THE ROLE OF SCIENCE AND TECHNOLOGY IN WINE PRODUCTION

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I. INTRODUCTION

"*Using only the very best grapes is a new phenomenon. For me, this is the crowning achievement of my work.*" (Emile Peynaud[1])

Winemaking in the last five decades has seen more changes than the previous two millennia combined. Before 1960, winemaking practices were not advanced nor well understood. Most wines were thin and tart and many showed signs of spoilage (Goode, 2010). Today's consumer has never had it so good in terms of choice, quality and value. To state, however, that we have progressed requires us to believe that what we gained outweighs what was lost (Smith, 2011). The following developments have had a major impact on the quality and price of wine.

1. Cellar sanitation

In the 1960s, science began having a greater influence upon commercial winemaking. It was discovered that uncontrolled microbial growth before, during and after wine fermentation can alter the chemical composition of the product, therefore affecting its appearance, aroma and flavour. Peynaud warned that, "[it] is micro-organisms, the yeasts that make wine. (…) But it is also bacteria, noxious ones, which in other circumstances can destroy it." (Peynaud, 1984, p.92) As a result, much more attention was paid to cellar hygiene, particularly keeping floors, vats, hoses and tanks clean, leading to cleaner and fresher wines.

2. Stainless Steel

Winemakers such as Jean-Michel Delmas[2] and Miguel Torres[3] consider the introduction of heat-regulated stainless steel equipment the major innovation of the last 50 years. As it is chemically neutral, it neither adds nor takes away flavours. It can be easily fitted with temperature controls, which provide the winemaker with a level of control over the fermentation process. (Lawther, 2009) According to Stimpfig (2002), "The dramatic results [of vinification in stainless steel] reinvented the taste of Spanish wine. Instead of yellow whites and maderised reds, Torres' wines were fruity, fresh and vibrant."

3. Fruit quality

Quality fruit is critical to a successful fermentation and a balanced wine. While poor quality grapes will never make great wines, Unwin (1996, p.45) suggests that, "modern methods of vinification can certainly make drinkable wines from mediocre grapes." Most experts confirm that much of the wine industry's success in the last decades led to improvements in fruit quality, as measured by sugar concentration, berry colour and the absence of contaminants (e.g., pesticide residues) (Henzell, 2007).

[1] Emile Peynaud, professor of oenology and consultant to many châteaux (including Château Margaux), quoted in an interview dating back to 1990 in Steinberger 2004. See also Faith 2004.
[2] Personal communication with the winemaker of Château Haut Brion on 6 September 2011 in Bordeaux.
[3] Torres introduced stainless steel tanks in Spain in 1975. See Radford 2004.

4. Mechanisation in the vineyard

Since 1960, the pace of technological change in the vineyard has begun to quicken. Activities that are generally mechanised include soil preparation, planting of vines and trellis poles, excess leaf removal and weed and pest control (Bosman, 1999; Mitham, 2011). Different types of canopy management[4] have affected yields and improved the fruit set (Vasconcelos, 2001). Clonal selection research[5] (Clarke, 2008) is helping to introduce the most appropriate vines for different conditions. Fertilisers and pesticides play a major role in modern viticulture (Theron, 2008b). After the excesses of the 1960s when it was a “heresy not to inundate the vines with chemical products of any kind” (Chaigneau 2011, p.95[6]), modern wineries have limited spraying and adopted different types of pest management (Morris, 2010). Machine harvesting has been introduced in the mid 1970s (mainly in the New World) in order to reduce labour costs and shorten the harvest time (Miller, 2011). Mechanical pruning by tractor-mounted machines is also becoming more common as hand pruning remains the single largest expense in vineyard operation (Gordon, 2006). The question remains, however, if this type of mechanisation can match the grape quality obtained by hand labour (Schildknecht, 2010). The use of vibrating (pre- and post-destemming) sorting tables now allows for the removal of all materials other than (healthy) grapes (Theron, 2006; Stewart 2009). According to Gérard Perse of Château Pavie (quoted in Anson, 2009), “the idea of manual sorting will be unthinkable in five years from now. But we must remember after a certain point, we can’t make any more difference to the grapes.” Vineyard mechanisation has definitely had a significant positive impact on the production cost of wine, in particular in the New World, and in many cases has improved the quality of the grapes and therefore of the end product.

5. New techniques in the winery

Significant innovation has taken place in the winery. The commercial availability of active dry forms of cultured yeast to inoculate musts has given winemakers a degree of control over fermentation (Goode 2006b; Gaffney 2011; Miller 2011). Other new methods are simple extensions of what occurred naturally in traditional winemaking. One such technique is cold soaking the fruit for several hours to postpone the start of alcoholic fermentation (Davies, 2005). This enhances colour intensity and preserves more of the fruit character in the wine (Rotter, 2009c). Cap management (Theron, 2008) is being automated with the introduction of techniques such as ‘pneumatage’[7]. Various types of filtration aids and techniques such as cross flow filtration enable the removal of almost any unwanted particle through a membrane cartridge filter. While serious clarity issues are generally unacceptable, sterile filtration, however, has come at the price of wines

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[4] An example is the Lyre trellis system introduced in the 1980s balancing leaf area and fruit weight.

[5] A trailblazer in this effort has been Château Ausone (Lawther, 2001). Critics such as Cazes of Château Lynch Bages accept the benefits but worry that it reduces the genetic diversity of a vineyard. (Cazes, 2011)

[6] Jean-Pierre Perrin of Beaucastel quoted in Chaigneau, 2011, p.95. Excessive pesticide and chemical use in the vineyard changed the acid-alkaline balance of the soil leading often to issues with low acidity despite very ripe fruit. (Morris, 2010)

[7] The use of compressed air to mix juice and skins.

stripped of aromatics and body (Rotter, 2009a). Highly controversial techniques include micro-oxygenation to soften the tannins in red wine (see next chapter), thermovinification[8] to better extract anthocyanins (Patterson, 2010) and the use of concentrators[9] to meet the demand of critics and consumers for bigger, more muscular wines (Teague 2005).

Rose (2005) asserts that, "Used properly, technology can be harnessed to help us understand why time-honoured practices work – or not." The past decades, however, have seen a trend for over-manipulation, resulting in wines that are soft and super-ripe but lack authenticity (Legeron, 2011). It comes therefore as no surprise that the pendulum is swinging towards 'natural wines' or "[wine] untouched by the evils of 20th Century technology (Smith, 2007)." Notwithstanding this, technology and science have now given winemakers choices and options that they can use for making better wine in a cost-effective way.

[8] The best-known equipment is Flash Détente manufactured in France. The process involves a combination of heating the grapes to 80 degrees Celsius and then cooling them in a vacuum chamber. (Daniel, 2011)
[9] The latter technique is very popular in Old and New World alike and extracts water from the grape must by reverse osmosis thus concentrating the wine. (Piggott, 1999)

II. IMPACT ON WINE PRODUCTION

(i) VITICULTURE: WATER STRESS MANAGEMENT

> *"Partial Rootzone Drying is a brilliant idea: a good example of a concept developed in the laboratory and then applied to real-world agriculture."* (Goode 2006a, p.78)

1. Background

Water is an important natural resource throughout the world. Grapevines need water to grow new shoots, effect photosynthesis and develop grape berries. In many regions, and particularly in New World vineyards[10], irrigation is an integral feature of winegrowing due to the climatic and soil characteristics. Grape growers need to carefully evaluate how water management affects production yields, vine vigour, wine quality and profitability (du Toit, 2004).

Without water, vines shut down due to hydric stress, and the resulting wine is tannic and lacks fruit (Bird, 2010). Moderate water stress, however, has several benefits and researchers (Jackson, 2008) have found that wine produced from minimally irrigated vines has more marked aroma and better fruit flavour. A vine that is kept at a threshold level of water availability just below what is needed for maximum growth closes its leaf pores to conserve moisture and synthesises a plant hormone, abscisic acid, which regulates its growth (Dry, 2000). As a result, the vines will be less vigorous and will develop a more open canopy with better exposure of buds and fruit (Skelton, 2009).

2. Application

The introduction of drip irrigation in the mid-1970s revolutionised vineyard practices. As Peterson (2011) wrote, "Drip irrigation created a brave new world for vineyard owners/managers (…)." The ability to water on demand, with precise applications and limited labour opened up a number of more advanced water management techniques (Dry, 2000).

Regulated Deficit Irrigation (RDI) is an irrigation practice originally used in fruit orchards applying water applications to maintain the vine water status (typically measured by using a pressure bomb)[11] within prescribed limits with respect to its water potential (Kriedeman and Goodwin, 2002). It is applied during parts of the growing cycle of vines and berries for the purpose of controlling vegetative growth and red berry[12] development early in the season and to increase the phenolics in the grape after véraison.

[10] Most Old World wine authorities forbid the general use of irrigation claiming that it dilutes the wines. In rare circumstances (e.g. weather conditions of 2003 in France) exceptions are granted. (du Toit, 2004)
[11] A leaf (where the petiole is cut) is placed in a plastic bag in a pressure chamber (bomb) until sap is exuded. The amount of pressure needed corresponds to how tightly moisture is held in the leaf as measured in bars. Most grapevines start to show stress at -12 to -15 bars. (McGourty, 2008)
[12] The technique has resulted in significant improvements in Shiraz wine quality. (McCarthy, 1997)

It will also improve water usage. Its skilled use ensures that there is minimal competition between ripening berries and vegetative growth (Dry, 2000).

An alternate technique is *Partial Rootzone Drying* (PRD) developed in the mid-1990s. The concept entails that one-half of a grapevine's roots is irrigated at a high frequency, while the other half is left to dry. This is alternated on a 1-3 weeks' cycle (du Toit, 2004). The roots on the dry side produce abscisic acid triggering physiological responses such as reduced vine growth. The watered side, however, provides sufficient amounts of water so that essential functions such as photosynthesis are not compromised (Jackson 2008).

3. Impact

Many winegrowers use the new irrigation techniques to conserve water, help with vine balance (especially in case of overly vigorous vines) and improve fruit quality. Partial Rootzone Drying has the additional advantage that there is no notable decrease in yield (Dry, 2000). The studies of Kriedeman and Goodwin (2002) and McMullin (2004) summarise the positive effects of water stress management on the grapes: reduced berry size and, especially when applied just before véraison, concentrated colour and flavour. The results generally confirm that (red-wine) quality (as measured by the concentration of anthocyanins and phenolics) is at least maintained if not improved (Greenspan 2009).

4. Conclusion

New water management techniques, which have been facilitated by the introduction of drip irrigation, haven given winegrowers some degree of control over water availability, which is a key factor influencing grape and thus quality. At the same time, they help to preserve this scarce resource.

(ii) VINIFICATION: MICRO-OXYGENATION

"*Micro-oxygenate!*" (Michel Rolland in Mondovino[13])

1. Background

Understanding how oxygen affects a wine at various stages of its development is essential for winemakers who want to produce quality wines. Its role can be either beneficial or detrimental depending on the stage of vinification (Goode, 2006a).

Micro-oxygenation is the measured addition of minute amounts of oxygen to wine in a manner that ensures a complete transfer of molecular oxygen from gaseous to dissolved state (Jackson, 2008). The process aims to imitate the effects of slow barrel maturation within a shorter period and at a lower cost (Robinson, 2006).

Patrick Ducournau developed the technique in 1991 when he was a winemaker at Chapelle Lenclos in Madiran and tried to smooth out the harsh tannins in the Tannat grapes (Cutler, 2009). He invented a device that allowed him to add low doses of industrial-grade oxygen to the wine in a controlled manner. Applications of low dose[14] oxygen would be an alternative to the slow diffusion of oxygen in barrels. Red wines that are matured in barrel will generally have a more intense colour and softer tannin than those in steel tanks due to the gradual and limited oxygen uptake. As a result, micro-oxygenation is frequently presented as a substitute for barrel maturation for red wines, with the added advantage of lower cost, and more control (Blaauw, 2009). Jackson (2008, p.434) states, "[whether] these procedures adequately mimic the limited oxidation in barrels is a moot point (…). What micro-oxygenation clearly offers is better control."

From a wine chemistry perspective, micro-oxygenation affects the phenolic structure of the wine as it promotes the formation of short-chain polymers between the anthocyanins and tannins, which are highly soluble (Cottrell, 2004). The limited oxygen causes a decrease in free anthocyanins content, which heightens the colour intensity, while the increased phenol polymerisation leads to a softer taste (Theron, 2009b).

2. Application

Essentially, the machine takes oxygen from a cylinder and doses it with a regulator through a (ceramic) sparger into the wine so that the bubbles are fine and easily absorbed Experiments (Nel, 2001) have confirmed that wines treated with micro-oxygenation in stainless steel vats will be similar to barrel-matured vines. This effect is accelerated by the addition of oak alternatives to the tank (Theron, 2009b). The novelty of micro-

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[13] Mr Rolland, France's most eminent (and notorious) wine consultant shouting at a client out of the window of his car while driving away at full speed. This image in the movie Mondovino (by Jonathan Nossiter, 2004) contributed to the controversy and image of this technique. Rolland has now declared that he is no longer a fan of micro-oxygenation (Goldfarb, 2007).

[14] An estimated 1-2 ml oxygen/litre/month is added to the wine (Theron, 2009b)..

oxygenation is therefore mainly in its ability to have real control over the total amount of oxygen and the timing and rate it is delivered to the wine.

The process usually follows two phases (Bird, 2010). The initial s*tructuring* phase (at the end of primary fermentation) stabilises colour due to high levels of oxygen (10-60 ml/l/month for 1-3 months) and is followed by a *harmonisation phase* (with small doses of oxygen of 0.1-10 ml/l/month for several months after malolactic fermentation) leading to a softening of the tannins.

The technological approach of micro-oxygenation has found favour between both Old World and New World winemakers since its worldwide introduction in 1996[15] (Feiring, 2001). The high take-up is remarkable considering that there is no conclusive scientific evidence of its benefits and few experimental data around the technique (Blaauw, 2009). Many winemakers consider micro-oxygenation as simply another arrow in their quiver, comparing it to an advanced type of the traditional racking technique. Asimov[16] (2007) therefore questions, “Is micro-oxygenation that different?” Large wineries (such as E. & J. Gallo) use the technique for cost-efficiency (avoiding the need to use expensive oak barrels and the labour costs of regular racking). Wines can come to the market place quicker (sometimes in a third to half the usual time), which reduces inventory costs and speeds up cash flow for wineries (Goldfarb, 2007).

3. Impact

Proponents of the technique claim that micro-oxygenation will result in higher quality red wines (Vinovation 2001; Blackburn 2004). A red wine treated with a course of micro-oxygenation will result in a softer, more integrated and accessible wine with improved colour, lower perceived vegetal aromas and fruit flavours that are more pronounced (Parish, Wollan and Paul, 2000). Nevertheless, micro-oxygenation must be used in a controlled manner. An excessive amount of oxygen added can lead to diminished wine flavours, an increase in reductive flavours and even the formation of acetic acid (Dempsey 2001; Easton 2009).

When moderately applied, experiments demonstrate that micro-oxygenated wines (when paired with the same wines made in a traditional manner) show more fruit, a rounder, brighter structure and more mouth-feel (Cutler, 2009). On the other hand, recent scientific evaluations of micro-oxygenation question its effects. While it can increase colour and colour stability and produces changes in the tannin structure, the actual impact on astringency and mouthfeel is less certain. There is also little empirical evidence that it enhances fruitiness in wine (Blaauw, 2009). In practice, the most widespread use of

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[15] Manufacturers include Oenodev (France) -set up by Ducournau in 1993-, Parsec (Italy) and Stavin (USA) (Blaauw, 2009). An estimated 5000 machines are currently in use in France alone (Work, 2007) and that nearly 20% of all New World wineries use this practice (Goldfarb, 2007).

[16] Eric Asimov is the wine writer of the New York Times and a known critic of new wine technologies, which makes his statement even more poignant.

micro-oxygenation is therefore as an alternative to barrel ageing for medium quality red wines intended for short to medium-term consumption (Goldfarb, 2007).

4. Conclusion

Micro-oxygenation has shown capabilities in improving the quality of certain types of wines subject to its judicious use. Goode (2006a, p.100) even reports that, “As soon as the science catches up with the technological push, micro-oxygenation looks set to become an established, mainstream technique throughout the winemaking world.” While its longer-term effects are not yet clear, the technique requires extensive tasting to monitor the progress of the wine. Therefore, if anything, it makes winemakers concentrate a lot more on the development of their wines.

III. CONCLUSION

> *"You can't throw tradition out the window, but you need innovation."* (Angelo Gaja[17])

Advances in technology and science in the past 50 years have provided winemakers with more choice and opportunity to make better wine in a cost-efficient manner in the light of changing consumer demand (Smith 2007; Rotter 2009a). Technology, however, must never become an end in itself. As Oz Clarke (1994, p.40) notes, "In the 1970s and 1980s winemakers genuinely believed that everything was possible (…). Through attempting to master technology, many modern winemakers had become slaves to it." Some of today's technologies and methods are destined to become obsolete and other will be tradition 50 years from now (Morgan and Moore, 2008). We expect that the next two decades will continue to bring new developments in the following areas.

Vineyard mechanisation thanks to agricultural technology

Vineyard mechanisation will further advance inspired by agricultural technology. Precision viticulture will leverage the geographic information system (GIS)[18] (used in field crop farming) to determine optimal vineyard sites, planting, spraying and harvest times (Landers 2008; Kurtural 2011). Vineyard managers will therefore be able to keep track of soil moisture, nutrient status and crop health throughout the vineyard (Ulrich, 2007). Robotic pruning of vines (as used in apple growing) and the optical sorting of grapes (as in the peas industry) will increase speed, reduce expert labour costs[19] and lead to the processing of higher quality grapes (Anson and Kakaviatos 2009; Ulrich 2011).

Quality control – the lessons from commercial brewing

Commercial beer brewing is years ahead in the adoption of advanced technology and methods. Larger wineries will want to implement its level of quality and process controls, tracking the grapes from the sorting table to the bottling line (Barwick, 2011). Being able to define quality is essential in this goals-oriented approach to wine making (Harpers, 2006). This requires a more advanced collection and interpretation of phenolic data about wine and its development[20].

Sustainable winemaking

The topic of sustainable grape growing and winemaking will become ever more relevant (Goode, 2010). Projected changes in climate will put political and environmental pressure on irrigated viticulture (Cahill, et al. 2008). Advanced plant management research will

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[17] Angelo Gaja quoted in Frank, 2011, p.46.
[18] GIS is a system that captures, manages, analyses and displays geographically referenced information and allows users to better understand the data.
[19] Costley (2011) estimates that robotic pruning can save up to 40% of vineyard costs versus hand pruning.
[20] As Halliday and Johnson (2007, p.201) state, "The chemistry behind the reductive and oxidative changes that take place in the bottle as the wine ages is very complex, and not fully understood."

therefore lead to the development of water-efficient rootstocks and cultivars (Clingeleffer, 2010). Reduced-risk ‘soft’ chemical pesticides will need to be developed (Franson, 2008). An evaluation of the environmental impact of oak in winemaking will lead to more refined oak alternatives (for ageing wine) (Theron, 2009c). Plastic containers may replace stainless steel tanks and oak barrels as they allow wineries to reduce their carbon footprint.

Biotechnology

The genetic modification of yeasts and grapevines is highly controversial for consumers and authorities alike. Biotechnology offers the potential to produce a vine that is stress and disease resistant (Pretorius, 2005). At the same time, it will allow for the design of wine yeasts that provide certain desirable options, e.g., lower alcohol wines (Pretorius, 2000; Fleet, 2008; Styger 2008) We can expect major continued research efforts in this field over the next decades.

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