CHAPTER

8

Nature and Origins of Wine Quality

Inherent in all wine tastings is an exploration of quality. Quality is a concept to which everyone genuflects. However, there is no agreement on what it means, or how it should be assessed or achieved. Reeves and Bednar (1994) consider that quality entails several factors: excellence, conformity with historical prototypes, exceeding expectation, and relative monetary value. These attributes are certainly components of what most experts would agree are essential elements of wine quality, but they themselves are nebulous percepts. Appellation control laws were enacted ostensibly to enshrine traditional views of regional quality, but in reality only act to provide some confidence in the authenticity of providence, and occasionally production features. High price is too often viewed as a predictor of quality. All high price guarantees is an element of exclusivity for the purchaser. Evidence suggests that, without knowing the price (and presumably origin), expensive wines are frequently not associated with enhanced sensory pleasure (Goldstein et al., 2008).

Quality is often viewed in intrinsic (physicochemical, sensory) or extrinsic (price, prestige, context) terms. In an ideal world, only intrinsic factors would have legitimacy. Nonetheless, extrinsic factors typically play a significant, if not preeminent, role in peoples' concept of quality (Hersleth et al., 2003; Verdú Jover et al., 2004; Priilaid, 2006; Siegrist and Cousin, 2009), and in their purchase decisions (see Jaeger, 2006). Although those with extensive wine experience and its assessment tend to associate appreciation with sensory quality (on a comparatively objective basis), this is not necessarily the situation even with consumers who consume wine regularly (Hopfer and Heymann, 2014).

Nonetheless, the most distinctive feature usually ascribed to quality can be encompassed within the expressions "good" versus "bad," or in less moralistic/emotional terms, "desirable" versus "undesirable." Or, in another way, as noted by Prescott (2012) relative to food:

> A food's hedonic value is based in the person, not the food itself.

Clearly this is not particularly helpful when attempting to understand the underpinnings of wine quality, but is an honest acceptance of reality for most people, wine critics included.

Despite the inherent subjectivity of the concept, one of the principal goals of sensory analysis is to understand the physiological, psychological, and chemical bases of quality. However, without a clear definition of what wine quality means, designing experiments to investigate this concept is fraught with difficulties, and success has been incremental at best. Nonetheless, attempts may not necessarily be fruitless. For example, even the concept of facial beauty has been analyzed sufficiently to develop a universal model of this seemingly nebulous attribute (Bronstad et al., 2008). Thus, beauty is not "just in the eye of the beholder." There is a conceptual model of physical beauty that seems hardwired in the human brain. This likely does not apply to wine.

Other than a few innate tendencies, such as a dislike of bitter substances and a liking for sweetness, human sensory responses seem to be primarily based on experience, not reflex. As a consequence, flavor preferences are potentially malleable and primarily culturally based, and there may be few absolutes relative to wine quality. Acquaintance and experience appear to be the predominant factors. For example, familiarity abets odor discrimination, and often enhances perceived intensity and pleasantness (Distel and Hudson, 2001; Mingo and Stevenson, 2007). Furthermore, repeat exposure often modifies preferences, promoting acceptance (Köster et al., 2003). Thus, we have the oft-expressed view that experience induces people to appreciate more complex (better quality?) wines. Although potentially valid, it clearly is not a consistent consequence. People are molded both by "nature" and by "nurture."

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The various and changeable nature of what constitutes wine quality, or at least expressed in popularity, makes defining the enigma of quality doubly difficult. For example, it is common to read wine critics complaining about overoaked Chardonnays. In addition, Hersleth et al. (2003) found that the Californian consumers they assayed preferred unoaked Chardonnay. Nonetheless, what people express on a questionnaire, or under an experimental tasting condition, does not necessarily reflect what they practice. For example, two of the most popular brands of Chardonnay in the United States and Canada (Lindeman's Bin 65 and Casella's Yellow Tail) are oaked. There may be as many ideas of wine quality as there are people. A stable and consistent viewpoint of wine quality has usually been considered one of the principal advantages of trained versus consumer panels. Nonetheless, consistency does not validity make, any more than strong correlation assures causation.

For many consumers, quality is a reflection of satisfaction, be that identification with the culture or history of the wine's provenance, the wine's quality/price ratio, or some other attribute. Because quality is a cerebral construct, it should not be unexpected that it has been detected on a neuronal level (Plassmann et al., 2008). The more marked the perceived quality/price differential, the greater was the perceived pleasure (at least under test conditions). The element of surprise also appears to be a major contributor to enhanced pleasure (Berns et al., 2001), potentially elevating enjoyment to stellar heights.

Effective marketing not only influences actions, such as purchasing habits, but also how the brain responds to stimuli, independent of clearly detectable sensory differences (McClure et al., 2004). Cultural influences and apparent sophistication can also override inherent sensory aspects, affecting both how a person views quality and its appropriateness. For many aficionados, quality appears to be a reflection of their desires, such as virtual experience of a wine's romantic heritage (e.g., a geographic region), a sophisticated lifestyle (e.g., refined food and wine), a sense of cultural identity (e.g., French, Italian), connection with individuality and uniqueness (e.g., *terroir*, estate bottling), a sense of physical and/or social warmth (e.g., Provence, Tuscany), feeling of relaxed elegance (e.g., Rheingau auslese), celebration (e.g., champagne), a social statement (e.g., identification as an oenophile, possession of wealth, or of some august vintage), or sensory exultation (e.g., broad flavor palette). For individuals where exclusivity and pride of ownership are paramount, wine may cease to be just a beverage, but a means of fulfilling a symbolic and/or psychological need (see Bhat and Reddy, 1998). That the wine may not live up to its expectation upon opening is often of less significance than the feeling derived during and after purchase, with purchase itself providing a vicarious experience of imagined places or experiences. These extraneous associations, donating a sense of empathy or community with the wine's origin, are not necessarily bad. They often amplify the appreciation and joy derived from whatever is purchased, be it wine, clothing, a car, or a computer tablet (Atkin, 2005). Although worshiping wine can provide its own pleasure, thankfully, most consumers view wine more rationally, as a savory and salubrious beverage.

Appreciation is frequently colored by context. For example, wine in the morning rarely seems appropriate, with the possible exception of champagne and orange juice with a stately breakfast. Although the thought is appealing, it does seem to be a waste of a good champagne (the orange juice masking the refined delicacy of the champagne). Expectation also significantly influences how quality is perceived, as well as how people view wine's combination with food (Wansink et al., 2007). At its most venerable, wine is an aesthetic experience (Charters and Pettigrew, 2005). As such, it is both sensual and ennobling.

Typically, objects considered to possess high quality are considered to be difficult to produce, obtain, or find. This often means that they are rare and expensive (possessing the attribute of exclusivity). For rarity to possess desirability, it must give the purchaser pride of ownership, being a recognized icon or an original (e.g., a painting). Why else would wines from reputed estates command prices frequently out of all proportion to their sensory quality? Hopefully, for those who can afford such wines, knowledge of the price is enough of an incentive to detect exquisite quality, if actual sensory quality is insufficient. The desire for ownership can also develop into a compulsion: a passion for collecting, occasionally masquerading as economic investment (Burton and Jacobsen, 2001).

Objects of any sort considered to be of high quality are viewed as possessing artistic attributes. These features are usually endowed with properties such as complexity, harmony, dynamism, development, duration, elegance, uniqueness, memorability, and pleasure.

For some of these hedonistic expressions, potential physiologic/psychologic explanations are possible. Complexity is almost assuredly related to the development of multiple olfactory patterns in the brain (odor/flavor memories). These may or may not be sufficient marked to trigger connections with objects or experiences, generating appropriate or illusory perceptions. The more a person has developed veridical olfactory models for different wines, the greater the likelihood the taster will perceive complexity. As the concentration of aromatics released from a wine fluctuate, different qualities materialize and fade, the olfactory equivalent of a kaleidoscope. When this dynamic complexity continues throughout the course of a tasting, it is referred to as development. Duration is used to express how long a distinctive aroma/bouquet remains detectable. Regrettably, most wines fail when it comes to significant development and duration. A wine's fragrance should linger, not dissipate. Harmony is harder to define or explain. It often involves how aromatic, gustatory, and trigeminal sensations are integrated in the orbitofrontal cortex, leading to the subjective perception of balance, with no one attribute dominating (to excess). Elegance is another subjective term relating to harmony, but considered of a higher hedonic order, involving activation of the amygdala (a major center for emotional expression). Uniqueness indicates that the sensory pleasures derived are sufficiently marked and distinct to be clearly noticeable. Memorability refers to unanticipated sensory qualities, branding themselves into an unforgettable experience–an apotheosis.

A wine's quality is also intimately linked with flavors that may donate distinctive stylistic, varietal, and possibly regional attributes. Aging potential is another prominent quality concept in the view of most aficionados, but not a feature that can be accurately predicted in young wines. Experience may be a guide, but no more. Aging potential is made manifest only long after purchase. Finally, sensory quality is (or should ideally be) independent of the conditions of sampling. Wine quality is at its most appealing when nothing is known about the wine. Even sampling in black wine glasses has its charm. It forces the taster to trust totally in the sensory qualities the wine itself expresses, the only legitimate indicator of greatness.

Although wine is often associated in peoples' minds with refined living (Lindman and Lang, 1986; Klein and Pittman, 1990), this can have a negative influence on some people. The common affiliation of wine with haute cuisine and musical events, so espoused by many wineries, is anti-chic to the grunge mores of the "X" generation, and countercultural to many left-wing thinkers. For them, beer provides a statement that is more in accord with their social self-image.

In the popular press, most wine critics appear to agree on what constitutes wine quality. This has been interpreted as support for its veracity (Goldwyn and Lawless, 1991). Alternatively, the appearance of a consensus may reflect no more than training, habituation, and acquiescence to accepted norms. In contrast, Brochet and Dubourdieu (2001) found no evidence for a consistent view of wine quality, or at least how qualitative attributes were described. Too often fealty is paid to the opinions of self-proclaimed arbiters of good taste, and far too little to personal sensory perception. In what other field would the ranking of products, developed more than a century and a half ago (the Grands Crus Classés de Bordeaux), be considered of any relevance today? The real damage of sheepishly following pied pipers is that it hinders little-known but superior wines, winemakers, and cultivars from receiving the respect and just financial return they deserve, and depriving consumers of experiencing the full range of sensory pleasures wine can provide.

SOURCES OF QUALITY

Although seldom acknowledged, the most critical factor in the development of a wine's quality is the winemaker (Fig. 8.1). Without the winemaker there would be no wine. It is ultimately on their decisions that a wine will evolve, and the attributes it will eventually possess; sculptors shape stone, winemakers mold grapes. The lack of winemaker credit partially reflects insufficient human sensory acuity, not humility. Human olfactory skills are rarely up to the task of recognizing the subtle features brought to bear on a wine by individual winemakers. In addition, winemaker identity is not yet a marketable commodity, though owner/producer name can be, if sufficiently well known and prominently displayed on the label. Thus, if the enologic equivalents of a Michelangelo or Mozart exist, their finesse largely goes unsung and unnoticed, except to some estate owners, believing that chiasmic "flying" winemakers can raise the quality of their wines into the stratosphere. In addition, maturation and aging modify, and eventually erase, the subtle influences that might distinguish the wines brought to fruition by particular winemakers. Even with considerable training, few individuals recognize the more marked effects of varietal origin. The subtle effects of regional factors are even more difficult to detect consistently, that is, under blind tasting conditions.

Grape cultivar(s) and production style donate more easily detectable differences than regional characteristics. Nonetheless, the vast majority of grape cultivars are not known to produce wine with a distinctive aroma, at least consistently. Even some famous cultivars are notorious for their elusive varietal aroma, Pinot noir being the most well-known example. It is not without reason that Pinot noir has been dubbed the "heartbreak grape." Production style more consistently stamps a distinctive flavor profile on a wine. For example, use of production procedures could convert the same red grapes into a red, rosé, or white wine, that could be dry, sweet, sparkling, or fortified, each potentially appearing in an incredible diversity of substyles.

Aside from varietal attributes, grape quality (maturity, health, flavor content) sets limits on potential wine quality. It is at this level that macro- and microclimate vineyard characteristics have their major impacts on wine excellence.

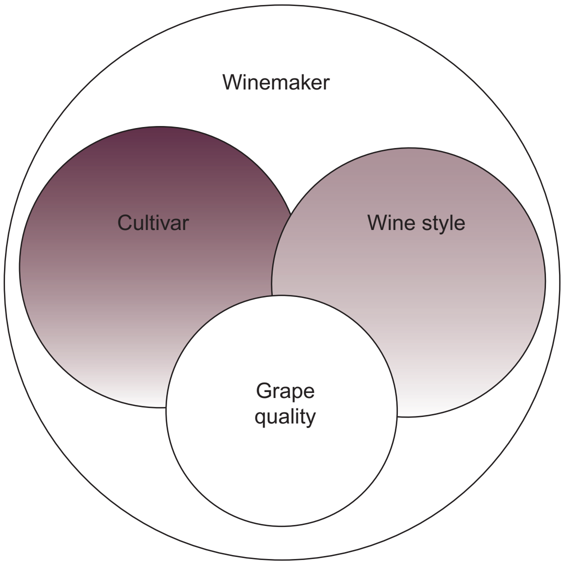

FIGURE 8.1 Diagrammatic representation of the major sources of wine quality.

However, aging eventually diminishes most of a wine's individuality, though, for premium wines, there is a temporary enhancement in character, or at least so interpreted by connoisseurs of aged wines.

What follows is a discussion of those features that influence wine quality. Although trends can be noted, quality involves the complex interaction of innumerable factors, where any one is likely to be influenced by others. For example, wine produced from older vines of Cabernet Sauvignon is considered to be more berrylike, and possess less of a vegetal character (Heymann and Noble, 1987). However, this might simply be a consequence of the vines' lower vigor, smaller berry size, and improved fruit–light exposure, generating more flavor per berry. Also, because of their anticipated greater quality, grapes from older vines may be given preferential treatment during fermentation and maturation. Correlation, as usual, is not necessarily causally related.

In addition, caution must be taken not to overextend the relevance of existing scientific research. Most studies are based on comparatively small samples and a few cultivars, without the control of additional factors typically considered essential in rigorous experimentation. For example, the effect of vine age noted in Heymann and Noble (1987) was based on an analysis of 21 wines. The results were consistent, though, with commonly held beliefs in the wine community, if that is of any significance.

VINEYARD INFLUENCES

Before the microbial nature of fermentation was discovered, wine quality was attributed to the soil and grape-production procedures. Subsequently, the significance of winery technology dominated explanations of wine quality, at least in the New World. More recently, winemakers have returned to ascribing quality to what occurs in the vineyard, possibly as a response to growing public distrust of technology, and a desire to distinguish their wines from the competition. In reality, both viticultural and enologic practices are of importance. In most instances, one would be hard pressed to say either was more important than the other. Although the adage "one cannot make a silk purse out of a sow's ear" applies to wine, without skilled guidance, the finest grapes can produce plonk. In a recent study of Pinot noir wines, winemaking conditions, barrel maturation and vintage appeared more significant in influencing the wines' characteristics than vineyard site or clone (Schueuermann et al., 2016).

Macroclimate

Macroclimate refers to those influences that can be ascribed to major regional or geographic features, such as latitude, proximity to large bodies of water, ocean currents, mountain ranges, or the size of the associated landmass. Clearly, these features have dramatic effects, not only on the styles of wine most easily produced, but also on whether viticulture is economically viable or even possible. For example, early cold winters are as essential to the efficient production of icewines, as is a dry hot climate conducive to sherry production. Equally, cool fall conditions favor acid retention during ripening and slow fermentation; both are conducive to producing stable, dry table wines. However, modern viticultural and enologic procedures can mollify, if not offset, many of the climatic influences that once limited regional wine production. Thus, no region or country can legitimately claim that it is preeminent in producing quality wine, although some may be inherently blessed in producing certain styles or growing particular grape cultivars. Although consumers may have favorites, justifiable quality is more dependent on the judicious and skillful application of technological know-how than geographic origin.

Meso- and Microclimate

Both terms refer to features that are, more or less, under the potential influence of the grower. Mesoclimate is typically defined as those climatic conditions on the scale of hundreds of meters. In contrast, microclimate refers to conditions immediately affecting the region enveloping individual or small groups of vines. In both terms, features such as local soil conditions and topography are involved, as well as the influences produced by vine training and the vine's growth habit. On the scale of individual vines, one is dealing with its immediate soil-atmosphere microclimate (SAM). In the popular wine vernacular, the mesomicroclimate is often termed *terroir*. Unfortunately, the term has been equally used to include local grape-growing and winemaking conditions, and occasionally imbued with elitist intimations verging on the mystic. The acronym SAM is a more precise, and devoid of any underlying supercilious connotations. To bring *terroir* into perspective, Hugh Johnson (Johnson, 1994) noted that "both one's front and back yards have distinct *terroirs*."

That a vineyard's mesoclimate and a vine's microclimate influence grapes, and thereby, wine chemistry, is beyond question. What is in question is whether the few, detectable, minute changes in grape chemistry, effected by the vineyard site, such as the concentration of trace elements (e.g., barium, lithium, and strontium), or the relative proportions of carbon, oxygen, and hydrogen isotopes generate humanly detectable differences. The answer is probably not, even though such chemical differences are the most easily identifiable effects of a vine's meso- and microclimate.

Soil conditions influence grape growth primarily through their effects on heat retention, water-holding capacity, and nutritional status. For example, soil color and textural composition can affect fruit ripening by influencing heat absorption and reradiation. Clayey soils, due to their huge surface area to volume ratio (2 to $5 \times 10^6\,cm^2/cm^3$), have an incredible water-holding capacity. This means that the soil warms slowly in the spring (retarding vine activation), but provides extra warmth to the vine during the autumn (reducing the likelihood of the localized damaging frosts). However, the small average pore size of clayey soils can induce poor drainage. The result can be waterlogging during rainy spells, and the associated potential for berry splitting and subsequent rotting. Vineyard practices that augment humus content can increase soil drainage and aeration by promoting the development of a fine soil aggregate. Humus is also a major reserve of mineral nutrients. These are held loosely in a form readily accessible to vine roots. This encourages optimal vine growth and fruit ripening.

Only rarely is the geologic origin of the soil of significance. Typically, centuries of weathering have fundamentally transformed the chemistry and structural character of the parental rock material. Thus, famous wine regions are as likely to be situated on geologically uniform (e.g., Champagne, Jerez, Mosel) as on geologically heterogeneous soils (e.g., Bordeaux, Rheingau), or on soils derived from any of the various igneous, sedimentary, or metamorphic types of rock. Homogeneity within a vineyard, however, is of significance. Soil nonuniformity is one of the prime sources of uneven berry ripening throughout a site, generally viewed as likely to lower wine quality.

Limiting vineyard variation to enhance grape uniformity is the principal aim of precision viticulture (PV). To achieve this, selective vineyard modification is applied, such as localized adjustment in soil nutrient and water-retention conditions. In addition, selectively harvesting particular parcels of a vineyard can further improve grape uniformity at the cellar door. Although PV can achieve a more uniform base material, does this necessarily equate to enhanced wine quality? Quality is often associated with aromatic complexity. However, it has yet to be established that grape uniformity at harvest equates to enhanced aromatic wine complexity. Aromatic complexity may in fact be better achieved with some grape nonuniformity (variability in aromatic composition).

Viticultural practices, such as adjusting vine density at planting, or training system modification affecting light penetration and wind flow within and among vines, can significantly affect fruit ripening, disease susceptibility, and flavor development. Each adjusts the potential of the fruit to generate high-quality wine.

Topographic influences, such as vineyard slope and solar orientation, affect the growing environment, and thereby, the potential of the vine to fully ripen its fruit. Sloped sites become increasingly significant the higher the vineyard latitude (providing enhanced solar exposure). Fig. 8.2 illustrates that the slope's major benefit, relative to

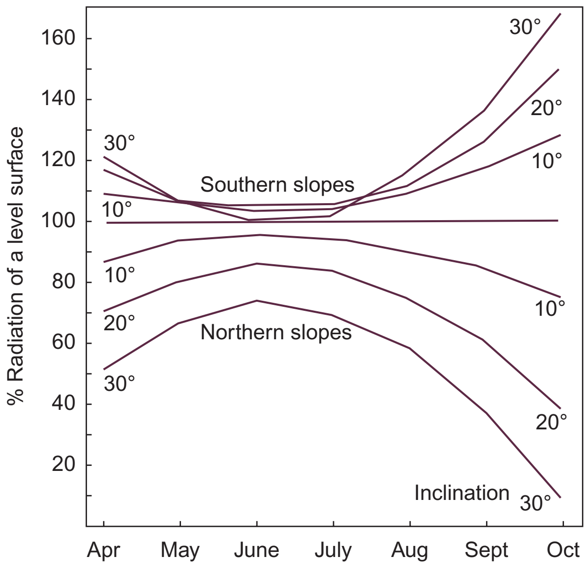

FIGURE 8.2 Reception of direct sunlight during the growing season in relation to position and inclination of slope in the northern hemisphere. This example is in the upper Rhine Valley, Germany: 48°15′N. *From Becker, N., 1985. Site selection for viticulture in cooler climates using local climatic information. In Proc. Int. Symp. Cool Climate Vitic. Enol. In: Heatherbell, D.A., et al. (Eds.), Agriculture Experimental Station Technical Publication No. 7628, Oregon State University, Corvallis, pp. 20–34, reproduced by permission.*

grape maturation, occurs late in the season, when extra solar radiation is most valuable. Slope also increases sunlight exposure reflected off nearby water bodies – a beneficial feature long realized in several famous river valleys. At low sun angles (<10 degrees), reflected radiation off water can amount to almost half the solar energy falling on vines on steep, sun-facing slopes (Büttner and Sutter, 1935). Slopes also facilitate water drainage and can direct cold (frost-inducing) air away from the vines.

Nearby bodies of water also can generate significant climatic influences. These may be beneficial, by reducing both summer and winter temperature fluctuations and their extremes, or detrimental, by shortening the growing season in cool maritime climates. Fog development can also nullify the potential for increased solar exposure associated with a sun-facing slope, as well as increase disease prevalence.

In a few instances, studies have demonstrated detectable sensory differences among wines produced in adjacent regional appellations (Douglas et al., 2001; Kontkanen et al., 2005; Tomasino et al., 2013; Fig. 8.3). Although interesting, whether these effects are consistently detectable (from year to year) has not been established. Features such as the vintage conditions, production procedures, and vine age have the potential to mask regional subtleties (Ribéreau-Gayon, 1978; Noble and Ohkubo, 1989; Schueuermann et al., 2016). In addition, sensory differences, based on averaged regional data, are just that: averages. Not all wines in a region will equally express similar characteristics. Nor can it be assumed that even skilled tasters will be able to distinguish among wines from adjacent regions, based on their sensory expression (Tomasino, 2011). In addition, producers may not wish to use regional designations (due to their restrictions), preferring more general appellation designations to achieve the brand consistency and reputation more important to consumer success. Broader geographic designations are often easier for consumers to grasp than the more ethereal sensory differences supposedly associated with vineyard or regional appellations. Nonetheless, the perception of uniqueness, real or otherwise, can be a powerful force in promoting sales of expensive wines, to the detriment of less well-known regional wines. Supporting local production is a significant factor in enhancing the profitability and survival of small producers. Winery door sales can give the consumer a sense of knowing the producer, and access to unique wine otherwise unattainable, as well as a means of avoiding the tyranny of choice (Schwartz, 2004) in wine outlets. Winery sales can also encourage consumers to sample a diversity of varietal flavors that they might otherwise not experience.

Species, Variety, and Clone

Conventional wisdom implies that only cultivars of *Vitis vinifera* produce wines of quality. Wines produced from other species and interspecies hybrids, even possessing *vinifera* heritage, are often considered unworthy of serious consideration. This prejudice was one of the reasons that provoked laws restricting the cultivation of interspecific hybrids

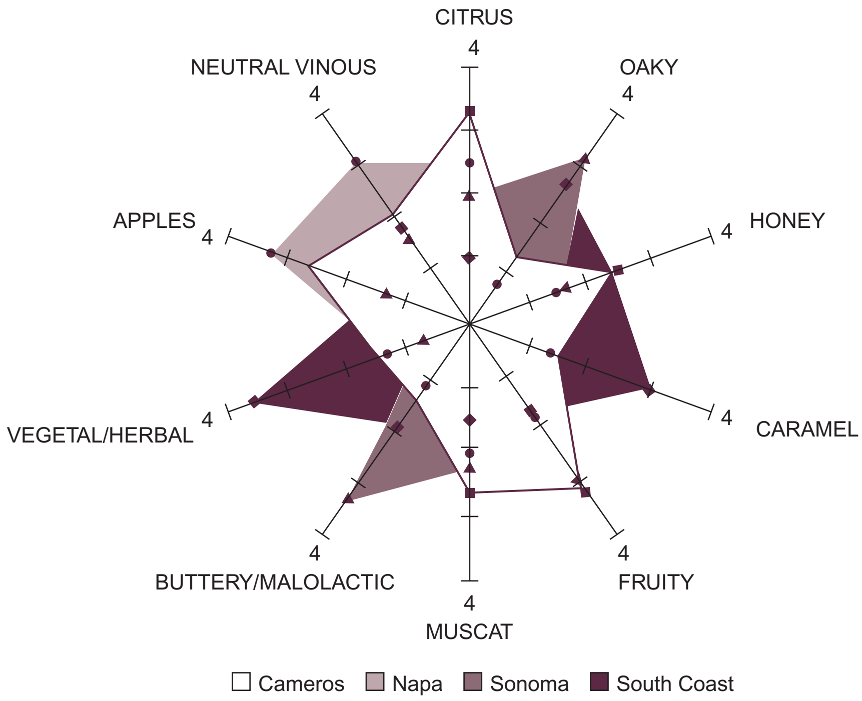

FIGURE 8.3 Polar plot derived from 10 aroma attributes of 1991 Chardonnay wines, showing regional variation within four viticultural areas of California. *Reprinted with permission from Arrhenius, S.P., McCloskey, L.P., Sylvan, M., 1996. Chemical markers for aroma of Vitis vinifera var. Chardonnay regional wines. J. Agric. Food. Chem. 44, 1085–1090. Copyright (1996) American Chemical Society.*

in France and then Europe. This decision partially arose from unfamiliarity with the "foreign" flavors occasionally associated with some interspecies hybrids, potentially threatening the reputations of established appellations. Additional concerns arose due to the higher yield of some hybrids. This became an issue due to excess grape production in Europe. The shortsighted response of governments legislating against planting interspecies hybrids is clear from the quality of the Chambourcin wines from Australia, or the fine Baco noir, Maréchal Foch, Vidal blanc, Cayuga White, and Traminette wines produced in North America. They are examples of the heights attainable with hybrid cultivars.

Even more maligned are non-*vinifera* wines. Part of this rejection may be derived from their association with the syrupy sweet wines produced from them in decades past. Many people came to believe that these were the only styles they could produce. Their non-*vinifera* aromas also conflicted with the sensibilities of those habituated to *vinifera* wines, desirous to emulate European wines, or achieve acclaim from wine critics. The aroma intensity of cultivars such as Concord, Catawba, and Niagara has also been claimed to be a negative attribute. However, if this were so, then *vinifera* cultivars such as Gewürztraminer and Muscat should also be abhorred. They are not. In the southern United States, considerable interest is shown in producing *V. rotundifolia* and *V. aestivalis* wines. Only prolonged experimentation and work by dedicated winemakers, willing to defy eurocentric naysayers, will reveal the full potential of non-*vinifera* wines.

The preponderance of Western European cultivars in world viticulture partially originated from favorable climatic and socioeconomic factors in these regions. The moderate climate of Western Europe provided conditions that permitted the production of wine that could age well (combined with the perquisite technological advances) (Jackson, 2016b). These conditions allowed better cultivars to be recognized as such. Coincidentally, the development of the Industrial Revolution in proximity to these wine-producing regions generated a burgeoning middle class, with the free capital to support the production of finer wines. With colonization and empire building, the views of wine-conscious Europeans spread worldwide. Correspondingly, their biases have significantly influenced the varieties chosen for planting in New World vineyards. Regrettably, Southern Europe (and its grape cultivars) did not enjoy the same benefits, either climatically or socioeconomically. Thus, their premium-cultivar equivalents have remained largely unknown, except locally. Their qualities still remain inappropriately appreciated. In addition, how many distinctive variations on a theme can be produced from the few, so-called premium cultivars that dominate commerce? Other cultivars might rekindle interest, and stimulate the relatively stagnant worldwide wine sales situation. It seems that most wine writers, possibly unintentionally, counteract such a possibility. However, increased varietal diversity (where named) could be counterproductive at the lower end of the market, leading to enhanced consumer confusion. The current bewildering array of essentially identical wines is already bad enough, leading to a depression in wine sales (Drummond and Rule, 2005). The mental paralysis many consumers experience in wine stores is an example of what has been termed Gruen transfer, named after Victor Gruen, the architect who created the concept of the shopping center. For the average consumer, blended wines without varietal designation, and skillful naming, are probably optimal. In such wines, the use of 'new' cultivars would not be noted (avoiding consumer confusion), but add novel and refreshing flavors.

Most cultivars exist as a collection of clones, forms that are genetically identical in all but a few mutations or epigenetic modifications. Occasionally, these differences significantly influence winemaking characteristics, by directly or indirectly affecting fruit flavor. For example, certain clones of Chardonnay possess a muscaty character, whereas particular clones of Pinot noir are better for champagne than red wine production. Clones can also differ significantly in yield. Until recently, growers typically planted a single clone. This is beginning to change, as winemakers search for new ways to increase aromatic complexity. This could generate a feature that might distinguish a producer's wine from those of neighboring wineries.

As part of the ongoing process of eliminating systemic pathogens from grape varieties, there is also selection for clones with both enhanced yield and improved grape quality. Fig. 8.4 shows that yield increase, by almost a factor of 4, has not depressed average fruit quality (as measured by sugar content) since the mid-1920s, except for an unexplained slight decline between the 1950s and 1980s. An aspect that has not been investigated (as almost heresy)

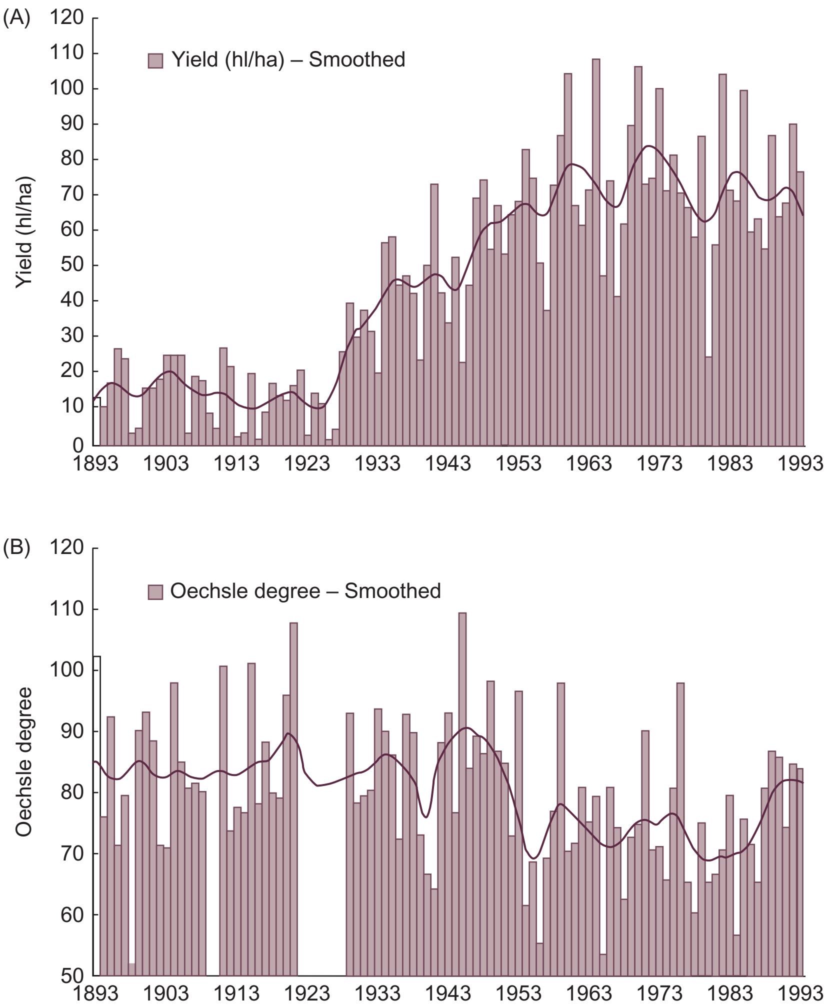

FIGURE 8.4 Grape yield (A) and must quality (B) of Riesling at Johannisberg (Rheingau, Germany) from 1893 to 1993. *From Hoppmann, D., Hüster, H., 1993. Trends in the development in must quality of 'White Riesling' as dependent on climatic conditions. Wein Wiss. 48, 76–80, reproduced by permission.*

in the possibility that eliminating viral infection from vines may have reduced aromatic complexity. For example, the source of the more flavorful clones of Gewürztraminer has been attributed to viral infection (Bourke, 2004), and many vines in Burgundy were once clearly infected with viruses.

Rootstock

Rootstocks produce the root system that supports the majority of the world's grapevines. Although providing the resistance or tolerance to soil-based problems, which permit commercial grape cultivation in most wine regions, rootstocks seldom receive the public acknowledgment they deserve, a case of "out of sight, out of mind." Besides providing the resistance factors noted above, rootstocks may also be used to regulate vine vigor and capacity (and thereby, the vine's potential to ripen its fruit), as well as influence vine nutritional and hormonal balance. Rootstock choice can also affect potential wine quality by improving vine health (donating resistance or tolerance to various aboveground pests, diseases, and unfavorable environmental conditions).

Grafting began in the late 1800s as the only effective means of combating the ravages being caused by phylloxera (*Daktulosphaira vitifoliae*). At the time, the root louse was decimating European vineyards. However, early rootstock selections were not well suited to the alkaline soils of most European vineyards. This may be the origin of the impression that wine quality suffered as a consequence of grafting. The only advantage to own-rooted vines (in the few places where this remains possible) is the economy of escaping the cost of grafting (assuming it is not needed to counter other viticultural limitations).

Yield

The relationship between vine yield and grape (wine) quality is complex. Increased yield has often been correlated with delayed sugar accumulation during ripening, a rough indicator of fruit flavor development. However, as Figs. 8.4 and 8.5 illustrate, the relationship between grape sugar accumulation or potential alcohol content and yield can be both inconsistent and highly variable. Although enhanced flavor is seemingly beneficial to wine quality, the advantages of increased aroma may eventually be offset by an augmentation in aggressive taste (Fig. 8.6).

What is commonly missing in most discussions of yield–quality relationships is acknowledgment of the importance of vineyard and climatic conditions. With vines growing on relatively dry or nutrient-poor hillside sites (common in several European viticultural regions), severe pruning tends to induce early cessation of vegetative growth, resulting in full ripening of the limited fruit crop. These observations presumably led to the generalization that small yields were inherently correlated with quality. However, the same procedure, applied to healthy vines, adequately supplied with nutrients and water (as in most New World vineyards), has the effect of promoting shoot growth, to the detriment of fruit maturation and quality. The error of assuming that a particular European generalization was universal became obvious when new training systems improved light exposure to large vines on moist, fertile soils in the New World. These new systems helped direct the increased growth potential of the vines (vigor) into improved fruit maturity (capacity), rather than enhanced shoot growth.

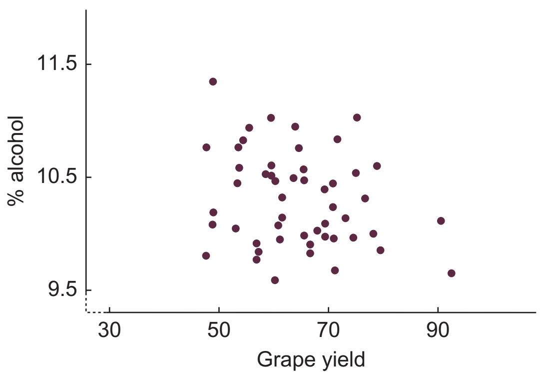

FIGURE 8.5 Relation between grape yield and alcohol content of the wines produced from 51 vineyards in the south of France. Data from each vineyard is averaged over 22 years. *From Plan, C., Anizan, C., Galzy, P., Nigond, J., 1976. Observations on the relation between alcoholic degree and yield of grapevines. Vitis 15, 236–242, reproduced by permission.*

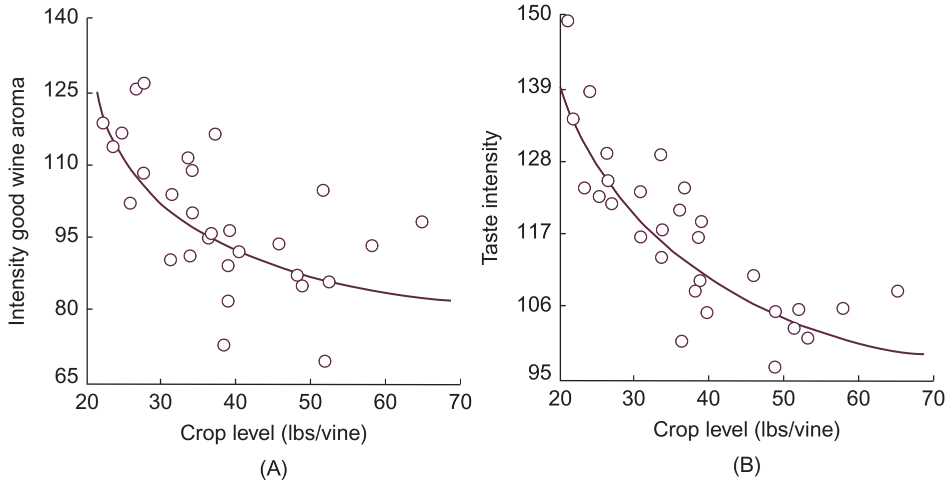

FIGURE 8.6 Relation between crop level of Zinfandel vines and (A) good wine aroma and (B) taste intensity. *From Sinton, T.H., Ough, C.S., Kissler, J.J., Kasimatis, A.N., 1978. Grape juice indicators for prediction of potential wine quality, I. Relationship between crop level, juice and wine composition, and wine sensory ratings and scores. Am. J. Enol. Vitic. 29, 267–271, reproduced by permission.*

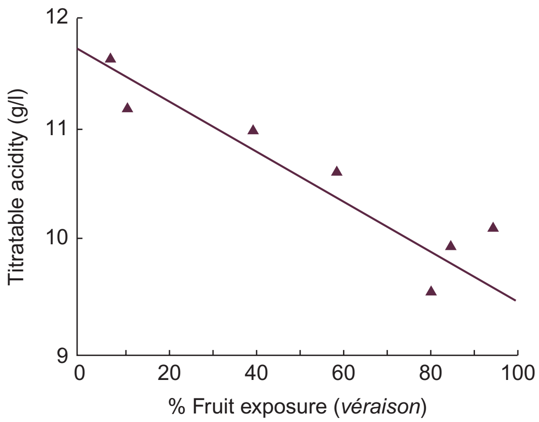

FIGURE 8.7 Relation between fruit exposure at *véraison* and titratable acidity at harvest of Sauvignon blanc. *From Smith, S., Codrington, I.C., Robertson, M., Smart, R., 1988. Viticultural and oenological implications of leaf removal for New Zealand vineyards. In Proc. 2nd Int. Symp. Cool Climate Vitic. Oenol. In: Smart, R.E., et al., (Eds.), New Zealand Society of Viticulture and Oenology, Auckland, New Zealand, pp. 127–133, reproduced by permission.*

Central to most new training systems has been the division of large vine canopies, possible on rich soils, into several, smaller, separate canopies (termed canopy management). The resultant increase in water demand helped to restrict postmidseason shoot growth. Judicious use of shoot topping and devigorating rootstocks further restricted mid- to late-season vegetative growth. The division of the canopy into several thinner canopies also opened the fruit to increased sun and wind exposure, tending to favor early and complete fruit ripening, as well as limit disease development. Fig. 8.7 illustrates how improved sun exposure can reduce excessive fruit acidity. The combined effects of canopy management meant that increased fruit yield was not associated with reduced fruit quality. Although improved light exposure is often associated with enhanced fruit coloration, this feature is cultivar dependent, and may not necessarily be reflected in more intensely colored wine. Fruit shading, however, is often associated with reduced flavor potential.

High-density planting (common in Europe) is an older alternative, tending to achieve the same results as modern, canopy-management training systems. Table 8.1 illustrates the value of high-density planting on color density. Regrettably, these benefits come at considerably enhanced vineyard development and maintenance costs (and clearly reflected in wine price). Canopy management is a more economic means of producing high-quality grapes on fertile soils with an adequate water supply.

TABLE 8.1 Effect of plant spacing on the yield of 3-year-old Pinot noir vines[a]

Plant spacing (m)	Vine density (vine/ha)	Leaf area (m^2/vine)	Leaf area (cm^2/g grape)	Yield (kg/vine)	Yield (kg/ha)	Wine color (520 nm)
1.0 × 0.5	20,000	1.3	22.03	0.58	11.64	0.875
1.0 × 1.0	10,000	2.7	26.27	1.03	10.33	0.677
2.0 × 1.0	5000	4.0	28.25	1.43	7.15	0.555
2.0 × 2.0	2000	4.0	15.41	2.60	6.54	0.472
3.0 × 1.5	2222	4.5	18.01	2.50	5.51	0.419
3.0 × 3.0	1111	6.3	15.36	4.12	4.57	0.438

From Jackson, R.S., 2014. Wine Science: Principles and Applications, fourth ed. Academic Press, San Diego, CA, data from Rapp, A., Güntert, M., 1986. Changes in aroma substances during the storage of white wines in bottles. In: Charalambous, G. (Ed.), The Shelf Life of Foods and Beverages. Elsevier, Amsterdam, pp. 141–167, reproduced by permission.
[a]*Data from Archer, 1987; and Archer et al., 1988.*

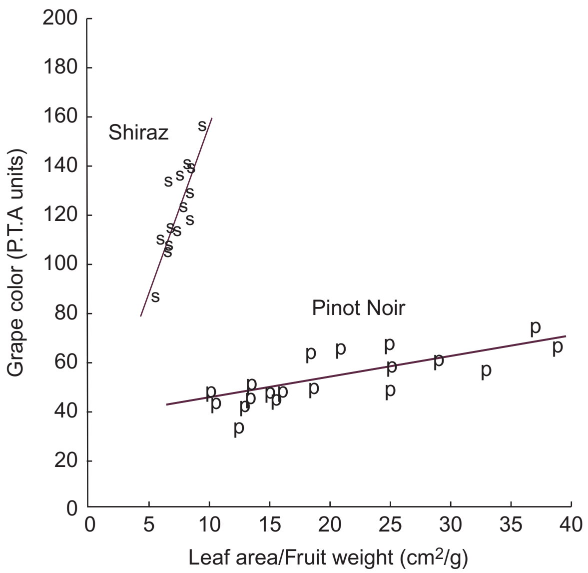

FIGURE 8.8 Relation between grape color and leaf area/fruit (LA/F) ratio for Shiraz and Pinot noir vines; *PTA*, potential total anthocyanin. *From Iland, P.G., Marquis, N., 1993. Pinot noir – Viticultural directions for improving fruit quality. In Proc. 8th Aust. Wine Ind. Tech. Conf. Adelaide, 13–17 August, 1992. In: Williams, P.J., Davidson, D.M., Lee, T.H. (Eds.). Winetitles, Adelaide, Australia, pp. 98–100, reproduced by permission.*

Other means of directing vine vigor into increased capacity involve procedures such as minimal pruning and partial rootzone drying. Minimal pruning allows the vine to grow and self-adjust its size. This usually takes several years, with most cultivars establishing a canopy structure that permits excellent fruit exposure (for optimal maturation), combined with high yield and limited pruning need. It seems particularly suited to comparatively dry climates. Another technique, particularly applicable under arid to semiarid conditions, and where irrigation is often obligatory, is partial rootzone drying. By alternately supplying water to only one side of the vine, the roots send hormonal signals to the shoots that suppress mid- to late-season shoot growth, despite an adequate water supply. The consequence is the increased likelihood of the production of an abundant fruit crop that ripens fully.

An apparently useful correlation, between fruit yield and quality, involves the ratio between the active leaf area of the vine and the mass of fruit produced (LA/F ratio). It focuses attention on a fundamental relationship between energy supply (photosynthesis) and demand (fruit ripening). For many cultivars, an appropriate value falls in the range of 10 cm^2/g. However, this value can be influenced by several factors, such as the cultivar (Fig. 8.8), training system, soil nutrient and water supply, and climatic conditions. The ultimate objective of any viticultural procedure is to establish long-term optimal canopy size and fruit placement to promote full fruit ripening.

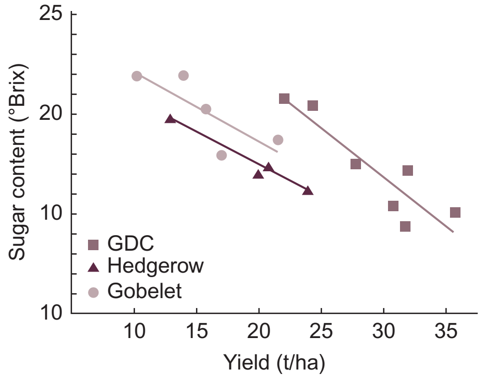

FIGURE 8.9 Relation between yield and soluble solids (5-year average) using three distinct training systems. *From Intrieri, C., Poni, S., 1995. Integrated evolution of trellis training systems and machines to improve grape quality and vintage quality of mechanized Italian vineyards. Am. J. Enol. Vitic. 46, 116–127, reproduced by permission.*

Training System

Training systems refer to techniques designed to position the fruit-bearing shoots to optimize both fruit yield and quality, consistent with long-term vine health. Hundreds of training systems exist, but few have been studied sufficiently to establish their efficacy. In contrast, several modern training systems, such as the Scott–Henry, Lyre, Smart–Dyson, and Geneva Double Curtain (GDC), have been shown to possess clear advantages in improving both fruit yield and quality (Smart and Robinson, 1991). Fig. 8.9 illustrates the influence of divided-canopy systems (GDC) versus older systems (Goblet and Hedgerow) relative to grape sugar accumulation. In addition to increasing vine capacity, improved fruit health (reduced incidence of infection) and cluster location can facilitate mechanical harvesting. These features enhance fruit quality and decrease production costs.

As previously noted, the vine's inherent vigor often needs to be restrained. On relatively nutrient-poor, dry soils, this has traditionally been achieved by dense vine planting (about 4000 vines/ha) and severe pruning (removal of upwards of 90–95 percent of the year's shoot growth). However, on rich, moist, loamy soil, less pruning is preferable, combined with wide vine spacing (about 1500 vines/ha). Under these conditions, it is prudent to redirect increased growth potential into greater fruit production, not prune it away. When an appropriate LA/F ratio is established, increased yield and quality can coexist. It is on rich soils that the newer training systems are most appropriate.

Nutrition and Irrigation

In the popular literature, stressing the vine is often viewed as promoting fine wine production. This view probably arose from the reduced-vigor, improved-grape-quality association views espoused by many renowned European vineyards noted previously. However, balancing vegetative and fruit-bearing functions, not stress, should be the goal. Exposing the vine to physiological stress, due to water or nutrient deficit, especially at particular growth stages, is detrimental. However, limited deficits, early or late in the season, can enhance wine color (Matthews et al., 1990). Flavor influences are more subtle and cultivar specific. Conversely, supplying nutrients and water in excess is detrimental, as well as wasteful.

In practice, regulating nutrient supply to improve grape quality is difficult. Because the yearly nutrient demands of grapevines are surprisingly minor (partially due to the nutrient reserves of the vine's woody parts), deficiency symptoms may express themselves clearly only months or years after deficiency starts. In addition, establishing nutrient availability to vine roots (versus nutrient presence in the soil) is still an inexact science.

Irrigation, as noted earlier (partial rootzone drying), can be used to regulate vine growth and promote optimal fruit ripening. Irrigation water can also supply nutrients and disease-control chemicals directly to the roots, in precisely regulated amounts, and only at times of need. These possibilities are most applicable in arid and semiarid regions, where most of the water comes from irrigation. Thus, climatic conditions that may initially seem unfavorable may be turned to advantage to produce some of the finest wines.

Disease

It may be unfashionable to contemplate disease abatement as a component of wine quality, but disease control is certainly necessary. However, exactly how most vine diseases depress fruit quality is poorly understood. One exception is powdery mildew. When it infects grapes, the fungus incites the development of a bitterish attribute and other flavor perturbations (Fig. 8.10). These effects are enhanced with increased maceration before or during fermentation. Some of these changes may result from the conversion of several ketones to 3-octanone and (*Z*)-5-octen-3-one (Darriet et al., 2002). The viscous/oiliness of the wine produced from diseased grapes has been unexpectedly correlated with the wine's phenolic content.

In only one instance can a grape infection occasionally be considered a quality feature. This occurs under the conditions of cyclical alternating sunny days with humid/foggy evenings in the autumn. Under these conditions, *Botrytis cinerea*, a normally destructive pathogen, can result in the concentration of grape constituents and synthesize its own special, and appreciated, aromatics. This is termed noble rot. Grapes so affected produce some of the most expensive, luscious, white wines available. Examples are German ausleses, beerenausleses, and trockenbeerenausleses, and French sauternes (Fig. 7.6). Infection with *B. cinerea* is only associated with an improved flavor of red wines when disease development occurs after visually healthy grape clusters are harvested and stored under cool dry conditions for several weeks to months (Fig. 7.4, Plate 7.2).

Although not a direct consequence of pathogenesis, the application of protective chemicals may indirectly affect wine quality. For example, the copper used in Bordeaux mixture can compromise the quality of Sauvignon blanc wine, by reducing the concentration of important varietal thiol aroma compounds, notably 4-mercapto-4-methylpentan-2-one. This effect can be reduced by prolonged skin contact (Hatzidimitriou et al., 1996), or more directly

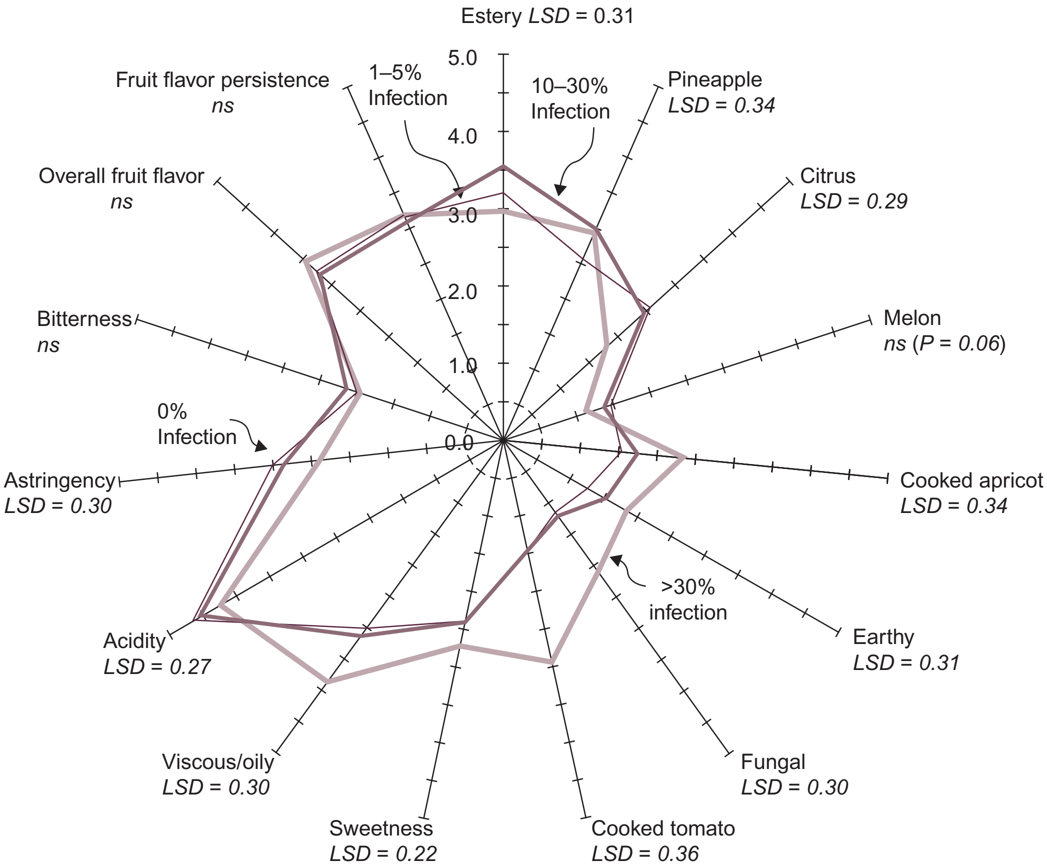

FIGURE 8.10 Mean ratings for sensory attributes of Chardonnay wines made from fruit with varied powdery mildew severity. Each value is the mean score from duplicate fermentation wines that were presented to 16 assessors in two replicate sessions. *LSD*, least-significant difference ($p = 0.05$); *ns*, not significant. *From Stummer, B.E., Francis, I.L., Zanker, T., Lattey, K.A., Scott, E.S., 2005. Effects of powdery mildew on the sensory properties and composition of Chardonnay juice and wine when grape sugar ripeness is standardised. Aust. J. Grape Wine Res. 11, 66–76, reproduced by permission of John Wiley and Sons, copyright.*

by limiting the application of Bordeaux mixture (Darriet et al., 2001). Even the chemicals used in organic viticulture are not devoid of potential detrimental effects. Various soaps and oils (used as organic pesticides) can contaminate wine with off-tastes or off-odors, and sulfur can seriously damage leaves and increase the incidence of some insect pests. Any detrimental effect of chemical pest control, organic or not, can be minimized or avoided if applied only when, and in the amounts, needed.

Maturity

Most vineyard activities are designed to promote optimal fruit maturity. Once maturity is achieved, the grapes are usually harvested and processed into wine. Measuring optimum maturity is, however, far from simple.

Maturity is often estimated by grape sugar and acid contents, their ratio, color intensity, and/or flavor characteristics. Depending on legal constraints, the sugar and acid contents of the juice may be adjusted after harvesting, to account for slight deficiencies or imbalances. However, color and flavor cannot be directly augmented. The only accepted methods of their adjustment relate to procedural or enzymatic techniques that enhance pigment extraction or the volatility of existing flavorants. Thus, there would be considerable interest if color or flavor intensity could be measured with sufficient accuracy to be used as indicators of optimal grape maturity.

For red wines, near infrared spectroscopy (NIRS) measurements correlate well with grape anthocyanin content (Kennedy, 2002). It also provides a good predictor of glycosyl-bound flavorants in Chardonnay grapes. However, fermentation and maturation conditions so affect color development and stability that no direct relationship exists between fruit coloration, and that of the wine. For flavor, monoterpene content is an indicator of potential wine flavor in Muscat cultivars, and those possessing a muscat character. For varieties with aromas not dependent on terpenes, other potential flavor indicators are required. One such indicator is provided my measuring the juice glycosyl–glucose content. Many grape flavorants are loosely bound to one or more sugars. Thus, determining the glycosyl–glucose (G–G)content has been investigated as a gauge of potential wine flavor (Gishen et al., 2002). Under some conditions, the accumulation of glycosyl flavor conjugates correlates well with the accumulation of sugars during ripening. In these situations, measuring sugar content is a simpler means of assessing potential flavor content. However, in cool climatic regions, there may be poor correlation between sugar content and juice flavor potential. Thus, the more laborious measures of free terpene or G–G contents may be required, if these indicators are determined to be valuable measures of optimal fruit maturity.

Once the decisions on maturity and harvest date have been made, the next issue involves the harvest method. In the past, hand-picking was the only option. Even today, for some wine styles, and grape varieties, manual harvesting is the only choice. For example, wine made by carbonic maceration (such as Beaujolais) involves a grape-cell fermentation that must occur before grape crushing. Grapes harvested for champagne production also involve manual harvesting, to permit the pressing of whole clusters (to minimize phenolic and color extraction). Where a significant portion of the crop is diseased, manual harvest is also essential to ensure maximal removal of infected grapes. In most cases, though, the choice between manual and mechanical harvesting has more to do with economics than wine quality. Premium wines can justify the expense of manual harvesting, but increasingly, mechanical harvesters are used for all quality categories of wines. Comparative studies have demonstrated no or negligible differences in the sensory characteristics of similar grapes harvested manually or mechanically (see Clary et al., 1990).

WINERY

Winemaker

Wine is primarily the vinous expression of a winemaker's practical and aesthetic skills. As such, no two winemakers produce identical wines. Every individual brings to the process the culmination of their experience and concept of quality. How well these are transformed into wine defines the difference between the skilled technician and the creative artisan.

Increasingly, the winemaker is in frequent communication with the grape grower. The interaction helps supply the raw materials the winemaker needs, as far as nature permits. Depending on the characteristics of the grapes reaching the winery, the winemaker must make decisions on how best to transform them into wine. Fig. 8.11 illustrates the basic sequence of events involved in this metamorphosis. None of the stages are without choices, the selection of which is likely to affect the wine's sensory attributes, for better or worse. While most decisions affect style, others primarily influence quality. Some of these decisions, and their quality implications, are briefly outlined below.

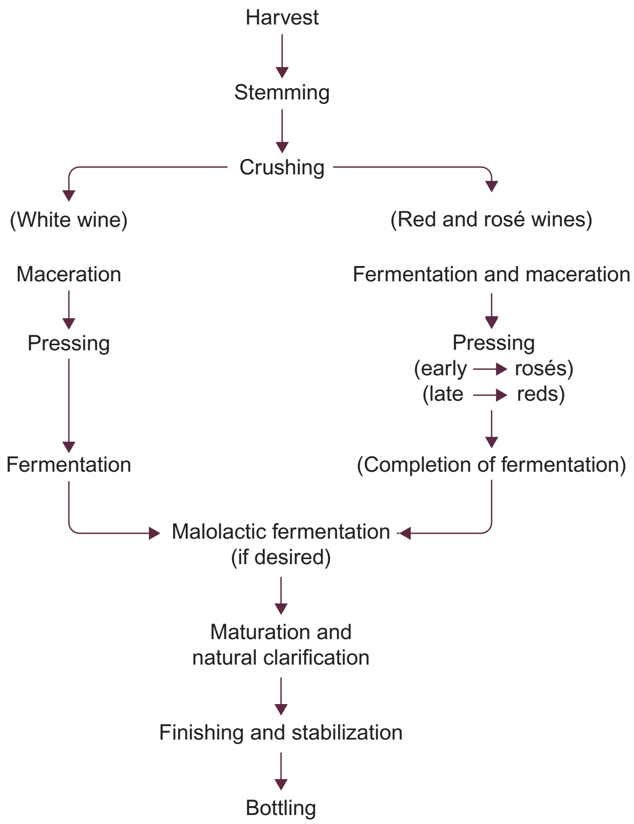

FIGURE 8.11 Flow diagram of winemaking. *From Jackson, R.S. (2014). Wine Science: Principles and Applications, fourth ed. Academic Press, San Diego, CA, reproduced by permission.*

Prefermentation Processes

Typically, grapes are crushed immediately upon reaching the winery. This disrupts the integrity of grape cells, allowing the release of nutrients, flavorants, and the escape of the juice. Crushing also liberates hydrolytic and oxidative enzymes that begin to react with grape constituents, further aiding nutrient and flavorant release. Until recently, exposure to air during, or after, crushing was considered detrimental (based on the belief that it made the subsequent wine more susceptible to oxidation). Although counterintuitive, early juice aeration limits subsequent oxidation by activating the expeditious oxidation and precipitation of readily oxidized phenolics. Thus, most winemakers now allow air access during crushing and/or actively aerate the juice after crushing. This enhances the shelf-life of white wines, as well as encourages complete fermentation (supplying a slight amount of oxygen that favors the near-complete metabolism of fermentable grape sugars). Except for some white and dessert wines, sweetness is best donated of sterile grape juice. It is added to dry wine shortly before or during bottling.

Depending on the intent of the winemaker, the juice from freshly crushed grapes may be left in contact with the seeds and skins (pomace) for up to several hours (white wines), or days (red wines). The duration of skin contact depends on the intensity of flavor to be extracted. Up to a point, flavor intensity and aging potential increase with prolonged skin contact. This period, called maceration, occurs before fermentation with white wines, but simultaneously with fermentation for red wines. The difference relates to the much longer period required for anthocyanin and tannin extraction, the primary chemicals that distinguish red from white wines. An example of the close correlation between wine pigmentation and quality is illustrated in Fig. 8.12. Skin contact also favors a quick onset and completion to fermentation, but also alters the synthesis of yeast-produced aromatics. Thus, the fundamental character of a wine is partially determined by the timing and duration of maceration, as well as the temperature at which maceration occurs (Fig. 8.13).

The next major process affecting wine quality is pressing (separation of the juice from the seeds and skins). Ideally this should occur with minimal incorporation of particulate matter (cellular debris and macromolecular complexes). This is achieved by applying pressure over as large a surface area as practical. Most modern presses are elongated,

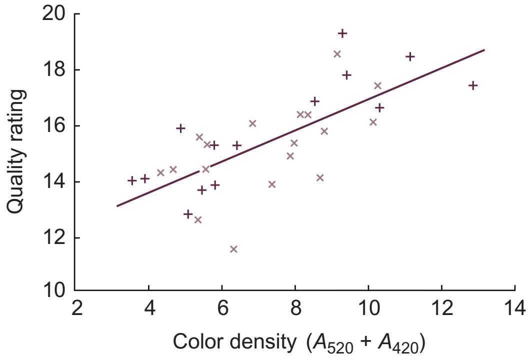

FIGURE 8.12 Relation between quality rating and wine color density in 1972 Southern Vales wines: (+) Cabernet Sauvignon; (×) Shiraz. *From Somers, T. C., Evans, M. E., 1974. Wine quality: Correlations with colour density and anthocyanin equilibria in a group of young red wine. J. Sci. Food. Agric.* **25**, *1369-1379. Copyright Society of Chemical Industry. Reproduced with permission. Permission is granted by John Wiley & Sons Ltd on behalf of the SCI.*

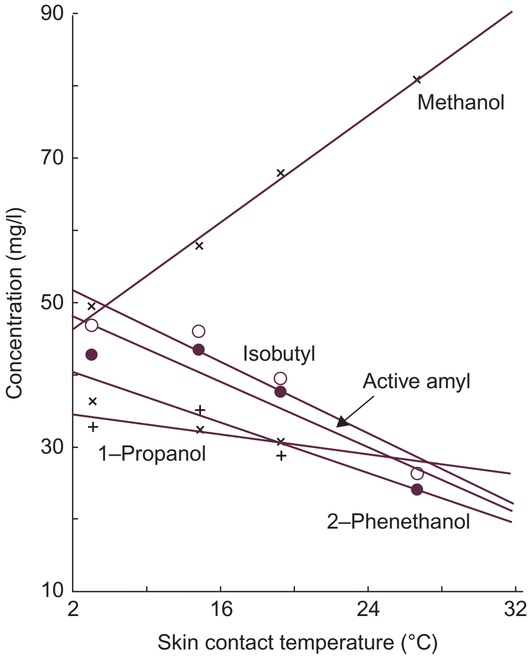

FIGURE 8.13 Concentration of various alcohols in Chardonnay wine as a function of skin-contact temperature. *From Ramey, D., Bertrand, A., Ough, C.S., Singleton, V.L., Sanders, E., 1986. Effects of skin contact temperature on Chardonnay must and wine composition. Am. J. Enol. Vitic. 37, 99–106, reproduced by permission.*

horizontally positioned, cylindrical chambers. Pressure is applied either via air pumped into a membranous bladder against the must (juice, seeds, and skins), or by plates that move in from one or both ends. The older, basket-type presses were positioned vertically and had pressure applied by a plate from the top. The gentler pressure applied by new press designs liberates juice that is less bitter and astringent, but rich in any potential varietal flavors. In contrast, the older presses produced rougher tasting wines with fewer fruit flavors. This partially resulted from the frequent use of grape stalks to produce drainage channels to ease juice drainage.

Regardless of the means of pressing, juice from white grapes usually needs some clarification before the start of fermentation. For this, winemakers have many means at their disposal. The selection typically has more to do with economics and speed than with quality concerns. Most clarification procedures have little effect on wine quality, if not used to excess. Because pressing in red wine production occurs at or near the end of fermentation, rapid clarification is rarely a critical issue. Correspondingly, clarification of red wines is initially by gravity-induced sedimentation.

If the sugar and acid composition of the juice is unavoidably inferior, the winemaker usually attempts to make adjustments at this stage. The addition of sugar and/or the addition of acidity (or its neutralization) can improve the basic attributes of the wine. It cannot compensate for a lack of color or flavor, though. As noted earlier, these desirable qualities frequently develop concomitantly with desirable grape acid and sugar levels.

Fermentation

Fermentor

The first fermentative decision facing the winemaker is the type of fermentor. Typically this will be a closed tank, as large as conveniently possible (economies of scale). However, small producers may choose fermentation in small (~250 L) oak barrels, especially for lots of high-quality juice. Those who favor this option justify the expense by the "cleaner" (less fruity) expression of the wine's varietal aroma. In-barrel fermentation modifies yeast metabolism, and thereby the aromatics they produce, as well as donates compounds extracted from the oak. These differences alone can generate features that can define the differences between wines from adjacent properties.

For the majority of white wines, fermentation occurs in comparatively simple tanks, except for the cooling required to regulate the fermentation temperature and rate. The tanks are usually made from inert materials, typically stainless steel. This permits transformation of the juice into wine without compromising the grape's natural flavors. Red wines are also frequently fermented in inert tanks. However, red wine fermentors vary considerably more in design than white wine fermentors. The difference is imposed by the need to extract color and flavorants from the skins during fermentation. As fermentation progresses, the carbon dioxide generated carries the seeds and skins to the surface of the juice, forming a cap. Various means have been developed to periodically or continuously submerge the cap into the fermenting juice. One of the more recent and effective designs is a rotary fermentor. It commonly possesses several blades attached to a central cylinder. These slowly rotate (or can be set to simply slosh) the fermenting must back and forth to a desired degree, gently mixing the seeds, skins, and juice. This process promotes rapid pigment and flavor extraction, while apparently favoring the extraction of soft tannins, while limiting the liberation of hard tannins. The result is a full-flavored wine, of intense color, but smooth enough to be enjoyed without requiring prolonged aging. Most other fermentors, giving intensely flavored and colored red wines, require several to many years to soften.

Yeasts

The next serious decision facing the winemaker is whether to permit spontaneous fermentation (by yeasts on the grape and winery equipment), or to add one or more commercial yeast strains (induced fermentation). There are advocates on both sides, equally claiming superior results. Spontaneous fermentations may yield more complex wines, but at the risk of wine spoilage. Most of the added complexity seems to come from acetic acid and diacetyl, but this may only reflect our lack of knowledge. At threshold levels, acetic acid and diacetyl can add an element of "sophistication," but at slightly higher concentrations, they generate off-odors. Preference likely depends on personal thresholds and/or habituation. Even where induced fermentation is the choice, the winemaker must decide on which species, strains, or combination thereof to use. As yet, there are no clear guidelines other than experience, and winemaker preference. These effects can be more than just subtle (Figs. 8.14 and 8.15).

If deciding which species or strain to use were not enough, yeast properties can vary with the fermentation conditions. The chemical composition of grapes (which varies from year to year and cultivar to cultivar), as well as the physical conditions of fermentation (e.g., temperature and pH), alter yeast metabolic activity.

Lactic Acid Bacteria

Most wines undergo two fermentations. The first, yeast-induced fermentation generates the alcohol and vinous bouquet that characterize wines. The second, bacteria-induced fermentation converts malic into lactic acid, reducing wine acidity. This alone can modify the wine's perception. However, byproducts released by bacterial metabolism further modify the wine's flavor (Fig. 8.16). In many instances, winemakers encourage malolactic fermentation more for its sensory contribution than its acidity reduction.

Malolactic fermentation is encouraged in most red wines, notably in moderate-to-cool climatic regions. It makes the wine more drinkable by mollifying a potentially overly sour, rough taste of the wine. In contrast, winemakers attempt to limit malolactic activity in warm-to-hot climatic regions, where the grapes (and wine) have a tendency to be too low in acidity. The action of malolactic fermentation could give the wine a flat taste under the latter conditions. In addition, malolactic fermentation has a propensity to generate off-odors in wines of low acidity.

Because malolactic fermentation is often sporadic, especially in wines low in pH, winemakers frequently inoculate their wines with one or more desirable strains (typically *Oenococcus oeni*). As with yeast strains in alcoholic fermentation, bacterial strains differ considerably in their aromatic impact. Fig. 8.17 illustrates the sensory effects

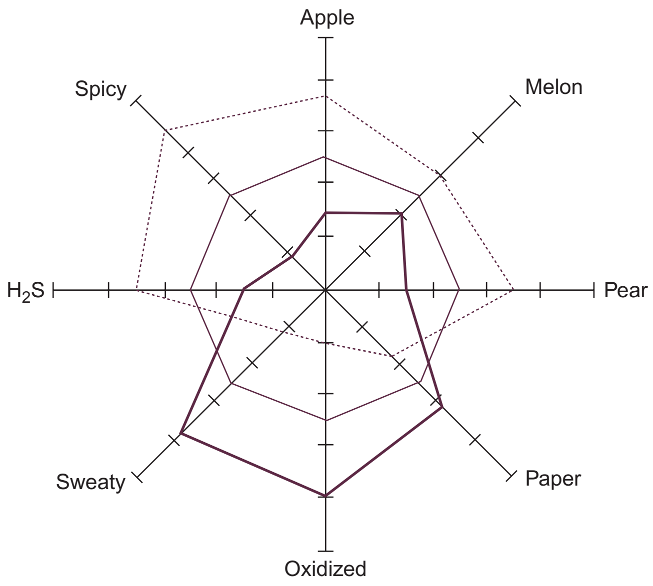

FIGURE 8.14 The effect of spontaneous (---) and induced (▬▬) fermentation on the sensory characteristics of Riesling wine; (—) mean score: H_2S, hydrogen sulfide. *From Henick-Kling, T., Edinger, W., Daniel, P., Monk, P., 1998. J. Appl. Microbiol. 84, 865–876; reproduced by permission.*

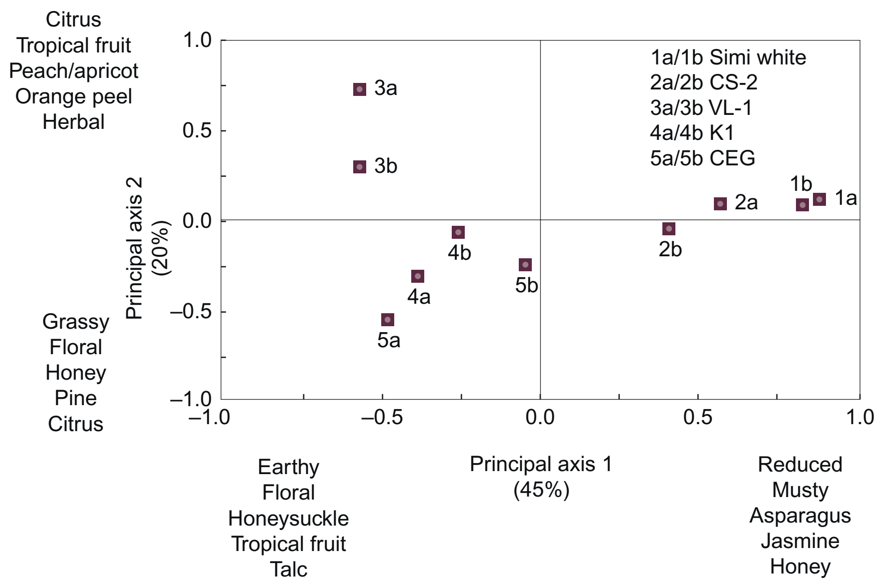

FIGURE 8.15 Profile of aroma of a Riesling wine (after 20 months) fermented with different yeast strain. From Dumont, A., Dulau, L., 1996. The role of yeasts in the formation of wine flavors. In "Proc. 4th Int. Symp. Cool Climate Vitic. Enol. In: Henick-Kling, T., et al. (Eds.), New York State Agricultural Experimental Station, Geneva, NY, pp. VI–24–28, reproduced by permission.

inducible by different strains of *Oenococcus oeni*. From the divergence of opinion demonstrated in Fig. 8.17, it should be no surprise that there are strong and diverse opinions concerning the relative merits of malolactic fermentation.

Postfermentation Influences

Adjustments

Ideally, a wine should require only minimal clarification, such as spontaneous settling and gentle fining before bottling. However, if the wine is bottled early, is imbalanced, or possesses some fault, additional treatment(s) may

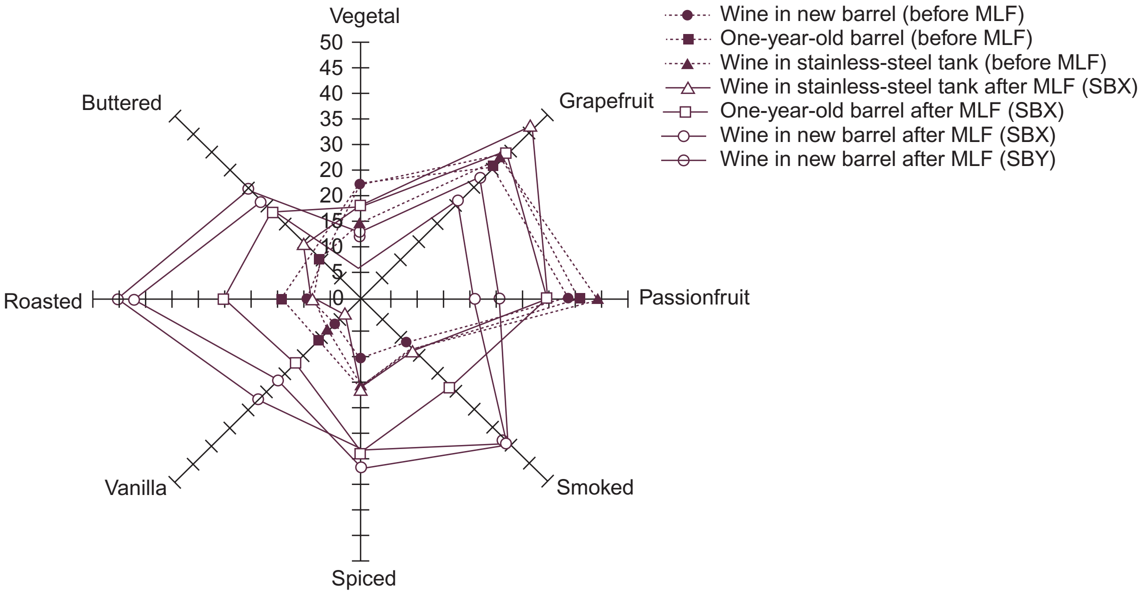

FIGURE 8.16 Differentiation of wine as affected by malolactic fermentation (MLF) in stainless steel or oak cooperage by two strains of lactic acid bacteria (SBX and SBY). *From de Revel, G., Martin, N., Pripis-Nicolau, L., Lonvaud-Funel, A., Bertrand, A., 1999. J. Agric. Food Chem. 47, 4003–4008. Copyright(1999) American Chemical Society).*

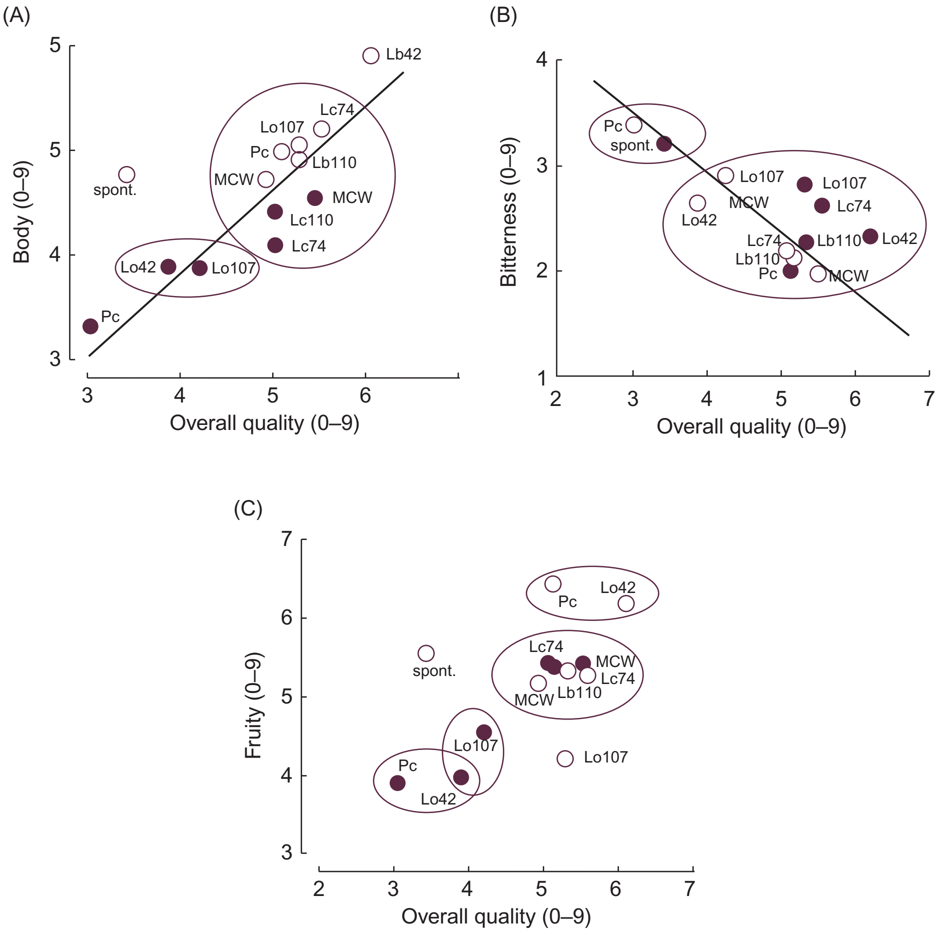

FIGURE 8.17 Relation of body (A), bitterness (B), and fruitiness (C) to overall quality of Cabernet Sauvignon wine fermented with various lactic acid bacteria. The relation was assessed by two different panels, one composed of winemakers (●) and the other a wine research group (○). *From Henick-Kling, T., Acree, T., Gavitt, B.K., Kreiger, S.A., Laurent, M.H., 1993. Sensory aspects of malolactic fermentation. In Proc. 8th Aust. Wine Ind. Tech. Conf. In: Stockley, C.S., et al. (Eds.), Winetitles, Adelaide, Australia, pp. 148–152, reproduced by permission.*

be required. Nevertheless, such treatments need to be kept to a strict minimum. Most forms have the potential to remove or neutralize the subtle distinctiveness that ideally should grace every wine.

Blending

Blending is one of the most misunderstood aspects of wine production, especially for some supposed wine connoisseurs. In one or more forms, blending is involved in the production of every wine. It can vary from the simple mixing of wine from different fermentors, to the complexities of combining wines produced from different cultivars, vineyards, or vintages. For several wines, notably sparkling, sherries, and ports, complex blending is central to their quality and brand distinctiveness. In other regions, blending wines made from several grape varieties supplies their traditional character (e.g., Bordeaux and Chianti). Blending tends to enhance the best qualities of each component wine, while diminishing their individual defects. Fig. 8.18 illustrates the general benefits of blending. It shows that blends between wines of roughly similar character and quality were considered as good or better than their component wines.

The negative connotation often attributed to blending arises primarily from those with a vested interest in appellation control, and smaller wineries promoting their wines' uniqueness (estate bottled). Authenticity of provenance and vintage derivation are marketed as essential ingredients in quality. Whether this is valid depends more on the skills of the producer and grape maturity than delimited geographic origin. Blending wines from different vineyards and regions is no more detrimental to quality than blending between wines produced from different grape varieties. Geographic identity does, however, give the consumer a readily recognizable identifier, and seemingly justify having confidence in the wine's sensory attributes. Much effort is being currently spent on studies to identify unifying sensory features that may characterize particular appellations. A review of techniques investigating wine typicity is found in Maitre et al. (2010). Examples of results are illustrated in Figs. 5.46 and 5.47. Although laudable, one has to wonder if much of the impetus behind these studies is the potential marketing advantage that may accrue to the appellation involved rather than esoteric academe.

Processing

An old processing technique receiving renewed attention is *sur lies* maturation. The process involves leaving white wine in contact with the lees (dead and dying yeast cells) for an extended period. The contact period typically occurs in the same container as did fermentation, traditionally barrels. *Sur lies* maturation can enhance wine stability and increase flavor complexity. This benefit, however, runs the risk of contamination with hydrogen sulfide and other odoriferous reduced-sulfur compounds (released from the lees). To reduce this likelihood, the wine is periodically stirred to incorporate small amounts of oxygen. Unfortunately, this, in turn, can activate dormant acetic acid bacteria that produce acetic acid and ethyl acetate off-odors. Thus, the wine in each barrel must be sampled frequently to assess the wine's development.

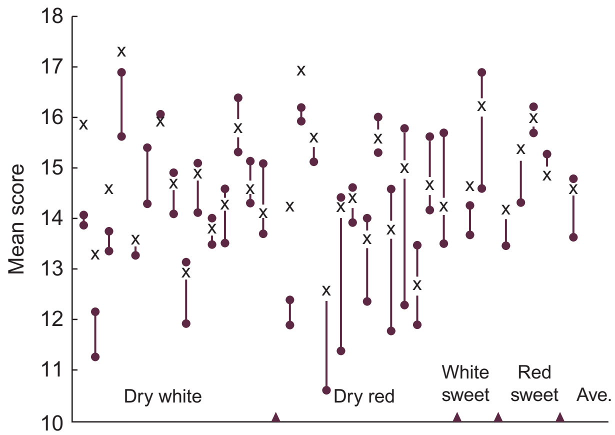

FIGURE 8.18 Mean quality scores of 34 pairs of wines compared (●) with their 50:50 blend (×), indicating the value of a complex flavor derived from blending. *From Singleton, V.L. (1990). An overview of the integration of grape, fermentation, and aging flavours in wines. In Proc. 7th Aust. Wine Ind. Tech. Conf. In: Williams, P.J., et al. (Eds.), Winetitles, Adelaide, Australia, pp. 96–106 [based on data from Singleton and Ough, 1962], reproduced by permission.*

Sparkling wine production also involves a form of *sur lies* maturation. In this instance, the process occurs in the bottle in which the second fermentation takes place. Because the amount of lees involved is small, the generation of reduced-sulfur odors is not a concern. On the contrary, yeast autolysis generates a toasty scent, if the wine remains on the lees sufficiently long, which is typically the case with champagnes. In addition, yeast autolysis liberates colloidal mannoproteins that favor the generation of continuous chains of small, semi-durable bubbles (Feuillat et al., 1988; Maujean et al., 1990). The helical structure of these proteinaceous polymers probably entraps carbon dioxide as it can volatile compounds.

Processing is also crucial to the flavor of most fortified wines. For example, fractional (*solera*) blending provides the consistency of character expected of sherries, and promotes the growth of *flor* yeasts required for *fino* production. Equally, baking (*estufagem*) is essential to development of a typical madeira flavor.

Oak

Wines with sufficient flavor and distinctiveness may be matured in oak cooperage. This can add a desirable element of complexity, as well as occasionally improve varietal expression (Sefton et al., 1993; Fig. 8.19). Fig. 8.20 further illustrates how the presence of one component (oak lactones) correlates with several wine attributes.

Oak can donate a spectrum of flavors, depending on a whole host of factors. These include the oak species (Fig. 8.21), the conditions under which the trees grew (Chatonnet, 1991), the method of wood seasoning (Chatonnet et al., 1994), the degree of "toasting" (heat applied during barrel coopering), and the number of times the barrel has been used (Fig. 8.22). Each aspect modifies the attributes contributed by the oak. For example, light toasting retains most of the basic oak flavors intact (e.g., oaky, coconut attributes); medium toasting partially degrades these, generating some pyrolytic byproducts (notably vanilla and caramel flavorants); and heavy toasting/charring degrades most natural oak flavorants and phenolic and furanilic aldehydes (initially produced on the inner surfaces

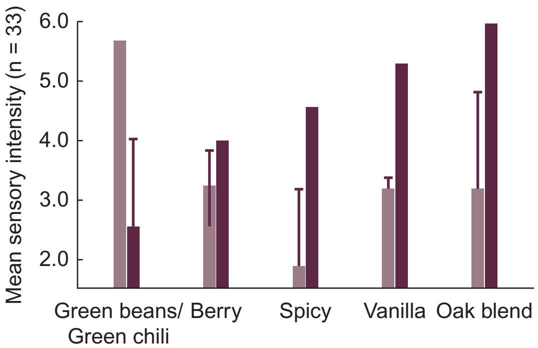

FIGURE 8.19 Mean intensity rating of aroma terms for Cabernet Sauvignon wines aged 338 days in glass (control) and in French oak barrels (*light bars*, control; *dark bars*, oak-aged; 11 judges, 3 replications). *From Aiken, J.W., Noble, A.C., 1984. Comparison of the aromas of oak- and glass-aged wines. Am. J. Enol. Vitic.35, 196–199, reproduced by permission.*

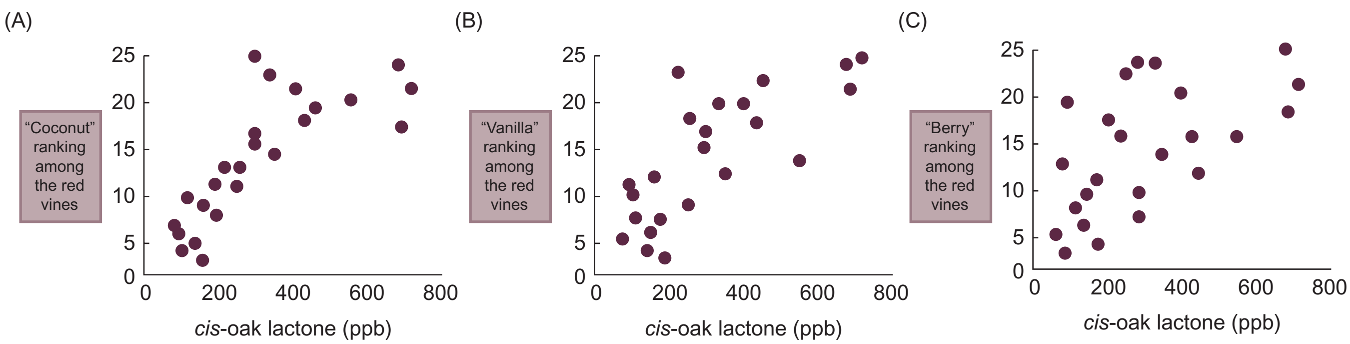

FIGURE 8.20 Correlation of the perception of several flavor characteristics with the presence of *cis*-oak lactones in red wines matured in oak barrels: (A) coconut, (B) vanilla, and (C), berry. The rank correlation was significant in all three cases ($p < .001$). *From Spillman, P.J., Pocock, K.F., Gawel, R., Sefton, M.A., 1996. The influences of oak, coopering heat and microbial activity on oak-derived wine aroma. In: Stockley, C.S., et al. (Eds.), Proc. 9th Aust. Wine Ind. Tech. Conf, Winetitles, Adelaide, Australia, pp. 66–71, reproduced by permission.*

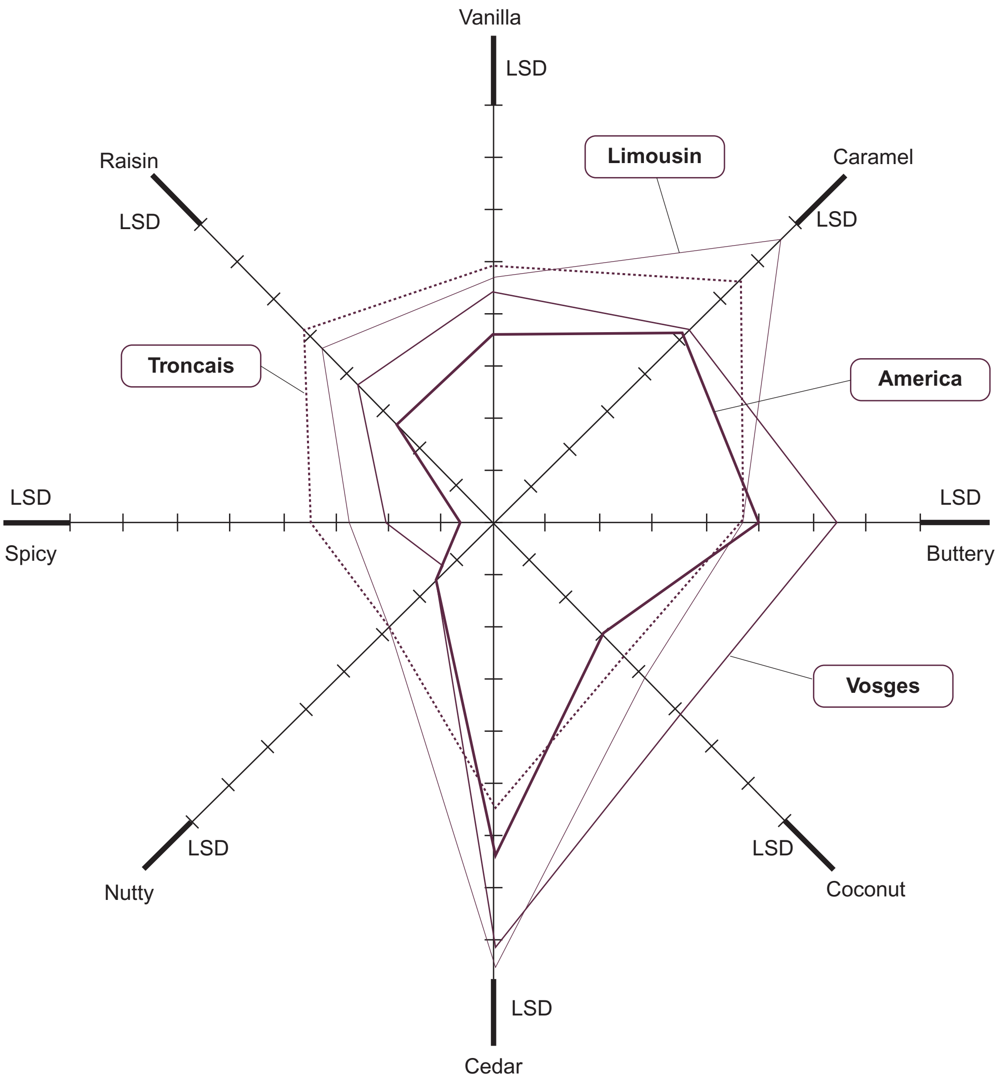

FIGURE 8.21 Polar coordinate graph of mean intensity ratings and least-significant differences (LSD) for descriptors by oak origin (n = 14 judges × 3 reps × 6 samples). *From Francis, I.L., Sefton, M.A., Williams, J., 1992. A study by sensory descriptive analysis of the effects of oak origin, seasoning, and heating on the aromas of oak model wine extracts. Am. J. Enol. Vitic. 43, 23–30, reproduced by permission.*

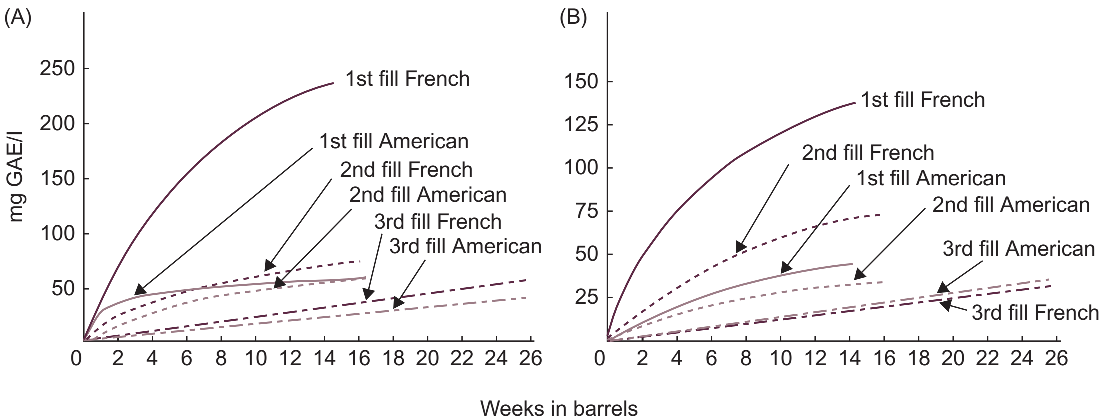

FIGURE 8.22 Changes in (A) total phenolics and (B) nonflavonoids over time for French and American oak barrels. *From Rous, C., Alderson, B., 1983. Phenolic extraction curves for white wine aged in French and American oak barrels: GAE, gallic acid equivalents. Am. J. Enol. Vitic. 34, 211–215, reproduced by permission.*

of the staves), producing volatile phenols with a smoky, spicy aspect (e.g., eugenol, quaiacol, 2-methoxyphenol). The former compounds still occur, but are now located deeper in the wood, requiring longer for their extraction.

The intensity of these respective aspects can be regulated by the duration of wine contact (varying from several weeks to years) and cooperage capacity. Whether the added flavors enhance or detract from the central character of the wine depends more on personal preference than chemistry. In some appellations, law dictates the type and duration of oak maturation. In such cases, a certain oakiness is considered an obligatory attribute.

Where economics demands alternatives to oak barrels, thin slats of oak may be submersed in tanks while the wine is maturing in the cooperage. Even less expensive options can involve adding oak chips or sawdust (in permeable sacks to facilitate removal), or oak extract to maturing wine.

Bottle Closure

For several centuries, cork has been the exclusive closure for wine matured in barrel or in bottle. In this role, cork has several distinctly desirable properties. These include compressibility (with little lateral expansion for ease of insertion), elasticity (rapid return to its original shape after compression), resilience (prolonged exertion of pressure against the bottle neck after insertion), chemical inertness (notably to wine acids and alcohol), relative impermeability to most liquids and gases, and a high coefficient of friction (adheres well to surfaces). Thus, it normally provides a long-lasting, tight seal that limits contamination and loss of aromatics, and severely retards any gas entrance or escape. Most cork stoppers of normal length possess a permeation barrier of about 300–500 cells/cm along their length. Because of the direction in which stoppers are punched out from the cork-oak bark, the principal porous regions of the cork (lenticels and crevices) are positioned at right angles to the stopper's length (Fig. 8.23).

Nevertheless, the dominance of natural cork is being challenged by alternatives. This has arisen primarily due to contamination of the cork with off-odors, either in the forest, during bark storage (seasoning), stopper manufacture, or during transport and storage to wineries. The most well known of these is 2,4,6-trichloroanisole (TCA). In addition to being a potential source of off-odors, cork can scalp (absorb) aromatics from the wine. Finally, variations in the internal structure and morphology of cork stoppers (difficult to assess visually) can affect their protective function. Unexplained examples of apparently random premature wine oxidation have often been attributed to faults in cork anatomy, permitting undue oxygen ingress, but maybe not (Lagorce-Tachon et al 2016). Common alternatives to natural cork for bottle closure include agglomerate cork, synthetic cork, and roll-on (screw) caps.

Premium quality corks possess sealing qualities equivalent to screw caps, but progressively lose their elasticity over time (~20 years). Thus, their sealing properties eventually fail. The deterioration progresses outward, from the end in contact with the wine. Thus, cork length affects how long a cork is likely to effectively seal the bottle, a relationship that has not gone unnoted by some producers, desirous of subtlety denoting their wine's greater quality (or aging potential).

A factor little recognized for its importance to sealing quality is the rate at which the cork tissue grew. Bark derived from cork oak (*Quercus suber*) that has grown slowly contains a higher proportion of resilient, spring-produced, cork cells (and correspondingly shows more annual growth rings in the stopper (Fig. 8.24). Thus, cork derived from trees grown in drier, mountainous regions has better sealing properties than cork derived from trees grown in moister, lowland regions.

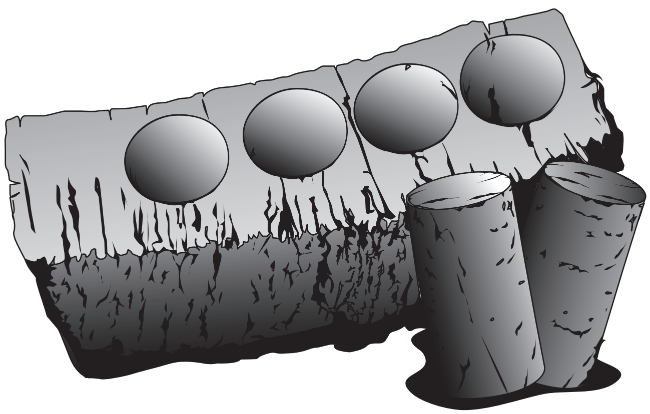

FIGURE 8.23 Slab of cork bark showing the direction of stopper extraction. *Diagram courtesy of H. Casteleyn.*

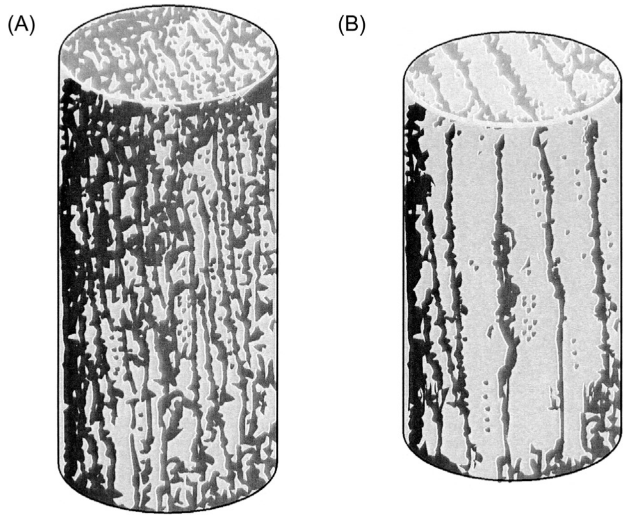

FIGURE 8.24 Representative diagrams of (A) high-quality corks, derived from slow-growing cork oak, and (B) lower-quality cork, derived from rapid-growth cork oak. Note the large number of growth rings (≥9) in the cork on the left compared with the one on the right (≤7) *Diagram courtesy of H. Casteleyn.*

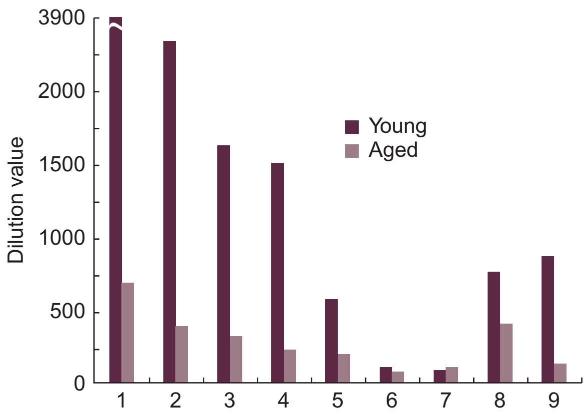

FIGURE 8.25 Loss of aromatic compounds during the aging of a Vidal wine (1, β-damascenone; 2, 2-phenylethanol; 3, fruity; 4, floral; 5, spicy; 6, vanilla/woody; 7, vegetative; 8, caramel/oatmeal; 9, negative aromas). *From Chisholm, M.G., Guiher, L.A., Zaczkiewicz, S.M., 1995. Aroma characteristics of aged Vidal blanc wine. Am. J. Enol. Vitic. 46, 56–62, reproduced by permission.*

Aging

The tendency of wine to improve, or at least change, during in-bottle aging is one of its most intriguing properties. Unlike most commercial food and beverage products, which have a "best before" date, no such precise designation applies to wine (with the exception of nouveau wines) (Jackson, 2016a). Unfortunately, most wines improve only for a few several years, before beginning a show, progressive, and irreversible loss of aromatic character (Fig. 8.25). Only rarely does this involve microbial spoilage, leading to the generation of off-odors or a vinegary character.

During the initial stages (maturation prior to bottling), loss of yeasty odors, excess dissolved carbon dioxide, and the precipitation of particulate material lead to sensory improvements. Additional improvements in character may commence during maturation and continue during aging (postbottling). Examples involve acid-induced liberation of terpenes and other aromatics from nonvolatile glycosidic complexes. Several hundred glycosides have been isolated from varieties such as Riesling, Chardonnay, Sauvignon blanc, and Shiraz.

One of the more obvious age-related changes is a color shift toward brown. Red wines may initially deepen in color after fermentation, but subsequently become lighter and take on ruby and then brickish hues. An initial decrease in color intensity can result from the dissociation of anthocyanin complexes found in grapes. This is usually

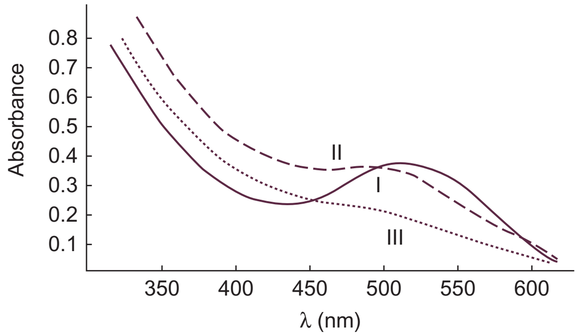

FIGURE 8.26 Absorption spectra of three red wines of different ages: I, 1-year old; II, 10-year old; III, 50-year old. *From Ribéreau-Gayon, P., 1986. Shelf-life of wine. In: Charalambous, G. (Ed.), Handbook of Food and Beverage Stability: Chemical, Biochemical, Microbiological and Nutritional Aspects. Academic Press, Orlando, FL, pp. 745–772, reproduced by permission.*

followed by polymerization between anthocyanins and tannins. These stabilize the color, but initiate a slow loss in color density and shift from red-purple to brickish, and eventually brownish red. These changes are detectable with a spectrophotometer as a drop in optical density, and a shift in the absorption spectrum (Fig. 8.26). Without polymerization, anthocyanins oxidize and the wine would permanently lose its vibrant color. The reasons why different cultivars vary in the rate at which their color changes during aging probably relates to the amounts and types of anthocyanins, and the copigments they possess. In addition, small amounts of acetaldehyde, produced following limited aeration (coincidental consequences associated with racking and other maturation procedures), are known to enhance anthocyanin–tannin polymerization. The storage temperature and pH of the wine are also significant factors affecting the rate of color change.

Age-related color changes in red wines are often assessed by measuring changes in optical density at two wavelengths (520 and 420 nm) (Somers and Evans, 1977). High 520/420 nm values indicate a bright-red color, whereas low values denote a shift to brickish tones. In contrast, white wines darken in color, developing yellow, gold, and eventually brownish shades. The origins of this latter color shift are poorly understood. Nonetheless, it probably involves a combination of phenolic oxidation, metal ion–induced structural changes in galacturonic acid, Maillard reactions between sugars and amino acids, and sugar caramelization.

The slow hydrolytic rupture of glycosidal linkages during aging not only liberates aromatic compounds, but also phenolics such as quercetin and resveratrol. The sensory significance of the release of these phenolics is unclear. However, their reduced solubility as free phenolics may accentuate crystallization and haze generation.

During aging, wines lose their original fresh fruity character. This is especially noticeable when the fragrance depends on fruit esters, whose concentration progressively declines (Figs. 8.27 and 8.28). Although the concentration of volatile carboxylic acid esters (e.g., diethyl succinate) increases, they are poorly volatile. In addition, the fruity/floral aspects of terpenes slowly degrade or oxidize to less aromatic or flavorless compounds. Oxidation of 3-mercaptohexan-1-ol is one of the principal reasons for the comparatively short shelf-life of most rosé wines (and the loss of its fruity fragrance) (Murat, 2005).

Wines that age well tend to show a varietal character that initially becomes more evident (e.g., Riesling), being finally replaced by a subtle, complex, aged bouquet. In white wines, their sensory attributes (if they develop) are often couched in terms such as hay or honey. For red wines, when the mature jammy character begins to fade, it is supplanted by an aged bouquet often described in terms of leather, cigar box, smoky, and truffle. Other than differences correlated with wine color, most aged bouquets seem similar and relatively independent of cultivar origin (see the descriptions of aged wines in Broadbent, 1980).

The chemical nature of most aged bouquets is poorly understood. However, it partially involves degradation byproducts of norisoprenoids and related diterpenes, carbohydrate derivatives, and the synthesis of thiols, and volatile and oxidized phenolics.

Of isoprenoid degradation products, 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN) appears to contribute to the aged bouquet of Riesling wines. Table 8.2 illustrates a few other age-related chemical changes that can occur in Riesling wines. The table also demonstrates the importance of temperature to the aging process, as does Fig. 8.28. Another isoprenoid, (*E*)-1-(2,3,6-trimethylphenyl)buta-1,3-diene, often accumulates during aging, and can donate a green or cut-grass aroma to several white wines. Although this compound has been isolated from red grapes, it has not been found in red wines. This seeming anomaly may to be due to its reaction with tannins (Cox et al., 2005).

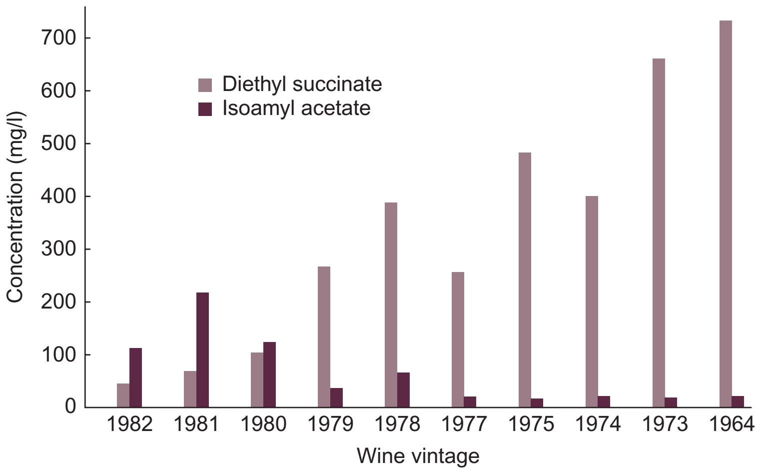

FIGURE 8.27 Examples of the influence of wine age on the concentration of esters, notably acetate esters (isoamyl acetate) and ethanol esters (diethyl succinate). *From Jackson, R.S., 2014. Wine Science: Principles and Applications, fourth ed. Academic Press, San Diego, CA (Jackson, 2014), data from Rapp, A., Güntert, M., 1986. Changes in aroma substances during the storage of white wines in bottles. In: Charalambous, G. (Ed.), The Shelf Life of Foods and Beverages. Elsevier, Amsterdam, pp. 141–167, reproduced by permission.*

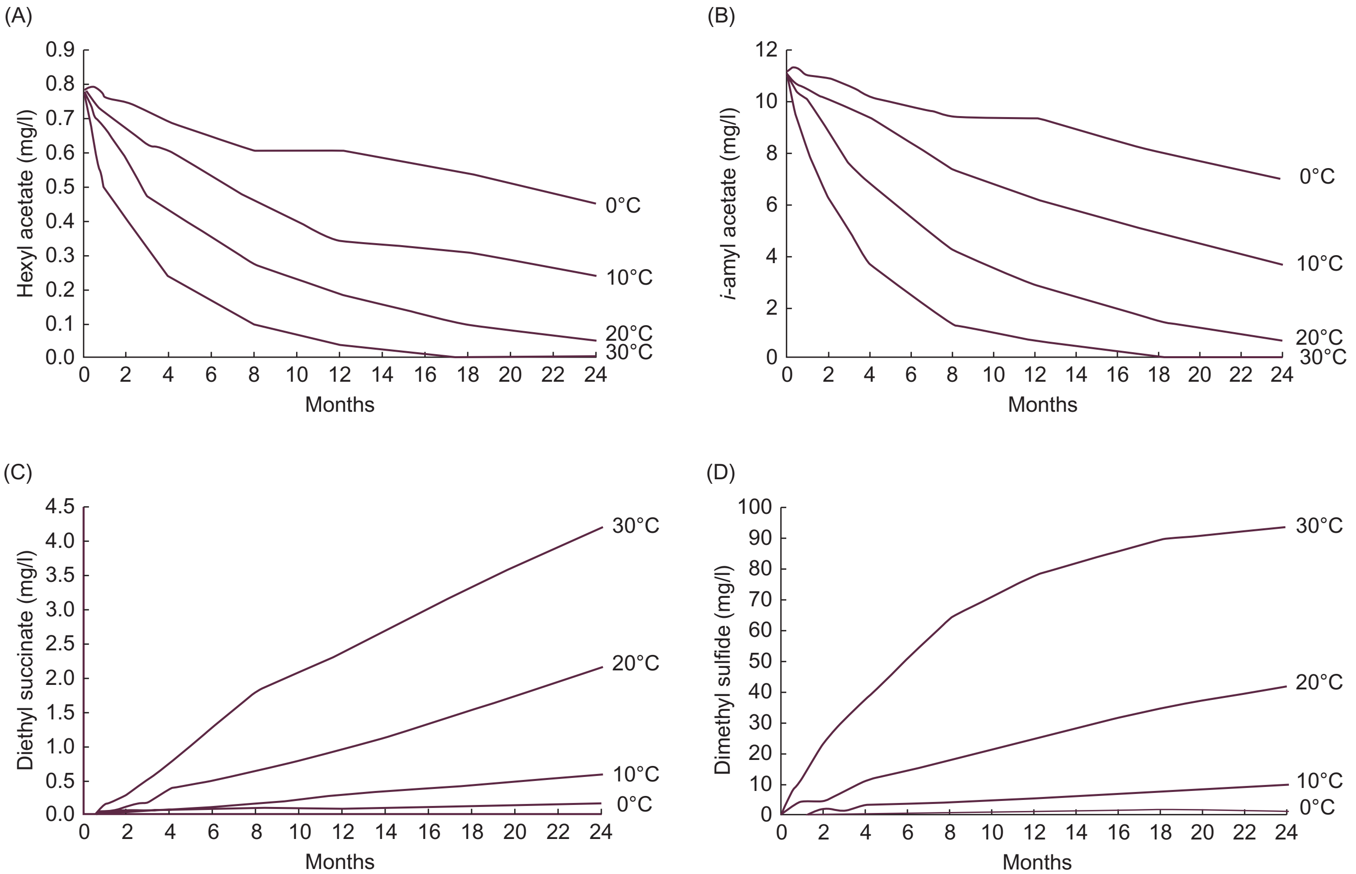

FIGURE 8.28 Effect of storage temperature and duration on the concentration of (A) hexyl acetate, (B) *i*-amyl acetate, (C) diethyl succinate, and (D) dimethyl sulfide in a Colombard wine. *From Marais, J., 1986. Effect of storage time and temperature of the volatile composition and quality of South African Vitis vinifera L. cv. Colombar wines. In: Charalambous, G. (Ed.), Shelf Life of Foods and Beverages. Elsevier, Amsterdam, pp. 169–185, reproduced by permission.*

TABLE 8.2 Changes in bouquet composition from carbohydrate decomposition during aging of a Riesling wine[a,b]

	Year					
Substance from carbohydrate degradation	**1982**	**1978**	**1973**	**1964**	**1976 (frozen)**	**1976 (cellar stored)**
2-Furfural	4.1	13.9	39.1	44.6	2.2	27.1
2-Acetylfuran	—	—	0.5	0.6	0.1	0.5
Furan-2-carbonic acid ethyl ester	0.4	0.6	2.4	2.8	0.7	2.0
2-Formylpyrrole	—	2.4	7.5	5.2	0.4	1.9
5-Hydroxymethylfurfural (HMF)	—	—	1.0	2.2	—	0.5

From Jackson, R.S., 2014. Wine Science: Principles and Applications, fourth ed. Academic Press, San Diego, CA.
[a]*Data from Rapp and Güntert (1986).*
[b]*Relative peak height on gas chromatogram (mm).*

Other isoprenoid degradation products, such as vitispirane, theaspirane, ionene, and damascenone appear little involved in the development of an aged bouquet.

Most changes in terpene content are negative, their oxidation not only changing their sensory quality but increasing their thresholds (Rapp and Mandery, 1986). However, accumulation of a monoterpene ketone, piperitone, contributes to the minty character of aged red Bordeaux wines (Picard et al., 2016).

Carbohydrate degradation products, notably Maillard products, develop slowly at ambient temperatures. These contribute to the brownish gold coloration of some white wines, as well as donating various flavors. The most familiar is a caramel fragrance. Another Maillard product, the ethyl ester, 2-(ethoxymethyl)furan, may contribute to a fruity, slightly pungent character. It has been found in aged Sangiovese wines (Bertuccioli and Viani, 1976).

The concentration and nature of reduced-sulfur compounds often change during aging. For example, the accumulation of dimethyl sulfide has been correlated with development of a desirable aged aspect in aged Colombard wines (Fig. 8.28D). Its addition (20 mg/L) to several wines has also been correlated with an increase in the wine's flavor score (Spedding and Raut, 1982), but higher concentrations ($\geq$ 40 mg/L) were considered detrimental. By itself, dimethyl sulfide has a shrimp-like odor. Occasionally, the production of dimethyl sulfide is so marked at warm temperatures that it can mask a wine's varietal character within several months (Rapp and Marais, 1993). Other thiols contributing to aged bouquets, in this case red Bordeaux, are 3-sulfanylhexanol and 2-furanmethanethiol (Picard et al., 2015). 2-Furanmethanethiol forms in oak-aged wine and reportedly possesses toasty, cooked meat, and roasted coffee notes (Tominaga et al., 2000).

In red wines, one of the best-understood aspects of aging relates to the polymerization of bitter, astringent tannin subunits into large complexes. Because increased polymer size usually correlates with enhanced astringency, at least up until precipitation occurs, polymerization has normally been assumed to increase perceived astringency. However, acetaldehyde-induced polymerization may reduce solubility (Matsuo and Itoo, 1982). Thus, the uptake of oxygen during barrel maturation and aging may partially explain the oft-noted progressive mellowing of wine astringency. The reverse process, proanthocyanidin breakdown (Vidal et al., 2002) may also play a role in age-related reduction in astringency. A summary of potential chemical modifications during wine aging is illustrated in Fig. 8.29.

Other than the initial benefits of aging noted earlier, older wines do not necessarily show greater quality than their younger versions. Younger versions demonstrate more fruitiness, and typically express a truer manifestation of any varietal character. As the wine ages, the fragrance tends to become less fruity; red wine fragrances taking on a more jammy character, becoming progressively less varietal, more subtle, and potentially developing an aged aspect. In addition, a well-aged wine often possesses the qualities of flavor development and an exquisite finish. It depends on personal preference whether the fresh young aroma of youth, the fuller, more complex bouquet of a mature wine, or the fully developed aged bouquet is more esteemed. They are certainly different, but equally enjoyable in their separate ways, but, given the choice, the author will always go for the finesse and elegance of the aging monarch (also, there is no shortage of excellent young wines). However, anyone aging wine must be cautious not to go overboard; what fragrance and flavor an old wine retains, if any, may rapidly dissipate upon opening. The wine may be rare, the tasting a unique and historic experience, but the sensory consequences may be bereft of any delight and a bathos. Regrettably, few consumers are likely to have a chance to sample well-aged wines, unless they have aged wine themselves. Finding wines in the range of 10–15 years old on store shelves is now exceptionally

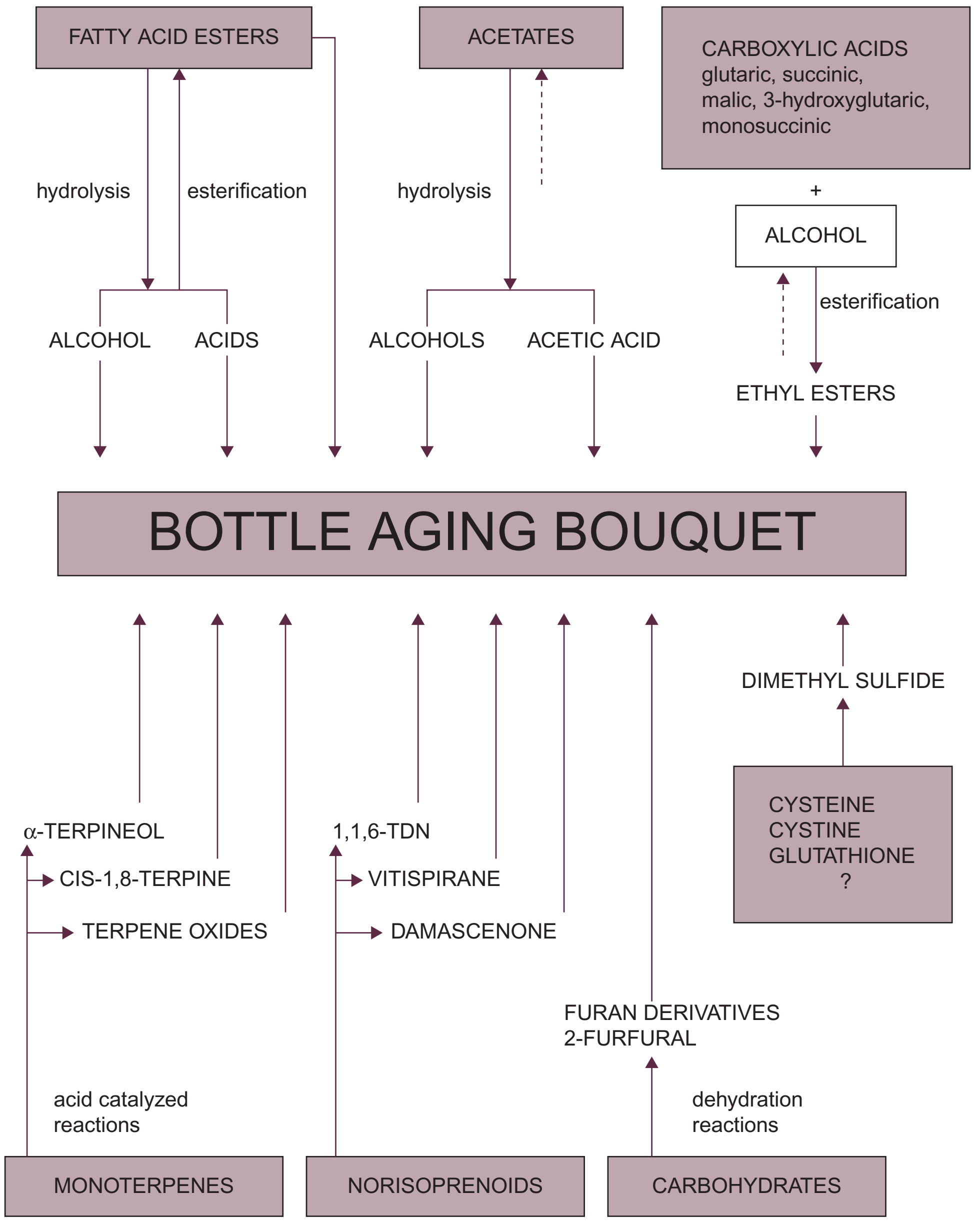

FIGURE 8.29 Illustration of the types of potential chemical changes in wine during aging. *Reprinted from Shelf Life Studies of Foods and Beverages. Chemical, Biological, Physical and Nutritional Aspects. (G. Charakanbous, ed.), Aldave, L., Almy, J., Cabezudo, M. D., Cáceres, I., González-Raurich, M., Salvador, M. D., 1993. The shelf-life of young white wine. pp. 923–943, with permission from Elsevier.*

rare, and, if the wines are not known to be from good producer and have been stored under ideal conditions, they may not be worth buying.

The effects of aging have usually been interpreted as changes in chemical equilibria (e.g., esters to their alcohol and acid constituents), hydrolysis of aromatic glycosides (e.g., terpenes, thiols, and norisoprenoids), oxidation reactions (e.g., formation terpene oxides), reduction reactions (e.g., formation of thiols), and breakdown products (e.g., hydrocarbons). However, other factors to consider are absorption (scalping) of aromatics by, and diffusion and loss of aromatic compounds via, the closure. The rate of loss of any compound is a function of how it is absorbed by, and diffuses through, or around the closure. These properties are affected by the absorptive and diffusion properties of the closure, the ambient temperature, the solubility and volatility of the aromatics (a function of their hydrophobic/hydrophilic properties, degree of hydration, association in ethanol micelles, and weak bonding with other matrix constituents), and the compound's molecular weight. Alone, the molecular weight of the compound suggests that a wine is likely to lose lighter-weight aromatics at a faster rate than heavier compounds. Thus, with age, a wine theoretically should become progressively more characterized by heavier aromatic compounds, i.e., those that tend to possess more ligands, and therefore react with a wider range of olfactory receptors. The result is that an aged bouquet becomes not only quantitatively simpler (being less varied chemically and present at lower concentrations), but also sensorially more complex (activating a wider range of olfactory receptors). Advances in headspace sampling are currently available to confirm and extend these views (Bicchi et al., 2012; Stashenko and Martínez, 2012).

Aging Potential

In most instances, the best guide to a wine's aging potential is experience. However, the problem is that few consumers have the opportunity to gain the requisite experience. Thus, they must depend on advice, which may be of questionable quality. Recommendations often show a distinct cultural bias, even from so-called experts. Relative to Bordeaux wines, earlier consumption is recommended by French experts more than by their British counterparts, with American authorities being somewhere in between. The personal value of such advice can be established only by experimentation. In the case of wines of repute, this would be as expensive as it would be long.

The situation is not helped by a lack of detailed information on the origin of a wine's aging potential. Usually it is considered to depend primarily on the wine's alcohol and phenolic contents, as well as sugar content with sweet wines. Increases in any of these constituents are thought to augment aging potential, up to a point. Varietal origin is also clearly important. For example, varieties depending predominantly on yeast-generated ethyl and acetate esters or most terpenes have truncated aging potentials. Riesling is a clear exception to this generality. In contrast, most red wines have longer aging potentials (often considered to be derived from the antioxidant action of their phenolic constituents).

Although variety and chemical constituents are important to aging potential, how the wines have been made and stored are equally important. Cool storage temperatures dramatically slow the effects of aging (Fig. 8.28), markedly enhancing aging potential. Aging is often considered optimal at about 10°C, but this may simply reflect habituation, many underground cellars possessing temperatures in this range. Having heard that temperature is important, people often asked at what temperature they should age their wines. I respond, somewhat facetiously, by asking how long they expect to live. If the response is long, it is safe to age wine slowly at cool temperatures, otherwise, store at near room temperature. Whether aging can be effectively accelerated at much about this point is a moot point. Heating promotes some aging reactions, but it also activates others that are generally viewed as detrimental (Singleton, 1962). Several commercial products supposedly produce the effects of aging within minutes. Except for magnets, none of these appear to have been subjected to scientific scrutiny. It the case of magnets, the results did not verify the claims of the producer (Rubin et al., 2005). Patience and time are the only known effective procedures.

Vibration has occasionally been reported as detrimental to wine aging. Only minor physicochemical changes have been observed, with marked and prolonged vibration (Chung et al., 2008), and they appear to have had no sensory significance. Another common view is that movement, whether it is from the store to home, or by overseas transport, is detrimental. The only evidence of any veracity to these views relates to potential exposure to temperature extremes during transport, not movement. The effect of temperature fluctuations may also be the origin of the idea that vibration is a detriment.

Unfortunately, consumers rarely have the opportunity to investigate these factors personally. For them, they must depend on extrinsic factors to guestimate aging potential. These typically involve the wine's price, as well as the repute of the vintage, winery, region, and producer. For additional, dubious sources of "precision," there are the plethora of books, magazines, and newspaper articles extolling the virtues of wines and their aging potential. Another indicator, suggesting the views (or hopes) of the winemaker, is the length and quality of the cork used to seal the wine.

CHEMISTRY

Although wine quality is typically framed in terms of age, vintage, style, provenance, varietal origin, prestige, or other attributes, its legitimate quality lies in its sensory characteristics derived from its chemistry. With more than 800 organic constituents known to be potentially present in wine, that chemistry is obviously complex. It also changes over time, as compounds volatilize, degrade, oxidize, reduce, polymerize, depolymerize, and undergo other transformations. Nonetheless, the vast majority of these compounds occur at concentrations below their individual detection thresholds. Even acknowledging synergistic interactions that may enhance detection, the number of sensorially important compounds may be less than 50 in any particular wine. Of these, only a few groups, notably sugars, alcohols, carboxylic acids, esters, and phenolics affect the sensory attributes of essentially all wines. They donate much of the basic vinous character of a wine.

TABLE 8.3 Visual, aroma and in-mouth (taste and mouth-feel) terms linked to high- and low-quality perception. Terms cited by less than 15% of experts have been omitted for clarity. Numbers in parentheses are the frequency of citation for a term expressed in %

	High quality	**Low quality**
Visual terms	Limpidity/clarity (81), high depth-intensity (71), red–purple color (43)	Oxidzed-brown color (81), turbidity (67), low color intensity (57)
Aroma terms	Fruit (71), integrated wood (71), intense aroma (43), complex aroma (29), varietal aroma (24)	Oxidation (57), reduction (52), dirt 48), low intensity (48), *Brett* (43), excessive old wood (33), fault (33), green/vegetal (24), mold (19)
Taste and mouth-feel terms	Balance (67), volume/body (48), round/smooth tannins (43), persistency (24), fatty mouth-feel (19)	Excessive astringency (67), excessive sourness (52), unbalance (48), light/short (33), green (29), bitterness (29), coarse tannins (19)

Reprinted from Sáenz-Navajas, M.-P., Avizcuri, J. M., Echávarri, J. F., Ferreira, V., Fernández-Zurbano, P., Valentin, D., 2015. Understanding quality judgements of red wine by experts: Effect of evaluation condition. Food Qual. Pref. 48, 216–227, with permission from Elsevier.

The features that distinguish fine from ordinary wine have usually been ascribed to the myriad of minor constituents that may occur in wine. Ritchey and Waterhouse (1999) conducted a fascinating analysis of the chemical differences between high-volume and ultrapremium Californian Cabernet Sauvignon wines. The most marked differences detected were in the wines' phenolics. Ultrapremium versions showed about three times the concentration of flavonols, with cinnamates and gallates being about 60–70 percent higher. Ultrapremium wines were also more alcoholic (14.1 versus 12.3 percent), but lower in residual sugar and malic acid contents. Another comparison of wines, categorized by price (low-standard, high-standard, and premium), looked at term-use frequency during assessment (Sáenz-Navajas et al., 2012). A complex pattern was observed, with several terms, such as dried fruit being noted as positive in premium wines, but negative in the other categories. The sensory pair woody/animal was the most significant in relegating quality status. Table 8.3 shows how terms were used to express the high- and low-quality red Rioja wines. How the wines were assessed (by visual, olfactory, taste, mouth-feel alone, or together) significantly affected how quality was perceived.

Studies on the effect of the molecular size (Zarzo, 2011) and complexity (Kermen et al., 2011) of aromatic compounds have yielded some intriguing findings. There appears to be a correlation between a compound's molecular size and its hedonic perception, with more oxygen atoms correlated with pleasantness, whereas for carboxylic acids and sulfur compounds, increased molecular size increased aversiveness. Structural simplicity was associated with unpleasant odors, whereas complexity was correlated with more numerous olfactory notes and pleasantness (reflecting likely activation of higher numbers of olfactory receptors). Some similar findings have been noted in functional magnetic resonance imaging (fMRI) (Sezille et al., 2015). Does this indicate that molecular complexity, not just diversity of a wine's aromatic constituents, may be a central tenet in wine quality?

Holistic expressions, such as balance, probably arise out of the interaction of sugars, acids, alcohols, and phenolics. Because balance can occur equally in dry, sweet, white, red, sparkling, and fortified wines, it is clear that this interaction is perplexing. For example, the high sugar content of botrytized wines is partially balanced by their acidity, alcohol content, or both. Balance is also influenced by fragrance. In full-bodied red wines, balance may develop as various phenolics polymerize, and depolymerize, during aging, losing many of their former attributes that generate bitterness and astringency. The alcohol content and moderate acidity of red wines are also likely contributors to balance. Balance in light red wines seems to be achieved at a lower alcohol content and higher acidity than full-bodied dark red wines. Phenomena such as duration and development are likely to arise from the action of polysaccharides, mannoproteins and phenolics that loosely fix aromatics, slowly releasing them, once the wine is poured into a glass, as free, volatile compounds (Lubbers et al., 1994).

Progressive sensory adaptation may also play a role in the expression of minor aromatic constituents. Nevertheless, our ability to explain sensory perceptions such as complexity, finesse, and power in precise chemical terms still lies in the future. It is undoubtedly a function of the interaction of multiple aromatic compounds, but at the moment this remains just conjecture. It may be decades before the chemical origins of wine quality yield their secrets.

Postscript

Wine quality can be viewed from many angles, but fundamentally, quality is dependent on the wine's physicochemistry, and how it is detected and processed sensorially. The wine chemistry is based initially on grape biochemistry and physiology, partially transformed by yeast and bacterial metabolism, and subsequent modified by physical and organic chemical changes during maturation, aging, and volatile release after pouring. All of this presupposes that the wine possesses relative chemical and microbial stability, nutritional quality, and safety. However, from a human perspective, wine quality is perceived in terms of sensory and psychological pleasure. Although our senses respond to the visual, taste, mouth-feel, and olfactory stimuli demonstrated by the wine, conscious perception is based on how their impulses are processed and collated in various parts of the brain, where they are integrated, analyzed, and interpreted in relation to experiences, including pertinent social pressures and emotional desires. In addition, for many consumers, extrinsic factors (exclusivity, provenance, price, renown, age, and rarity) are potentially more important than the wine's intrinsic (sensory) quality. Finally, there is the influence of the context in which the wine is tasted, and one's state of relative hunger or satiety.

In analyzing a wine's intrinsic quality, psychological influences should be reduced to the absolute minimum. Nonetheless, psychological factors are a major promoter of sales, especially of higher-end wines. Hopefully, the wine also possesses, or will obtain with aging, a refined character. Its absence probably explains why some expensive wines are euphemistically said to exhibit *subtlety*. Wine quality, like beauty, is quixotic, existing only for a short time in the glass and, as it must, in the eye of the beholder. Also it is sobering to realize that quality does not necessarily correlate with consumer appreciation (Hopfer and Heymann, 2014).

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