EMBO reports

analysis

In vino scientia

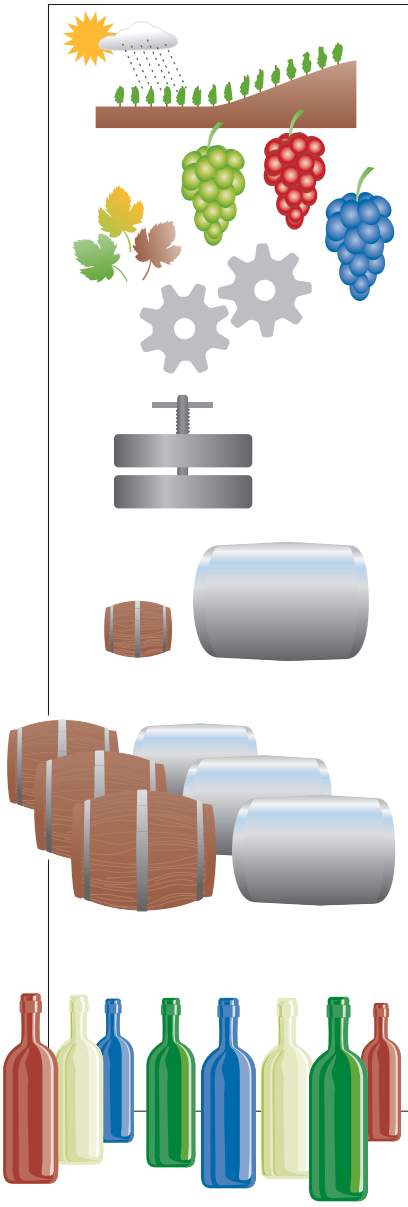
Although science has much to offer winemakers, skill and experience will always prevail over technology

A blue autumn sky spans the vineyards that cover the east-facing hillsides of the Palatinate in southern Germany. The vines are depleted—their grapes harvested weeks ago—although there is still some warmth in the sunshine on a mid-November day. The summer of 2006 in Germany was unusual: a hot dry July followed by a cold rainy August, and a warm, moist September and October. The climate during these last two months caused the grapes to swell and their skins to rupture, increasing the risk of spoilage by fungal infections, so that the winemakers had to rush to bring their harvest in early.

The fickleness of nature is not the only challenge facing winemakers. During the past few years, consumer tastes for wine have drastically changed, and they generally expect better quality for their money. Among other responses, both small and large producers have turned to science for advice on how to make better wines. Science has had a long relationship with winemaking, from breeding new grape varieties to improving the fermentation process, and, most recently, advising on which vines to grow in a given location. Today, many research fields—including geology, chemistry and microbiology—are involved in improving the steps from vineyard to bottle (Fig 1). However, it might disadvantage small producers—and therefore the diversity of wine and winemaking—if only large estates with big budgets can afford the latest technologies.

Large changes in the international wine market are now taking place and are driving a wave of innovations. As Florian Bauer, Professor of Wine Biotechnology at Stellenbosch University in South Africa, pointed out, "There is an increasing penetration by New World wine industries into the European market," which is the world's largest and most sophisticated. In general, the global market used to be ruled by producers and an elitist industry, Bauer added, but today "the wine industry is much more aware of what consumers want." Furthermore, the market is saturated with an annual production of approximately 27 billion litres of wine from 8 million hectares of vineyards, which is approximately 5 billion litres more than it can absorb (Pretorius & Bauer, 2002). For wine lovers, this is good news. "We now have a wine glut, so there is certainly no need to increase quantity," commented Jancis Robinson, a British wine critic, author and wine correspondent for the *Financial Times*. "Quality is increasing substantially every year through sheer ambition, determination and passion on the part of a new generation of quality-orientated producers—and a very competitive marketplace."

As a result of these changes, many French producers have had to lower their prices—sometimes drastically—as consumers are becoming less willing to pay large amounts for a brand name. In the meantime, producers from other countries have caught up. Spanish growers have improved the quality of their wines, and Italian growers in Tuscany have turned Chianti—once known as a cheap red wine sold in 5-litre bottles—into a premium product by accepting the Denominazione di Origine Controllata e Garantita (DOCG) label and its quality requirements from the Italian government. Further north, a new generation of ambitious winemakers in Germany now produce some of the best white wines in the world, notably Rieslings. The rest of the world is not standing still



White wine	Rosé, Rosato	Red wine	
Viticulture Harvest	Viticulture Harvest	Viticulture Harvest	Viticulture Harvest
Destemming Crushing	Destemming Crushing	Destemming Crushing	Destemming Crushing
Pressing Removal of mucilage	Preliminary fermentation (12–24h) Pressing		Heating of mash Pressing Removal of mucilage
Primary fermentation (and malolactic fermentation)	Primary fermentation (and malolactic fermentation)	Primary fermentation (and malolactic fermentation) Pressing	Primary fermentation (and malolactic fermentation)
Filtering Secondary fermentation Bulk ageing Sedimentation	Filtering Secondary fermentation Bulk ageing Sedimentation	Filtering Secondary fermentation Bulk ageing Sedimentation	Filtering Secondary fermentation Bulk ageing Sedimentation
Filtering Fining Blending	Filtering Fining Blending	Filtering Fining Blending	Filtering Fining Blending
Bottling Closure Storage	Bottling Closure Storage	Bottling Closure Storage	Bottling Closure Storage

Mackensen

Fig 1 | Rough scheme of processes in winemaking (facultative processes are shown in grey).

either: the USA, Australia and South Africa are increasing their wine exports, while Chile, Argentina and New Zealand are also entering the market.

As consumers become more demanding in response to a greater choice of wines, and low-price products become increasingly uneconomical, producers all over the world are aiming to improve quality. So, what makes a good or premium wine? According to Manfred Grossmann, Head of the Department of Microbiology and Biochemistry at the Geisenheim Research Centre, Germany, which specializes in wine and horticulture, "the quality of a wine is determined by its compounds." These provide what consumers cherish: bouquet, balance, complexity of aromas, ageing potential and so forth. However, to achieve the ideal combination of these characteristics—which ultimately depends on consumer preferences—neither viticulture nor fermentation alone makes a great impact on the final product. "One should not separate these two but rather see winemaking as a holistic process," Grossmann said, which makes it an interesting but also difficult problem for science to tackle. "From the science point of view, it is rather a frustrating field to work in because of the complexity," Bauer commented.

"A great wine is made in the vineyard," Bauer said, and starts with the quality of the grapes. Consequently, research is now beginning to focus on this aspect, selecting the optimal variety for a given location. "Viticulture has in the past received less attention," Bauer said, "but that is about to change." The focus on varieties and location is also welcomed by

sophisticated consumers. "Wine's joy is that it is capable of communicating the character of a single site in a bottle and I think it's wonderful that more and more winemakers are once again celebrating this," Robinson commented.

As a result, not only winemakers but also scientists are turning their attention to how the interplay between geology, soil chemistry, biology and environmental conditions produces wines with complex and distinctive flavours in one area but not in neighbouring regions. Different grape varieties also need different conditions to flourish; for example, Riesling thrives on light soils and a moderate climate, whereas red grapes, such as Pinot Noir and Nebbiolo, require heavy rich soils and a lot of sunshine to fully develop their flavour. Planting the right grape variety in a particular area is of serious economic importance: a newly planted vine must grow for several years before producing grapes and can stay in service for up to 50 years, which makes it a life-time investment.

…not only winemakers but also scientists are turning their attention to how the interplay between geology, soil chemistry, biology and environmental conditions produces wines with complex and distinctive flavours in one area…

Consequently, 'terroir', as this concept of location is called, has become the target of some of science's biggest instruments. By using satellites, earth-penetrating radar and analytical tools, scientists have already mapped the soil conditions in large areas of the western USA. Taking a more traditional approach, the Geisenheim Research Centre has spent decades creating maps of wine-growing areas in the region, which detail climatic and geological information. In addition, the centre offers winemakers a detailed analysis of their soil with the aim of choosing the optimal variety. The current interest in terroir is also spawning new businesses: companies such as Terra Spase (St Helena, CA, USA) and Wine Network (Oakleigh, VIC, Australia) provide detailed scientific analyses to winemakers that advise them on how to establish their vineyards.

However, not everyone sees the need for such advice. Helmut Darting is a traditional wine producer with a successful family-run estate in Bad Dürkheim, southern Germany—his 2001 Riesling Michelsberg Kabinett was chosen as one of 15 best Rieslings worldwide in 2002 by a panel of 160 tasters. Darting is wary of the recent rush to use the latest scientific expertise. "Nobody needs to tell me where I should plant which variety," he said, with the calm confidence of someone who knows his trade. "This is knowledge any well-trained and experienced winemaker should have."

Come autumn, producers must decide when to harvest the grapes. Traditionally, their ripeness is determined by the sugar and acid content; however, these parameters do not provide the full picture, and so winemakers are increasingly employing the services of analytical laboratories, particularly to ascertain the amounts of phenolic compounds in grape skins, which give red wines both their colour and their distinctive taste.

For some time, scientists have also focused on optimizing the fermentation process itself. Historically, winemakers have used spontaneous fermentation, allowing the yeasts and bacteria living on and in the grapes to do the work. However, as the phrase implies, spontaneous fermentation is an uncontrollable process; whole ecosystems of microorganisms live on the grapes and help to produce complex and interesting wines, but can also spoil the process. Purified yeast strains, which became available at the end of the nineteenth century, allow producers to have more control over what happens in the fermentation tank. Since then, the subsequent identification of different yeast strains has further helped to refine and optimize the process.

Modern analytical tools, including mass spectrometry and gas chromatography, now allow scientists—such as the members of Grossmann's research group in Geisenheim—to investigate the role of various microorganisms to better understand the fermentation process. The aim is not only to identify and isolate 'good' yeasts, but also to analyse the role of other microorganisms—in particular the lactobacilli that metabolize acids—and their interactions with each other and yeasts. "Yeasts do not live off sugar alone," Grossmann explained, but rather need a range of nutrients. If the wine yeast *Saccharomyces cerevisiae* fails to win the competition for nutrients and other microorganisms take over, fermentation leads to unwanted compounds that can spoil the bouquet or taste. Bacteria might also contribute their share of metabolites at different stages of the fermentation process, and so understanding their involvement might help producers to better control wine fermentation.

In addition, researchers in Geisenheim are investigating why and how some wines acquire an unwanted cork taste after bottling, as well as the emergence of foul-smelling hydrogenated sulphuric compounds that render a whole batch useless. Their aim is not only to gain knowledge but also to drive fermentation towards a predetermined outcome; various companies now offer a wide range of yeasts, enzymes and other additives to suppress or enhance certain reactions. The list of what is possible does not stop there. The US Food and Drug Administration (Bethesda, MD, USA) has approved two genetically modified yeasts for wine fermentation: one containing a malolactic enzyme gene from the lactobacillus *Oenococcus oeni*, and the other containing a gene encoding urea amidolyase to prevent the formation of the suspected carcinogen ethyl carbamate. "I think in Europe, [genetically modified yeast] will not catch on for a while because there is a fear of negative consumer reactions," Grossmann said, but "it is just a matter of time." Despite the general public's aversion to genetically modified foodstuffs, their use in improving the health values of foods might help to change attitudes.

...winemaking depends on the winemaker's skills and experience

In direct contrast to many producers, some winemakers are relying on spontaneous fermentation to produce more complex wines. This might just be a marketing tool: "Scientifically, it is not better than inoculated fermentation," Grossmann said. Darting sometimes uses this approach, but not with a 'difficult' vintage, such as the 2006, because the risk of spoiling a whole batch is too great. Usually, Darting inoculates with yeast "simply to speed up fermentation" and to prevent the creation of unwanted metabolites. In addition, if he

uses spontaneous fermentation, he also relies on the analytical laboratory of a nearby wine school to determine whether it is proceeding as expected; if not, he has to filter the whole batch and restart the fermentation by adding yeast. Darting added that microbiology in general has a lot to offer simply because it is "helpful to know what is happening in the wine" when it ferments. In the end, however, winemaking depends on the winemaker's skills and experience. As Darting commented, education is key and is best combined with research into the complexities of wine making.

For Darting, the biggest problem in wine production will not be economic, but rather the effects of climate change—and this is where he thinks science can help. The hot and dry summer of 2003, for example, caused serious problems for winemakers throughout Italy, but probably created the best vintage for German wines in the past few decades. "For years, [winemakers] begged for any sun rays, but in a few years it may even be too much," Grossmann said. Indeed, the weather is already affecting the characteristics of some wines. For example, a classic Riesling is a dry, fruity wine with 10–12% alcohol, but this percentage has increased as a larger amount of sugar—the result of a long and warm summer—must be fermented to retain its dry, lightly acidic characteristics. To meet the challenge of climate change, Darting believes it might become necessary to turn to genetically modified vines, even though European consumers have yet to embrace the idea. To cope with a hotter climate, producers could benefit from plants that are more resistant to water stress or grapes with skins that do not burst easily. "You should never say never," Darting added.

> **"Science is of course invaluable, even if only to confirm that what has been done traditionally is worthwhile"**

In the rush to please increasingly demanding consumers, the question remains as to whether science will predominantly benefit large producers and leave small traditional producers behind. Grossmann can envisage such a possibility: "The willingness of consumers to pay the price for individually made wines is decreasing," he said. This could

H. Breithaupt

favour large estates, such as Ernest & Julio Gallo of Sonoma, the biggest producer in the USA, which owns vineyards equipped with weather-monitoring stations all over the state of California and sells more than 40 varieties of wine worldwide. A producer of this size can clearly afford all the expertise they need, whereas a small producer with just a few hectares and a few different varieties might be at a disadvantage.

> **…the industry needs both small growers who cater to specialist consumers and large estates with brand names who guarantee quality for the mass market**

For Bauer, however, the problem is not so much small versus large producers, but rather how to attract new customers, particularly young people. "There is a mix [of producers] and it is important because it makes wine something special," he said. To this end, the industry needs both small growers who cater to specialist consumers and large estates with brand names who guarantee quality for the mass market. "It is a win–win situation if they do it right," he said. "[The wine industry] needs both sides. They need big producers to compete with beer and other beverages [to attract people to wine] and the more they become interested in wine, the more they become attracted to smaller producers."

Darting is confident that small traditional businesses, such as his own, will prevail. "For large estates, science is important, but small producers have a much better understanding of what is happening in their vineyards," he said, adding that small producers are also more flexible and more inclined to take risks, thereby creating complex and interesting wines. In this regard, science does not necessarily threaten traditional methods and might actually do the opposite. "Science is of course invaluable, even if only to confirm that what has been done traditionally is worthwhile," Robinson commented.

In the end, the nature of wine itself might also work to prevent tradition being overshadowed by technology. "We are making a luxury product," Darting said. Winemaking might therefore resist any trends towards more economical production or against individualism and diversity in favour of a mass market. "I think wine is such a fragmented market that there will always be a place for aspects of tradition in wine," Robinson said. "It is one of the few comestible products capable of evolving over decades, even centuries, so we have, naturally, a very special, rather romantic relationship with it."

REFERENCE

Pretorius IS, Bauer FF (2002) Meeting the consumer challenge through genetically customized wine-yeast strains. *Trends Biotechnol* **20:** 426–432

Holger Breithaupt

doi:10.1038/sj.embor.7400883