in the bloodstream for driving a vehicle on public roads.

No alcohol is permissible (or is only permitted below the detection threshold of available measuring equipment) in Nigeria, Eritrea, Malawi, some countries in the Middle East that proscribe consumption of alcohol, as well as many countries in Eastern Europe. In contrast, a few countries (including Congo and Ethiopia) set no limits at all on blood alcohol concentration. Most countries have limits in between these extremes, with the value of 0.05% blood alcohol concentration being common (Wikipedia 2006).

The South African legal limit for driving a passenger vehicle is 0.05% alcohol in the bloodstream, with an even lower limit of 0.02% applying to professional drivers (South African Government 1996).

Suppose a person requires three units of alcohol to reach the legal limit for driving a passenger vehicle; this is roughly equivalent to a 60kg woman consuming the alcohol over four hours, or an 82kg man consuming over one hour. This means that the person can drink one-third of a bottle of 12% wine (or two 125ml glasses), but only 200ml (1.6 glasses) of a 15% alcohol wine, before reaching the legal limit. In France, a decrease in wine sales in restaurants of up to 15% has been attributed to more vigorous policing of the legal blood alcohol limits (Lechmere 2003).

Not only does it take less wine with higher alcohol to reach the legal limit, but alcohol is absorbed into the bloodstream more quickly from alcoholic drinks with an alcohol content in the range 15 to 30% (Robinson 1988, p.109). This provides a further reason to seek moderate alcohol levels in table wines. However, if wine is consumed with food, the alcohol will tend to be absorbed more slowly than if the wine is consumed on its own (Robinson 1988, pp.61–62).

2.3.3 Food

In many countries wine is seen as a foodstuff and forms an essential part of meals. The prevalent view in much of the wine trade is that excess alcohol in wine detracts from its suitability as a foodstuff, by dominating the other flavour components in the wine as well as the food with which the wine is paired. Here is a slightly extreme example of this view:

> The influence of the producers and propagators of these ‘full frontal’, opaque, fruit-packed wines with an almost obscenely high alcoholic content, is, in my opinion, disastrous. It is now admitted – though not by all – that they are too heavy for food, too heady as a drink. (Broadbent 2005)

2.3.4 Stylistic choices in winemaking

Although “there is no doubt that *Wine Spectator* and Robert Parker prefer bigger, richer, more intense wines” according to Bob Lindquist of Qupe Wine as quoted by Kakaviatos (2006), not all winemakers or consumers are looking for this style of wine. The classic lighter styles, like Mosel Riesling at Kabinett ripeness level, Vinho Verde, and lighter Italian reds, have been making a comeback in the last few years, with hot summers in the Northern Hemisphere in 2003, 2005 and 2006, and more diverse flavours in food.

There is now growing commentary that high alcohol wine can be tiring, difficult to drink, does not refresh, and there seems to be a move by consumers internationally to demand wine with moderate alcohol levels.

> Wines relatively high in alcohol – over 13 per cent for example – can taste sweet even if they contain practically no residual sugar. Wines whose alcohol level robs them of their balance may 'burn' or taste 'hot', especially in the after-taste. (Robinson 1999, *Ethanol)*

2.4 Trends

There is some evidence that alcohol levels in wines have been rising over the past two to three decades.

Icon wines such as Sassicaia have increased from 12% to 14% between 1995 and 2003 (Rand 2006). Ornellaia, another icon Italian wine, was 12.5% for the 1985, 13% between 1988 and 1994, 13.5% from 1995 to 1996, 14% for 1997, and 14.5% subsequently (Lowe 2006).

Unfortunately South African Wine Industry Information & Systems, which tracks production statistics in South Africa, does not report statistics that could be used to analyse trends in alcohol concentration.

Some statistics are available for average final alcohol levels for Australia, although detailed statistics are only available to those who have paid the Australian research levy (Australian Wine Research Institute 2005, p.30). Based on published graphs, it is clear that there is a trend of increasing alcohol in the red wines analysed by (Australian Wine Research Institute 2005, p.44), with average and mean alcohol levels rising from 12.4% in 1984 to 14.2% in 2002. Godden (2000) suggests linear models that over the period 1985 to 2000 show an increase of about 0.07% alcohol by volume per annum in red wines, and 0.05% alcohol by volume per annum in white wines.

Alcohol levels are not reported for Bordeaux, France, but some average sugar concentration levels have been published. Alcohol concentration is also not available for California, USA, but the average degrees Brix readings for the grapes crushed at wineries are available.

Sugar concentration levels are not a very accurate measure of the final alcohol level. The same Balling level in a cool and a warm region can translate to different levels of alcohol in the final wine (Boulton et al. 1996, p.196). The stems, stalks, skins and pips can also contain significant amounts of sugar, with the skin itself constituting about 20% of the weight of the crop (Peynaud 1984, p.59). Finally, the various winemaking interventions discussed in Chapter 5 can lower the final alcohol by several percentage points. Since final alcohol levels are not available, data about sugar levels has been used here for California and Bordeaux simply to illustrate trends.

Table 2.2 lists average Brix readings for each harvest in Napa County, California, for the period 1976 to 2005, based on raw data from the United States Department of Agriculture (2006). These statistics show a clear increasing trend over this 30 year period, with average levels around 25 degrees Brix for the last few years, up from 22 to 23 degrees Brix in the 1970s.

Year	Cabernet Sauvignon	all varieties
1976	22.9	22.4
1977	22.5	22.1
1978	23.1	23.0
1979	23.4	22.2
1980	23.3	22.5
1981	23.0	22.4
1982	22.7	21.8
1983	22.3	21.5
1984	23.1	22.1
1985	23.1	21.9
1986	22.7	21.8
1987	22.9	21.9
1988	22.6	21.8
1989	22.6	21.6
1990	23.1	22.1
1991	23.0	22.2
1992	23.3	22.6
1993	23.3	22.6
1994	23.2	22.7
1995	23.6	23.0
1996	23.7	23.1
1997	24.5	23.6
1998	24.0	23.4
1999	24.3	24.0
2000	23.9	23.8
2001	24.8	24.2
2002	25.4	24.8
2003	24.9	24.8
2004	25.8	25.3
2005	25.4	24.8

Table 2.2: Average °B measurements at harvest in Napa County, California, for Cabernet Sauvignon grapes and across all wine grape varieties (United States Department of Agriculture 2006)

The data from Table 2.2 is graphically represented in Figure 2.1, which also shows the straight lines that best fit the two datasets: these are linear models obtained by the least squares method. These linear models show that over the period 1976 to 2005, the average Balling levels of Napa County grapes increased by 0.088 °B per annum for Cabernet Sauvignon (with a standard error of ±13%), and 0.1 °B per annum across all wine grapes (with a standard error of ±14%).

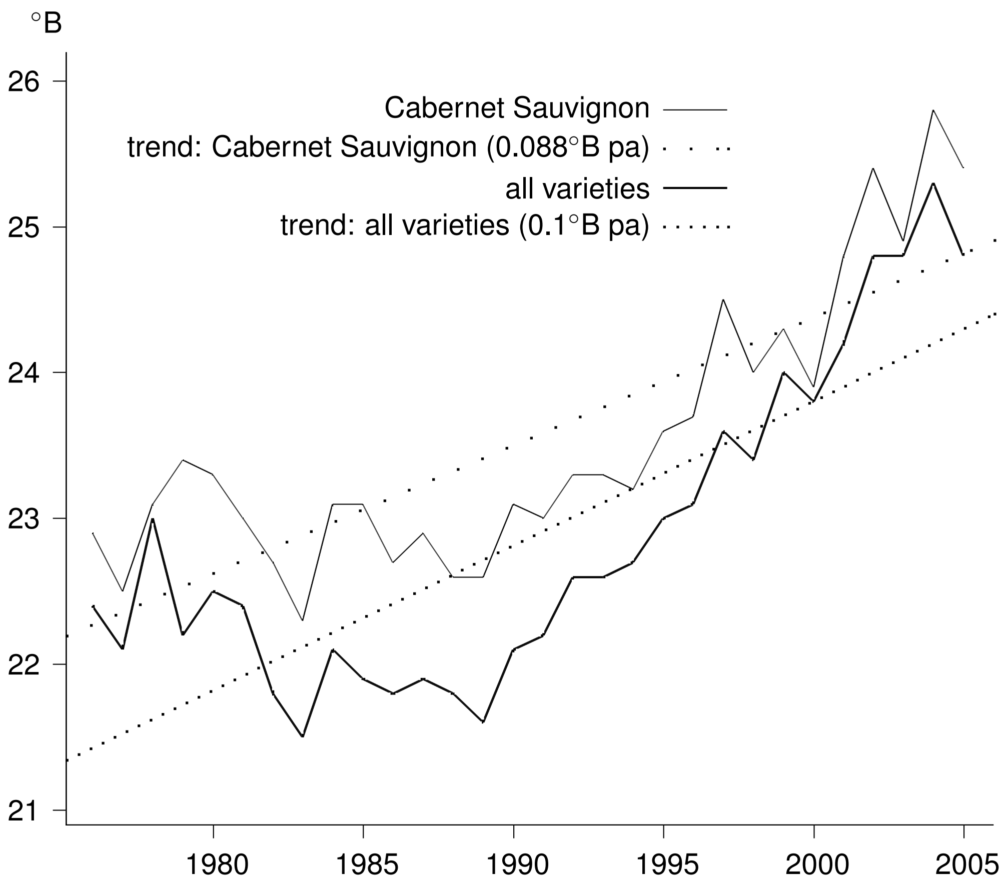

Figure 2.1: Average °B measurements at harvest in Napa County, California, with trends via least squares

The trend to increased sugar in California is not an isolated regional aberration. Bordeaux shows similar rises, as illustrated in Table 2.3[1] with figures from Brook (2006). These figures are only for "notable" vintages, which are typically those with the ripest grapes.

The data from Table 2.3 is graphically represented in Figure 2.2. This figure also shows the straight lines that best fit the datasets: these are linear models obtained by the least squares method. In this case, the average annual increase in sugar concentration is about 1.1g/l for Cabernet Sauvignon and 1.3g/l for Merlot;

[1]Note that the value of 134g/l given in the article for Merlot for 1986 is a statistical outlier. This value is identical with the weight value for that year, so it appears to have been incorrectly transcribed. It has therefore been removed from consideration.

Year	Cabernet Sauvignon	Merlot
1982	200	212
1986	202	n/a
1989	207	230
1990	199	220
1996	216	226
2000	220	245
2003	222	238
2005	222	244

Table 2.3: Average sugar measurements at harvest (in g/l) for notable recent vintages in Bordeaux, for Cabernet Sauvignon and Merlot grapes (Brook 2006, p.7)

the respective standard errors are ±14% and ±21%. Since the data is only for selected vintages, it is difficult to make categorical statements about trends in this region. However, it seems safe to conclude that there is some evidence of a rise in average grape sugar levels in Bordeaux, at least in “notable” vintages.

Each of the three regions for which statistics have been presented shows a trend of increasing alcohol or increasing sugar concentration in the grapes being harvested.

2.5 Summary of background

A framework to understand moderate alcohol was first presented. The term was deliberately left flexible. A case was then presented for moderate alcohol being desirable, from the perspective of health, of the legal proscriptions on driving while intoxicated, and of stylistic choices.

Trends were presented showing increased alcohol in red wines in Australia, and increased sugar concentration in California and Bordeaux, over the past 20 to 30 years.

Viticultural interventions to help avoid these high sugar levels and to achieve moderate alcohols are reviewed in Chapter 4.

Winemaking techniques also affect the final alcohol level. These are discussed in detail in Chapter 5.

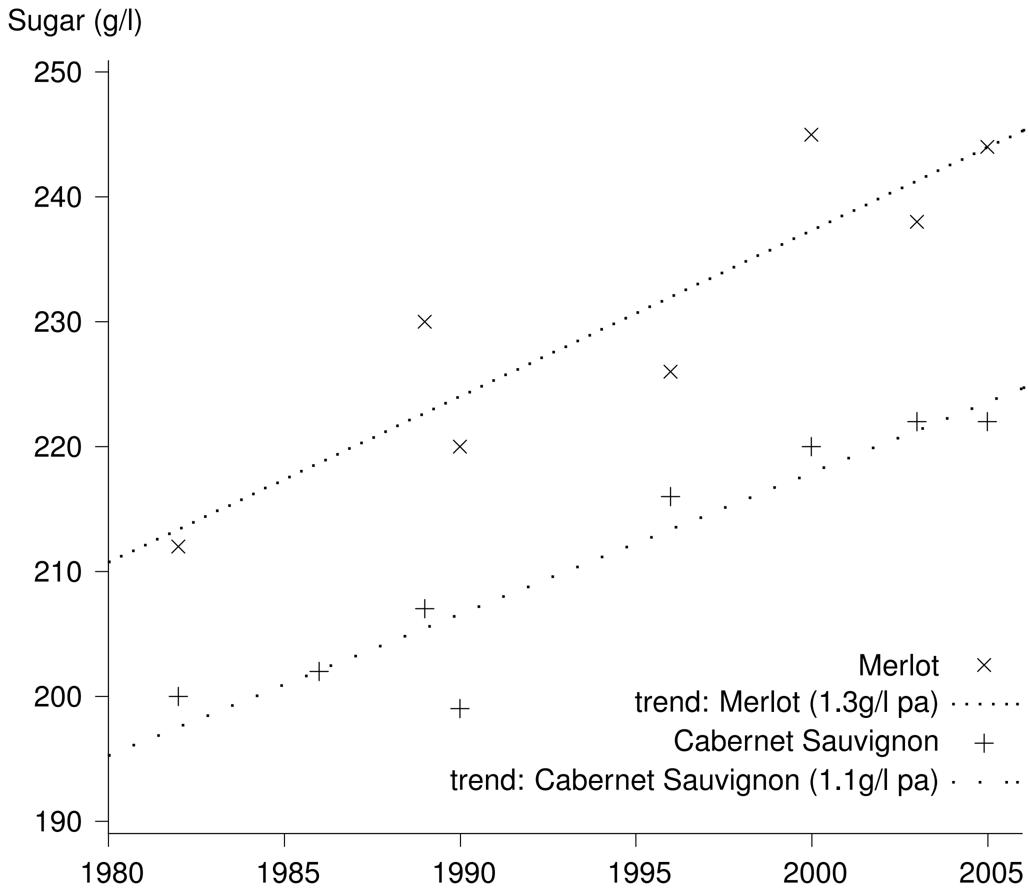

Figure 2.2: Average sugar measurements at harvest (in g/l) for notable recent vintages in Bordeaux, with trends via least squares

3. Alcohol production during fermentation

Yeast ferments the sugar in grape must into alcohol and other substances, resulting in wine. This is the basic process of alcohol formation, and it is therefore important to understand this process in some detail if one is to tackle the question of how to achieve moderate alcohol.

This chapter first reviews the theory of alcohol production. A given quantity of sugar yields a specific amount of alcohol, and the formula governing this is determined here from first principles. The theoretical values are then contrasted with values observed by experimental observation, and modified to take into account practical considerations.

3.1 Chemistry of alcohol production

The Embden-Meyerhof glycolitic pathway describes the main reaction in alcoholic fermentation. Approximately 92% to 95% of the sugars used during fermentation are converted to ethanol and carbon dioxide (Boulton et al. 1996, p.146). The main energy pathways involved in fermentation are illustrated in Figure 3.1, with the glycolitic pathway in the upper middle, producing mainly ethanol from glucose and fructose.

The important thing to note is that the main glycolitic pathway has a particular sequence, and ways can be investigated to disrupt the steps in the sequence. This is discussed further in Chapter 5.

Alcohol is a primary product of fermentation. The amount of alcohol produced during fermentation can be described by the formula

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2. \quad (3.1)$$

In short, every molecule of sugar is converted to two molecules of alcohol and two of carbon dioxide. The alcohol remains in the must, while the carbon dioxide gas mostly escapes into the atmosphere during and after fermentation.

Let c stand for the volume of alcohol obtained per gram of sugar in the must. The theoretical weight of alcohol produced by this formula is 0.5134g for every gram of sugar (Peynaud 1984, p.93). This can be converted to a volume by dividing by the specific gravity of alcohol of 0.7893 (Rankine 1998, p.124). It then follows that

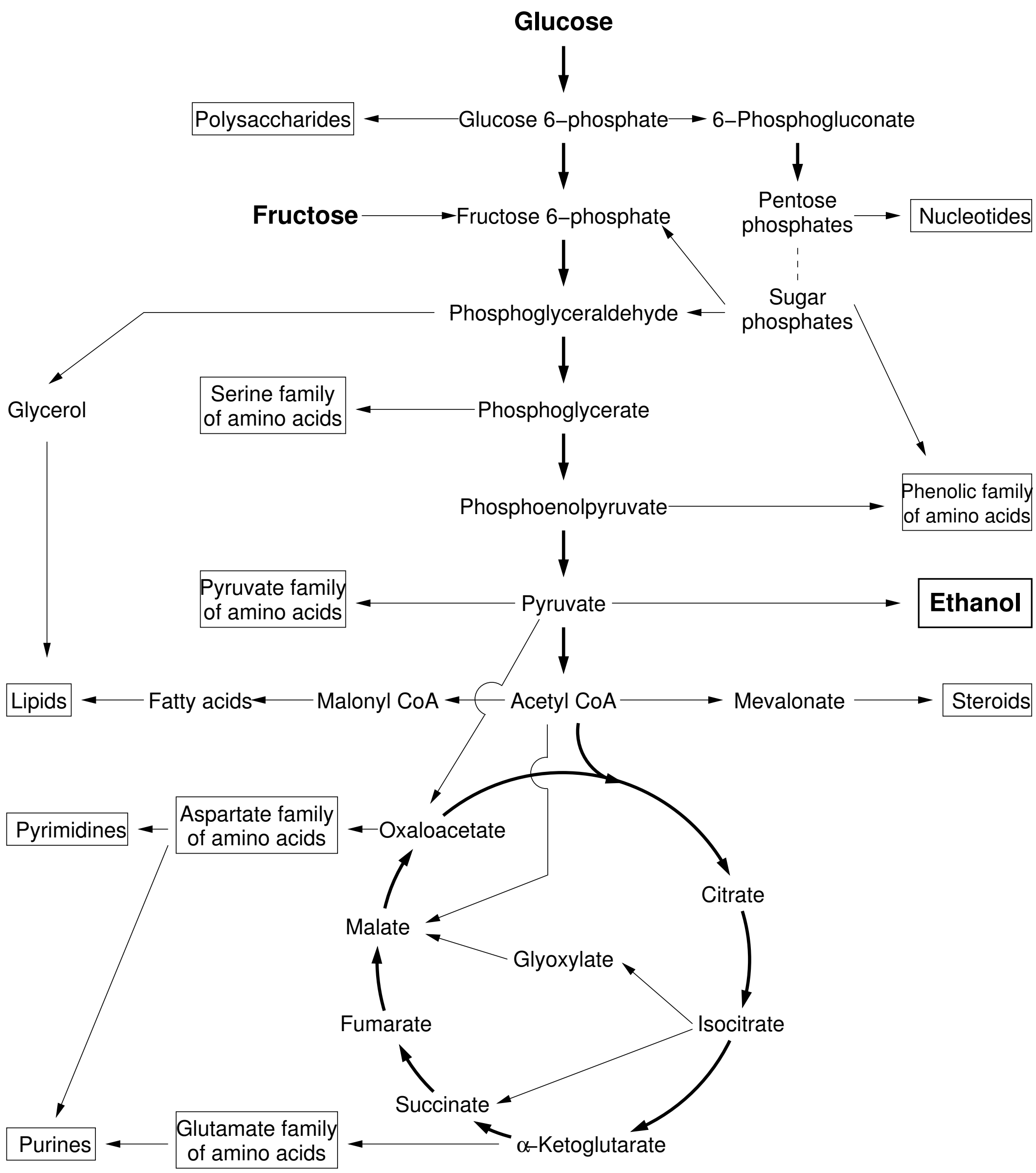

Figure 3.1: Main fermentation reactions, showing major energy-yielding pathways (in bold) and products (in boxes). Simplified from Jackson (2000, p.303) and Boulton et al. (1996, p.136).

every 1g of sugar in the must will be converted to 0.65045ml of alcohol, so yielding 0.65045ml/g as the value of c.

3.2 Alcohol by volume from sugar concentration

Consider 100g of a sugar solution, containing x grams of sugar and $100 - x$ grams of water. When this solution undergoes fermentation, alcohol and carbon dioxide are produced, and the alcohol remains in the resulting wine together with the water that was already there.

Note that x is also the initial concentration of sugar in the solution, expressed in degrees Balling, or equivalently, x per cent by weight.

For now, suppose that all the sugar in the solution is converted to ethanol and carbon dioxide by equation 3.1. This predicts that 51.34% of the weight will be alcohol and the remaining 48.66% will be carbon dioxide. Further suppose that no water or alcohol is lost during the fermentation through evaporation.

The value c is the volume of alcohol produced per gram of sugar, so cx is then the volume of alcohol produced. The solution initially has $100 - x$ grams of water, and since 1ml of water weighs 1g, the wine produced will also have $100 - x$ ml of water. The cx volume of alcohol produced, together with the volume of water, is then the final volume of wine.

The theoretical final alcohol by volume percentage can then be expressed in terms of the initial sugar concentration x and the theoretical volume c of alcohol per gram of sugar, as

$$100 \frac{cx}{100 - x + cx} = \frac{100c}{1-c}\left(\frac{100}{100-(1-c)x} - 1\right).$$

Using the value of 0.64045 for c derived previously, this can be simplified and expressed as

$$184.052\left(\frac{100}{100 - 0.35205x} - 1\right). \tag{3.2}$$

This curve is illlustrated in Figure 3.2. Note how formula 3.2 predicts that starting with 100% sugar content would yield pure 100% alcohol. This shows that the model in formula 3.2 is an oversimplification, and that further factors need to be taken into account.

3.3 Yeast inefficiency

In practice, some sugar is used by the yeast for its own growth, and some will be converted to products other than alcohol. Compared to the theoretical 51.34%

weight of alcohol produced from a given weight of sugar, Pasteur's original experiments indicated 48.5% alcohol by weight, with 4.8% going to glycerol, yeast cells, and other products, or 94.5% of the expected sugar to alcohol conversion (Boulton et al. 1996, p.137). The range 92 to 95% has been suggested for this efficiency ratio (Boulton et al. 1996, p.137).

Based on figures from Peynaud (1984, p.94), assume that 8% of the initial sugar is converted into products other than ethanol and carbon dioxide (in other words, a 92% conversion efficiency), and suppose that the volume of these products is approximately 10% of the volume of alcohol formed. Yeast cells can be up to 2% by weight but are typically removed from the wine after fermentation, so assume that the 10% of non-ethanol products excludes yeast cells.

Formula 3.2 derived above then has to adjusted to take these factors into consideration. Less alcohol is formed, so the dividend has to be adjusted by the conversion efficiency, becoming $0.92cx$. To the volume of alcohol formed also needs to be added the non-alcohol products, so this becomes $1.1 \times 0.92cx$, or $1.012cx$.

Using 0.65045ml/g as previously for the value of c, this yields the approximation

$$\frac{100 \times 0.92cx}{100 - x + 1.012cx} = 175.1 \left(\frac{100}{100 - 0.3417446x} - 1 \right). \tag{3.3}$$

which is illustrated in Figure 3.2. Note how this more realistically predicts that starting with 100% sugar content would result in a solution containing 91% alcohol by volume.

3.4 Linear approximations

The equations derived above from first principles are non-linear: when plotted they form a curve, not a line, as can be seen in Figure 3.2. This is inconvenient, and in practice a simpler expression is desirable. Some kind of *conversion factor* would be desirable, allowing a quick estimate of the expected alcohol concentration level from the Balling reading by simple multiplication by the conversion factor.

Linear approximations do exist for ethanol in terms of degrees Balling, although these are only valid for some useful range of values Boulton et al. (1996, p.195). One such approach is to express the final percentage ethanol linearly in terms of the sugar content, as

$$C(x - y)$$

where x is the Balling reading as measured, y is an adjustment to take into account the non-sugar content (so that $x - y$ gives the concentration of sugar as a percentage weight), and C is called the conversion factor (Boulton et al. 1996, p.196). In practice, y is sometimes ignored (Boulton et al. 1996, p.197).

Attempts have also been made to model the final alcohol concentration using an expression of the form

$$a + bx$$

where again x is the raw Balling measurement. Here, b is a conversion factor, which will differ from C, unless $a = -Cy$ when the two models are equivalent. Since C is usually in the range 0.55 to 0.62, and y is between 0.6 and 3.5, this means that a is usually in the range -2.17 to -0.33. A range of values for b from 0.49 to 0.79 is cited by Boulton et al. (1996, p.196), obtained by linear regression over measured data, whiile a varied between -4.92 and 4.37.

3.5 Comparison of models

Different attempts to derive final alcohol concentration from the initial Balling reading are contrasted in Figure 3.2. The part of the graph that is of practical use in winemaking is shown in Figure 3.3 at a larger scale.

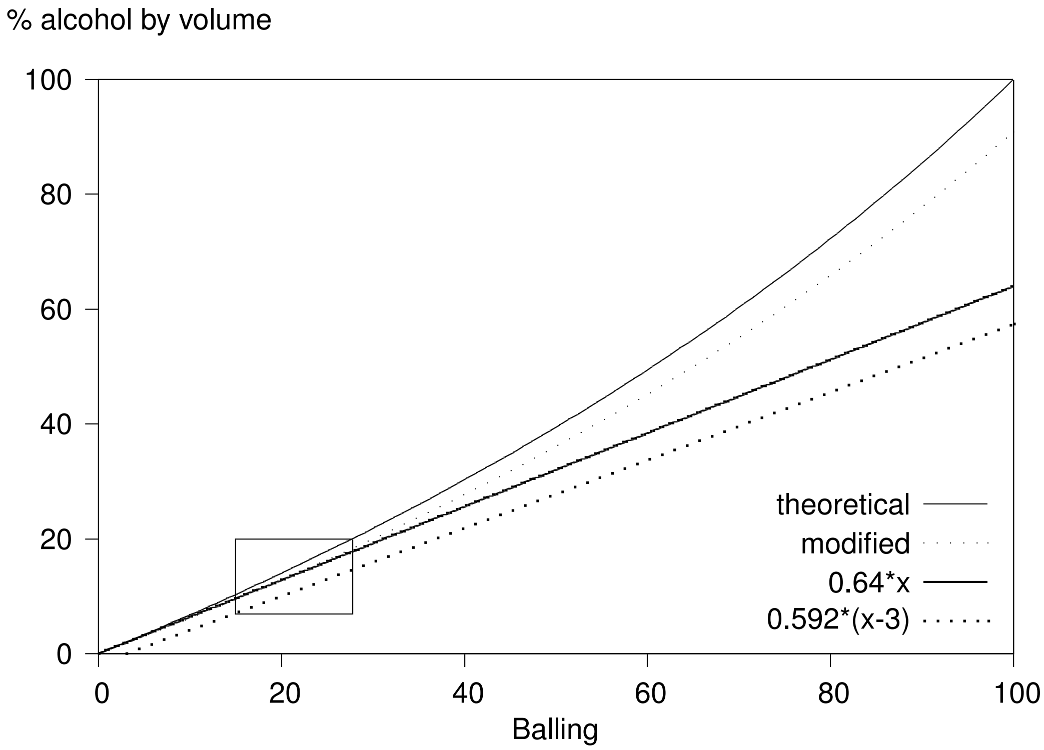

Figure 3.2: Comparison between different models of alcohol concentration in terms of measured Balling level. The boxed area is shown in more detail in Figure 3.3.

Although non-linear, the modified theoretical formula 3.3 predicts that the resulting wine will have about 0.63 to 0.65% ethanol by volume for every degree Balling of sugar, in the range 15 to 25°B. This closely matches figures reported by Margalit (2003, p.9) and Boulton et al. (1996, p.195), which suggests that if the theoretical formula is valid, then it can be approximated by setting C to be 0.64 and y to be 0, yielding $0.64x$ for the approximate rate of conversion of sugar to alcohol.

Figure 3.2 makes clear just why a linear approximation to the theoretical model is inaccurate in general, but as can be seen from Figure 3.3, a linear approximation is fairly accurate for most of the usual range of Balling readings useful in winemaking.

Peynaud (1984, p.84) suggests the practical rule of thumb of 17g sugar per liter for 1% alcohol by volume. If y is ignored (set to zero), this yields a conversion factor C of 0.588. A more precise value of 16.83g per liter is mentioned by de Barros Lopes et al. (2003): this translates to a conversion factor C of 0.5942, again with y being zero.

Assuming a fixed amount of approximately 2.1% by weight non-sugar content as suggested by Margalit (2003, p.3), if one divides alcohol levels predicted by the modified formula by the raw Balling reading, then this yields 0.55 to 0.60% alcohol by volume for every degree Balling. This closely matches the 0.55 to 0.61% range suggested by Boulton et al. (1996, p.138) based on experimental data.

In practice it is not possible to use a fixed value like 2.1% by weight for the non-sugar content y, since these vary widely. Values for the concentration of non-sugar content have been reported as ranging from 0.673% to 3.25% by weight (Boulton et al. 1996, p.197). This means that a value of 0.673 to 3.25 degrees Balling for y needs to be subtracted from the measured Balling x to obtain the actual sugar concentration. The adjustment that needs to be made for white wines is lower than for reds (approximately 1 degree Balling less) (Boulton et al. 1996, p.197).

Since the non-sugar content decreases with time, very ripe grapes will have lower values for the non-sugar content y (Peynaud 1984, p.164). This also seems to apply to grapes from warmer regions (Zoecklein 2003).

Higher conversion factors C also seem to apply to cooler regions and lower factors to warmer regions, with 0.62 reported for upper Monterey County in California by Zoecklein (2003).

The theoretical curve clearly overestimates the alcohol levels to be expected. The curve modified to take into account yeast conversion inefficiency and some volume taken up by products of fermentation other than alcohol, is somewhat more realistic. The simple model $a + bx$ with a value of 0.64 for b and a value of 0 for a is a reasonably close approximation for this range of values, tending to underestimate at the higher Balling levels. The $C(x - y)$ model with 0.592 for C and 3.0 for y, as suggested by Boulton et al. (1996, p.196), consistently underestimates the alcohol levels. This is to be expected, since the two theoretical models developed here are based on x being the Balling reading for sugar only, while this last model assumes

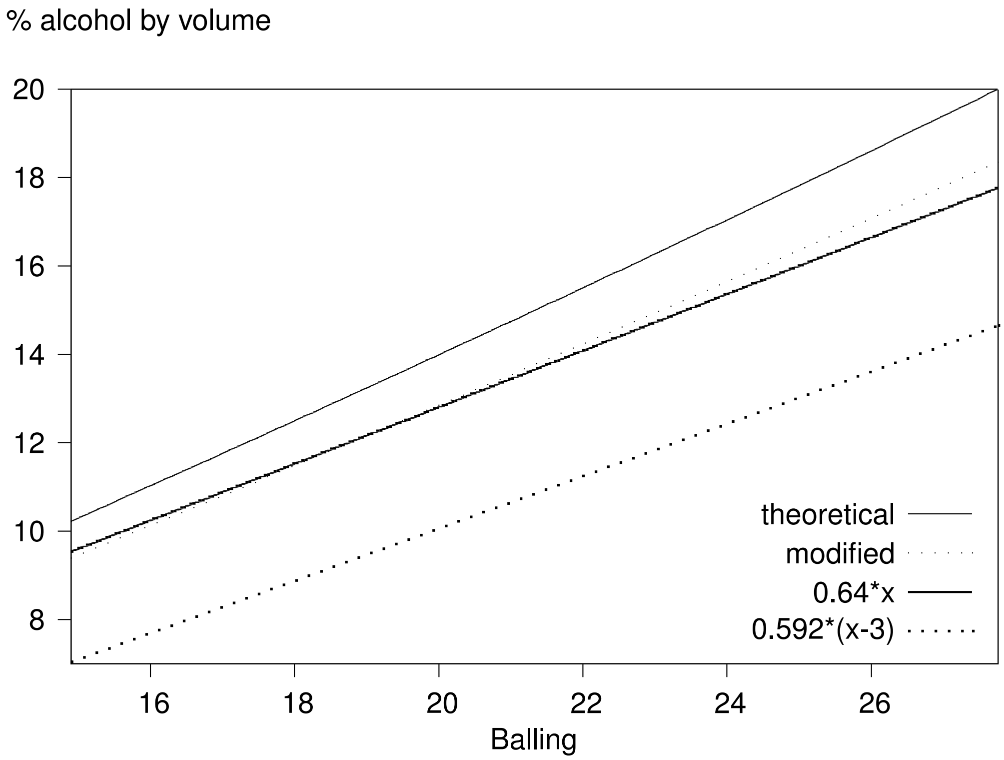

Figure 3.3: Comparison between different models of alcohol concentration in terms of measured Balling level (detail).

that x includes 3 degrees Balling of non-sugar content. There does still remain a discrepancy, with model 3.3 being quite close to a straight line with slope 0.64, while 0.592 would be a suggested value. This needs to be investigated: effects such as evaporation of both alcohol and water during fermentation probably need to be taken into account to obtain a more realistic model.

Another method used by some winemakers is to ignore the non-sugar content y, simply using the raw Balling reading x and multiplying by a notional conversion factor to obtain an estimate of expected alcohol. However, y is often in the range 1 to 3 degrees Balling, so this method will introduce an error of between 0.6 and 1.9 for the estimated final alcohol by volume percentage unless the conversion factor is also adjusted (Boulton et al. 1996, p.197). Using this method, Ellis (2006) reports conversion factors of 0.568 to 0.626 for a range of white wines made at Elsenburg, and 0.537 to 0.645 for a range of reds.

Putting it differently, if one has the raw Balling reading x and the wine has reached a given alcohol concentration after fermentation, and one then divides the alcohol concentration by x, this will give an overestimate for the value of the conversion factor C. This estimate will be significantly overstated overstated if the nonsugar content y is high and is left out of the calculation.

Factors between 0.54 and 0.61 were documented during 1981/2 by Jones and Ough (1985). Duncan Savage of Cape Point Vineyards reported an average conversion factor of 0.62 for Sauvignon Blanc from the 2006 vintage (Savage 2006). Values between 0.57 to 0.65 have recently been reported by Grier (2006). Some winemakers stated that they had seen an increase over the last few seasons, for instance increases from 0.55 to 0.58 (Walker 2006; Jordan 2006). It is quite possible that much of the reported increase in conversion factors actually stems from changes in the non-sugar content of grapes. Further work is required to investigate this.

Since the non-sugar content has a significant effect on the behaviour of any of these models, ideally it should be taken into account. Note also that without taking into account the non-sugar content, it is only possible to compare conversion factors from different fermentations if they have the same concentration of non-sugar content.

3.6 Summary of alcohol production

The production of alcohol follows the main Embden-Meyerhof pathway. Other reactions can also be significant, for instance that of yeast growth, or production of glycerol.

Yeast therefore plays a significant role in determining the proportion of fermentation products other than alcohol.

The mathematical relationship between sugar concentration in grapes and the final alcohol concentration in wine was discussed. A theoretical model was compared to two linear models and a simplified model used in practice that is based on a conversion factor only. It seems that using a conversion factor has merit, but that the effect of non-sugar content of grapes is significant and should be taken into account.

It is also possible for the conversion ratio to be lowered further, through disruptions of the glycolitic pathway. This would lower the efficiency of glucose to ethanol production. This is discussed in Chapter 5.

4. Viticultural options

Final alcohol levels are largely determined by the sugar content of the grapes coming into the winery. It is therefore important to look at the viticultural issues relating to achieving moderate alcohol.

This chapter first reviews the process of grape ripening, and highlights the strong link between sugar concentration and alcohol level. The remainder of this chapter outlines the most important viticultural issues related to obtaining moderate alcohol levels. First the choice of vineyard site is discussed, followed by a review of options when establishing a new vineyard. Ongoing practices in an established vineyard are then outlined, highlighting the main techniques that can prove useful in achieving moderate alcohol levels.

4.1 The ripening process

Plants produce organic compounds from carbon dioxide and water and the energy of sunlight, through the process of photosynthesis. The major organic product produced this way is sugar (Jackson 2000, p.56). These compounds are stored in the leaves, branches and stems. At the onset of véraison, the sugars migrate to the grapes over a period of 3 to 8 weeks (Peynaud 1984, p.62).

Berry development proceeds by distinct phases (Rankine 1998, p.26). First, the hard green berry forms from the flower, accumulates acid, and grows rapidly. Then the berry 'rests', with little growth in size. Pigment then appears in the skin, in a fairly rapid process called *véraison* (Peynaud 1984, p.58). Finally, the berry softens and continues growing until full maturity.

The water and sugar content of the berry increases during ripening. Once full maturity has been reached, no further sugar accumulates, but the berry starts dehydrating, and the sugar concentration then rises.

The sugar concentration in the berry therefore increases during ripening, and continues to increase during berry dehydration. Sugar (and specifically glucose) is the main input for the process of alcoholic fermentation, and the sugar concentration directly determines the final alcohol level as discussed in Chapter 3. Therefore, from a viticultural point of view, achieving moderate alcohol requires sugar concentration to be kept in check, while still achieving other flavour characteristics.

The optimal temperature for photosynthesis is 25 to 28°C, with the rate dropping off below 20°C and above 30°C (Burger 1981, p.37). This has viticultural implications, since canopy temperature can be controlled using canopy management and irrigation, as discussed in Section 4.4.

Viticultural choices affect the ripening cycle in different ways. The time taken for this cycle, from flowering to harvest, depends on region, variety, the ripeness level at picking, and vintage conditions. Rankine (1998, p.25) provides an example of Shiraz in Adelaide, Australia which takes about 180 days from flowering to harvest, and also suggests that the average time from véraison to ripeness in Australia is 24 days. Burger (1981, p.466) provides examples of véraison to ripeness of over 60 days. Peynaud (1984, p.59) suggests that maturation takes 40 to 50 days.

The viticultural choices affecting the ripening cycle are now discussed in more detail.

4.2 Choice of vineyard site

Where to establish a vineyard is perhaps the most important decision that can be taken to influence the ripening of grapes. Macroclimate (the climate of the region) and mesoclimate (the climate of the site) largely determine the pattern of temperature in a vineyard, as well as its exposure to light (Smart and Robinson 1991).

4.2.1 Climate change

There is evidence for climate change, and specifically for global warming. However, even the most pessimistic models predict temperature increases of at most 1°C over the next 50 years (Lomborg 2001, p.285). Also, climate change does not appear to have had any observable effect on vineyards in Stellenbosch over the past 20 years (Grier 2006).

Only a small minority of vineyards are productive for longer than 50 years. For the choice of vineyard site the effect of climate change is therefore likely to be a lesser factor than choosing to locate a vineyard in a cooler region over a warmer one, which slopes on a property to use for planting, or opting for a vineyard site that has access to water over one that does not.

For instance, the topography of a region and its surrounding area is largely immutable, so the aspect of a slope, its elevation, and the influence of nearby hills and mountains on winds usually can be taken as fixed. It is of course possible to remove or reshape hills and even mountains, but this is likely to be too expensive to be practical, so this aspect will be assumed to be fixed in this document.

4.2.2 Macroclimate

Regional patterns in ripening conditions are relatively constant over time.

In South Africa, altitude and proximity of the wine growing areas to the moderating effect of the ocean are important factors in determining overall temperature. It has been estimated that average temperatures decline 0.5°C for every 100m increase in altitude, and increase 0.6°C for every 10km distance from the ocean (Myburgh 2005).

4.2.3 Mesoclimate

The specific location of a vineyard block within its region largely determines its mesoclimate (Smart and Robinson 1991, p.4). Most properties in South Africa used for grape growing are large enough that they benefit from multiple mesoclimates. North facing slopes will tend to be warmer than south facing slopes; some blocks may be close to hilltops and exposed to severe wind while others may be sheltered; some parcels may be shaded by mountains for part of the day while others are in full sunlight. It is therefore usually possible to choose to locate vineyards to take into account mesoclimates appropriate to the specific conditions sought, such as avoiding sheltered north facing slopes if moderate alcohol levels are sought, using south facing slopes, parts of the property exposed to some wind, or shade from neighbouring hills.

4.2.4 Soil

The composition of the soil in the vineyard provides a baseline. It is possible to make adjustments (see the next section), but large scale changes to the soil profile are very costly. It is therefore important to consider the soil in the potential vineyard sites, especially as it affects water requirements and the style of wine sought.

4.3 Establishment of the vineyard

Several choices affecting alcohol levels can be made when establishing the vineyard. These include the type of soil preparation, the choice of rootstocks, varieties and clones, and the type of canopy desired.

4.3.1 Soil preparation

Soil composition in some vineyards is deficient in minerals necessary for proper ripening, and therefore may need to be adjusted to ensure a successful vineyard. Soil composition can be, and in South Africa often is, adjusted prior to establishing a vineyard.

Many soils in grape-growing areas in South Africa are relatively acidic (Burger 1981, p.376). Addition of up to 30t/ha lime, primarily in the form $CaCO_3$ and

$CaMg(CO_3)_2$, is therefore a routine practice when preparing to plant a vineyard (Dobrovic 2006; Burger 1981). Some South African vineyards have been treated with excessive amounts of non-dolomitic lime, resulting in a magnesium deficiency (Dobrovic 2006). This affects photosynthesis negatively (Burger 1981, p.350), causing delayed ripening and necessitating long hang time to achieve reasonable aromatic quality, while the grapes are affected by dehydration. To avoid excessive alcohol levels, it is therefore important to ensure such deficiencies have been corrected.

Soil is commonly also adjusted by the application of nitrogen fertilisers (Winkler et al. 1974, p.412). Availability of nitrogen enhances photosynthesis (Keller 2005). Hence, heavily fertilised vineyards should yield higher sugars in grapes. On the other hand, excess nitrogen application also tends to lead to increased grapevine vigour, with resulting lower grape sugars, accompanied by a decline in overall fruit quality. It is possible that the effect of excess vigour can cancel out the more efficient accumulation of sugar, but the exact effect remains to be investigated. On balance, excessive nitrogen application should probably be avoided if moderate alcohol levels are sought.

4.3.2 Rootstocks

Choice of rootstock influences grapevine yield. Lower yield tends to result in slightly higher sugar levels (Jackson 2000, p.126), which means that the rootstock effect on yield will translate into different sugar levels.

In a climate where grapes do not struggle to ripen, it appears that an important influence of rootstock on sugar levels is actually the length of the ripening period. In practice, the same variety grown in the same location on different rootstocks can take an extra week longer to ripen (Barnes 2006). This can provide a wider picking window and help to avoid excessive sugar in the grapes by making available resources to pick at the correct time.

4.3.3 Varieties

The choice of which grape varieties to plant is determined by the projected demand for grapes of specific varieties at the time the vineyard starts producing, and the required financial return for the vineyard project. Suitability of various varieties to the specific vineyard also needs to be taken into account. The design of the cellar, if wine production is envisaged, may determine whether red or white varieties are to be preferred. Finally, lack of availability of labour may rule out varieties that are difficult to cultivate.

If the correct varieties are chosen for the site and available conditions, it is likely that moderate alcohol levels can be achieved more easily.

4.3.4 Clones

Different clones can provide markedly different flavour profiles. It may be possible to achieve a profile closer to that sought by appropriate choice of clones, rather than pushing vines to extreme ripeness. Moderate alcohol is not usually a goal of clonal selection, although this area may prove important in the long run to help to achieve lower sugar levels while still attaining ripeness (Barnes 2006).

4.3.5 Vine shape

Trellising and the shape that the vine is initially trained can have a marked impact on sugar levels, through varying the amount of light that reaches the leaves and fruit (Keller 2005). It has been argued that this is simply due to whether the vine canopy is open or not, with open canopies achieving substantially higher wine quality and sugar levels (Smart and Robinson 1991, p.12). This is discussed further in Section 4.4.1 on ongoing canopy management.

4.4 Vineyard management

The term "hang time" is sometimes used to indicate the practice of leaving grapes on the vine beyond the point where they would have been considered ripe by traditional measures. There is some debate about what ripeness is.

Mia Klein of Selene Winery in California, who also consults for Dalla Valle, indicates the extent to which avoiding vegetative characters has come to dominate winemaking in California: "[for] Sauvignon Blanc, the skin starts to fall apart and becomes translucent. It's not unlike Syrah in the red grapes. You don't wait for Cabernet Sauvignon or Merlot to get there, but with Sauvignon Blanc you definitely do if you don't want vegetative flavors." (Cutler 2004). It seems likely that skins that are falling apart would be regarded as completely overripe by many viticulturists, and that such wine would lack the distinctive varietal character of Sauvignon Blanc. However, this illustrates how "hang time" in California has become essential in avoiding vegetal flavours – even when those flavours are part of the varietal character.

Some commentators have dismissed the trend to later picking as a way to compensate for poor sites, shoddy viticulture, or the use of inexpert pickers. By picking later, any slow ripening bunches and berries are given time to catch up to the rest of the crop, without requiring identification and removal of the unripe fruit at the winery. The argument is that vines that are in proper balance, planted on sites that are suitable, will ripen fruit evenly. Richard Smart has stated bluntly that "if grapes need hang time, they are not being grown properly in the first place". His opinion is that

> all other factors such as climate being equal, the first vineyards to be harvested make the best wine. This is a sign that the vine is in good balance and able to ripen fruit easily. Problems with the vine translate into delayed harvest. (Smart 2005)

Grapes grown on an unsuitable site will tend to ripen unevenly. Any pathological bunches should be removed during regular viticultural maintenance, left on the vine, or otherwise removed during sorting.

Several options are available for managing excessive alcohols in the vineyard. These include canopy management, bunch thinning and bud removal, virus status, water management, specific interventions to manage methoxypyrazine formation, and harvest timing. Each of these issues is discussed in the remainder of this section.

4.4.1 Canopy management

Light intensity is the most important factor for ripening, since it is the main driver of photosynthesis. Below a threshold level of around 200 to 1000 lux, leaves are net consumers of the photosynthesis products of other leaves (Burger 1981, p.37). Since only 6% of incident light passes through a typical leaf, for maximum efficiency of photosynthesis it is therefore important to limit the number of leaves inside the leaf canopy, shaded by the leaves at the edges of the canopy, to 10% or less (Smart and Robinson 1991, p.22).

An existing, established vineyard has the shape of the leaf canopy largely determined by the method used to train the vine and the trellising system used. It is possible to retrain and to change the trellising system if a different canopy is sought. This has been performed with some success, for instance at Cullen Wines, one of the top quality wine producers in Western Australia (Smart and Robinson 1991, p.47). However, this is very expensive.

Given a fixed method of vine training and an existing trellising system, it is still possible to affect the canopy of the vine. Canopy management is the umbrella term applied to these techniques.

Leaf removal is a common practice, used to increase the exposure of bunches to light and to reduce susceptibility to rot (Smart and Robinson 1991, p.38). However, if overdone this can cause the berries to dehydrate, by allowing excess sunlight on the ripening bunches (Burger 1981, p.424).

Since dehydration increases sugar concentration, to achieve moderate alcohol it is important to avoid dehydration through appropriate canopy management. Specifically, excessive leaf removal should be avoided.

Increased shade in the vine canopy causes decreased sugar levels (Smart and Robinson 1991, p.12). Shade in the canopy can also have negative effects on quality, since it can increase ‘herbaceousness’ and can lead to reduced varietal character. If the vineyard is yielding grapes with excessive sugar levels, then it may be worth considering whether the canopy can be made more dense.

If the canopy is too open due to incorrect trellising or pruning, if the vines are affected by virus, or if the vines generally struggle to achieve reasonable canopy cover for other reasons, then it may be desirable to change practices in the vineyard to obtain a denser canopy.

It has been argued by Smart and Robinson (1991, p.3) that even in hot regions open canopies are always best, and they cite some supporting studies performed in a warm region of Australia. However, most of the published work on canopy management seems specifically targeted at cooler climate regions like New Zealand, north-western France and Virginia in the USA. It does appear as if in warm climate regions like South Africa, where sunlight is not in short supply, that denser canopies might have some benefit. It is not clear if densification of overly open canopies has practical value; no research seems to have considered this, and more work would be required before it could be regarded as a serious alternative.

4.4.2 Bunch thinning and bud removal

Bunch thinning is a practice used to achieve more concentration of flavours in the berries, by removing clusters of berries at or before véraison. It is also often referred to as “green harvesting”. Bud removal has similar aims, but occurs even earlier, before flowering.

The remaining berries will have less competition for the sugars and flavour compounds stored in the vine. Hence, bunch thinning can also lead to an excess of sugar buildup in the remaining bunches, and having fewer buds is correlated with more vegetal character (Bogart and Bisson 2006). Reducing the routine use of bunch thinning and bud removal may therefore contribute to achieving lower alcohols in the resulting wines, without needing to increase hang time for the vegetal characters to decrease.

4.4.3 Virus infection

Leaf roll virus has been prevalent in some South African vineyards in the past. In the quest to replant with vines free from virus infection, it appears some desirable characteristics might have been lost (although this point of view is controversial and not widely accepted). For instance, anecdotal evidence suggests that in some circumstances, it is possible that presence of leaf roll virus allows full ripening of

Chardonnay grapes without excessive sugar buildup (Dobrovic 2006).

Leaf roll virus has many undesirable consequences (Burger 1981, p.416), so it cannot be regarded as a panacea. It has been suggested that this virus can work to enhance quality if it is the primary source of vine stress, such as parts of France where vineyard soils are rich in nutrients and there is adequate precipitation for the vines (Barnes 2006). However, leaf roll virus is probably undesirable in most South African vineyards, since water stress on the vines is usually already high.

By delaying the harvest date for blocks that are virus infected, it is also possible to stagger the harvest dates and so achieve more cellar flexibility. If cellar capacity is fully used, it might be necessary to delay harvesting a block, leading to overripe grapes and excessive alcohol in the final wine. Retaining some virus infected blocks may therefore be a possible way to avoid this type of delay.

Vineyards planted to white varieties that are virus infected but meet the desired quality and yield criteria do not necessarily have to be replaced, since the virus infection can help to achieve lower sugar in the grapes and can allow more efficient processing in the winery.

In summary, the presence of leaf roll virus in a vineyard that is producing reasonable sized crops of good quality, should perhaps not be seen as the main reason to replant. This may help to achieve lower alcohol levels in musts from the affected blocks. Steps should be taken to avoid it otherwise. Further study is required to establish whether this point of view has practical merit.

4.4.4 Water management

Water management relates to dealing with the water supply available at the vineyard. In warm climates this is mostly related to applying irrigation, but where rainfall is high it can also relate to techniques to remove excess water. In areas of high rainfall excessive alcohol levels are not usually cited as being a problem. This document therefore only considers how irrigation can be used to lower the final alcohol levels in wine.

Irrigation is commonly thought to be related to a reduction in quality. However, it appears that quality can be maintained as long as the amount of water retained in the soil between applications of irrigation is allowed to reduce to 20% or less of the water retention capacity of the soil. The resulting moderate water stress appears to be related to achieving good quality (Myburgh 2006).

In South Africa in 2005, 19,896.58ha of vineyard was not irrigated (SAWIS 2006a). Almost all of this was planted to grape varieties used for winemaking, which covered 101,607ha in total (SAWIS 2006b). This means that approximately 80% of the area planted to wine grapes was under some form of irrigation. Irrigation is therefore likely to be an intervention that is available to most South African grape growers.

Canopy temperature Anecdotally, the temperature of the grapevine canopy can be reduced by up to 15°C through irrigation (Dobrovic 2006). Strongly supporting this observation, in a controlled experiment held in the Douro Valley of Portugal, Ferreira et al. (2002) reported that the temperature of the canopy in irrigated vines was up to 14°C lower than ambient air temperature. These measurements were taken over several days, after irrigation had ceased: trickle irrigation equivalent to 300mm of rainfall was first administered over a twelve week period. In contrast, there was essentially no canopy-air temperature differential in the unirrigated control vines in this experiment. It therefore seems likely that ongoing irrigation can provide a lowering of canopy temperature compared to unirrigated vines, and that this effect may persist for a period after irrigation has ceased. Further investigation seems warranted to establish whether this also holds in South African conditions.

Lower canopy temperature contributes to a microclimate which may more closely resemble that expected in a cooler region, so is worth considering as an intervention if moderate alcohol levels are sought.

Reversing dehydration Irrigation can affect hydration levels in the grapes, especially if the grapes exhibit shrivelling or dehydration. This is one of the main characteristics of overripe grapes: once ripeness is reached, the grapes rapidly begin to dehydrate on the vine (Peynaud 1984, pp.72–73). Rain or artificial irrigation in the few days before harvest can then reduce sugar concentration of the must by 0.5 degrees Balling without significantly diluting flavours (Dobrovic 2006). Using rain as a way to reduce sugar concentration cannot yield guaranteed results, but if artificial irrigation is available, by drip irrigating vines carrying overripe grapes it is possible to reduce the density of the must in the winery. This only applies if the vines are healthy and not virus infected, since virus infected vines will generally have shut down by the time the crop is overripe, so will not process the additional water (Dobrovic 2006). If irrigation is available it may therefore be a useful tool to slightly correct a block where the optimal picking window has been missed.

4.4.5 Methoxypyrazine management

Methoxypyrazines are one of the main causes of vegetal/green character. Avoiding such vegetal character in the wine is an important reason cited for longer “hang time” and consequent increased grape sugar concentrations in California.

Bogart and Bisson (2006) has reviewed some of relevant literature, the salient points of which are summarised here.

Vegetal character due to methoxypyrazines is especially significant in Cabernet Sauvignon and Sauvignon Blanc, but can occur in other varieties also. Since one of the aims of extended hang time is to reduce “greenness” in the wine, control of methoxypyrazine formation can help to attain such a style without the grapes becoming overripe.

Methoxypyrazine is highly extractable, so levels of these compounds in wine are not easily controllable in the winery. Although thermovinification can help to break down these compounds, this may also adversely affect quality so cannot be relied on (Peynaud 1984). It is therefore important to apply the correct viticultural techniques to ensure methoxypyrazine levels are at an acceptable level at harvest.

Methoxypyrazine formation can be controlled using several techniques.

Leaf removal Removing leaves is a standard part of canopy management, with one of its aims being to increase exposure of the bunches to wind and sunlight (Smart and Robinson 1991, p.38). It is usually performed around véraison.

This practice can also reduce the uptake of methoxypyrazines in the grapes. There is some evidence that these compounds migrate from the leaves to the grapes before véraison (Bogart and Bisson 2006). If leaf removal is planned as part of canopy management, doing so before the onset of véraison will therefore result in less of these compounds ending up in the grapes. Leaf removal after the onset véraison seems to have little effect on methoxypyrazine levels in the grapes (Chapman et al. 2004).

Deficit irrigation Irrigation is usually designed to reduce water stress. When it is specifically timed to take place before véraison, it can also reduce methoxypyrazine formation.

Yield management Crop thinning is often applied to increase concentration of nonsugar extract in the must. However, reducing the yield can also lead to high sugars in the grapes. Therefore excessive bunch thinning should be avoided.

Hence, leaf removal and deficit irrigation before véraison, as well as avoiding overly aggressive bunch thinning, can result in wines that have less green character at a similar alcohol level than wines from vineyards where these practices are not followed.

4.4.6 Timing of harvest

The timing of the harvest is perhaps the most critical viticultural choice made during each year (Jackson 2000, p.184).

About 25 years ago, 22 to 24 degrees Balling was the accepted average sugar content of fully mature Cabernet Sauvignon (Orffer 1979, p.27). It is not clear whether this Balling level is for sugar only or is the general reading for density.

In contrast, Mark Beringer of the Duckhorn Wine Company in Napa Valley says, "In Napa we have a much warmer climate, and the vines are just not done with their vegetative cycle at 22–24°Brix. We don't see good physical maturity until Brix levels of 25-plus, thus the higher alcohol levels." (Kakaviatos 2006).

Geoff Johnston of Pirramimma in McLaren Vale, Australia, goes even further: "with the advent of drip irrigation the vines have the potential to maintain photosynthesis to develop higher flavour and mature tannin levels before the grapes turn jammy and porty. In fact, we have a lot of wine even higher in alcohol than 16.7% from the 2005 vintage, without any overripe characters". Note that this particular wine was was subsequently dealcoholised to 12.4% (Robinson 2005a).

Finally, Craig Williams of Joseph Phelps in California believes the current preoccupation with ripeness and extraction was originally a reaction to the thin wines in fashion during the 1980s (at that time called "elegant food wines"), which themselves were reactions to the trend for overripe, overblown reds of the late 1970s. "A lot of those wines weren't very good," says Williams, "and for the past 15 years or so, we've been moving back in the other direction, toward greater ripeness. Have we tipped too far in that direction? Probably so, and we probably need to move back to the center." (Hock 2004).

It appears that harvest timing is responsible for some of the increased alcohol levels, and that the trend to later picking has been overdone. It is worth reconsidering long "hang times" in order to keep alcohol levels in check.

4.5 Summary of viticultural techniques

There are a variety of viticultural approaches that can be taken to achieve moderate alcohol levels.

Choosing a site, regions with cooler macroclimate and sites with cooler mesoclimate are desirable.

When establishing a vineyard, it is important to ensure the correct balance of nutrients. Excessive fertilisation should be avoided. Rootstock choice can affect the speed of ripening and possibly also the final sugar levels, so needs to be considered in some detail beyond the usual criteria. Matching the right varieties, clones and trellising system to the right site can also help to avoid excessive sugar uptake.

Several ongoing practices can also be considered. The main aim should be seeking vines in balance, and canopy management is an important tool to achieve this. Bunch thinning and bud removal should not be performed indiscriminately, since this will tend to raise grape sugar levels. Consideration should be given to retaining vineyards planted to white varieties that are virus infected but meet the desired quality and yield criteria. Irrigation appears to be helpful in achieving lower canopy temperature so may partially compensate for a warm site. Irrigation just before harvest can also partially reverse effects of overripening, resulting in a lower overall sugar concentration. Finally, methoxypyrazine formation can be controlled using leaf thinning and irrigation before véraison, and avoiding excessive cluster removal – this can reduce the herbaceous character of especially Cabernet Sauvignon, allowing picking at lower sugar.

5. Winemaking interventions

Several interventions are possible during the winemaking process, after the grapes have been harvested. These include choices prior to and during fermentation, and decisions to be made in the subsequent management of the wine.

The most significant determinant of final alcohol level is the amount of sugars in the must. However, it is still possible to significantly tweak the final alcohol levels in the winery. In the case of dealcoholisation treatments, it is possible to achieve any desired level of reduction of alcohol, but even less drastic interventions can have significant influence.

Some processes are outside the regulations and laws governing winemaking, depending on the jurisdiction. These include watering, using excess water in processing, various types of reverse osmosis. Processes that are in contravention of some or all the commonly accepted regulations for winemaking are noted in each section.

Two main interventions exist for direct manipulation of the alcohol level in the winery: sugar can be removed from the must prior to fermentation, or alcohol can be removed after fermentation is complete. These are discussed in the respective sections.

5.1 Prefermentation treatments

The free run juice can differ from the actual sugar content of the must after sugars are extracted from the skins by as much as 1°B. An example of free run juice at 22°B compared to must after pressing of 23°B was mentioned by Dobrovic (2006).

In contrast, it has been observed informally by winemakers that juice obtained from saignée (free run juice drawn off from the tank to increase the skin to liquid ratio of the remaining juice) can have lower Balling readings but higher final alcohol levels. This has been observed by winemakers producing Rosé styles from the drawn off juice (Dobrovic 2006).

5.1.1 Glucose oxidase

Pickering et al. (1999a) analysed the effect of introducing glucose oxidase enzymes into grape must. These enzymes break down glucose into gluconic acid, but are deactivated in the presence of alcohol in concentrations greater than about 1% by volume. They therefore need to be added to must before it has begun fermenting, and are more likely to be useful for the production of white wine than for red wine. This research showed that most of the glucose can be converted to gluconic acid using glucose oxidase enzymes, which can nearly halve the alcohol content of the resulting wine. However, the must was deacidified before enzyme treatment to approximately 0.5 grams per liter titratable acidity, and the additional gluconic acid brought the titratable acidity back up to 4.5 grams per liter, so it is not clear how well this method would perform in practice. In addition, persistently high acid levels were seen as a problem in the wines produced by this method Pickering et al. (1999b).

Glucose oxidase enzyme converts glucose into gluconic acid. Since glucose oxidase enzyme has to be used before yeast has started converting the glucose to ethanol, applying the enzyme requires precise timing and so may not be practical. Further technology development may well make using this enzyme more practical; see Section 5.2.1 for progress on this.

5.1.2 Membrane treatments

A combination of two types of filtration treatment can be applied to remove sugar from grape must (Legrix de la Salle 2006). The process is applied to a portion of the must. First a cross-flow filter is used to separate out a solution consisting of water, sugar and acids, leaving behind the substances which are composed of relatively larger particles, for instance anthocyanins and other pigmentation. The concentrate containing these larger particles is added back to the must. The sugar, water and acid solution is then processed using reverse osmosis to remove sugar, and the water and acid solution is also added back to the must. An implementation of this technique is the REDUX process, which is claimed to be especially gentle since no distillation is involved.

The portion of the must to be treated depends on the efficiency of the process at removing sugar, and on the amount of sugar to be removed in total.

Reverse osmosis treatment of must to remove sugar is currently not permitted in terms of the regulations, but is apparently being considered for future legalisation in South Africa Theron (2006a).

5.1.3 Addition of water

Water addition is illegal in many jurisdictions around the world, specifically in South Africa, the EU, Australia and New Zealand. In contrast, water addition is allowed in the USA. Even the more restrictive state legislation in California has been reinterpreted to allow water addition, supposedly to avoid stuck fermentations (Galpin 2006, p.36).

John Caldwell, a California grapegrower, is very frank about current practices in the California industry to both seek extreme ripeness and to deal with the consequences. He states

> When I deliver grapes at 27° or 28° Brix, they are so concentrated and dehydrated, and a lot of that additional Brix is from dehydration... What happens at the fermenter is that they are seriously, legitimately just adding back the water that's dehydrated to get those flavors. So we're not diluting, we're actually adding it back. (Cutler 2004)

Michael Fridjhon believes that this practice also occurs in South Africa:

> this is expressly forbidden by law in South Africa, forcing an increasing number of producers to do their business on the wild side...the miraculously reduced alcohol levels we are beginning to see on a great number of wine labels simply confirm that the culture of fraud runs deeper than we would like to believe. (Fridjhon 2005)

It has been suggested that winemakers are routinely instructing grapegrowers in California to leave grapes on the vine to dehydrate and adding water in the winery to compensate, a process sometimes known as "humidification" or "breaking back" (Robinson 2003). Andrews (2005) claims that "much of the wine output" of the Californian wine industry is "watered back". More specifically, Ben Drake, chairman of the California Association of Winegrape Growers, has been quoted as stating "anybody getting sugars over 26.5°B is adding water" (Andrews 2005). Considering that the *average* in Napa County over the last few growing seasons is over 25°B, as can be seen from Table 2.2, this statement would imply that a significant portion of the California grape crush is routinely diluted with water.

The regulations in the EU only allow the sale of wine for human consumption if it has undergone practices that are permitted in the EU, unless covered by separate agreement (Galpin 2006, p.59). Since none of the agreements covering wines from outside the EU permit addition of water, it appears that it is illegal to sell wine in the EU that has undergone such treatment, whether under the guise of avoiding stuck fermentations, or otherwise.

If routine water addition leads to a perception by consumers that winemaking is just another industrial process, this could depress profit margins throughout the wine industry. It therefore seems to be more of a long term threat than an opportunity.

This document reviews many options to achieve moderate alcohol without the shortcut of adding water. South African producers should continue to respect the legal framework, since it seems likely this can provide a significant long term marketing advantage over regions where excessive input costs or specific market pressures force producers to take such shortcuts.

5.2 Fermentation

The major variables that can be controlled during the fermentation phase are the yeast cultures involved, the temperature of the fermenting must, and the amount of evaporation that is allowed to take place. Each of these aspects is discussed in the following sections, and some other methods are briefly dealt with in the final section.

5.2.1 Yeasts

It has been claimed that some commercial yeast strains have markedly lower ethanol yields per gram of sugar utilised than other commercial yeast strains (Anonymous 2005). This would clearly provide a method for achieving more moderate alcohol levels.

As discussed in Section 3.5, some winemakers also believe that yeast conversion factors have increased over the last few years. It is possible that yeast conversion factors are not much changed while differences in viticultural practices have caused increases in the non-sugar content of grapes brought into the winery. This is an area for further research.

Addition of yeast nutrients may enhance conversion rates. There is some anecdotal evidence that routine addition of DAP or vitamins, while good for reducing the incidence of stuck fermentations, can lead to high alcohols in the resulting wine (Dobrovic 2006). This needs to be investigated further.

It is possible to disrupt or lessen the efficiency of the reaction expressed by the Embden-Meyerhof glycolitic pathway. For instance, this can be achieved by introducing substances that react with some of the intermediate products, leading to lessened quantities available for the main reaction (Pretorius 2002).

Malherbe and van Rensburg (2004) report that yeasts have been successfully genetically engineered to produce glucose oxidase enzymes during fermentation. A significant reduction of several percentage points in final alcohol level was observed on completion of fermentation. Further work is required to assess the suitability of such yeasts to practical wine production, but this research does demonstrate that it is possible for fermentation to take place at the same time as the glucose to gluconic acid reaction.

Some yeasts have also been modified to increase production of glycerol. This can be achieved by diverting phosphoglyceraldehyde away from the main glycolisis reaction (see Figure 3.1), resulting in lower alcohol production. However, this led to excess acetic acid production, and when this was corrected by further modification of the organism, the aroma profile of the resulting wine was dramatically altered (Australian Wine Research Institute 2003; de Barros Lopes et al. 2003, p.27).

An initiative at the Australian Wine Research Institute is now underway to attempt to breed yeasts that achieve similar results (either through production of glucose oxidase or by greater production of glycerol) but using traditional yeast breeding and selection techniques that do not involve direct genetic manipulation (Australian Wine Research Institute 2005, p.24). This may also allow this technique to be extended to red wines.

The practical value of such yeasts is still several years away, but appears promising for future use.

It is also possible to pick grapes at lower sugar levels and still obtain characterful wines by using the appropriate choice of yeasts to release aroma precursors that otherwise would remain bound. Treating wine that has fermented to dryness with β-glucosidase enzyme can help release bound monoterpenols from their precursors, leading to more intense aromas. Some yeasts have been shown to release this enzyme during fermentation. A mixture of a commonly used Saccharomyces cerevisiae strain (Vin 13) with a strain of Debaromyces pseudopolymorphus was used for fermenting Chardonnay must (Cordero Otero et al. 2003). This resulted in higher concentrations of citronellol and geraniol. These are two common terpenes associated with positive wine aromas (Jackson 2000, p.258). Such mixtures of yeasts are widely used in practice to achieve more complex aromas in the finished wine. This can be achieved by letting wild yeasts start the fermentation and then inoculating with a cultured yeast strain, or using a commercially prepared mixture (Dobrovic 2006).

5.2.2 Evaporative losses

Large quantities of carbon dioxide escape during fermentation. The volume of carbon dioxide gas produced is approximately 50 times the volume of must (Jackson 2000, p.321). Some alcohol is lost through entrainment with the escaping gas. This loss has been estimated at 13.4ml/l in red wines fermented at 30°C and 5.1ml/l in white wines fermented at 15°C (Boulton et al. 1996, p.205), although it is possible that it is greater in practice. This can mean a difference of over 1% in the final alcohol by volume percentage.

In addition, open fermentations lead to greater losses than those in closed fermentors. It is estimated that up to 0.5% alcohol can be lost through evaporation in an open tank compared to a close fermentation vessel (Peynaud 1984, p.155).

Promoting alcohol loss through evaporation, through higher fermentation temperatures and open fermenation vessels, may therefore be an approach to help achieve moderate alcohol levels. If this approach is considered, it may also be worth investigating the recovery of aromatic compounds from the escaping gas and reintroducing these to the wine.

5.2.3 Temperature

It has generally been observed that lower fermentation temperatures will produce higher alcohol levels (Grier 2006). However, it is not clear if this effect is mostly due to reduced evaporation or due to other effects, such as different metabolic activity of the yeasts.

Increased losses through evaporation can be substantial, as discussed in the previous section. It appears that fermentation temperature can also affect the final alcohol more directly. At different temperatures, yeasts will convert more sugar into products other than alcohol. For instance, mannoprotein and glucanase production is higher at 28°C (Dobrovic 2006).

It is not yet clear exactly how fermentation temperatures can influence production of alcohol during fermentation. This is an area for further investigation.

5.2.4 Residual sugar

While it is usually desirable to ferment to dryness, some residual sugar can be perfectly acceptable. With postfermentation treatments like microfiltration, it is possible to ensure good microbiological stability even with relatively high residual sugar levels. This can be achieved by removing microorganisms that can cause instability (Jackson 2000, p.368).

Perhaps partially in recognition of this, the legislated definition of the maximum residual sugar for dry wines in South Africa was changed from 4g/l to 5g/l (South African Government 1990, as amended by Notice No. R.343 of 7 March 2003). Australian company Casella Wines' [yellow tail] brand of wines has been commercially highly successful, with over 7 million cases sold during 2005 (Colman 2006). Yet, several of the wines in the range (such as the Chardonnay and Shiraz) are reputed to have too much residual sugar to qualify as dry. This is difficult to verify authoritatively, since the marketing of the wines deliberately ignores technical analysis. Tasting the 2004 Chardonnay and Verdelho, these wines do appear off-dry on the palate, although this is simply a subjective impression.

5.3 Postfermentation management

The French term *élevage* is often used to describe management of wine after fermentation is complete. Here two main interventions are highlighted: removal of alcohol through one of several direct methods, and evaporative loss of alcohol through barrel maturation.

5.3.1 Dealcoholisation

A variety of techniques can be applied for dealcoholisation.

Processes to remove alcohol from wine rely on differences in the physical properties of alcohol and non-alcohol components of wine: to date differences in size, boiling point, or density have been exploited in various commercially available technologies.

Since the various compounds in wine form aggregates of different sizes, it is possible to separate out the different components using various types of membranes. Reverse osmosis, nanofiltration, electrodialysis and evaporative perstraction are all processes that employ a membrane and high pressure to separate components based on particle size and electric charge, with nanofiltration working on the level of molecules, reverse osmosis at the ion level, and electrodialysis being even more selective than reverse osmosis. Evaporative perstraction uses different vapour pressures to achieve similar goals (Wollan 2005).

Distillation uses the difference in boiling temperatures of the various compounds in wine, and centrifugation relies on their different densities. Centrifugation is a less efficient process than membrane or distillation processes, but the small difference in densities is amplified in the spinning cone process. This employs a design involving columns of cones that rotate rapidly, to allow a greater volume of wine to be treated and thereby achieve comparable efficiency (Theron 2006b).

Evaporative perstraction can be used instead of distillation as the second part of an alcohol removal process (Wollan 2005).

Most of the practical applications to remove alcohol combine several of the different underlying processes.

Clark Smith of Vinovation, a company providing filtration services to California wineries, claimed in 2001 that 30% of premium California North Coast wine had undergone alcohol adjustment (either spinning cone or reverse osmosis). Tony Dann of ConeTech, a California company providing services to adjust the composition of wine using the spinning cone process, claimed at the same time that about 110 million liters of Californian wine had had a component processed by the spinning cone method (Hay 2001). Given the increasing average Balling readings of Californian grapes at harvest as illustrated by Figure 2.1, it would seem that the proportion of Californian wines that has been affected by dealcoholisation is likely to have stayed high, and has possibly increased even further. Smith has in fact recently stated that 45% of North Coast wine had undergone alcohol adjustment (Robinson 2005b).

In South Africa, removal of alcohol from wine has recently been permitted. Processes envisaged in the regulations are reverse osmosis, nano-filtration, distillation or centrifugation, as long as the vinous character of the treated wine is not altered (South African Government 1990, as amended by Notice No. R.814 of 11 August

2006).

It is not quite clear what is meant by vinous character in the regulations. In South Africa excise tax is based on volume of wine, not alcohol concentration. In some other jurisdictions, reducing the tax payable is often cited as a reason to reduce alcohol (Hay 2001). Therefore, the main reason to remove alcohol in South Africa would seem to be precisely to change the vinous character of the wine.

From a practical perspective, there are some legal considerations to take into account. Current EU regulations do not allow South African wine that has been subjected to removal of alcohol to be sold in the EU, although exports to the USA are allowed (Matthee 2006). Alcohol removal can therefore be considered for correcting wines with excessive alcohol levels, but only for wines destined for local consumption in South Africa, or for those where the USA is the only envisaged export market. Even so, it seems worthwhile to be aware of the different commercial options.

5.3.2 Barrel maturation

An important part of the premium wine segment is associated with extended barrel maturation. Many red wines are matured for 18 to 24 months, and sometimes longer, in small oak barrels, typically 225 or 228l capacity. Barrels form a semi-permeable membrane and permit significant evaporation over time. Depending on the relative humidity in the barrel store, it is possible to see greater evaporation of either alcohol or water from the wine. Alcohol concentration of wine in barrels increases slowly in dry cellars and decreases if the cellar is kept humid. It appears that 70% relative humidity is the point at which these effects balance out (Boulton et al. 1996, p.406). A barrel cellar that is kept at relative humidity of greater than 70% will therefore tend to favour a slow decrease in alcohol concentration in the wine being stored. This theory is borne out in practice: it has been suggested that up to 0.6% alcohol by volume is lost over a two year period in a very humid cellar (Dobrovic 2006).

It therefore seems worth considering increasing relative humidity in the barrel store to at least 70%, if a wine is to spend extended time maturing in barrel and it is desired that it not gain in alcohol concentration during that time. By increasing relative humidity to 90% or more it also becomes possible to reduce the alcohol level.

It is not necessarily practical to humidify an existing barrel store, but when planning a new barrel store it is worth considering siting it underground or in a similar location which maintains a high natural humidity level.

5.4 Summary of winemaking interventions

Prior to fermentation starting, it is possible to convert some of the glucose in white wine must to gluconic acid using enzymes. Genetically modified yeast strains have been investigated that perform this action as part of fermentation, and research is ongoing to achieve the same result using traditional yeast breeding and selection, which may also allow this to be applied to red wines. This appears a promising area for further developments. Membrane treatments can be used to remove sugar from must before fermentation, although this is at present not catered for by South African regulations. Water addition is legal and apparently widespread in California, but it is illegal in South African and this practice should probably not be emulated.

During fermentation, choice of yeast strain and yeast nutrition can affect final alcohol levels, and some yeasts can release bound flavour precursors from must, allowing picking less ripe grapes. Temperature of fermentation can affect the fermentation directly, or can combine with evaporation to reduce alcohol. Additionally, some residual sugar can be retained.

After fermentation, alcohol can be directly removed using several different processes. Regulations now permit the use of several major techniques to achieve alcohol reduction, and it is recommended that South African winemakers familiarise themselves with these processes. Finally, for wines that undergo extended barrel maturation, alcohol levels can be reduced by maintaining the relative humidity of the barrel maturation store above 70%.

6. Summary and conclusions

Alcohol concentration in wine and measures of must density were discussed in Chapter 2. Moderate alcohol concentration in wine was presented, and it was argued that achieving moderate alcohol is desirable. However, there is a trend to increased alcohol levels in wine around the world, and statistics illustrating this trend were presented.

Chapter 3 reviewed the conversion of sugar into alcohol during fermentation. A mathematical framework was derived from first principles to relate sugar concentration to final alcohol levels. This non-linear model was then compared with published linear approximations. Various forms of conversion factors were discussed and contrasted with data from commercial wineries, showing that the non-sugar content plays an important role and needs to be taken into consideration.

Viticultural options to achieve moderate alcohols were reviewed in Chapter 4. Choices about vineyard site, establishment of a vineyard and viticultural practices can all help to achieve moderate sugar levels in fully ripe grapes. Ongoing viticultural practices can also be important. Canopy management can be used to control excessive sugar levels. Bunch thinning and bud removal should probably be limited. It may be worthwhile reconsidering the status of virus infection in some vineyards. Effective water management can help to achieve lower canopy temperature and to reverse dehydration in overripe blocks. Correct timing of leaf removal and deficit irrigation, as well as moderating bunch thinning, can reduce reduce methoxypyrazine levels and consequent vegetal characters. Finally, the timing of the harvest remains a key decision point.

Chapter 5 then considered options available in the winery. Glucose oxidase enzymes can be applied to transform some of the glucose in the must into gluconic acid. Once the regulatory environment is changed, sugar can then be removed from must using membrane treatments. Finally, water addition appears to be widely practiced in the USA, but is illegal in South Africa. For fermentation, the choice of yeasts, temperature, control of evaporation, and residual sugar all can help to achieve moderate alcohol levels. After fermentation, alcohol can be removed using several processes (although use of these restricts export options), and a damp barrel cellar can increase evaporation during maturation.

There are many interventions possible to achieve moderate alcohol levels. Of these, the choices in the vineyard appear more important than the corrective action that can be taken in the cellar, even though some of the more drastic winemaking interventions can significantly reduce alcohol levels.

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