WINE

1. Introduction

The unmodified word *wine* signifies the juice of grapes fermented by wine yeast and appropriately (and legally) finished into an alcoholic beverage. Small amounts of wine are made from other fruits and, particularly by amateur winemakers, from other food materials such as honey. These products require modifiers for the term wine, eg, honey wine (*mead*), cherry or blueberry wine, etc. Rice's starchy carbohydrates have to undergo conversion into yeast-fermentable sugars prior and concurrent to the alcoholic fermentation. Thus, it has more in common with beer, and its product should be referred to as *sake* instead of rice wine. Fruits other than wine grapes typically are too low in sugar and too tart to make satisfactory wine directly. They must be *ameliorated* (within legal limits) by addition of sugar and dilution or neutralization of the fruits acids.

As commercial food products, wines and the industry that produces them are unique in many ways. Whereas a few very large producers account for the majority of U.S. production volume, there are thousands of small producers who may grow their grapes, convert them into wine, bottle it, and sell or even ship much of it directly to consumers. This high degree of vertical integration often applies even in the largest of the winemaking operations, which may own vineyards and wineries, as well as wine bottle and closure manufacturers. However, the degree of vertical integration is limited by the enforcement of the so-called three-tier system that dates back to the post-Prohibition era which separates producers, distributors (wholesalers) and retailers, such as wine shops or restaurants. This system has been challenged legally in recent years, in particular by small wineries which wish to ship their wines directly to consumers across the U.S. Direct shipment of wine is still considered a felony in certain states all of which have legal power over the local alcoholic beverage industries. Whereas wineries can be extensive operations employing specialized equipment, they may be successful, even today (2006), if small, modestly equipped, and focused on regional types and styles of wines. Owing to a short season of ripe fruit (usually only about two to six weeks depending on grape varieties grown) and the very limited possibility of adapting a winery to process other foods, much winery equipment has only a short and intensive period of annual use. This and the high cost of vineyard land is often coincides located in prime real estate markets makes the capital investment into the wine business costly and limits short-term returns on such investments.

While standardization is usual in most (food) products, diversity and variation is sought and admired in wines. No other product has a similarly extensive aficionado's literature, including dedicated and influential magazines, wine and food writers' newspaper columns, winery and wine club newsletters and websites, etc, as well as specific scientific and technical journals on *viticulture* (grape growing) and *enology* (wine science and technology). Diversity is sought not only between classes of wine, eg, sparkling wines vs Sherries, but more significantly among wines of the very same class.

Most of these differences are related to the grape variety, to the topography, geology (soil structure, eg, drainage and water holding capacity) and

meso/micro-climates of the vineyard and especially to the seasonal weather pattern of a particular year or *vintage*. Even if these are essentially similar, individual wines have cachets and nuances that are not always attributable to specific technical differences, but which nevertheless distinguish them to the discriminating consumer. Different winemakers and sometimes different lots made by the same winemaker capitalize upon these subtle differences in style to maintain consumer interest. For example, each red table wine labeled as a single grape varietal, of the same vintage and from the same area, is almost certain to differ in style among producers from that winegrowing area. One winemaker may emphasize later, riper picking of the grapes, another one storage in new oak barrels, a third longer *pomace* (skins and seeds) contact with the wine, etc. To retain satisfied customers, consistency in objectively hard-to-assess quality is sought, but differences among styles as much as the winery's image are important in sustaining interest in the "art of winemaking," and may partially explain why a bottle of wine from the same vintage and same growing region may sell for less than $1 or more than $1,000.

Wines retain an aspect of mystic power and connections to art and culture. Detailed connoisseurship and wine appreciation are occasionally deplored as a form of pretentious snobbery. They are, nevertheless, important in themselves and can prove entertaining to understand without being intimidating. Pure technology cannot fully displace or even explain the romance of wine. Today most of the world's wine is produced by modern technology and is improved thereby, but winemaking is still something of an art, as far as the attainment of its ultimate quality is concerned. Considerable experience and study are required to appreciate fully all the kinds of wine available. It is very important to realize that the inherent qualities of a wine are based solely on an individual consumer's preference, experience and personal associations and do not require absolute ratings by self-proclaimed wine experts.

2. History

The important role wines and their production have had in ancient times as well as in more modern periods of history, particularly in relation to science and technology, deserves wider appreciation.

Molecular archeologists have found evidence of winemaking in northern Iran dating back to 5400 BC. In ancient Egypt, wine that originated in Jordan was buried with King Scorpion in his tomb around 3125 BC.

Winemaking and grapegrowing was certainly well developed by 3000 BC in ancient Egypt, Mesopotamia, and the other areas considered the cradle of Western civilization. At the beginning of recorded history, wines were described, their production portrayed, and their properties critically examined. By 2500 BC, the Egyptians had evolved hieroglyphics describing various types of wine. As part of the funerary goods in King Tutankhamen's 1339 BC burial, included were wine amphorae stamped with the region of growth, the estate, the vintage, and the winemaker's name. One was 35 years old at the time, and recent chemical analysis of syringic acid [530-57-4] suggests that King Tut may have been a red wine drinker when he died at age 18. The findings also indicate that the

Pharaohs and members of the ruling class drank wine regularly, while common people consumed it only during religious festivals and special events.

The progenitors of the present wine grapes still grow wild in the Near East. In the wild state, grapevines grow in trees and are propagated by seed-scattering birds. A sugar content higher in the ripe grape (200 to 250 g/L) than in all the other common fruits adapted grapes especially to attract birds, is an actual problem for grape growers to this day. It also adapted them to ferment into wine. Broken open, grapes and their associated native yeasts ferment juice spontaneously to wine. One can imagine a small amount of wine forming briefly in a depression in a rock under wild vines. A passing person would likely find it pleasant and be entranced by the euphoria it produced. The impetus to reproduce this phenomenon must have been very great, in fact and soon proved successful.

A case can be made that winemaking was a cause, not just the result, of the early transition from nomadic to specialized, sedentary agricultural civilization. Cereals can be grown in many places. The plants have a relatively short lifetime, but the ripe grain can be gleaned over a considerable period and is readily transported. Grapes, however, are perennials taking a number of years (usually 4–5) to develop good crops of fruit from new plantings. Vines need to be pruned and tended to fruit well and must be guarded against depredations by other people as well as by birds and animals. This is true particularly during the short and intense ripening stage. The fruit is very perishable, yet wine's low pH (3.0–4.0) and alcohol content (10–14% by volume) allowed it to be produced and aged under most the primitive conditions.

Compared to grain, wine is less easily portable. Although beer can be made from grain throughout the year, the production requires the involved, but necessary, process to hydrolyze the grain's starch before beer can even be made. The grape's sugar, in contrast, is directly fermentable to wine. Both wine and beer were very early beverages, but of the two, wine deserves the greater consideration in assessing the origins of agriculture and associated civilization. It is the easiest to make, and was probably the first alcoholic beverage where grapes grew.

In addition to its ancient origins, part of the traditional mysticism about wine relates to its euphoric effect. Certainly this would have seemed magical in earliest times. It contributed to involvement of wine in religion, in rituals, and in celebration. It has been said that the intoxication from wine let people re-enact the chaotic world prior to the order established by religions and their gods. This fact today is still reflected in the special ritualistic place accorded wines.

Grape cultivation is very ancient. One knows this from the steps necessary to convert the wild to the domesticated vine as well as from early writings and drawings. The earliest Egyptian tomb paintings show all vines productive with sizable crops. Wild grapevines grow as separate male and female plants, only the latter bearing fruit. Spontaneous mutants are hermaphroditic males, but they usually bear only a small amount of fruit. There were many varieties of grapes described, especially by Roman times. A long period of human intervention would have been required to convert the dioecious wild European vine into a large number of distinguishable *Vitis vinifera* varieties all self-fertile and bearing good yields. The term "variety or varietal of grape" signifies a cultivar

(cultivated variety) representing a vegetatively propagated selection with specific characteristics (including, perhaps, a distinguishable varietal flavor in its wines) such as Cabernet Sauvignon or Chardonnay analogous to Red Delicious or Granny Smith apples.

Because grape vines are heterozygous, seeds cannot be used to propagate a new vine if the characteristics of the mother vine are to be maintained. Rather, a clonal vine must be grown by rooting a cutting from a cane of the mother vine. The grapevine is naturally adapted to such propagation. Canes touching the ground easily take root and can be transplanted. A new vine takes at least four years to produce an appreciable amount of fruit from small rootings. Furthermore, if managed by pruning, the vine produces more consistent crops of better quality fruit. Earliest depictions and writings, especially from Rome and Egypt, show a well-developed agriculture, utilizing specialized tools for pruning and otherwise managing vineyards. These and other considerations make wine an important, but neglected, contributor to the development and maintenance of civilization.

Writings from Ancient Greece and Rome frequently mention wine as part of everyday life. Interpretations of the Jewish Torah suggest that Eve pressed grapes from the Tree (or rather Vine) of Knowledge and gave Adam wine to drink. Thus, the claim that the original sin of Adam and his wife was with wine strengthens the influence of this unique beverage. The universality of knowledge about wine was used to make scriptural ideas clear to the common people. The Old and New Testaments of the Bible contain many references to wine. For example, Christianity reveres Jesus' first miracle that involved turning water into wine when the supply of wine ran out at a wedding feast. The account not only shows the importance of wine in the celebration, but also it tells that the guests were surprised the later wine was better than the first. Good wine was recognized, but uncommon and lesser or spoiled wine was served after the guests were less critical. Because of alcoholic beverages' exciting properties, many religions address their consumption specifically, eg, Islam does not permit the earthly drinking of wine but rewards its followers with it in the afterlife.

During the Middle Ages, wine and winemaking along with other sacraments and knowledge were husbanded in cloisters and enclaves which maintained the pockets of sophistication that enabled the later flowering of the Renaissance. Wine became further associated with art, letters, religion, and culture, and it remains so. As a major processing technique to preserve the quality and ageability of wine, the burning of elemental sulfur (sulfur dioxide, sulfites) in barrels of wine was widely practiced and so common that it had to be regulated as early as the 1500s. The sulfites, still the most important wine additive in today's wineries, added to the self-preservation of wine by its fruit acids and ethanol, and created the mostly reductive styles of wine we know to this day.

Much of the development of modern microbiology resulted from initial studies focusing on wines. Being relatively large compared to bacteria, yeasts were early observed microscopically. Their causative role in fermentation was shown by Louis Pasteur in 1864, insofar as sterilization by heating killed them and prevented fermentation as long as they were not reintroduced. The investigation into the mildest conditions needed to achieve this prevention so as to minimize flavor changes, the procedure now called pasteurization, was indeed originally

developed for wine, not for milk. Pasteur's work on the so-called diseases of wine, ie, acetic or undesirable malolactic fermentation, etc, led directly to clarification by him and others of the microbiological nature of anthrax and other infectious diseases of humans and other animals.

Biochemistry resulted from the early elucidation of the pathway of enzymatic conversion of glucose to ethanol by yeasts and its relation to carbohydrate metabolism in animals. The word enzyme means "in yeast," and the earlier word ferment has an obvious connection. Partly because of the importance of wine and related products and partly because yeasts are relatively easily studied, yeasts and fermentation were important in early scientific development. They still figure widely in studies of biochemical mechanisms, genetic control, cell characteristics, etc. Fermentation yeast was the first eukaryote to have its genome elucidated.

Wine studies were crucial in the development of organic chemistry as well as microbiology and biochemistry. Polarized light was known to be rotated by products from living systems, but not by apparently identical synthesized compounds. The molecular reasons for this were unknown. Tartaric acid [87-69-4] is the major acid of grapes, but is present in very few other plant sources. It occurs in the L (+) form. Racemic acid [133-37-9] was the optically inactive form produced by racemization of the natural acid in alkali, raceme being the term for the kind of stem a grape cluster has, derived from a Latin word for grape clusters. Pasteur found that when the racemic derivative was allowed to crystallize slowly, two mirror-image crystals were produced. Separated by hand, the two forms rotated polarized light in opposite directions. The crystal structure mirrored the asymmetry of the molecules of tartaric acid. From such studies the whole field of stereochemistry was derived. Pasteur became famous for these studies in 1847 at the age of 26. It is said that it was a good thing Pasteur worked under less than ideal conditions, because, if his laboratory temperature had exceeded about 20°C, separate crystals would not have formed.

Scientific studies involving wine and grapes continue to build on past discoveries. As the genetic code of wine yeast and bacteria as well as the grape vine itself are being uncovered, many new answers to old questions are becoming available. More recently, the genetic determination of the parentage of important winegrape varieties led to a significant revision of the history of winemaking. For example, the variety Shiraz (Syrah) named after the ancient Iranian city did not originate in the Middle East at all, nor was it brought to the French Rhône Valley by the Roman legions. Instead it appears to be a spontaneous cross between the two established varieties, Dureza and Mondeuse Blanche, that probably occurred in the Middle Ages. The same is true for Cabernet Sauvignon, the famous red grape of Bordeaux, has two completely unrelated parents, one of which is in fact a white variety (Sauvignon Blanc) (see Table 1).

Natural grape phenols as desirable dietary components in wine and novel functional foods have gained much scientific attention for their role as antioxidants and blood vessel regulators as well as anti-cancer agents. The study of wine color and the role of copigmentation in the color intensity of young red wines has helped explain traditional winemaking practices such as the cofermentation of red and white grapes in Chianti or the Rhône to make better red wine that at first sight did not make sense. The use of artificial neural networks and

Table 1. **Genetic Parentage of Wine Grapes**

Variety	Parents
Syrah	Dureza and Mondeuse Blanche
Cabernet Sauvignon	Sauvignon Blanc and Cabernet Franc
Petite Sirah (Durif)	Peloursin and Syrah
French Colombard	Gouais and Chenin
Chardonnay	Pinot and Gouais
Gamay	Pinot and Gouais
Aligoté	Pinot and Gouais
Müller-Thurgau	Riesling and Madeleine Royale

mathematical modeling allows scientists and winemakers to approach the vast array of historic production variables from vintage weather conditions to specific winemaking techniques. It allows them to separate those parameters most important to making the best wine possible while considering folkloric myth, outdated tradition, or very locale-dependent practice. Viticultural as well as enological research continues to improve grapes and the wines made from them, and makes high quality wines available to everyone, not just kings and noblemen.

3. Wine Classification

3.1. Types and Styles. In classifying wines, many parameters might be used: fruit (species, variety, or condition), composition (color, alcohol, sugar, acid, or carbon dioxide), fermentation procedure (carbonic maceration, alcoholic, aerobic yeast film, malolactic), regulations (taxes, etc), geography, climate, weather (vintage). The last three are considered important in determining prices and reputations for individual wines, but are not very helpful in wine group classification. All of the above legally permitted variations, different producers, and marketing descriptions contribute to an almost infinite number of kinds of wines.

An effort to categorize all the significant classes of wine in the general form of a dichotomous key follows. A number of all-or-none alternatives are useful here, eg, does or does not the wine have added flavors, added alcohol, red color, significant sweetness, appreciable carbon dioxide, oxidized character, or recognizable flavor from the grape variety. It must be borne in mind that there is considerable leeway among styles within each type of wine. Not every wine fits neatly into such a classification. Regulations, taxation levels, geographical specifics, and tradition impose some limits on wines available in or from a specific locale.

Most wines with less than 14% alcohol are classed as table wines because they are usually consumed with meals. Note that as used here, premium wines are included. (In the countries of the E.U., the classification "table wine" is usually a region's lowest quality category and consists of inexpensive everyday wines.) Sparkling wines are included in this group because producing the sparkle and retaining it during consumption of a bottle necessitates a modest alcohol level. The fortified group of wines have had distilled grape spirits added in

order to reach, usually, at least about 18% ethanol. Such dessert and aperitif wines are intended to be consumed after or before a meal. Sweet and otherwise strongly flavored wines have gravitated here because they are more stable and thus can be consumed over several sittings. Other pertinent notes follow the list.

1. "Natural" wines, <14% alcohol. Their nature and keeping qualities have traditionally depended heavily on complete fermentation and protection from air.
   A. "Still" wines without obvious carbon dioxide.
      1. Red wines containing anthocyanin pigments
      2. White wines not containing anthocyanin pigments
      3. Blush or Rosé wines made either by brief skin contact from red grapes, or by blending of white and red wines. Blush wine styles tend to be lighter in color than rosés, although there is no official definition.
   B. "Sparkling" wines with obvious carbon dioxide. Color predominantly white or rosé, occasionally red.
      1. From second fermentation of added sugar; usual gauge pressure about $2.026–6.078 \times 10^3$ hPa (2–6 bar)
      2. Wines with residual excess carbon dioxide from first alcoholic fermentation, not from refermentation of added sugar; usual gauge pressure about $0.2026–2.026 \times 10^3$ hPa (0.2–2.0 bar)
      3. Artificially carbonated wines.
2. Wines with 14–17% alcohol.
   A. Traditionally, miscellaneous, white and red, usually sweet types, mainly with proprietary names. Note that is nowadays not unusual to find natural red still wines, especially from California, in the 14–15% alcohol range when produced from very ripe, often slightly dehydrated fruit.
   B. Special types.
      1. Sacramental, kosher, ecclesiastical, etc wines: usually sweet, eg, *vino santo*, with dessert-type names produces for special markets
      2. Blending wines to increase the alcohol (or other component) or to impart a special character to other wines
      3. Wines re-fermented with aerobic yeast: flor (Spanish Fino or Manzanilla) Sherries, California submerged-culture dry Sherry.
3. Fortified Wines, 18–21% alcohol. Their nature and keeping qualities depend heavily on the addition and quality of distilled wine spirits.
   A. Without added food flavoring materials.
   B. With added (natural) food flavors or plant extracts.

3.2. Regional Names. European countries have been very keen on protecting their wine's regional names, especially Champagne, Burgundy, Chablis, Port and Sherry. Trade negotiations between the E.U. and the U.S. in 2005 have provided protection for those names but at the same time have grandfathered in

U.S. labels that have used these names generically in the past. It can be argued that the continuing popularity of the original wines in the world's second largest export market is at least partially based on the name recognition stemming from usually lower-priced American products. However, given the enormous cost and time required to market a specific region, and a continuing trend among the New World wine producers to distinguish grapegrowing areas, global protection of regional trade names is likely to eventually succeed. There were more then 170 American Viticultural Areas (AVA) in the United States in 2006, the first official one being "Augusta," Missouri, recognized in 1980, directly followed by the first California one, "Napa Valley." Ironically, since that time, many wine exporting countries have also adopted the California approach to labeling wine based mainly on the grape variety it is made from. It is now common to see wine labeled California Chardonnay next to Chardonnay from Australia and France, even Spain or Germany. Fierce competition for market share and shelf space has resulted in an often multinational consolidation of the wine business.

Two other general observations seem in order. First, proprietary wines are those whose characteristics are held by a specific producer as an owned secret and which are marketed as a brand-named wine. Their formulas must be approved by the TTB, if flavors are added, and are referred to as formula wines.

For example, products with natural flavors from other fruits added to artificially intensify the varietal aroma of the grape wine, such as a peach Chardonnay or raspberry Merlot, are formula wines and must be labeled accordingly.

Second, many wines are blends of wine lots from different varieties, vineyards, barrels or even producers, and can be much better balanced and complex than some of the individual wines in the blend. The more evocative French term for a wine blending-and-shipping company, *négociant-éleveur*, can be translated as merchant-rearer or raiser. Traditionally these shippers gathered wines from many small producers and improved them not only by blending, but also by further processing and maturation.

4. Composition

Clearly, with so many types (eg, dry white table wine) and styles (eg, oaky or not) within a type of wine, composition is quite variable, but table wines have certain consistencies in constituents and sweet wines overall tend to be similar, with some allowance given for their extra sugar and perhaps alcohol in certain cases. Components tend to be in two categories: those produced by fermentation (ethanol is a prime example) and those from the grapes (eg, red anthocyanin pigments). Of course, the constituents characteristic of a grape vary by variety and climatic and soil conditions, and they are modified by winemaking techniques. It is seldom that the wine's varietal aroma is fully recognizable in the grape, for example, because many aroma components are present in the grape only in a (sugar-)bound, nonvolatile form, only to be released during the wine making and aging process.

A rough comparison of typical compositions of wines without unusual additions is given below. The apparent simplicity is, however, deceptive. Extensive

listings of hundreds of identified wine constituents are available, of which the data presented in the table are only a crude summary. Each group of chemical constituents usually includes several, sometimes many, individual substances. As groups, sugars contribute sweetness and, combined with proteins, "mouthfeel" and "body," and acids provide tartness. The tartness (and corresponding low pH) is what distinguishes wine in general from other major alcoholic beverages such as beer or distilled spirits, and is thereby a quite peculiar taste to be acquired by the novice wine drinker. Sweetness and tartness are important and stylistically adjustable sensory properties, but are relatively obvious and qualitatively if not quantitatively similar among compounds of the group. Together they account for much of the extract (nonvolatile solids) of wines. Glycerol is produced by fermentation, along with ethanol and a number of the volatile substances, especially acetaldehyde and higher alcohols and their esters. The latter contribute to the typical vinous flavors of wine, but are rather similar among wines. At the concentrations produced, glycerol itself does not contribute to noticeably higher viscosity or richer mouthfeel in wine. A number of the other constituents, eg, metal ions or vitamins, may be useful in comparing wines analytically, but do not ordinarily contribute to recognized sensory distinctions among wines. For example, detailed analysis of the metallic cations has been used to group wines by locality because the trace elements, depending on their uptake mechanism by the grapevine, may reflect the soil composition without contributing directly to aroma. Table 2 shows a typical gross composition.

Most of the sensory differences among wines, other than sweetness and acidity, are attributable to the very large number of different volatiles, terpenoids, and phenols, that make up less than one percent of the wine's gross composition. Rarely is a single volatile compound responsible for differences characteristic of a grape variety or wine type. Linalool [78-70-6], ionone, and other terpenoids and norisoprenoids account for the distinctiveness of Muscat-aroma varieties and contribute to Riesling, Gewürztraminer, and related varieties. Pyrazine derivatives, notably 2-methoxy-3-isobutylpyrazine [24683-00-9], produce the herbaceous aroma found in varieties of the Cabernet group and Sauvignon Blanc. Methyl anthranilate [134-20-3] and aminoacetophenon are strong in Concord and related varieties, although in this and other examples these significant top-notes do not fully account for their complex aromas. As a

Table 2. **Typical Gross Composition of Wine**

Components	%wt in grapes	%wt in wine
water	75	86
sugar	22	0.2
alcohol	0.0	12
acids	0.8	0.6
minerals	0.5	0.2
phenolics	0.8	0.2
pectin	0.4	0.2
glycerol	0.0	0.5
amino acids/protein	0.5	0.1
volatile aromas	0.0	0.04
Total	*100*	*100*

rule, especially in the case of the more subtle flavors, the holistic wine aroma depends on a characteristic and synergistic mixture of active components that is individually perceived by the wine taster and cannot be fully quantified by analytical chemistry alone.

Phenols make up an interesting group. Red wines are notably higher in phenol content. This is partly a result of the fact that the red pigments themselves, anthocyanins, are flavonoids. In making such wines, the skins (and seeds) of the grape are more thoroughly extracted so that not only the anthocyanins of red grapes are extracted, but also other phenols including astringent tannins, bitter catechins, and oxidation-browning substrates. White wines from immediately clarified juice will have 0.1 g/L of phenols or so, mostly caftaric (caffeoyl tartaric) acid. Rosé wines will add to that a few mg/L of anthocyanin and young, tannic red wines perhaps two g/L each of anthocyanins and other flavonoids including condensed tannins, explaining the additional health benefits of red wines vs whites. However, even wines of the same variety or style differ both qualitatively and quantitatively in phenolic components.

The phenols are genetically regulated in the grape and are different in presence or absence and relative amounts in different varieties, the most obvious example being white vs red grapes. Among red varieties there are many different patterns of the glycosides of malvidin [643-84-5], petunidin [1429-30-7], delphinidin [528-53-0], peonidin [134-01-0], and cyanidin [528-58-5]. Pelargonidin [134-04-03] is important in strawberries, but is absent in grapes. The anthocyanins are the 3-glucosides of these anthocyanidins in the European varieties, and in those derived from other *Vitis* which are also the 3,5-diglucosides. The ratios vary, and although most varieties have Portions of their anthocyanins acylated with acetic or hydroxycinnamic acids, some lack acylation. Unless they are degraded to smaller fractions, these compounds are not volatile, but are crucial to red color and, together with other natural phenols, to astringency, bitterness, and oxidizability of wines. Also, golden and amber colors of most white wines result from phenol oxidation and reaction.

Volatiles account for the wine's aroma by nose and retro-nasal action. These include some already mentioned plus other groups such as esters. Esters account for part of the fruitiness of a fresh young wine and its varietal distinctiveness, if it has any. Some of these esters and other odorants are present in the grape, others are made or released from grape components during winemaking, and still others (or Portions of the same ones) are produced by the fermentation. Owing to the low pH and high ethanol content, but limited amounts of the acids making up many esters in wines, there is major loss of many esters and great increase in others. *n*-Hexyl acetate [142-92-7] is important in fresh fermentation aroma of wines from white juice fermented at cool temperatures. It is lost in relatively few days at room temperature because the equilibrium is too far toward hydrolysis and its pear-like note disappears. In contrast, monoethyl tartrate [608-89-9] forms slowly as part of aging owing to high content of both tartaric acid and ethanol. Whereas this ester is not volatile or odorous, a sufficient amount of it forms to lower the free acid and the tartness of the aging wine, thus mellowing it. Ethyl lactate, formed from lactic acid produced during the secondary malolactic fermentation, has no odor of its own but is said to improve the complexity of wine and brandies.

5. Winemaking

Figure 1 compares the simplified typical processing flows for different major wine styles: white (Fig. 1**a**), rosé (Fig. 1**b**), and red (Fig. 1**c**) table wine; sparkling wine made by the traditional bottle-fermentation method (as in Champagne) and the bulk "Charmat" tank process (Fig. 1**d**); nouveau style red wine, as in Beaujolais (Fig. 1**e**); and prominent dessert wines styles such as ice wine (Fig. 1**f**) and the ethanol-fortified Port-style (Fig. 1**g**) and Sherry-style (Fig. 1**h**) wines.

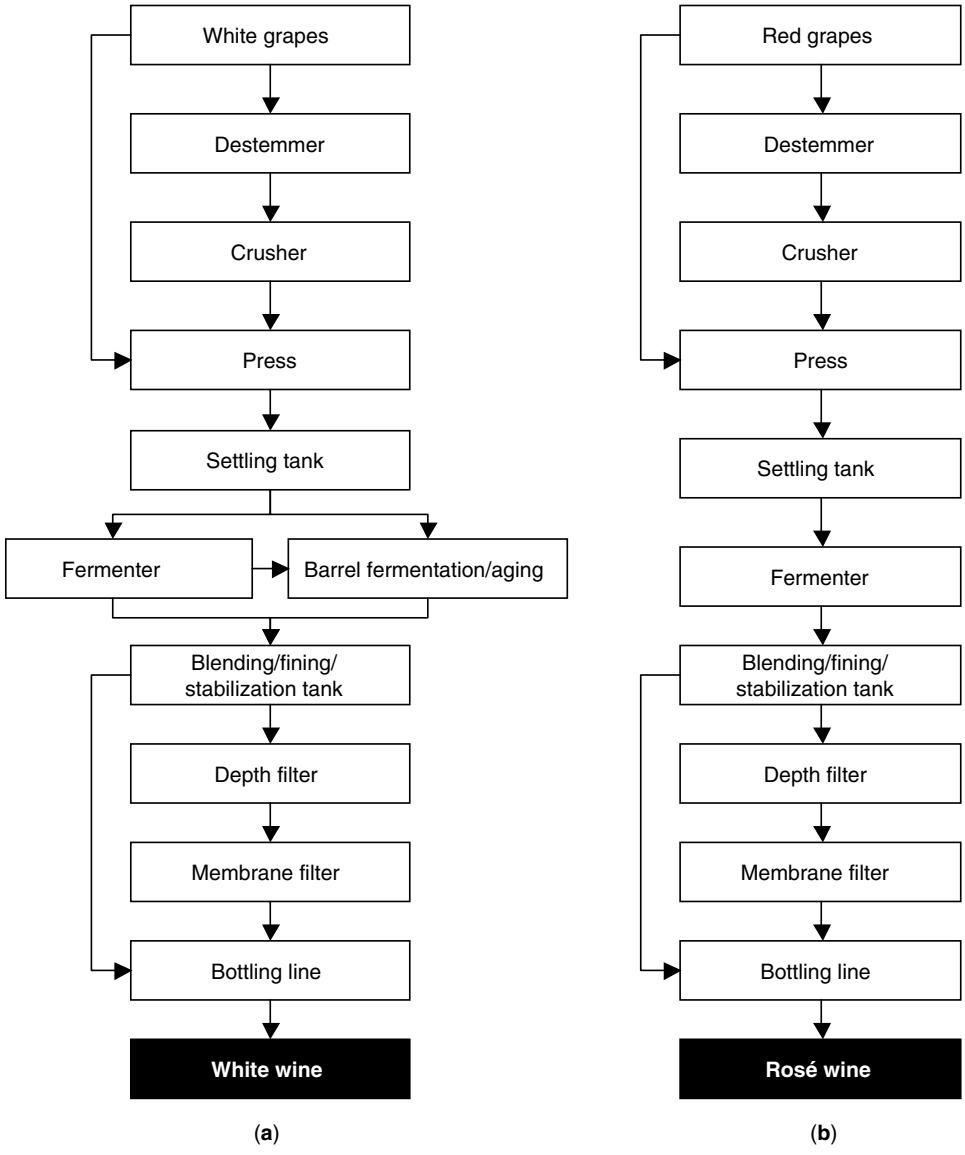

Fig. 1. Comparison of typical processing flows for different major wine styles.

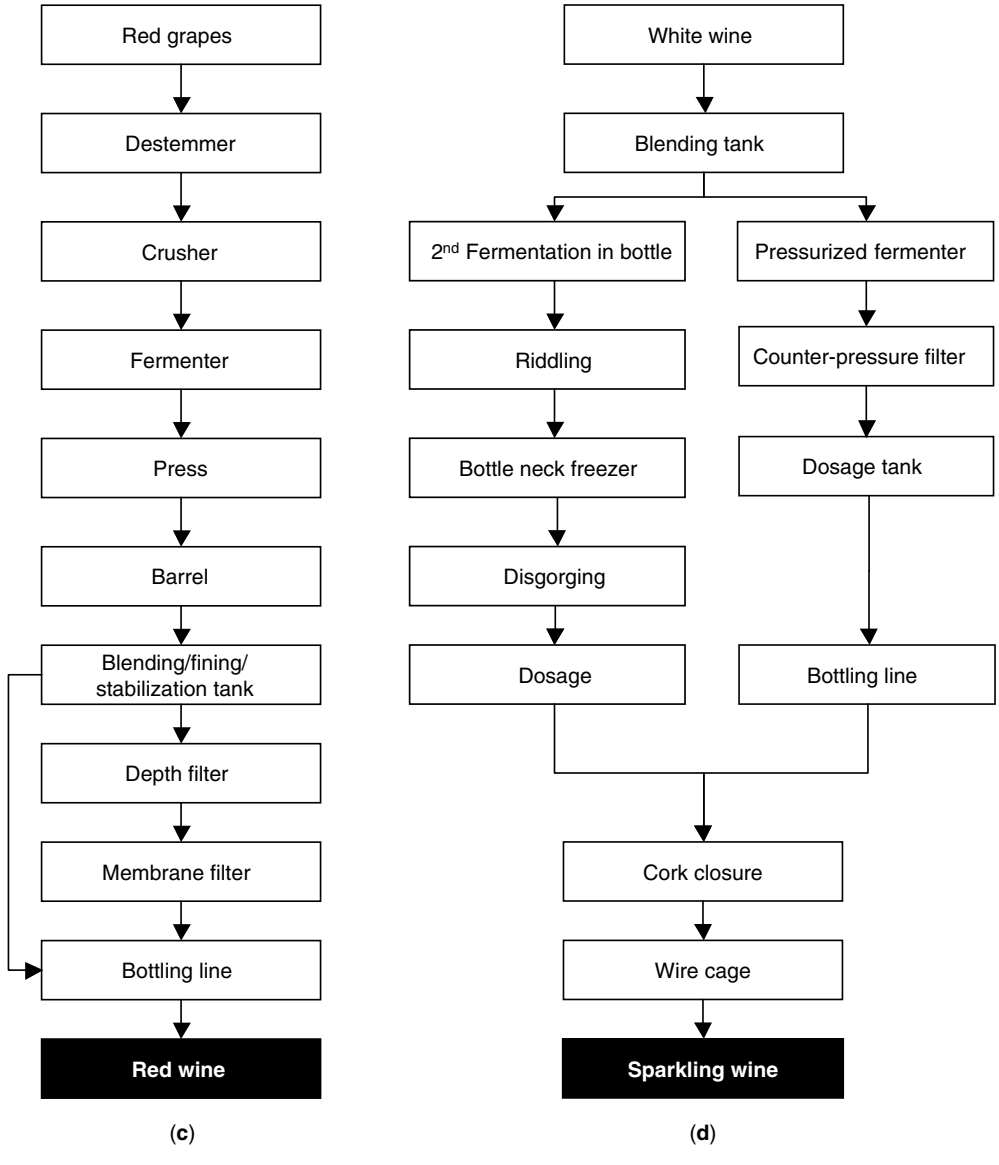

Fig. 1. (*Continued*)

5.1. Variety Selection, Fruit Production, and Harvest. The traditional European wine grape is *Vitis vinifera* and there are several hundred varieties used commercially worldwide. The list of important, widely planted varieties is much smaller. The grape variety involved is one of the most important factors in the final wine's characteristics. In California, 1993 was the first year total varietal wine shipments exceeded those of generally named wines.

White varietals Chardonnay and Sauvignon Blanc and especially the red wine varieties, Cabernet Sauvignon, Merlot, Zinfandel, Syrah (Shiraz) and

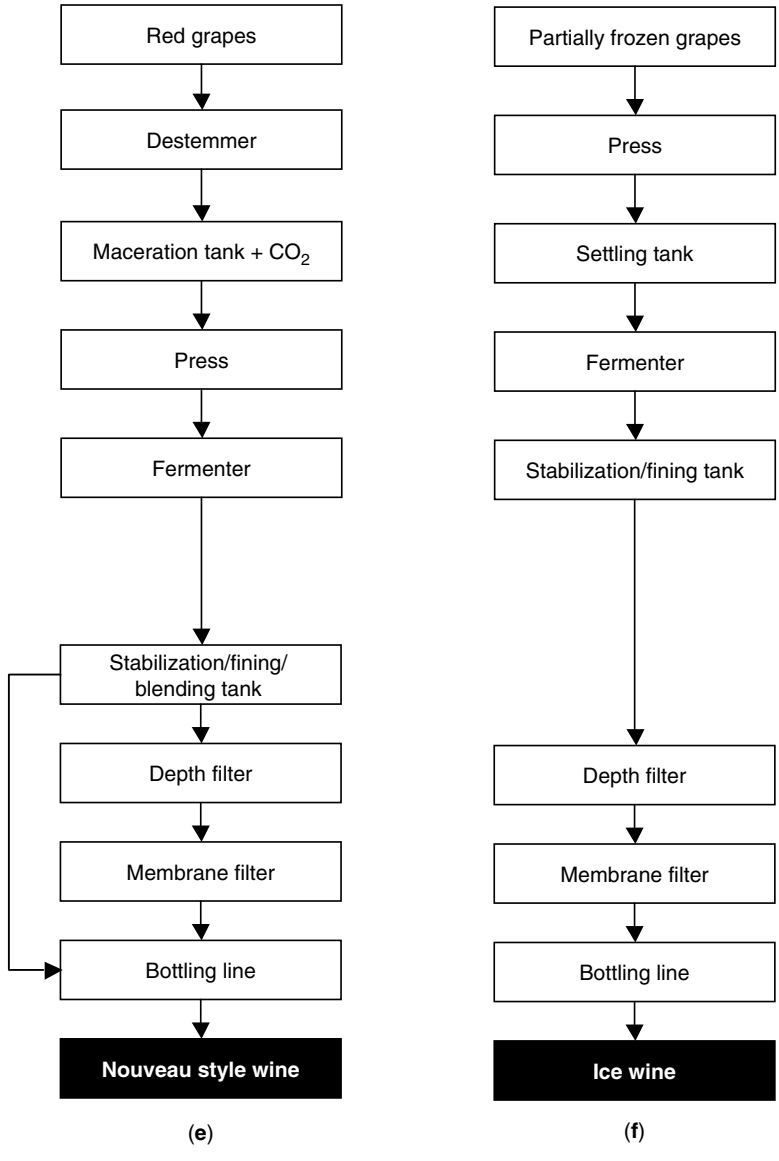

Fig. 1. (*Continued*)

Pinot Noir have increased at the expense of others less noted for premium wines over the past thirty years. In the U.S., consumer acceptance of new or currently less popular varieties depends on a number of difficult to predict factors, not just the quality of the resulting wine, but surprisingly also the ability to pronounce the variety's name (eg, when ordering the wine in a restaurant), its often random association with trends and fashions, such as movies and television shows, and, most importantly, marketing efforts by a particular region or part of the industry.

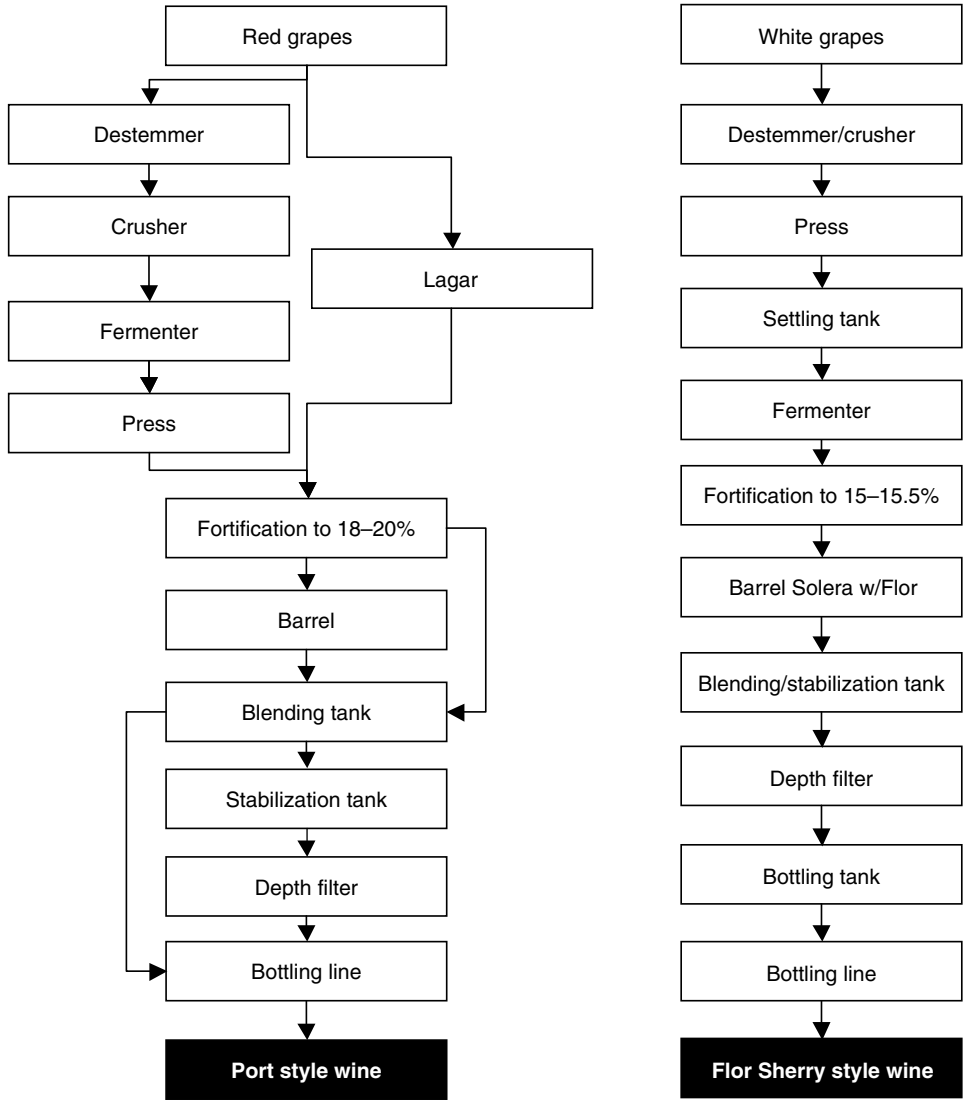

Fig. 1. (*Continued*)

Few varieties actually make desirably distinctive wines and often even the most experienced wine experts cannot easily identify the grape origin. With most *Vitis vinifera* varieties the flavor is subtle and more intensity is often sought. Notable exceptions are red Cabernet Sauvignon and its white parent Sauvignon Blanc which contain varying amounts of methoxypyrazines giving the resulting wines herbaceous notes of bell peppers and asparagus, especially when the wine is made from slightly under-ripe or shaded fruit. With varieties and hybrids from other grape species, such as Concord from *Vitis labrusca*, the flavor may be quite strong and an acquired one, ie, more acceptable to consumers who grew

up drinking or eating Concord-based grape juice products. This "foxy" character of Concord grapes has become a popular flavor additive for many other food products as well as consumer products from cigars to condoms.

Varietal labeling is still an important quality factor in the United States, and indirectly elsewhere because only certain specific varieties are planted in each prestigious foreign area. U.S. law currently requires that 75% of the wine must come from the *V. vinifera* variety named on the label. Concord-type varieties only require 51%, owing to their intense, distinctive flavor. If more than one variety is named, the relative amounts must total 100%, ie, the entire blend must be quantitatively identified. This does not apply if a proprietary name for such blend is used and no varietal name is mentioned.

Vineyard site and the local meso/micro-climates are most important to wine quality and character and interact with the grape variety. The general climate must not be too cold, too hot, or too humid. A mild, dry climate that still induces a dormant season, like the Mediterranean area and California, is desirable. A relatively constant weather pattern year-to-year is also sought, as weather has the greatest impact on vintage quality which is sometimes listed in rather arbitrary "vintage charts" covering an entire region. The nearer to the limits of cold tolerance, for example, that the climate comes, the more likely are disastrous vintages. The modifying influence of close bodies of water, like large rivers, lakes or the ocean, sun-facing slopes, or frost-resisting air drainage can make one vineyard more desirable than another not too far away.

Among satisfactory vineyards, the warmer site or vintage ripens the fruit earlier with more sugar, fewer acids, and less flavonoids including red anthocyanins. If the situation is cool, the fruit may be held on the vine as long as possible to allow accumulation of adequate sugar with as much decrease in acidity as possible. In a hot vineyard or vintage, sugar increases early and fruit should be picked before acidity has declined unduly.

Proper management of the vines and vineyard are important for yield of high quality wine grapes. Pruning of the dormant vine controls the next season's fruit set because cluster primordia for next year's crop are formed during the current year. Pruning canes too long may allow more fruit to start than the photosynthetic capacity of the vine can ripen. Such "over-cropped" fruit develops sufficient sugar for good wine either late or never and has other deficiencies, such as greater loss of acid in hot vineyards owing to delayed harvesting.

There are many details of good vineyard management as there are for any crop, but grapes are relatively tolerant, being woody perennials with deep roots and not high in water or fertility requirements. A few pests are special, notably grape phylloxera, a root louse native to America, but spread nearly worldwide. It can kill *Vitis vinifera* and requires that the vine be grafted to an apparently resistant root stock derived from certain native American vines of other *Vitis* species. Another important grape vine disease is Pierce's Disease, a bacterial infection spread by flying insects feeding on the vine, particularly the "glassy-winged sharp shooter." This disease makes it impossible to grow *Vitis* grapes in most of the southeastern United States, and it has recently (2005) been spreading into southern and central California.

Having made the most of the available vineyard, chosen the variety and rootstock, and properly managed the vineyard, the winegrower must watch the

ripening fruit and determine the optimum stage for harvest. Varieties differ in ripening date and one variety in the same vineyard may ripen at considerably different times in different years. The proper stage of grape ripeness is different for different wines. Sparkling wines, much like wines for brandy distillation, need lower sugar and more tartness; dessert wines need more sugar but need to avoid raisining. Fruit acidity declines as sugars accumulate, more so in hotter climates. At a very minimum, the decision to harvest is based on sugar content, acidity, and close observation of the fruit's manner of changing in other parameters, including taste. However, it is rather difficult to assess the quality of grape juice or berries as many important aromas that will develop later as the wine ages, are present only as sugar-bound and thus nonvolatile precursors.

Depending on a number of variables, sugar in the range of about 20–25 Brix (% sugar) is chosen, with sparkling wines at the low end and dessert wines at the high end of this range. Brix is calibrated using solutions of sucrose by weight in water, ie, 1 Brix = 1 g sucrose/100 g of solution. It is measured by hydrometry or refractometry of a juice sample and includes dissolved solids other than sugar, although fermentable sugars are on the order of 90% of the value. Higher than about 25 Brix may indicate berry shriveling (dehydration) or raisining; lower than about 20 Brix indicates under-ripe or over-cropped grapes.

Acid content calculated as tartaric acid is around 5.5–8.5 g/L for best flavor and stability, resulting in a pH of roughly 3.2 to 3.8. It is lower for tart low Brix grapes (for sparkling wine production), and occasionally approaching 4.0 in some red wines. High acid levels coincide with a higher level of the second most important acid of grapes, malic acid. The concentration of free acid anions are responsible for the tartness of a wine one tastes. The pH of the wine, which depends both on the ratio of tartaric to malic acids and on the rate of exchange of hydrogen ions with potassium ions, determines the chemical and microbial stability of the wine. In particular the availability of antimicrobial molecular sulfur dioxide is directly and exponentially pH dependent, eg, a wine at pH 4 requires a 10 times higher sulfite addition than a wine of pH 3.

5.2. Specific Processes. *White Wine.* Ideally, grapes are picked quickly at the stage of maturity chosen by the winemaker and transported to the winery. Both manual or gentle mechanical harvesting is suitable, given adequate prevention of extraction and oxidation, premature fermentation, etc, during harvest and transport. For white table wines, rapid juice separation is essential, whereas for red wines, fermentation of the whole grape "must" (pulp, skins, seeds) is needed. As soon as possible after harvest, the grapes are ordinarily passed through a "destemmer–crusher" to remove the stems and subsequently break each berry open to release the free-running juice. Together with the wine press the most important piece of winery equipment, a destemmer-crusher consists of a fast-revolving cylindrical metal or plastic cage with holes large enough to allow loose grape berries to pass through. In the center of the rotating cage sits a counter-revolving axle spiked with metal bars that beat the berries off the clusters thereby separating them from the stems. The metal bars also act as an auger for the stems that are, thus, transported out of the cage and collected for composting. At the same time, the loose but otherwise intact berries fall onto the crusher part of the equipment directly underneath the destemmer. The crusher consists of two spinning rubber rollers that are close

enough together to crack, or "crush," the berry open so its juice can run off. The rollers are far enough apart to avoid any cracking the bitter seeds of the wine grape. The crusher part is what in historic times was accomplished by the treading of grapes by human feet (and similarly avoiding damage to the seeds). This ancient practice can still be seen today in traditional making of Port wine, where it is performed in stone troughs or "lagares." The mash of juice, skins and seeds is referred to as "must," and is immediately pumped directly into the press. Frequently, but not invariably, a small amount, 50–75 mg/L, of sulfur dioxide in one form or another is added to minimize any effects of aroma oxidation, inhibit undesirable microorganisms as well as grape polyphenol oxidases and related browning. The juice that leaves the berries without pressing is known as "free-run" and accounts for approximately 80% of the total juice yield. A modern wine press aims at a very quick and gentle separation of skins and seeds ("pomace") and the juice. As soon as the free-run is drained off, a typical membrane press will squeeze the remaining juice out of the must by inflating an internal membrane much like an air balloon inside a large stainless steel cylinder that is perforated with slots. This allows the juice but not the seeds to escape. The most delicate white wines, eg, Chardonnay, are often made by "whole cluster pressing" which by-passes the destemmer-crusher entirely by loading the press directly with intact clusters of grapes. Although this practice reduces the press capacity by at least half, the stems inside the press create drainage channels for the juice and thereby minimize the skin contact the juice receives even in the brief period between traditional crushing and pressing. Free-running, readily separated fluid gives the lighter products; heavier pressing leads to eventually coarser wines.

An exception to the rapid separation of juice and pomace is the processing of grape varieties that contain most of their desirable varietal aromas in the skins, such as Gewürztraminer. In this case, a brief skin contact after destemming and crushing the grapes is warranted, lasting up to 24 hours depending on the temperature of the must. With this winemaking technique, it is essential to balance aroma extraction while avoiding excessive extraction of skin and seed tannins that would make a white wine taste coarse and astringent.

Before the alcoholic fermentation is initiated, white juices are cold-settled for one to three days at between 5–10°C. This minimizes the amount of solid grape particles present during fermentation which would result in a less delicate wine. The clean juice is then "racked," ie, drained off the solids ("lees") that have settled to the tank bottom, into another tank or oak barrels (in the case of a "barrel fermentation") which integrates toasted oak aromas into wine even during fermentation. Fermentation temperature for white wines is kept relative cool at between 12 and 18°C.

Rosé Wine. Because all the red color is in the skin of most wine grapes, proper conditions can give pale pink or even white wine from red grapes. This is the source of the blush "white" Zinfandel wine, or the lightly pink sparkling wines from red Pinot grapes (in French: *blancs de noirs*). Here, the grapes are pressed either immediately or within minutes, and the resulting juice is settled and then fermented, just like a white wine. Rosé wines can also be created by first producing a white wine and blending red wine back into it at a later stage to achieve the desired color.

Red Wine. To extract as much of the red color from the skins of red wine grapes as possible, the entire must consisting of pomace and juice is fermented together. After the grapes pass through a destemmer-crusher, the resulting must is pumped as such into a tank to await fermentation. The color extraction is managed concurrently to the alcoholic fermentation and is normally finished before the actual fermentation. There are two major techniques to extract color and tannins from red must. As a CO_2-induced floating cap of skins (and some seeds) forms as soon as the alcoholic fermentation proceeds, the pigment-containing skins become physically separate from the fermenting juice and the two need to be put back in contact to enhance color extraction. In the "punch down" technique, the skin cap is actively pushed back down into the juice either manually or with the help of a pneumatic punch down device. Alternatively, when "pumping over," the fermenting juice is actually drawn off through a racking valve on the tank just above the layer of seeds that have settled on the tank bottom. After usually passing over a screen to remove seeds and aerate the juice, its entire volume is pumped evenly over the top of the cap where it percolates through the layers of skins. Either pump-over or punch-down is commonly conducted once or twice a day during fermentation which usually lasts about a five to seven days. A higher frequency does not benefit the wine nor does it extract more stable color.

Some wineries employ elaborate (and expensive) mechanized fermenters that bring the juice and skins in contact with each other by either rotating the entire tank ("rotary fermenters") around or by utilizing the evolving carbon dioxide gas pressure during fermentation to push the juice automatically over the top of the cap. Neither of the cap management techniques has truly proven to be superior to another. It shall be noted that the amount of red color in a wine is due almost entirely to the composition and solubility of its color pigments and their colorless co-factors ("copigmentation"), not to the extraction technique used. Different red grape varieties vary in their ability to provide stable color and copigments: even in an inky Cabernet only about 25% of the color present in the skins may end up in the finished wine, while in the notoriously color-challenged Pinot Noir, less than 15% of the skin's original color remains stable.

5.3. Fermentation. It is fairly universal to inoculate the must with a selected yeast strain. Yeasts are chosen for conducting predictable, prompt, and complete fermentations under the conditions applicable for the particular wine. It is true, in most wineries, that grape juice will start to ferment with yeasts "naturally" present. However, those yeasts reside mostly around the winery itself, eg, on used equipment such as crushers, presses, barrels, etc, rather than on the grape surface. At times it was argued that part of the special regional character of wines was the result of the local yeasts. This is seldom claimed today, and inoculation at about 5×10^6 cells/mL is usual, using a selected, commercially grown strain, usually in the active, dry form at a dose of 240 g/kL.

Among the reasons for choosing a particular yeast strain may be its ability to ferment at cold temperatures or under pressure, separate for clarification easily, or avoid production of hydrogen sulfide or ethyl carbamate during or after typical fermentations. Wine yeasts (different strains of *Saccharomyces cerevisiae*) ordinarily do not consistently produce characteristically distinguishable

aromas. Certain "wild" yeasts can and, although they are inhibited at perhaps 6% alcohol, may produce uncontrollable or off flavors persisting from the early stages of fermentation. They can be inhibited by the addition of low levels of sulfur dioxide, because the traditional wine yeast is relatively resistant. One of the reasons that heavy inoculation (high cell numbers) with wine strains is now usual is to raise the alcohol level quickly and overwhelm the wild forms without needing as much sulfur dioxide to control them. However, with more recent abilities to track yeast population by PCR techniques, it has been shown that some wild yeasts such as *Candida* strains can survived much longer and contribute possibly more to a wine's aroma than previously thought. Traditional microbiological plating techniques apparently cannot account for microbes that are viable but not culturable, and can only be detected via their molecular DNA/RNA activity.

The kinetics of and factors affecting fermentation are now well studied. Heat is released as well as a considerable volume of carbon dioxide (2 moles per mole of sugar fermented, about 55 times the must volume at 22 Brix). To avoid excess pressure in closed fermenters, provision for escape of the CO_2 without admission of oxygen from the air is required. Uncontrolled, the temperature would rise about 1.4°C per Brix fermented. Since the Brix by hydrometer (refractometers, used to measure Brix in unfermented grape juice, are affected by ethanol's refractive index) falls through zero during fermentation, the original must Brix can be used for this estimate. Similarly, the ultimate alcohol content at dryness (all fermentable sugar consumed) varies between 0.55 to 0.60 times the must Brix or about 11.0–14.5% by volume for the 20–25 Brix range exemplified which is nearly theoretical (2 C_2H_5OH per $C_6H_{12}O_6$).

Heat liberated during fermentation must be removed to prevent ill effects. In small fermenters such as 225-L barrels this can be by loss to ambient conditions, eg, in an air-conditioned barrel house, but in larger fermenters the temperature rise can become inhibitory, even fatal at about 37°C, to the wine yeast. Such a fermentation stopping before proper completion is said to be a "stuck fermentation" and is difficult to restart. Sticking from this cause is prevented by circulating refrigerant through jackets on stainless steel tanks to control the fermentation temperature at the desired level. A large winery needs large refrigeration capacity. White table and sparkling wines are ordinarily better (more fruity, etc) if fermented cool, at about 10–16°C. Of course, the fermentation is slower the lower the temperature.

Red table wines should be fermented at about 21–29°C for proper character. They are fermented with the pomace, and carbon dioxide generation buoys the grape skins up to form a cap. For proper extraction and to prevent excessive temperatures in this cap, it is mixed with the main volume at least twice a day by punching it down or pumping the wine over it. Other procedures involve fermenters with internal baffles to submerge the cap. In modern, closed fermenters, regularly scheduled pumping from lower levels through a sprinkler over the cap is usual. This steeping and fermentation on red pomace is varied from a few hours for pink wines, down to about 6 Brix (1–5 days) for maximum color, and up to several weeks for more complex wines to be aged for the premium market.

In addition to the primary alcoholic fermentation, a malolactic fermentation by certain strains of the lactic acid bacterium *Oenococcus oeni* needs to be

considered. Malolactic fermentation is desirable in many red table wines for increased stability, more complex flavor, and for decreasing acidity. Today, selected strains are often added as freeze-dried cultures towards the end or after alcoholic fermentation. The fermentation is conducted over several weeks at temperatures of 16–20°C. During malolactic fermentation, all the malic acid naturally present in wine is converted into lactic acid, with a resultant decrease of acidity and liberation of small amounts of carbon dioxide. Obviously, this has more effect on the acidity the more malic acid is present, and this is especially the case in wine from acid-rich grapes grown in cool climates. Once malolactic fermentation has occurred, it does not recur unless another susceptible wine is blended. The malolactic fermentation can also introduce additional aromas, especially, and dependent on the bacteria strain used and premature disruption of the fermentation, diacetyl, a buttery-smelling aldehyde. This stylistic choice gained popularity in California Chardonnay in the 1980s.

Although it is often encouraged in white wines, particularly barrel-fermented Chardonnay, this fermentation tends to lower perception of fruitiness and be considered undesirable in other varietally more distinct white wines unless acidity is too high. This is also true for pink and light red wines. If it occurs after bottling, a spritzy and cloudy wine results. In such wines, it can be avoided by careful attention to clarification or filtration sufficient to remove the bacteria, and by adding SO_2, or more recently lysozyme, at appropriate intervals as an inhibitor.

5.4. Other Wines. *Sparkling Wine.* A limited number of varieties, eg, Chardonnay, Pinot Noir and Pinot Meunier in Champagne, and also Colombard, Chenin Blanc and Burger in California, are primary in making sparkling wines. Champagne is often used synonymously with sparkling wine but refers only to wines made from the particular appellation of northern France. Grapes for sparkling wine production are usually the first ones to be harvested in a given season because a relatively low initial sugar concentration and high acidity of slightly under-ripe fruit are desirable characteristics to make a base wine for Champagne. Direct and gentle (up to only about 1×10^5 Pa) pressing of whole clusters is used to give the lightest, clearest initial juice possible. A light, dry, moderate alcohol, tart, stable, white or nearly so (see Rosé winemaking) table wine is the preferred base wine. From the base wine, the "bubbly" is created by encouraging a second alcoholic fermentation, this time in either a bottle ("Méthode Champenoise, Traditionnelle, or Classique") or a tank ("Charmat" process). At this point, sugar is added in the precise amount needed to give the desired carbon dioxide pressure (about 24 g/L for 6.078×10^5 Pa (6 atm) at the end of re-fermentation). Special wine yeast selected to ferment at high alcohol and CO_2 concentrations (mostly *Saccharomyce bayanus* strains) and yeast nutrients are added to start the second fermentation. If the wine is held on the yeast lees for a year or more without off-flavor development, a special and desirable yeast-autolysis aroma develops.

If fermented in large pressure fermenters, the re-fermented (now sparkling) wine is filtered and bottled under pressure. If it is fermented in individual bottles, they are subjected to a clarification process called riddling that leaves the sediment-free wine to be re-corked in the same bottle. Riddling involves the systematic turning and moving of the bottles that are initially stored sideways over a

number of days until the bottles are positioned upside down and the yeast sediment has deposited itself in the bottle neck atop the crown cap that closes the bottle during fermentation. To minimize wine losses, the yeast deposit is removed ("disgorged") after appropriate aging by freezing a small Portion of the bottle neck in a refrigerant bath, followed by carefully ejecting the frozen pellet after opening the bottle. The wine then receives a dosage of aged or sweetened wine to fill up the bottle and to stylistically adjust the residual sugar level in the then cork-finished sparkling wine. The "dryness" of Champagne or Champagne-style sparkling wine is somewhat loosely defined by their residual sugar content: Natural (no sugar added), Extra Brut (<6 g/L), Brut (<15 g/L), Extra Dry (12–20 g/L), Sec (17–35 g/L), Demi-sec (33–50 g/L), Doux (50+ g/L).

Wines can be made effervescent by artificial carbonation rather than re-fermentation in a closed system, but that must be stated on the label.

Dessert Wines. Sweet table wines can be made depending on local regulations, by adding a small amount of sugar, grape juice or concentrate, or by refrigerating and centrifuging or filtering out the yeasts before fermentation is complete. In any case, such wines are unstable and the residual sugar will ferment if not prevented from doing so. In bottle, gassy and cloudy wines result. Sulfur dioxide is not effective against wine yeasts, but helps inhibit malolactic bacteria. Sorbic acid added (as potassium sorbate) at around 200 mg/L can control yeasts, but at this concentration its own flavor also may become noticeable. Properly dosed, dimethyl dicarbonate (DMDC, at 200 mg /L) can kill yeasts without undesirable or antimicrobially active residue. Pasteurization can kill the microorganisms, but flavor change is then a problem. The most satisfactory procedure is to sterilize the wine by membrane filtration, but this option requires a high level of expertise to execute it and to test its integrity. All equipment must be sterilized so that the wine does not encounter any source of viable cells downstream from the filter, until it is finally enclosed in a sterile bottle.

Table wines of higher sweetness can be made by extension of the same treatments, but late harvest wines such as Sauternes (French), Trockenbeerenauslesen (German), and specialty wines elsewhere are made from dehydrated grapes. Such grapes have been colonized by the mold *Botrytis cinerea* ("noble rot"), which makes the skin porous. In dry weather the grapes then lose water and the juice becomes concentrated. Not only are special, intense flavors produced, but also the sugar becomes so high the yeasts cannot ferment it all and the wine remains sweet. The noble rot produces its own flavors and metabolizes some of the acid, so that is not concentrated equivalently to the sugar. Raisin flavor is to be avoided in such wines, as it is in the few wines made from grapes shade-dried post-harvest, a technique known as Recioto in Italian, but it is featured in a few wines.

A third method to make sweet dessert wines is by concentrating sugar, acids and aromas by freezing the grapes. When pressed at temperatures around −9 to −7°C, frozen grapes can yield a juice that is about twice as high in sugar as the corresponding unfrozen fruit. Water ice crystals form a snow-like substance that stays behind when the berries are pressed partially frozen, thereby concentrating the resulting juice. These wines are known as "ice wines," a term that enjoys vague legal protection. It is debatable if the quality of ice wine is improved if it is made from grapes frozen on the vine, as much as the definition for "frozen" is rather broad and arbitrary. Again, similar to botrytized wines, a high-Brix

juice (containing about 26 to 40% sugar) can only be partially fermented, thus creating still naturally sweet wines of extraordinary varietal intensity.

A fourth method of making sweet wines is by arresting the fermentation through use of high-proof alcohol so that the alcohol concentration reached prevents further fermentation and leaves the wine sweet. Most of the traditional sweet wines of the world, Portuguese Port wine as the most famous example, are made by such fortification. Apparently owing to osmotic effect, both high sugar and high alcohol inhibit further fermentation and more of one can substitute for less of the other. Port style wine fortifications are made to an alcohol concentration of 18 to 20% to create a stable wine often ageable for decades. In the U.S.A., the alcohol used must come from the same type of fruit making up the wine, ie, in the context being discussed, grape-distilled spirits of high (90–95% vol) ethanol concentration, but this is not always the case elsewhere.

Port-type red dessert wines require skin contact time to extract the anthocyanins, but the fermentation must be short to retain the sugar level near the 6–10% desired. The winemaker cannot always achieve the desired composition in individual lots. In order to reach a desired standard, it is necessary to make several lots to enable blending to that standard. The right volume of a more alcoholic, deeper colored, less sweet wine will need to be made to bring to standard a lot with low color and more sugar, for example, while keeping the alcohol within the desired limits.

Oxidized Wines. Oxidized color and flavor are considered defects in most wines, but certain ones capitalize upon oxidation. (Spanish) Sherry falls in this group and include wines that are at least moderately high in alcohol and may or may not be sweet. Access to air is required during processing or maturation and may take the form of chemical autoxidation (as in oloroso Sherries) or aerobic microbiological metabolism. Aerobically, yeasts produce aldehydes from ethanol and other alcohols in the production of Spanish Sherry type wines (Fino or Manzanilla). This, accompanied by more or less aging in wooden barrels, yeast autolysis, and involved blending results in a complex flavor. These Sherries are first fermented dry and then fortified to about 15 to 16% alcohol. This concentration is high enough to inhibit acetic acid bacteria (also aerobic) and yet allow aerobic growth of "flor yeast" as a surface film on the wine.

Other wines falling in this class are amber and usually sweet (Madeira-types, Malaga, Marsala, etc). Their oxidation also results from exposure to air and often long maturation, but it may also involve heating, cooking must, or raisining to produce the particular type. Considering the wide variety of interesting oxidized and sweet wines made, it is unfortunate that interest in them has fallen to such a low level currently. The first year post-Prohibition in California that the shipment of fortified dessert wines did not exceed that of the table wines was 1967, and it has fallen steadily since then.

6. Processing

6.1. Stabilization. When the wine has been fermented and matured to the desired stage, it is clarified and stabilized so that it will remain clear and not be undesirably changed when bottled and marketed. Processing is held to

the essential minimum to avoid flavor change and loss. Microbiological stabilization has already been mentioned, and growth of microbes in bottles is invariably undesirable in modern wines. At the end of fermentation and at each transfer thereafter wines are "racked," ie, the relatively clear Portion is transferred without disturbing the yeasts and the other sediments in the lees. Much of the early clarification is accomplished by this method.

Chemical stabilization is considered necessary in the United States to prevent formation of crystals of potassium bitartrate in the bottled wine. This is commonly done by cooling the wine to barely above its freezing point, holding it to allow crystallization, and filtering it cold. Contact with preformed seed crystals and tests to verify that stability has been reached are helpful. Ion-exchange can be used, depending on the regulations of the country, but if hydrogen ions are exchanged, the acidity is raised. If sodium ions are exchanged for the excess potassium, the nutritional advantage of wine as a low sodium, high potassium food can be lost. Sometimes acidity is adjusted downward by the use of such agents as potassium bicarbonate or calcium carbonate. This procedure also affects stability, and calcium tartrate is relatively insoluble, but slow to precipitate from wine at very low levels. In Europe, tartrate crystals are tolerated or even welcomed as evidence of genuine wine.

6.2. Filtration. In addition to microbes and tartrate crystals, precipitates and hazes can be formed in wines by proteins, phenolic substances, pectins and related carbohydrates, and combinations thereof. Insoluble particles are removed by coarse depth filtration usually followed by a sterilizing membrane filtration. A wide range of types and capacities of filters have been used in the wine industry, often incorporating a pre-coat or mixed feed, using diatomaceous earth (DE) as a filter acid. Finer particles often quickly plug and foul filters, so that a sequence of decreasing porosity depth filters is often needed.

6.3. Fining. Incipient hazes may not be removed at all by simple filtration. An array of fining procedures has been developed to achieve stable clarity in such cases. Fining agents are substances that are or become insoluble in wine, and, as they precipitate, adsorb or co-precipitation sources of cloudiness. Properly used, the fining agents themselves are only minimally retained in the wines and their effect is subtractive rather than additive.

Minerals, particularly the montmorillonite clay bentonite (sodium aluminium phyllosilicate), are used to remove proteins that tend to cause haze in white wines. The natural tannin of red wines usually removes unstable proteins from them. Excess tannin and related phenols on the other hand can be removed and haze from them prevented by addition of proteins or synthetic adsorbents such as poly(vinylpyrrolidone) (PVPP). As proteins, preparations of gelatin, egg white albumen or milk-derived casein are frequently used to fine over-extracted red (or white) wines. Historically, animal blood was sometimes used for the same purpose as it was readily available, but it has long been omitted from international winemaking practices.

Because each wine is likely to differ, the treatment is chosen after experimental fining tests to determine the best agent and the minimum satisfactory level. Sediment (lees) volume is held to the minimum level possible in order to avoid extra loss of wine. Usually a single well-chosen treatment is sufficient, and some wines are not fined at all. Proprietary fining agents are usually

mixtures and include other agents, such as carbohydrate polymers from seaweed. These and other specialty chemicals sold for wine treatment are not large in tonnage, but are costly because of their special preparation for wine and food use.

7. Waste Disposal

Wineries generate proportionally little and practically organic waste. Solid waste consist of stems, pomace (pressed skins and seeds), mineral filter aids such as DE or filter pads made from DE and cellulose, as well as the protein-adsorbing natural clay bentonite. As solid waste regulations are becoming stricter in general, wineries have, with varying success, employed alternatives to traditional filtration, such as cross flow filtration, and the use of recyclable resins to prevent protein hazes. Stems and pomace are not considered industrial waste and are normally spread back out into the vineyard or are composted on premise. Liquid waste consists of grape juice run-off during the harvest season and lees (a sludge of yeast, grape particles, tartrates, fining agents and residual wine) from the racking of wine containers after fermentation, during aging and before bottling. Cleaning of tanks and barrels is usually accomplished with chlorine-free hot and cold water, with additional peroxycarbonate and citric acid rinses to dissolve tartrate deposits. A weak iodine solution is often used to sanitize stainless steel tanks after use. Any cleaning products that contain hypochlorite should not be used in and around a winery because of the risk of 2,4,6-trichloroanisole (TCA) formation. TCA, usually associated with tainted wine bottle corks, imparts a musty, moldy off-odor into wine at concentrations as little as 5 ng/L.

The annual water demand for winery operations ranges from one to four liters per liter of wine produced depending on the size of operation. Winery waste water is usually collected in sealed-bottom ponds with mechanical aeration because it has a relative high biological oxygen demand due to its benign organic composition (about 950 mg O_2/L on season average). It can occasionally create a nuisance if allowed to develop off-odors but generally it is innocuous. The pond water can be used for vineyard irrigation, fire protection or recreation. CO_2 emissions from wineries are more than offset by CO_2 absorption in the vineyard, and ethanol emissions from wine fermentations have not been demonstrated as a contributor to air pollution.

Value-added by-product recovery from pomace or lees, eg, cream of tartar (potassium bitartrate allowing subsequent conversion to tartaric acid), distillate from fermented pomace, glycerol, red pigment for food coloring, grape-seed oil, or pharmaceutical grade antioxidant flavonoids and tannins, is encouraged, but rarely practiced in the U.S. wine industry.

8. Storage (Maturation and Aging) and Blending

One of the prime requisites of an interesting premium wine is complexity of flavor. Maturation (bulk storage and associated final processing), aging (properly speaking, the storage of packaged wine ready for the consumer), and blending are the principal ways of achieving that complexity. Ideally, the varietal and

desirable vinous characters of the wine remain prominent and recognizable, but are supplemented by these grace notes.

Maturation is conducted in closed, full containers to prevent oxidation and aerobic growth of microorganisms. Free air contact with low alcohol wine soon leads to vinegar. Except for those Sherry types already mentioned, wines are exposed to air minimally and temporarily. During transfers incident to bulk storage and processing, some air exposure is almost inevitable, more in total the longer the wine is held. In the cases of white and pink table wines, it is ordinarily as near zero as possible, and stainless steel or other impermeable containers, inert gas headspace, etc are employed. Red wines withstand and even benefit from small, but repeated exposures to air.

In oaken barrels, slow evaporation of water and alcohol through the staves is ordinarily compensated for by refilling and topping each barrel by addition of the required amount of the same wine every week or so. This special process and the transfers necessary in the course of normal processing inevitably slowly permit a little oxidation, but wet wood and cork essentially do not pass oxygen. Oak barrels, unless exhausted by previous extraction, contribute extractives and flavor to wines. Such flavors, unless they overwhelm the other desirable characteristics of the wine in question, contribute desirably to complexity and quality.

Maturation regimes vary from as little change as possible in many white and pink wines (stainless steel tanks, cool storage, minimum time) to considerable modification in red table and a few white table wines. Fermentation and storage in fairly new 225-L barrels for about 6 months is not uncommon for Chardonnay and white Burgundy wines. Many robust red table wines such as those from Cabernet Sauvignon grapes are often stored similarly, after fermentation and initial clarification, for up to about 3 years in such barrels.

When they have suitably matured and been fully processed and blended, wines are bottled. Ideally, all the changes which should result during the bulk stage have been completed and the bottling itself should preserve all the desirable characteristics. Freshly bottled, the wine must be aseptic if not sterile, with minimum headspace preferably filled with nitrogen, argon or other inert gas, and well sealed. Changes that are too slow to have been completed continue after bottling, eg, formation of ethyl tartrate, and new reactions dependent on the lowered oxidation–reduction potential can occur. Development in bottle, ie, aging proper as opposed to bulk maturation, is limited by economics to the essential few weeks or months at the winery. It may be continued in merchant and customer cellars for much longer. Special bouquets develop over several years and are the source of endless admiration and debate by the cognoscenti. The specific chemistry has not been completely clarified, but after about four years in bottle a “sun-dried linens” bouquet can be noted in many white table wines and, usually longer, a “fruity–cedar–lacquer” one in certain old red table wines. Both can be very attractive even to the uninitiated, despite some inevitable loss in grape aroma.

Conditions for proper storage of bottled wine include a fairly low and constant (empirically about 13°C for whites; up to 18°C for reds) temperature, restricted (especially uv) light and vibration. Wine bottles with natural or synthetic cork should indeed be stored sideways, as this minimizes the gas exchange between the wine and the outside environment. The romanticized “breathing” of

wine through the closure during aging is highly variable (up to three magnitudes) especially in natural bark cork and is not necessary or desirable to properly age a wine. In general, the bottle closure should not have any impact on the quality of the wine that the winemaker intended. However, the cork closure which requires a special tool for its ceremonial removal is a not unimportant image and marketing issue that separates wine from other beverages. Unfortunately, natural corks frequently (1–5% of the time) impart a musty-moldy, fruit-masking off-odor ("cork taint") to the affected wine. The taint is a result of environmental conditions in the cork oak forests and the processing of the corks during manufacture. The impact component for cork taint is 2,4,6-trichloroanisol (TCA), which can form from any combination of phenolic materials (eg, wood) and chlorine (eg, from environmental pollution or bleaching) followed or preceded by a detoxifying microbial methylation by certain molds and bacteria. The sensory recognition threshold for TCA is less than 5 ng/L for most individuals, making it one of the most potent odorants in nature. Many wineries have made a transition to more reliable closures in recent years, with modern screw caps evidently preserving wine quality best though being a much less romantic choice.

Extended aging of red wines often leads to some phenol/protein-derived precipitate which can be avoided by decanting before service. Due to the complex composition and multiple concurrent aging reactions with very different reaction constants, not every wine improves to the same degree, and complete "bottle bouquet" development is likely to take ten years or more for suitable reds. Proper and consistent storage temperature is crucial as the speed of the aging reactions is highly and variably temperature depended. Most white wines are probably best consumed within three years after they were made, with few exceptions, eg, certain botrytised dessert wines. Most American wines today are released by the winery for immediate consumption. It has been estimated that 95+% of wine bought in the United States is consumed within a day of purchase.

9. Economic Aspects

Production of grapes and wine is the most important value-added agricultural commodity in several countries and, notwithstanding the importance of table fruit and raisins, commercial grapes mostly go into wine and brandy production. Wine growing is limited in both the Northern and Southern hemispheres to the areas between the 10 and 20°C isotherms, below the 50° northern (above 50° southern) latitude. Total tonnage produced annually has been larger for grapes, worldwide, than any other commercial fruit. In fact, grape tonnage in recent history has been about double that of oranges or bananas, and more than all other common sweet fruits combined.

Annual global wine production of 26×10^9 L translates into about 35×10^9 bottles, or about 5 for every person on the planet. Owing to overproduction, major producing countries especially in the European Union (E.U.) have instituted programs designed to decrease wine production by restricting vineyard yields, replanting vineyards with in-demand varieties, or even by providing incentives to remove vineyards from production altogether. Grape tonnage has not always

Table 3. **World Wine, Table and Raisin Grape Hectareage (2004)**

Country	10^3 ha
Spain	1,198
France	884
Italy	856
Turkey	590
China	450
United States	391
Iran	285
Portugal	610
Romania	244
Argentina	230
World	*7,905*

fallen in proportion to the decrease in vineyard area, however, because the least productive vineyards are often removed first and the number of metric tons per hectare, t/ha, has risen. The yield of wine from grapes varies by winemaking technique, and about 0.58 kL/t or more should be obtained for white table wine and as much as 0.73 kL/t for red. It must be noted that all statistical compilations depend on reports from different countries where reporting practices and reliability of data vary. Table 3 gives world grape hectareage.

The percentage by country of world wine production is given in Table 4. The three largest producers, France, Italy, and Spain, together produce about 50%. The "New World" wine-producing countries (United States, Australia, New Zealand, Argentina, Chile, and South Africa) have increased their share of the world wine market to 23%. Countries with the largest production, not surprisingly, have large consumption, usually both in total and per capita. The U.K. is the only country with substantial per capita wine consumption, but only a minute domestic wine industry. The world's largest importer of foreign wines is Germany (1.4×10^6 kL) followed by the U.K. (1.0×10^6 kL) and the U.S. (0.53×10^6 kL). The U.S. exports about 12% of its wine production while other countries such as Australia (57% of production exported), New Zealand (33%),

Table 4. **World's Wine Producing Countries**

Country	2003 (10^6 kL)	1990 (10^6 kL)	% Change 2003 vs 1990
France	4.6	6.6	−30
Italy	4.3	5.5	−22
Spain	4.0	3.9	+4.7
United States	2.0	1.6	+29
Argentina	1.3	1.4	−5.7
China	1.1	n/a	n/a
Australia	1.1	0.44	+146
South Africa	0.89	0.90	−1.1
Germany	0.82	0.85	−3.5
Portugal	0.71	0.11	−37
World	*26.1*	*28.3*	*−7.8*

Table 5. **Global Annual Wine Consumption**

Country	Total 2002 (10^6 kL)	Per capita[a] 2002 (L)	Per capita[a] 1980 (L)	% Change 2002 vs 1980
France	3.3	57	95	−40
Italy	2.9	53	93	−43
United States	2.3	8.7	8.4	+3.6
Germany	2.0	24	26	−7.7
Spain	1.4	35	65	−46
Argentina	1.2	33	76	−57
China	1.1	0.87	n/a	/
United Kingdom	1.1	17	7	+143
Russia	0.51	3.4	n/a	/
Portugal	0.50	47	77	−39
World	*23.4*	*3.7*	*6.5*	*−43*

[a]Ordinarily based upon total population, not just adults. A small fraction of the population usually accounts for a major portion of the consumption, eg, in the United States, 13% of the population consume 86% of all wine (2004, www.winemarketcouncil.com).

South Africa or Moldova, with a relatively small population of their own, rely heavily on growing wine exports. At the same time, decreasing global consumption per capita has been quite general and prolonged (−7.8% since 1990), and there is a substantial amount of wine (ca 10%) produced in the world today (2006) that is not consumed but ends up being distilled into beverage or pharmaceutical high-proof alcohol. France and Italy consumed nearly 100 L/person annually as recently as 1980, almost twice today's average consumption. A glut of excess wines from such countries affects markets widely, because the excess drives prices of ordinary wine down and increases efforts to export. Tables 5 and 6 give data on global wine consumption and exports.

The United States is unusual among wine-producing countries in having sizable production, but low per capita consumption, yet high imports relative to exports. Consumption varies by region, and is more pronounced along the coasts, ie, either in major producing areas (West) or in those states with a major population of immigrants or descendants from countries with traditionally high wine consumption (North East). Consumption ranges from nearly 11 L/person/yr in

Table 6. **Global Wine Exports**

Country	2003 (10^6 kL)	1990 (10^6 kL)	% Change 2003 vs 1990
France	1.5	1.2	+22
Italy	1.3	1.4	−1.5
Spain	1.2	0.43	+186
Australia	0.54	0.04	+1,250
Chile	0.40	0.05	+700
United States	0.33	0.10	+230
Portugal	0.31	0.16	+94
Moldova	0.29	0	/
Germany	0.27	0.28	−3.6
South Africa	0.24	0	/
World	*7.21*	*4.44*	*+62*

Table 7. **United States Wine Production**

State	2004 (10^3 kL)	%
California	2,040	89
New York	114	5.0
Washington	66	2.9
Oregon	10	0.44
all others	62	2.7
Total U.S.	*2,292*	*100*

California to Utah and West Virginia at 2 L/person/yr. A very high proportion of U.S. wine (89%) is made in California, and the top four winegrowing states (California, New York, Washington and Oregon) produce more than 97%, while today (2006) all 50 states have some commercial wine industry (see Table 7). A state's wine industry can be a significant contributor to the local economy, especially when considering the agri-tourism associated with the wineries. In California alone, the economic contribution of the wine industry was estimated at $45.4 billion in 2004.

Wines may be imported for reasons at either of two extremes: because they are relatively inexpensive or because they are in high demand, and thus command a higher price. Those exported from the United States tend to be the former, and those imported, the latter. There is some market, even in countries that are over-producing wine, for wines with exotic or prestigious labels. This tendency illustrates another way in which wines differ from other products. Travel to, information on, and cuisine from foreign countries associated with their wines serve as the vehicles for a form of a cultural exchange, besides the strictly commercial one.

Although, owing to changes in ownership, etc, it is impossible to give a permanently accurate number, there are presently (ca 2006) about 1,300 active bonded wineries and 4,800 grape growers in California and about an equal number in other states. In California, the wine industry is extremely consolidated. Of the 264 million cases of wine produced in 2003 (1 standard case contains 12 bottles at 750 mL each), the top two wineries in the United States (and the world) bottled 57%. The five largest wineries bottled about 75%.

The large wine producers often offer their wines in a wide array of different price points and a variety of brand names and labels in order to compete for retail shelf space with the thousands of competitors and wine styles, thus creating an impression of choice for the consumer. While overall wine consumption in the U.S. has slowly grown by 25% over the past 25 years, with fluctuations following the general state of the economy, the "ultra premium" wine market (>$14/bottle) has become the fastest growing segment in recent years.

Grape and wine production, marketing, and serving worldwide are estimated to employ directly tens of millions of persons (there are two million grape growers in France alone), and grapes occupy nearly 1% of the total agricultural land, worldwide. Clearly, they are important economically, not only as both everyday and premium beverages, but also in their contribution to feelings of contentment and perceptions of material well-being and sophistication.

10. Analytical Methods and Quality Control

10.1. Chemical and Physical Analyses. Many analyses have been applied to wines and grapes, ranging from simple sugar (Brix) and acid (pH) readings to detailed solid phase micro-extraction based gas chromatography as well as preparatory hplc, capillary electrophoresis, atomic force microscopy, etc. Wine contains extraordinarily small quantities of chemicals, often in fractions of nanograms per liter that make up the subtle aroma that is distinguishable by the human nose. Wine is also the most complex of all food matrices, and requires the most sensitive analytical equipment available to further the understanding of grape composition or long-term aging reactions. Some are routine and needed by all wineries, and some are reserved for special situations and are usually offered by commercial laboratories catering to the wine industry. New techniques are continually being developed or adapted, and applied by enologists at wineries and universities. In the U.S., the only quantitative chemical information on a wine bottle is that for ethanol (in percent by volume), while other countries may require certain analyses (metals, pesticide residues, etc) before wine can be exported to them. No specific official analytical methods are required for wine in the U.S., but two other wine components are also regulated: "volatile acidity" and "total sulfur dioxide" (see section 12 Regulations). Those interested in regulatory aspects should consult the publications of the Association of Official Analytical Chemists International (AOAC) in the United States, or the Organisation Internationale de la Vigne et du Vin (OIV) in Europe. The American Society for Enology and Viticulture (ASEV) established a winery laboratory proficiency testing program in 2001 that allows commercial wineries to test their analytical capabilities as part of their operation's quality system.

10.2. Sensory Analysis and Wine Appreciation. There is no combination of chemical or physical analyses that can, or is ever likely to, replace human sensory evaluation completely. Sensory examination of wines employs two major approaches: detecting differences and evaluating quality or, more briefly, analytical and hedonic. The former can be objective and the latter is inevitably somewhat subjective regardless of the expertise of the judges.

Almost everyone has sufficient sensory ability to become an expert wine taster. Most can develop the knowledge about wine, concentration, and sensory memory needed by an expert. Regardless of expertise, however, one person is not always able to reach the same conclusion, even in repeat blind tastings of the same wines. Experts often disagree in ratings in spite of diligent efforts to judge according to a standard for the wines in question. For these reasons, a panel of judges is needed, and, if possible, replicated trials for every judge.

Various methods have been developed to eliminate biases which otherwise can skew results. The wines must be presented without identification, although the taster should be told the type of wines (the best strawberry wine should rate poorly in a Cabernet Sauvignon class). For the most informative results, many details of coding, presentation order, replication, etc must be considered. The results must be statistically examined to estimate whether or not they could have been obtained accidentally. Statistical analysis is an entire field in and of itself, and wine studies have contributed greatly to its present sophistication, as applied in the flavor field.

The simplest analytical tasting can be a paired test: is the wine coded 67 more or less tart than that coded 19? Of course, the acids present and the pH can define chemical acidity. Sensory examination is still necessary to show whether or not an average person can detect the difference and how other tastes such as sweetness influence that detection. The paired test has the disadvantage that a leading question must be asked ("more acid?"). The next simplest analytical tasting method is the triangular test, which does not require such a question. Three samples are presented, two identical. The judge is asked to select the one of the three which differs from the other two. There is a right answer.

By such methods, the threshold (minimum) concentration to produce a detectable sensory difference in wines for an individual can be determined. By modifications of the questions asked, a recognition threshold concentration can also be determined. For example, a process producing a faint trace of extra acetic acid might make a wine detectably different from the untreated wine, but not certainly worse. At the point acetic acid is recognized as such, the wine would be downgraded as vinegary. To make such thresholds meaningful in relation to the general population, again, a sizable panel of individuals, replicated tests, and statistical validation are necessary.

For hedonic tasting, the judges and the panel manager should be clear on the question. Is it "How much do you like it?" or "How do you rank these wines?" or "How do these wines compare with a perceived ideal wine?" For the first two questions anyone can answer for themselves, but the answer must be replicated by several individuals, if it is to have general meaning. If the judges on the panel are able experts, the third question can be addressed. Even in such situations, as at well-run wine competitions, at least three or four judges are used. Discussion is not permitted in analytical or research tastings. Neither is it at fairs until after separate examination, but it may be allowed before final awards in case one judge failed to note something the others did. Regardless of expertise and experience, for reasons already outlined, a single judge's evaluation is suspect and opinions can be influenced by the circumstances.

Descriptive analysis is the appropriate tool to standardize wine aroma terminology and is used today by wine scientists and winemakers alike. The underlying idea of such analysis is to characterize a wine in terms familiar from other common sources such as fruits (cherry, raspberry, etc), vegetables (bell peppers, asparagus, etc), flowers (violet, rose, etc), spices (cloves, mint, vanilla, etc), and others (hay, fresh-cut grass, etc). It must be noted that those descriptors are found naturally in wine without the addition of the respective fruits or spices. Defects can be noted by comparison with characteristic chemicals like acetic acid (vinegar), ethyl acetate (the ethanol ester of acetic acid having the odor of nail polish) or hydrogen sulfide (smell of rotten eggs, a sulfur reduction product). A wide selection of descriptors appropriate for wines has been organized into a "Wine Aroma Wheel" that can help a winemaker, judge, or consumer to recognize, remember, and discuss an individual wine as well as to distinguish among different varieties, regions, and styles. Combined with carefully designed panel studies and multivariate statistical analysis such as principal component analysis (PCA) of the results, descriptive analysis can be used as a tool to confirm the typicity of wines from a certain regional appellation or grape varietal.

10.3. Spoilage. Few commercial wines today are frankly spoiled. It must be noted that spoilage of wine does not pose a health risk to consumers. Because some of the spoilage odors and flavors are not easily analyzed chemically, sensory evaluation is the final judge. What is spoilage in one wine may not be in another. Yeast growth as a surface film on wine in the cask soon produces serious defects in other wines, but is required for the production of the aldehydes of flor Sherries. If it is present at a recognizable level, unless it is part of the particular wine's nature and contributes to its attractiveness, an odor is considered "off" unless adopted by the producers as part of their "style." There are yeasts of the *Brettanomyces* or *Dekkera* species that produce an odor in wines consisting of 4-ethylphenol, 4-vinylphenol, 4-ethylguiacol and isovaleric acid, often described by enologists as the smell of a wet dog, a horse blanket, or band aid, and referred to as "animal" in French. In high concentrations this is considered a defect, and while many people do not appreciate the odor, certain wineries, winemakers and wine writers make a virtue of it. Friendly disagreements among wine judges are a result and an expression of the subjectivity of what an individual considers "wine quality." In summary, the quality or better qualities of a wine can be defined either by the varietal intensity or complexity of its aroma, the absence of noticeable defects, or simply by the style an individual wine drinker, experienced or not, enjoys the most.

11. Health and Safety Factors

Recent recognition of healthy effects of moderate wine consumption has been overdue. Pasteur is often quoted to the effect that wine is the most healthful and hygienic of beverages. This is correct from the viewpoint that properly made wine cannot be a vehicle for food poisoning. None of the vectors of human disease and food toxicity, even acid-resistant *E. coli* strains, *Listeria*, *Salmonella*, or *Staphylococcus* species, can propagate or even survive in traditional wines if they have low pH, a high alcohol and tannin content, and adequate sulfur dioxide additions. This is less crucial in modern societies, but is thought to be the justification of the earlier practice of giving babies water mixed with wine.

This may have also been a factor in the expansion of the Roman Empire. Expeditionary forces, even today but much more so then, are at risk for waterborne diseases, such as typhoid fever or cholera. The practice of the Roman army to carry with it substantial wine supplies is seen as sound militarily for health reasons, rather than just from the standpoint of improved morale of the soldiers. Roman soldiers were required under penalty to drink their daily ration of wine, as it appeared to protect them from dysentery and other diseases associated with unsafe drinking water. The limits of the empire eventually overlapped well with the Romans ability to grow wine grapes in the territories under their rule.

Cristóbal Colón took Spanish Sherry aboard his ships to the Americas in the 1490s, and Magellan is said to have spent more money on wine than weapons when he set out to circumvent the Earth in 1519. Recent study indicates that tourist-type diarrheas are less frequently encountered if wine is consumed rather than water, even bottled water.

Owing to the residua of the Puritan Ethic and Prohibition as well as the undoubted contribution of over-consumption to the evils of drunk driving and alcoholism, alcoholic beverages have been seen as uniformly bad by health specialists. All the effort has gone into proving how bad they are and eliminating them. Wine was considered somewhat less dangerous because it was fairly dilute and consumed with meals, but most public health specialists did not credit wine or any other such beverage with desirable effects. Ethanol is readily metabolized by the body, providing about 435 kJ (104 kcal) of energy from a glass of dry table wine, and any alcoholic beverage can have favorable effects, eg, on Type II diabetes, when properly consumed.

Only recently have the government and other health agencies bowed to the preponderance of clinical, experimental, epidemiological, and historical evidence that moderate consumption of wine is not only not detrimental, but is beneficial. The proven benefit is in lowered incidence of cardiovascular complications in wine consumers. A flurry of recent studies further suggests that wine, particularly red table wine, has an additional favorable effect over other alcoholic beverages. This is attributed to the antioxidant, free-radical chain-breaking effect of the wine's natural phenolic compounds. The ability of phytochemicals in wine to reduce platelet aggregation and prevent oxidation of blood cholesterol and its subsequent deposit on artery walls seem to be the major effects. In combination with their ability to moderate the dilation of blood vessels, their presence in both red and white (though to a lesser degree based on their limited extraction during the white wine making process) wines may explain the so-called French Paradox. This epidemiological phenomenon shows that the population of France and other Mediterranean countries have a higher life expectancy and much lower rate of heart attack and stroke than the U.S. population despite a higher intake of foods rich in cholesterol and saturated fats such as whole-milk cheeses or liver pâté.

The *1995 Dietary Guidelines for Americans* acknowledges that moderate drinking of alcoholic beverages with meals is associated with a lower risk for coronary heart disease, the leading cause of death in this country. Moderation is defined very conservatively as one drink per day with a meal for a woman and two for a man (150 mL or 5 oz of table wine per drink).

Wine bottle labels contain a warning about their content of sulfites (sulfur dioxide in its various stages of dissociation and binding) because about 5% of people with asthma can suffer from a severe potentially deadly adverse reaction. This translates into about 1 in 600 people affected by sulfites. There is no evidence however, that sulfites contribute to a "wine headache," which is likely due to dehydration or other allergens. The aforementioned effect on blood vessel dilation due to phenolic materials may explain the more common complaints about headaches from red wines which on average also contain more alcohol. It is a good idea to drink a glass of water with each glass of wine consumed. Partly due to international enological practices agreements, there is no general difference between global wine-producing regions and the sulfite (or other additive) levels found in their in wines. As mentioned below, optional wine fining agents such as egg white protein are only minimally retained in wine after the treatment but residues could trigger allergic reactions in some of the most sensitive individuals. If in doubt, it is often possible to ask the winery about their winemaking practices.

Wine consumption has been proven beneficial to a number of vision problems, such as macular degeneration, cataract and glaucoma. Grape phenols' role as an anticancer agent appears relevant in regard to prostate cancer in men. Much of the epidemiological wine and health research however is inconclusive, as much as Cogan commented in his 1584 Haven of Health, "Drink wine and have the gout, drink none and have it, too!"

Moderate, daily drinkers' average longevity exceeds that of those who abstain completely from alcoholic beverages (teetotalers), and both greatly exceed heavy drinkers in long and healthy life. In addition to direct health benefits, moderate consumption of wines with meals vs consumption at either extreme or consumption of other drinks is believed to promote conviviality and social health.

12. Regulations

Wine, along with other alcoholic beverages, was nationally prohibited in the United States by Constitutional Amendment (18th Amendment, repealed by 21st) during the period 1919 to 1933. Wine did get a unique dispensation to allow production at home for family use of 200 gallons (757 L) per year. This appears to have been in recognition of traditions of wine consumption on the part of many recent immigrants to the United States during that period. Also, there was a very small amount of commercial production for sacramental or medicinal use, but winemaking outside the home was essentially defunct. That it has been so quickly reborn, and now thrives, is a great tribute to the resiliency of American winemakers and their willingness to innovate.

When Federal prohibition was repealed, states and localities were allowed to retain local prohibition. Today most of the states have similar laws to the Federal ones, except for the imposition of additional taxes. A state can be more restrictive, but not more lenient, because then Federal law would supervene. Although universal prohibition has long since been abolished, alcoholic beverages remain subject to very stringent controls and a high level of taxation, compared to other food industries. Their production is described as a permissive industry, ie, unless specifically permitted, all practices are prohibited. Some attitudes in the United States are still to an extent, holdovers from the Prohibition era; for example, a U.S. citizen can vote, marry or become a soldier at age 18, but cannot legally consume alcohol until age 21. In the E.U., in contrast, 16 is generally the minimum legal age for buying and drinking alcoholic beverages.

A special government agency branch, now called the Tax and Trade Bureau (TTB) and formerly part of the Bureau of Alcohol, Tobacco and Firearms (BATF) within the U.S. Department of the Treasury was empowered to regulate the alcoholic beverage industries. Although less adversarial, but strictly enforced even today (ca 2006), the regulations and their application remain voluminous and detailed. They focus mainly on tax collection and label compliance as they are of direct interest to the federal government as well as consumers, but they also contain all the details of permitted processes for and additions to wines. However, the U.S. wine industry has no legal restrictions when it comes to what grape varieties can be grown in what location, and the yields or total amounts grapes and wines produced.

The regulations have several underlying purposes: to hold composition within specified boundaries, to allow good commercial winemaking practices, to assure identity and authenticity of the product, to prevent unfair or fraudulent practices for the benefit of both the consumer and the conscientious producer, to ensure healthfulness, and to produce tax revenue. TTB regulations are not identical to those in other countries, but the United States has generally allowed import of wines made legally in other countries as long as they are properly labeled and healthfulness has not been compromised. The reverse is often not the case.

Every aspect of winemaking and marketing is regulated; to fully enumerate these regulations is well beyond the scope of this article. In the United States, winemakers must meet all requirements even before beginning production and must follow in detail the regulations of the TTB, particularly as listed in Title 27 of the *U.S. Code of Federal Regulations*. A permit must be obtained and the winery bonded before the making of wine for sale may be begun. The winery must be posted, equipped, and secured. Federal Inspectors must be allowed to make unannounced inspections. Of course, applicable state and local regulations must also be followed. For regulations in force within or those applying to the exporting of wine to European countries, the OIV in Paris or the laws of the particular country in question should be consulted. The U.S. government and wine industry terminated its 23-year membership in the OIV in 2000, and now works through the World Wine Trade Group, founded in 1998 by the leading New World wine producing countries (Australia, Argentina, Brazil, Canada, Chile, New Zealand, South Africa, and the United States) with a goal to better harmonize and open up the international wine trade.

12.1. Labeling. Every bottle of wine sold in the United States must have two government warnings cited on the label as follows: (*1*) According to the Surgeon General, women should not drink alcoholic beverages during pregnancy because of the risk of birth defects. (*2*) Consumption of alcoholic beverages impairs one's ability to drive a car or operate machinery and may cause health problems. In addition, each label must contain the alcohol content (in percent by volume +/− 1.5%) and the phrase "Contains Sulfites" if the amount of total sulfur dioxide in the wine exceeds 10 mg/L, even if these sulfite have been produced naturally by the wine yeast.

The U.S. regulations are, in effect, being continually considered for change, but the requirements for holding public hearings, the likelihood of predictable opposition, etc, make changes slow. Sweeping change in the law occurred in 1990, when the entire wine code was revised and updated. Amendments have been and will continue to be made, as industry practices and the prevailing legal climate evolve and change over time. Most recently (2005), the U.S. Supreme Court struck down state laws that allowed intra-state direct shipping of wine to consumers, but banned interstate shipments.

Despite consumer confusion, the establishment of new AVAs by the TTB has been popular. Since its approval in 1981, Napa Valley alone was granted 14 sub-appellations, such as Oakville, Carneros or Rutherford. If a specific AVA is designated on the bottle, the minimum requirement is that 85% of the winegrapes were grown in the defined geographical area. A wine may be labeled as the product of a politically defined area (state, county) if 75% of the grapes

from which it was made grew there. If they did not, it is labeled "American." If a specific vineyard or estate is named, 95% of the wine must be grown and produced from it. If the wine is labeled with a vintage date, 85% of the wine must have been made from grapes grown in that year. Opportunity for blending of wines having these labels is restricted, but diversity among commercial wines is promoted.

Compositional aspects that are regulated include a label statement within ±1.5% for table wine (for dessert wines, ±1.0%) of the wine's alcohol content. For tax identity reasons, alcohol of 7–14% is required for table wines and 17–21% for dessert and appetizer wines. U.S. federal excise tax rates in 2006 were $0.28/L for table wines and $0.41/L for wines 14–21% alcohol (state excise tax rates varied from $0.05 to $0.66/L) with significant tax breaks given to small wineries producing less than 42,000 cases/year. Sparkling wine is taxed at $0.90/L and carbonated wines at $0.87/L. The borderline concentration to incur these taxes is CO_2 above 3.92 g/L.

TTB permits no more acetic acid ("volatile acidity" or V.A.) than 1.4 g/L in red table and 1.2 g/L in white and dessert wines, California and the European Union slightly less. California requires a minimum fixed acidity as tartaric of 4.0 g/L for red table, 3.0 g/L for white table, and 2.5 g/L for dessert wines. California also requires a minimum extract (nonvolatile dissolved solids) in dry wines of 18 g/L for red and 17 g/L for white, but other states generally do not specify a minimum. In the United States, maximum total sulfur dioxide is 350 mg/L. Far less is usually used today, and less than 75 mg/L can be found on average in American wines according to the TTB. European regulatory maxima (but not necessarily averages in wine) are lower for dry wines and higher for sweet table wines.

Regulations specify a considerable list of additives and treatments which may be permitted under controlled limits and conditions. It is important to note that no wine receives more than a few of these treatments, and many have none. For example, most grape musts ferment readily without additions, but some extra nitrogen source for the yeasts is occasionally beneficial. If some is required, diammonium phosphate (DAP) is the most commonly used.

12.2. Protection of Regional Names. Codification to protect regional names for wines was perfected in France and, by treaty, extended for their wines internationally under the *appellation d'origine contrôlée* nomenclature (AOC, or just AC). In general these regulations delimit the region protected, limit the varieties of grapes that can be used, restrict the wine production per hectare, and require approved enological practices. Several other countries, notably Italy, Germany, Spain and Portugal, have adopted somewhat similar regulations. It should be clearly noted that these regulations are aimed at guaranteeing type and authenticity, not necessarily quality, although there is usually an official panel that disapproves a few wines most years which are outside the presentable quality range for the region. Table 8 lists international wine classifications.

Under these systems for assuring authenticity in regional names for wine, the larger region indicated is assumed to produce the normal minimum standard wine, and smaller subdivisions within the regions customarily attract more avid followers and command higher prices. To give a very simple example, Bordeaux

Table 8. **International Wine Classifications**

Country	Acronym	Classification
France	AOC	Appellation d'Origine Contrôlée
Germany	QbA	Qualitätswein bestimmter Anbaugebiete
Italy	DOC	Denominazione di Origine Controllata
Portugal	DOC	Denomiacao de Origem Controlada
Spain	DOCa	Denominación de Origen Calificada
United States	AVA	American Viticultural Area

includes any wine produced in the delimited district of Bordeaux. Bordeaux, one of the largest and most renown wine grape growing areas in the world, produces (ca 2001) about 650,000 kL from 125,000 ha (14% of France's total acreage), of which 119,000 ha fall into the AC classification. Delimited subdistricts of Bordeaux, like the Médoc, are further divided into specific properties or estates, called there châteaux. The proprietor of a specific château zealously guards its reputation. If the wine of a given vintage from that property does not come up to the expected quality, it can be labeled and sold as Médoc, and if it is of an even more questionable quality, as Bordeaux. Owing to vagaries of vintage and the changing economic straits of owners, not to mention differences of style preference, quality fluctuates even if authenticity does not.

12.3. Conclusion. Careful records must be kept to enable verification of compliance. Each lot of wine must be traceable back to the grapes and vineyard. Tanks must be carefully gauged and the capacities recorded on them. If the wine is to be labeled "estate bottled," not only must the wine be fermented, processed, and bottled by the state winery at their listed address, but the vineyard must also be owned or controlled by that winery. Other label terminology, subject to some further intricacies, are "cellared," ie, subjected to cellar processing or aging; "blended," ie, mixed at the stated address with other wine of the same type; and "bottled" by the stated winery. These terms are occasionally used to distract the consumer from the origin of the grapes the wines were made from. Consequently, it is often worthwhile for an educated wine consumer to purchase wine directly from the vineyard and winery where the grapes were grown and the wine was made, where the authenticity of the product can be verified, and an association to the land, the winegrower and winemaker can be made.

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CHRISTIAN E. BUTZKE
Purdue University
VERNON L. SINGLETON
University of California, Davis