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The present and future of the international wine industry

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Wine production is both art and science, a blend of individual creativity and innovative technology. But wine production is also business, with economic factors driving manufacturing practices. To be successful in the modern marketplace, a winemaker must integrate the artistic and economic aspects of wine production, and possess a solid understanding of the intrinsic and extrinsic factors that underlie purchase motivation.

Wine is a unique commodity. Its production predates recorded history, as does the discovery of the healthful benefits of wine, now largely attributed to the antimicrobial activity of ethanol[1]. Throughout antiquity the conversion of grapes into wine was considered a gift from the gods and the best wines were thus reserved for the elite of society. The image of wine as a beverage of the affluent persists even today. Wine was also one of the first commodities to be bartered by early civilizations engaged in international trade. Then, as now, the most successful wine producers were those who grasped market forces of supply and demand, and whose products met the prevailing definition of quality.

Today, wine is an integral component of the culture of many countries, a form of entertainment in others, and a libation of choice for advocates of its health benefits. Unlike many modern foods, wine's attractions rely not on bold consistent flavours, but upon a subtle array of shifting sensations that make its charm difficult to define. In essence, wine producers are selling a sensory experience to the consumer. Wine consumers in developed nations are typically prosperous, but wine is also consumed in impoverished areas where it is still safer to drink than the local water supply. Regardless of the region in which the wine is produced or the economic status of the consumer, all wines are expected to be pleasant experiences for the imbiber.

In past generations, the definition of quality was the preserve of the wine producer, and consumers who did not like a particular style of wine were often made to feel uncultured. But globalization and the accompanying rapid worldwide access to information has resulted in a more knowledgeable and empowered consumer with a more sophisticated understanding of product value and a discriminating demand for quality. The control of the definition of quality has thus shifted to the consumer. Success as a wine producer in the twenty-first century requires a thorough appreciation of human behaviour and product choice.

Wine is again a unique commodity in this respect. The intrinsic sensory aspect of wine taste and aroma are only one component in the modern consumer definition of quality. Extrinsic factors such as bottle and label design and the perceived artistic talents of the winemaker are equally important motivators of human preference in wine selection. In addition to a product that is enjoyable in all sensory aspects, consumers expect wines to be healthful and produced in an environmentally sustainable manner. In the future, these last two factors will become increasingly important economic drivers of profitability.

These issues are complex, requiring producers to understand the latest developments in wide-ranging disciplines of science and technology. The present-day wine industry is focused on optimizing the attractiveness of the product within the bottle. In the future, the industry will need to go beyond this, paying more attention to the extrinsic factors motivating product choice, while ensuring that production remains cost-effective and economically sound.

The economics of wine production

In contrast to other types of crops, grapes can be grown in diverse climates and soils. Although scientifically still unproven, environmental stress is believed to improve the sensory characteristics of grapes and wine, resulting in a better product. The French concept of *terroir* states that the composition of grapes produced in a specific growing region will be influenced by the local environment, which will carry through to the wines of the area[2]. This concept also includes as an element minimal intervention in modification of the growing environment so that the *terroir* may be evident. Thus, in contrast to other agricultural commodities, wine is marketed by the geographical location of production, and quality is associated with minimal vineyard inputs or manipulation.

Consumers expect wine from a particular region to possess unique qualities that differentiate it from other wines of the same varietal from other regions. This peculiarity of the industry is a great economic equalizer across the globe. It means that wines perceived to be of high quality can be produced anywhere. Indeed, quality wines are currently being produced on all six arable continents, and affluent as well as emerging nations are active in the international wine trade. The heightened tourism that accompanies the 'discovery' of a new wine-producing region is economically important to many countries. This 'value added' economic aspect of wine production is remarkable, and the main reason that many governments support strong research programmes in the development and improvement of their wine industries.

The wine industry is actually a composite of several individual economic or market segments. In the United States, roughly 70% of the market is comprised of the 'economy' wines, those that retail for less than US$7 per 750-ml bottle. Wines range from economy to premium, ultra-premium and artisan, with wines in the latter two

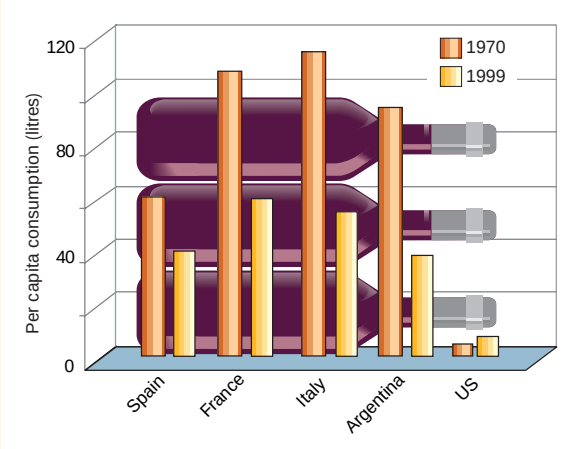

Figure 1 Changes in total consumption of wine by country over the past three decades. Data from refs 3, 4.

categories comprising only 2–3% of the market and commanding high prices. However, consumers have high expectations for product quality in all price categories. The actual sensory attributes desired may differ, but not the expectation of a pleasing sensory experience.

During the last third of the twentieth century the world wine market became significantly more competitive. Consumption declined in the traditional wine producing and consuming countries, while competition emerged from such 'New World' nations as the United States, Australia and Chile, and prosperous consumers chose quality rather than quantity in consumption. In 2001, France, Italy and Spain combined to produce slightly more than half of all the world's wine, but in the past 30 years their own per capita consumption has fallen 40–50% (Fig. 1), leading to an oversupply of 'Old World' wine[3,4]. During this same period, US per capita wine consumption has almost doubled and, more important, US consumers have chosen to drink more expensive wine in a search for quality, a trend that seems to be true of European wine consumption as well. The New World producers have been quick to respond to global perceptions of quality, and have gained significant market share in the past 20 years, moving from 2 to 15% of the world export market (Fig. 2), largely at the expense of the European producers[5].

Factors other than enhanced product quality have fuelled the increase in US consumption of wine. In1991, a study by Serge Renaud coined the term 'French paradox' to describe the relationship between the high intake of fats in the French diet and the low incidence of coronary heart disease[6]. This well-turned phrase galvanized the attention of the media, the public and other scientists. Although there are many differences between the French and American diets, attention quickly focused on the disparity in wine consumption between the two countries. This was because of the long recognized benefit of moderate alcohol consumption[1,7]. Renaud had no mechanistic explanation for the paradox, which led many to doubt its validity, but Kinsella and colleagues[8] proposed that the natural antioxidant phenolic compounds of wine and fruits and vegetables of the Mediterranean diet might protect against heart disease. This conclusion was based partly upon a new theory advanced by Steinberg[9] that linked oxidation in the blood to disease.

The power of the antioxidant hypothesis, coupled to the high visibility of Renaud's report and strong pressure from the public sector, promoted investigation into the chemical and biological activities of alcohol, dietary phenols and flavonoids. Today there is scientific evidence that moderate alcohol and/or wine consumption protects against the incidence of many diseases of modern society — cardiovascular disease, dietary cancers, ischaemic stroke, peripheral vascular disease, diabetes, hypertension, peptic ulcers, kidney stones and macular degeneration — in addition to stimulating resistance to infection and retention of bone density[10–13]. The benefits of antioxidants are more pronounced in red wines as these wines contain a higher phenolic content, but white wines also offer some benefit to the consumer.

The impact of the French paradox and the popularization of this study by the media had a pronounced impact on the international wine industry. Consumers were willing to pay more for a product with a perceived health benefit, while still expecting a satisfying sensory experience. This market remains highly competitive, as wines produced anywhere in the world may possess the same health-promoting effects. Some growing regions are even marketing their wine based on antioxidant content.

Oenology in the twenty-first century

Wine has long been considered an art form. In 1880, Robert Louis Stevenson coined the term 'bottled poetry' to describe the quest for perfection by wine producers[14]. As with all art forms, the term 'quality' is subjective and what one consumer considers to be attractive may be perceived as spoiled by another. The diversity of preferences has been both a blessing and a bane to the wine industry. Producers must develop a clear style by which to distinguish their product from competitors, but know that not all consumers or critics may find that style appealing. In contrast to other commodities, the region of production, the artistic reputation of the producer, and the conditions of production are important factors in the perceived value of wine[15]. For these reasons, it is important that the complex interplay of physiological, genetic and environmental factors that underpin human choice and preference be understood. This is the challenge to scientists and producers for the new century.

The completion of the human genome project together with advances made in the field of neurobiology of behaviour are providing crucial information on the basis of preference and the subjective definition of quality. It has been estimated that roughly 2% of the human genome is devoted to olfactory receptors[16]. Studies have suggested that many of these genes (60–70%) are non-functional or pseudogenes in most primates[17,18], but this still leaves hundreds of functional receptors. Although the neurobiology of olfaction and taste is less well studied than the non-chemical senses, interesting findings have emerged. For example, there is a strong connection between perception of an odour and emotion, be it pleasant or unpleasant[19]. Genetic factors such as variation in the aldehyde dehydrogenase 2 genotype in humans, which leads to adverse reactions to alcoholic beverages, have been shown to influence acquired preferences[20]. In addition to genetic factors, perception is also clearly influenced by prior experiences and expectations.

Over the past few decades, the field of sensory science has made critical contributions to our understanding of the variables that influence and contribute to the sensory perception of foods and beverages. Initially, sensory analysis was used simply as a component of quality control — to make certain that a product did not contain any objectionable odours or flavours that would make it unpalatable to most, if not all, consumers. The field has developed into a sophisticated endeavour relying on the use of human tasters as analytical tools. This poses significant challenges given the diversity of human experiences and therefore of preferences for various aromas, and the complex aroma profiles comprising wide arrays of detectable scents and odours.

Like sensory analysis, chemical analysis was limited initially to detection of defect compounds present in high concentrations. However, sampling procedures and analytical tools that can detect trace compounds present at nanomolar concentrations, now make it possible to understand the subtle nuances associated with varietal wine flavour[21]. Understanding the chemical composition of wine is insufficient in the prediction of human preference, and recent efforts of flavour chemists have been focused on linking chemical and sensory measurements of flavour. In one such application, a trained human subject sniffs the effluent from a gas chromatogram. As the compounds elute from the column, the qualitative and quantitative

responses of the sniffer are recorded and related to the signal provided by a chemical detector. By incorporating the human sense of smell in the analytical process, gas chromatography–olfactometry can link the detection and quantification of odorants to their sensory impact in wine[22]. Complex chromatograms can be reduced to a small subset of compounds that have significant odour impact. When the subset of compounds is recombined, the aroma properties of the mixture will closely mimic the properties of the original wine[23–25].

There is also growing recognition that the volatility and release of flavour compounds can be altered by interaction with other matrix components (for example, the presence of sugar, ethanol, lipids and polyphenols)[26–28]. These studies reinforce the idea that flavour perception is dynamic and the result of a complex pattern of chemical and physical interactions in the food and in the mouth, which trigger the brain's response to gustatory, trigeminal and olfactory stimuli. Statistical tools of multivariate analysis and artificial neural networks are being used to relate the chemical and sensory information to the subjective preference responses of consumers. Descriptive analysis is used to characterize wine flavour quantitatively[29]. Using this technique, judges identify sensory attributes that differentiate among a group of wines and then evaluate the wines for the intensity of each individual attribute. Flavour profiles (Fig. 3) can then be drawn that visually compare the differences in wines[15]. Finally, the role that non-sensory characteristics such as pricing, winemaker reputation and label information play in influencing consumer preferences[15] can be related to the chemical and sensory models developed. These analyses document not only the enormous complexity of individual perceptions and preferences[15,21], but also the complexity of the tools that will be needed in the future to understand the relationships among chemistry, perception, preference and behaviour.

Sustaining viticulture in the twenty-first century

As consumers become more aware of the vulnerability of our global environment, the demand for sound agricultural production practices is increasing. In the future, the perception of the producer as a conscientious environmental steward will be an important influence on the consumer's purchasing decision. This is due in part to the fact that the typical wine consumer is well educated and affluent. The wine industry has taken a leadership role through the formation of international associations of governments, scientists and producers to reach a consensus on the practices that should be allowed for products destined for the international marketplace. These associations are developing farming practice guidelines that limit the impact of site-development issues such as removal of native vegetation, erosion and water use. The farming protocols also address disease and pest control and encourage pesticide applications that have the lowest possible environmental impact while maintaining efficacy[30].

Although the global normalization of viticultural practices is some years away, the efforts underway are laying an important foundation for other agricultural industries. Controlling the introduction of new pests and diseases, the adaptation of existing pests to current control strategies, and managing pests and diseases with attention to increasing public concern over short- and long-term environmental impacts are the greatest challenges facing viticulture. The globalization of the wine industry has intensified the need for new solutions to these problems.

A devastating example of the consequences of inadvertent pest distribution was the introduction of grape phylloxera to Europe from North America in the mid-1850s. This root aphid was able to decimate the European *Vitis vinifera* wine and table grapes, which lacked the evolved resistance to its feeding found in the North American grape species[31]. The European economy of the late 1800s was based largely on the production and distribution of wine, and phylloxera had a crippling economic impact. The problem was solved by a massive rootstock breeding and evaluation effort using the North American grape species in hybrid combinations to address phylloxera resistance and combine tolerance to soils and ease of propagation. This effort involved all wine producing countries and continues, on a smaller scale, to this day.

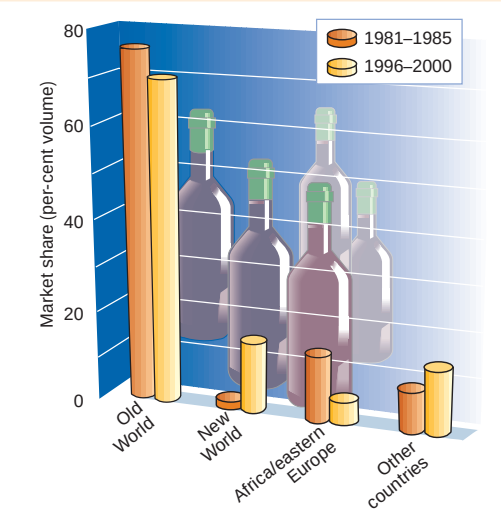

Figure 2 Changes in market share by region of production. 'Old World' is defined as western Europe; 'New World' as Australia and North and South America; 'other countries' includes Asia. Data from ref. 4.

Although most grape-growing countries have quarantines on the movement of grape planting stock, the inadvertent movement of grape pests and diseases continues. The introduction of the glassy winged sharpshooter (*Homalodisca coagulata*) into California, most likely from Florida, has the potential to destroy large portions of California vineyards. This insect is an effective vector of Pierce's disease, a bacterial disease spread by xylem-feeding insects and native to the southern United States[32]. This introduction has led to mobilization of industry and government agencies and the allocation of millions of dollars for research and vector control (http://www.cdfa.ca.gov/gwss/). The primary focus of these efforts is control and, where possible, eradication of the vector. However, given that this insect is now established in southern California, its eventual movement throughout much of the state seems inevitable. In addition, the causal agent, the bacterium *Xylella fastidiosa*, is widely spread in a broad range of native and weedy plants, although limited in terms of its ability to cause disease by relatively inefficient native vectors[33]. This combination of a new vector and common disease agent has heightened the need for new disease-resistant grape cultivars.

Disease-resistant grapes have been bred for the past 150 years. Because *V. vinifera* wine, table and raisin grapes do not possess any notable disease resistance, new cultivars must introgress or incorporate resistance genes that are most often found in the North American grape species. Resistance to a wide range of diseases is needed, but the production of wine is almost exclusively based on *V. vinifera* cultivars and even new hybrids within *V. vinifera* are poorly accepted owing to the industry's reliance on traditional and easily marketed classic wine grape cultivars. Classical breeding efforts to control Pierce's disease in table grapes are underway through introgression of resistance genes from southern US grape species into large-berried seedless *V. vinifera* table grapes. However, the production of wine grapes resistant to Pierce's disease will require the incorporation of resistance gene(s) via genetic engineering, owing to the reliance on classic *V. vinifera* wine grapes. There is an ongoing debate in the industry and by regulatory agencies as to the impact of a change in the genetic constitution of a grape cultivar and the ability to still refer to it as that cultivar. Varietal labelling is an important factor in wine marketing, and it is unclear how this will be impacted by the generation of genetically modified plants.

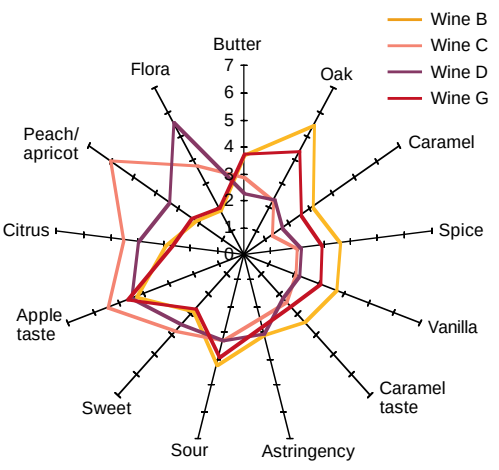

Figure 3 Flavour profiles of four inexpensive Chardonnay wines. Mean intensities for each term are plotted. The centre of the diagram corresponds to low intensity and the perimeter to high intensity. Data from ref. 15.

To meet the challenge of Pierce's disease and to develop greatly needed resistance to other pests and diseases, grape breeders and geneticists are beginning to direct much of their efforts towards mapping genes and genomics[34–36]. These efforts are focused on developing a better understanding of the mechanisms, genetics and expression of pest and disease resistance and will lead to the development of *V. vinifera* grapes capable of being grown without pesticides or resistant rootstocks. The need for rapid progress is due not only to increased political and environmental pressure, but also to relatively unrestricted world travel and the internationalization and merger of the giants of the agricultural commodity industry, which virtually guarantee the spread of devastating pests and diseases to all corners of the world. Controlling these pests and diseases will require scientists to develop an exhaustive appreciation of native mechanisms of plant disease and pest resistance.

The future of the wine industry

The challenge to wine producers in this new century is daunting — to understand the fundamental motivation behind consumer choice and to produce wines of enhanced attractiveness while simultaneously developing and implementing sustainable production practices for both grape growing and wine making. Success in this endeavour necessitates determining the role of both intrinsic and extrinsic factors that underlie preference, perception and behaviour, and putting that information into practice.

As wine production has evolved from a cottage industry to global networks of consumer-aware producers, so has science. The challenges to scientists are the same as those to producers: to meet the demands of an inquiring public on issues that require an international and multidisciplinary approach. But beyond the wine sciences and the wine industry, the French paradox has had an equally dramatic impact on the fields of nutrition and preventive medicine and on food and beverage industries in general. The paradox has heightened consumer interest in the role of diet in health and health promotion, an interest society, as a whole would be wise to exploit. Sensory scientists are joining forces with neurobiologists to understand the allure of excess calorie consumption and to design a better yet equally attractive human diet. Wine will likely be a component of that diet — a lesson we could have learned from physicians throughout antiquity. This then is the future of food as gleaned from the experiences of the wine industry: a blending of nutritional benefits and sound environmental practices with the human perception of quality.

What then is the future of the industry? As we gain knowledge of the basic biology of human perception and flavour preferences, wines will become even more targeted to the genetic differences of the consumers. Consumer olfactory profiling will be common and used to guide production decisions as well as marketing of wines. Studies currently in progress will continue to document the healthful properties of wine. In addition, the industry will need to play a highly visible role in the promotion of sound and sustainable environmental stewardship, as this will be a strong motivating factor in the purchase of wines. The stakes of success in meeting consumer expectations are high, as the value-added aspects of enhanced tourism are undeniable and economically beneficial for the entire region. □

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