Wine Tasting

A Professional Handbook

Ronald S Jackson

Food Science and Technology, International Series

WINE TASTING:

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Food Science and Technology
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About the author

Ronald S. Jackson received his bachelor's and master's degrees from Queen's University, and doctorate from the University of Toronto. His sabbatical at Cornell University redirected his academic interest toward viticulture and enology. While Professor and chair of Botany Department, Brandon University, he developed the first wine technology course in Canada. For many years he was a technical advisor to the Manitoba Liquor Control Commission, developing sensory evaluation tests to train and assess members of its Sensory Panel. He was also a long time member of the MLCC External Tasting Panel. In addition to preparing this book, he is author of *Wine Science: Principles, Practice, Perception, 2e* (2000), *Conserve Water Drink Wine* (1997) and several technical reviews, including Grape-based Fermentation Products in *Biotechnology: Food Fermentation* (1999) and *Modern Biotechnology of Winemaking in Wine: A Scientific Evaluation* (2002) and articles in the Encyclopediae of Agricultural Science and Food Sciences and Nutrition. Dr. Jackson has retired from teaching to devote his time to writing, but is allied with the Cool Climate Oenology and Viticulture Institute, Brock University. For questions or suggestions, he may be reached at jackson@globetrotter.net.

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Preface

The text presents the practice of critical wine tasting, in the context of human sensory perception. Thus, it attempts to differentiate between perception (the human response to sensation) and sensation itself. Training and experience are usually required to separate one's subjective response from objective evaluation.

The techniques described are primarily designed for those involved in wine tastings (judging relative quality or conformity to traditional varietal or regional styles). These skills are required not only for professional wine evaluation, but also successful winemaking. Although analytic, these procedures can be adapted by the restauranteur or wine merchant, as well as individuals desiring to fully appreciate a wine's sensory attributes.

The reader is first guided through the steps of tasting wine. Subsequently, the psycho-physical and neuroanatomical aspects of sensory response are discussed. This is followed by a discussion of the optimal conditions for wine assessment and evaluation, the selection and training of judging ability, preparing various types of tastings and the analysis of significance. Wine classification and the origins of wine quality are covered with a brief discussion of what can confidently be said about wine and food combination.

References are largely limited to the most recent data whereas Suggested Reading primarily covers major reference texts.

R.S. Jackson

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Acknowledgments

I should like to express my appreciation to those innumerable researchers who have dedicated their lives to unraveling the mysteries of human sensory acuity and the complexities of wine perception.

I must also thank my students, participants of sensory panel tests, and compatriots on the External Tasting Panel, and especially Andy Tekauz, for their insights and views on wine quality.

It is also essential to express my appreciation for the assistance provided by staff at Academic Press, notably Sara Gorman. Their help and encouragement have helped bring this book to completion.

Finally, but not least, my thanks must go to my wife who has again suffered from the author's widow syndrome.

Dedication

To the members of the Manitoba Liquor Control Commission.

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Contents

Introduction

1

Tasting process

As befits one of life's finest pleasures, wine deserves serious attention. Nevertheless, no wine tasting procedure has achieved universal acceptance. Most experienced wine tasters have their own sequence of steps they follow. Although essential for critical tasting, these steps are too detailed for the dinner table. The difference is equivalent to the gulf that separates the analysis and enjoyment of music. Critical tasting compares one or several wines against a real or theoretical standard. In contrast, wine with a meal is intended to be savored as a liquid refreshment. Although critical wine assessment is ill designed for the dining room, because of distractions of conversation and the interference of food flavors, the concentration involved in wine analysis can greatly enhance appreciation.

The technique discussed in Figure 1.1 incorporates suggestions from several authorities (Broadbent, 1979; Peynaud 1987; Johnson, 1994) and experience gained from assessing tasters for many years. The synopsis provided is only a starting point. No technique is ideal for everyone. Probably the most important properties of a serious taster are the willingness, desire and ability to focus attention on the wine's characteristics.

Some authorities advocate rinsing the mouth with wine before embarking on serious tasting (Peynaud, 1987). This familiarizes the senses with the basic attributes of the wines to follow. Where tasters are unfamiliar with the characteristics of the wines, this may be of value. Otherwise, rinsing the mouth with wine seems unnecessary. Peynaud also cautions against rinsing the palate between samples. He feels that water alters sensitivity, and complicates comparing wines. In this recommendation, Peynaud is at variance with most authorities. Only when the palate seems fatigued does he support palate cleansing.

Most wines are best sampled in clear, tulip-shaped goblets (Fig. 1.2). The primary exception involves sparkling wines. These are better judged in elongated, flute-shaped glasses. They facilitate observation of the wine's effervescence. All glasses in a tasting should be identical and filled to the same level (about one-quarter to one-third full). This permits each wine to be sampled under equivalent conditions. Between 30 and 50 ml is adequate for most analyses. Not only are

Figure 1.1

Each sample should be poured into identical, clear, tulip-shaped, wine glasses. They should each be filled (1/4 to 1/3 full) with the same volume of wine.

I. Appearance

1 – View each sample at a 30° to 45° angle against a bright, white background.
2 – Record separately the wine's:
  clarity (absence of haze)
  color hue (shade or tint) and depth (intensity or amount of pigment)
  viscosity (resistance to flow)
  effervescence (notably sparkling wines)

II. Odor "in-glass"

1 – Sniff each sample at the mouth of the glass before swirling.
2 – Study and record the nature and intensity of the fragrance[a] (see Figs 1.3 and 1.4)
3 – Swirl the glass to promote the release of aromatic constituents from the wine.
4 – Smell the wine, initially at the mouth and then deeper in the bowl.
5 – Study and record the nature at intensity of the fragrance.
6 – Proceed to other samples.
7 – Progress to tasting the wines (III)

III. "In-mouth" sensations

(a) Taste and mouth-feel

1 – Take a small (6 to 10 ml) sample into the mouth.
2 – Move the wine in the mouth to coat all surfaces of the tongue, cheeks and palate.
3 – For the various taste sensations (sweet, acid, bitter) note where they are percieved, when first detected, how long they last, and how they change in perception and intensity.
4 – Concentrate on the tactile (mouth-feel) sensations of astringency, prickling, body, temperature, and "heat".
5 – Record these perceptions and how they combine with one another.

(b) Odor

1 – Note the fragrance of the wine at the warmer temperatures of the mouth.
2 – Aspirate the wine by drawing air through the wine to enhance the release of its aromatic constituents.
3 – Concentrate on the nature, development and duration of the fragrance. Note and record any differences between the "in-mouth" and "in-glass" aspects of the fragrance

(c) Aftersmell

1 – Draw air into the lungs that has been aspirated through the wine for 15 to 30 s.
2 – Swallow the wine (or spit it into a cuspidor).
3 – Breath out the warmed vapors through the nose.
4 – Any odor detected in this manner is termed aftersmell; it is usually found only in the finest or most aromatic wines.

[a] Although fragrance is technically divided into the *aroma* (derived from the grapes) and *bouquet* (derived from fermentation, processing and aging), descriptive terms are more informative.

IV. Finish

1 – Concentrate on the olfactory and gustatory sensations that linger in the mouth.
2 – Compare these sensations with those previously detected.
3 – Note their character and duration.

V. Repetition of assessment

1 – Reevaluate of the aromatic and sapid sensations of the wines, beginning at II.3—ideally several times over a period of 30 min.
2 – Study the duration and development (change in intensity and quality) of each sample.

Finally, make an overall assessment of the pleasurableness, complexity, subtlety, elegance, power, balance, and memorableness of the wine. With experience, you can begin to make evaluations of its *potential*— the likelihood of the wine improving in its character with additional aging.

small volumes economic, but they facilitate holding the wine at a steep angle (for viewing color and clarity) and vigorous swirling (to enhance the release of aromatics).

Appearance

Except for rare situations, in which color must not influence assessment, the visual characteristics of a wine are the first to be judged. To improve light transmission, the glass is tilted against a bright, white background (35° to 45° angle). This produces a curved edge of varying depths through which the wine's appearance can be viewed.

Visual stimuli often give a sense of pleasure and anticipation of the sensations to follow. The appearance may hint at flavor attributes as well as potential faults. The effect of color on perceived quality is illustrated in Fig. 2.5. It is well known that a deep red color increases perceived quality, even by seasoned judges. Therefore, visual clues must be used with caution to avoid unfair prejudgement of the wine.

Clarity

All wine should be brilliantly clear. Haziness in barrel samples is of little concern because it is eliminated before bottling. Cloudiness in bottled wine is considered unacceptable, although it seldom affects the wine's taste or aromatic character. Because most sources of cloudiness are understood and controllable, haziness in commercially bottled wine is uncommon. The major exception may involve some well-aged red wines. Careful pouring or prior decanting can separate the wine from sediment that may have formed in the bottle.

Color

The two most significant features of a wine's color are its **hue** and **depth**. Hue denotes its shade or tint, whereas depth refers to the relative brightness of the color. Both aspects can provide clues to features such as grape maturity, duration of skin contact, fermentation cooperage, and wine age. Immature white grapes yield almost colorless wines, whereas fully to over-mature grapes generate yellowish wines. Increased grape maturity often enhances the potential color intensity of red wine. The extent to which these tendencies are realized depends on the duration of

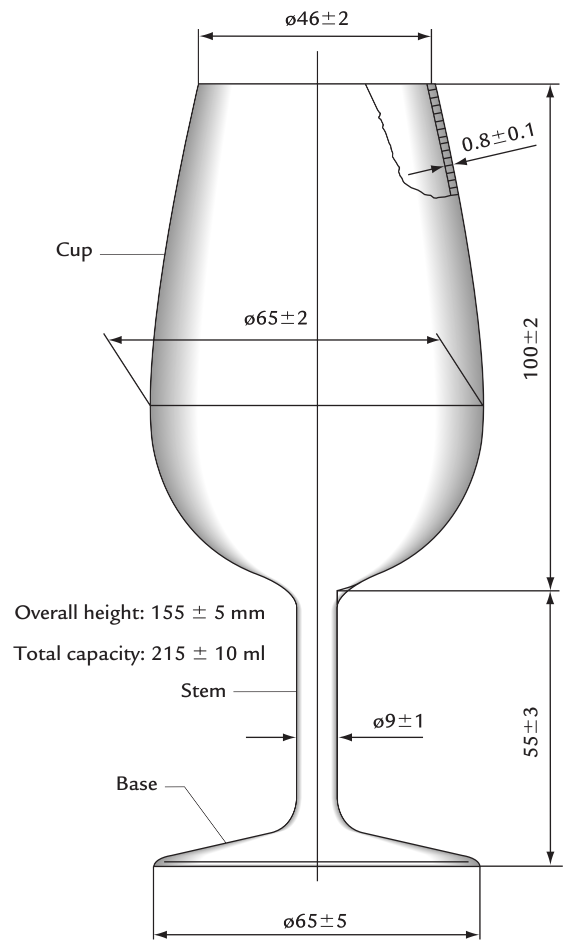

Figure 1.2 International Standards Organization wine tasting glass. Dimensions are in mm (courtesy of International Standards Organization, Geneva, Switzerland).

maceration (skin contact). Maturation in oak cooperage speeds age-related color changes, but it temporarily enhances color depth. During aging, golden tints in white wines increase, whereas red wines lose color density. Eventually, all wines take on tawny brown shades.

Because many factors affect wine color, it is impossible to be dogmatic about the significance of a particular color. If origin, style, and age are known, color can indicate the "correctness" of the wine. An atypical color can be a sign of several faults. The less known about a wine, the less significant color becomes in assessing quality. If color is too likely to be prejudicial, visual clues can be hidden by using black glasses.

Tilting the glass has the advantage of creating a gradation of wine depths. Viewed against a bright background, a range of color characteristics are observed. The rim of wine provides one of the better measures of relative wine age. A purplish to mauve edge is an indicator of youth in a red wine, a brickish tint along the rim is often the first sign of aging. In contrast, observing wine down from the top is the best means of judging relative color depth.

The most difficult task associated with color assessment is expressing one's impressions meaningfully. There is no accepted terminology for wine colors. Color terms are seldom used consistently or recorded in an effective manner. Some tasters place a drop of the wine on the tasting sheet. Although of temporary comparative value, it does not preserve an accurate record of the wine's color.

Until a practical standard is available, use of a few, simple, relatively self-explanatory terms is preferred. Terms such as purple, ruby, red, brick and tawny, and straw, yellow, gold and amber, combined with qualifiers such as pale, light, medium and dark can express the standard range of red and white wine colors, respectively.

Viscosity

Viscosity refers to the resistance of wine to flow. Factors such as the sugar, glycerol and alcohol contents affect wine viscosity. Typically, detectable differences in viscosity can be found only in dessert or highly alcoholic wines. Because these differences are minor and of diverse origin, they are of little diagnostic value. Viscosity is ignored by most professional tasters.

Spritz

Spritz refers to the bubbles that may form, usually along the bottom and sides of a wine glass, or the slight effervescence seen or detected in the mouth. Active and continuous bubble formation is generally found only in sparkling wines. In the latter case, the size, number, and duration of the bubbles are important quality features.

Slight bubbling is typically a consequence of early bottling, before the excess dissolved carbon dioxide in newly fermented wine has escaped. Infrequently, a slight spritz may result from malolactic fermentation occurring after bottling. Historically, spritz was commonly associated with microbial spoilage. Because this is now rare, a slight spritz is generally of insignificance.

Tears

Tears (rivulets, legs) develop and flow down the sides of glass following swirling. They are little more than a crude indicator of the wine's alcohol content. Other than for the intrigue or visual amusement they may cause, tears are sensory trivia.

Odor – *in-glass*

Tasters are often counseled to smell the wine before swirling. This exposes the senses to the wine's most volatile aromatics. When comparing several wines, it is easier to position oneself over the glasses than to raise each glass to one's nose. It makes the taster aware of one of the wine's most ethereal attributes.

The second and more important phase of olfactory assessment follows swirling of the wine. Although simple, effective swirling usually requires some practice. Until comfortable with the process, start by slowly rotating the base of the glass on a level surface. Most of the action involves a cyclical arm movement at the shoulder, while the wrist remains stationary. Holding the glass by the stem provides a good grip and this permits vigorous swirling. As they become familiar with the motion, people usually shift to swirling by wrist action. Some connoisseurs hold the glass by the edge of the base. While effective, its awkwardness seems an affectation.

Swirling increases contact between air and the wine, promoting the release of aromatic compounds. The in-curved sides of tulip-shaped glasses not only permit vigorous rotation, but they also concentrate the released aromatics. Whiffs are taken at the rim of the glass and then in the bowl. This permits sensation of the fragrance at different concentrations, potentially generating distinct perceptions. Considerable attention is usually required in detecting and recognizing varietal, stylistic, or regional attributes. Repeated attempts may also be required. As the primary source of a wine's unique character, the study of fragrance warrants this attention.

Occasionally, glass or plastic covers[1] are placed over the mouth of the glass. These covers serve two purposes. With highly fragrant wines, they limit aromatic contamination of the immediate surroundings. Such contamination can seriously complicate the assessment of less aromatic wines. The primary function, though, is to permit especially vigorous swirling of the wine (if held on tightly with the index finger). This can be valuable when the wines are aromatically mild.

No special method of inhalation seems necessary when assessing wine (Laing, 1986). Inhalation for more than half a second rarely improves odor identification, at least of single compounds (Laing, 1982). For wines, breathing in for about 2 s seems fully adequate. Longer periods probably lead to adaptation and loss of sensitivity. Nonetheless, extended inhalation can be informative with some aromatically complex wines, such as ports. As olfactory receptors become adapted to certain wine constituents, masked aromatic sensations may become apparent. Although the wine should be smelled several times, each sniff should be separated by about 30 to 60 s. Olfactory receptors take about this long to reestablish their intrinsic sensitivity. In addition, measurements of the rate of wine volatilization suggest that the headspace (volume just above the wine) takes about 15 s for replenishment (Fischer *et al.*, 1996). In comparative tastings, each wine should be sampled in sequence. This avoids odor fatigue from sampling the same fragrance over a short period.

Ideally, assessment of olfactory features should be spread over about 30 min. This period is necessary to evaluate features such as **duration** and **development**. Development is often likened to watching a flower open. Development, and the finish, (see below) are highly regarded attributes, and particularly important to premium wines. The higher costs of these wines are justifiable only if accompanied with exceptional sensory endowments.

Regardless of the technique employed, recording one's impressions clearly and precisely is important. This is difficult for everyone, possibly because we are not systematically trained from an early age to develop verbal-olfactory associations. The common difficulty in recalling odor names has been aptly dubbed "the-tip-of-the-nose" phenomenon (Lawless and Engen, 1977).

In technical assessments, tasters are usually trained using samples specifically

[1] For example, watch glasses, 60 mm Petri dish bottoms, or plastic coffee-cup lids.

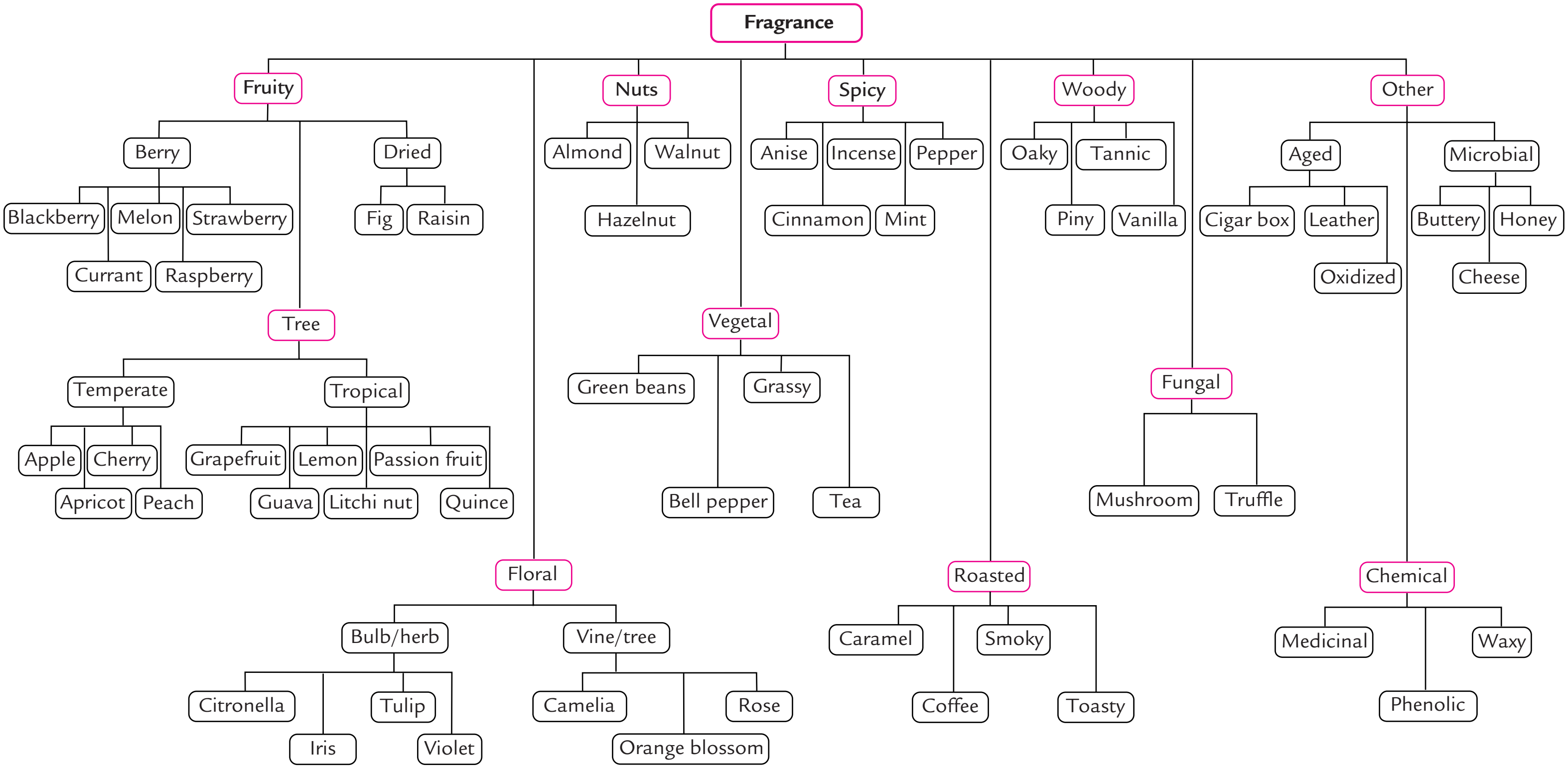

Figure 1.3 Wine fragrance chart (from Jackson, 2000, reproduced by permission).

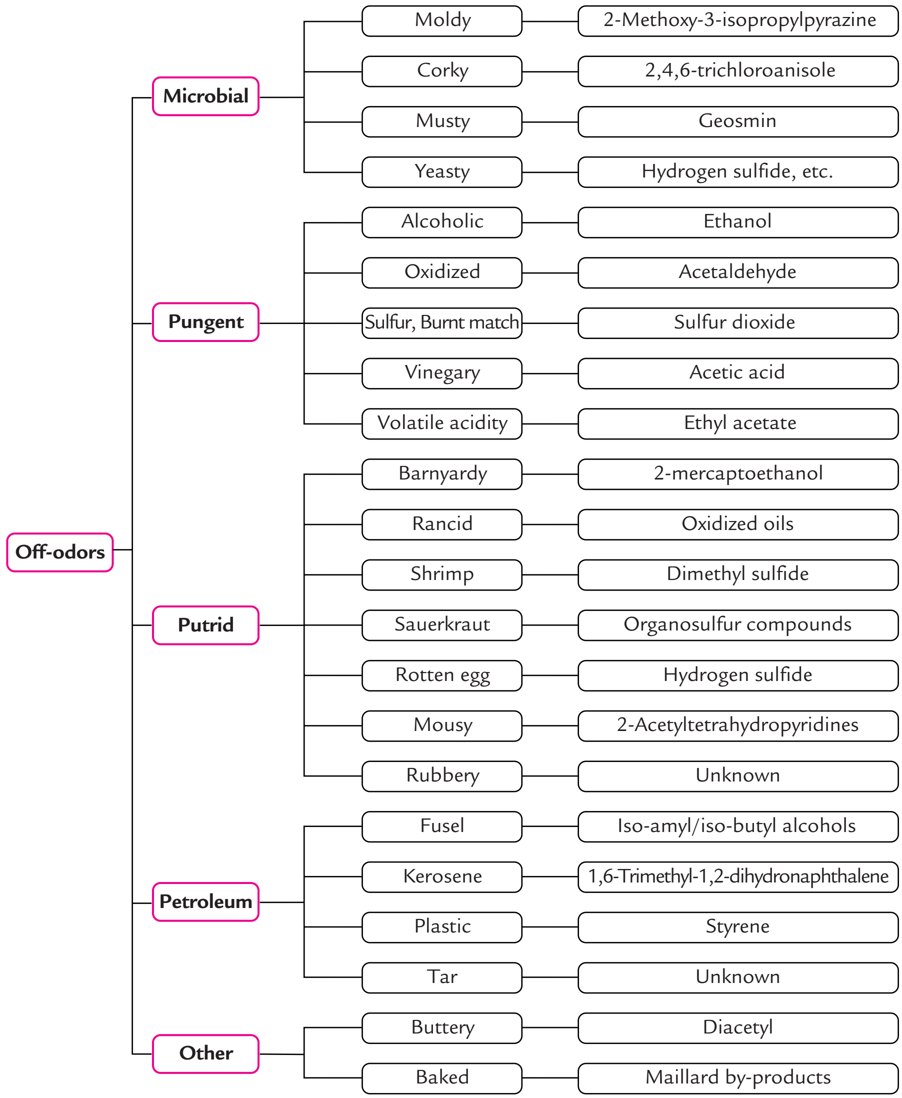

Figure 1.4 Wine off-odor chart (column at right notes examples of casual chemicals) (from Jackson, 2000, reproduced by permission).

designed for the purpose. Reference samples for the various terms used are commonly available during tastings (Appendices 5.4 and 5.5). Fragrance and off-odor charts (Figs 1.3 and 1.4) can assist in developing a common and consistent wine terminology. In a few instances, these terms help define the aromatic attributes of varietal wines. However, inappropriate use of odor analogies can mask inability to accurately describe a wine's aromatic features.

Emphasis on descriptive terms can be misinterpreted, especially in wine appreciation courses. Charts should be used only to encourage focusing on the wine's fragrance. Once students recognize the importance of studying the wine's olfactory traits, description in terms of specific fruits, flowers, vegetables, etc. can become counterproductive. For example, fanciful terms are often invented in a vain attempt to be informative. This tendency is enhanced by the legitimate difficulty people have in adequately describing olfactory sensations. It is generally more advantageous for consumers to concentrate on recognizing the differences that exemplify varietal characteristics, production styles, and wine age than verbal description. Except for educational purposes, lexicons of descriptive terms are best left for the purposes for which they were primarily developed—descriptive sensory analysis.

Impressions (both positive and negative) should be recorded. For this, selection of an appropriate tasting sheet is important. Figure 1.5 provides an example of a general wine tasting sheet for wine appreciation courses. Designed for enlargement to 11 × 17 inch paper, the circles indicate the placement of six glasses of wine. Reduced photocopies of the labels can be placed in the blank spaces above the six comment columns. Alternatively, a simple hedonic tasting sheet, such as illustrated in Figure 1.6, may be adequate. Tasting sheets are discussed in Chapter 5. In addition to verbal descriptions, a line drawn on a hypothetical scale can visually illustrate shifts in flavor intensity throughout the tasting (Fig. 1.7). Qualitative changes in fragrance can easily be noted on the graph as they occur. The process can rapidly, clearly, and succinctly express impressions.

In-mouth sensations

Taste and mouth-feel

After an initial assessment of fragrance, attention turns to taste and mouth-feel. About 6 to 10 ml is sipped. As far as feasible, the volume of each sample should be kept equivalent to permit valid comparison among samples. Active churning ("chewing") brings wine in contact with all regions in the mouth.

The first taste sensations potentially recognized are those of **sweetness** and **sourness**. Sweetness (if detectable) is generally most noticeable at the tip of the tongue. In contrast, sourness is more evident along the sides of the tongue and inside of the cheeks. The sharp aspect of acidity typically lingers considerably longer than perceptions of sweetness. Because **bitterness** is detected later, its increasing perception may coincide with a decline in the detection of sweetness. It can take upward of 15 s before bitterness reaches its peak, usually in the central, posterior portion of the tongue. Therefore, it is advisable to retain the wine in the mouth for at least 15 s. Subsequently, the taster should concentrate on mouth-feel sensations, such as the dry, dust-in-the-mouth aspect of **astringency**, and the perceptions of **burning** (alcohol or phenol-induced sensations), or the **prickling** aspect of carbon dioxide (if present at concentrations above 0.3 g/100 ml). These and other tactile sensations are dispersed throughout the mouth, without specific localization.

As indicated, differences in the sequence of detection can confirm specific taste sensations (Kuznicki and Turner, 1986). However, the duration of these sensations is not particularly diagnostic. Persistence reflects more the concentration and maximum perceived intensity of the tastant than its category (Robichaud and Noble, 1990). Although significant in some critical tastings, the purpose of noting sapid

Figure 1.5 General wine tasting sheet (usually enlarged to 11 × 17 inch paper).

	WINES 1	2	3	4	5	6
APPEARANCE *Color* – hue – depth – clarity *Spritz* Score (Maximum +/−1)						
FRAGRANCE **General Features** *Duration* *Intensity* *Development* *Varietal Character* **Fragrance** *Berry Fruit* – Blackberry, Blackcurrant, Grape, Melon, Raspberry, Strawberry *Tree Fruit* – Apple, Apricot, Banana, Cherry, Guava, Grapefruit, Lemon. Litchi, Peach, Passion Fruit, Quince *Dry Fruit* – Fig, Raisin *Floral* – Camellia, Citronella, Iris, Orange blossom, Rose, Tulip, Violet *Nuts* – Almond, Hazelnut, Walnut *Vegetable* – Asparagus, Beet, Bell pepper, Canned Green beans, Hay, Olives, Tea, Tobacco *Spice* – Cinnamon, Cloves, Incense, Licorice, Mint, Pepper *Roasted* – Caramel, Coffee, Smoke, Toast *Other* – Buttery, Cheese, Cigar box, Honey, Leather, Mushroom, Oak, Pine, Phenolic, Truffle, Vanilla Score (Maximum 5)						
TASTE **General Features** *Duration* *Development* *Intensity* *Balance* **Specific Aspects** Sweetness, acidity, astringency, bitterness, body, heat (alcohol level), mellowness, spritz (prickling) Score (Maximum 3)						
OVERALL ASSESSMENT *General quality* *Potential* *Memorableness* Score (Maximum 1)						
TOTAL SCORE (Maximum 10)						

Sample Number: ____	Wine Category: ____	Exceptional	Very Good	Above Average	Average	Below Average	Poor	Faulty	Comments
Visual	Clarity								
Odor (orthonasal)	Intensity*								
	Duration**								
	Quality***								
Flavor (taste, mouth-feel, retronasal odor)	Intensity								
	Duration								
	Quality								
Finish (after-taste and lingering flavor)	Duration								
	Quality								
Conclusion									

* *Intensity*: the perceived relative strength of the sensation—too weak or too strong are equally undesirable.
** *Duration*: the interval over which the wine develops or maintains its sensory impact; long duration is usually a positive feature if not too intense.
*** *Quality*: the degree to which the feature reflects appropriate and desirable varietal, regional or stylistic features of the wine, plus the pleasure these features give the taster.

Figure 1.6 Hedonic wine tasting sheet for quality assessment (from Jackson, 2000, reproduced by permission).

sensations is not as important as focusing on how they interact to generate the overall perceptions of **balance**, **flavor**, and **body**.

There are differing opinions on whether taste and mouth-feel should be assessed with the first sip or during subsequent samplings. Tannins react with proteins in the mouth, diminishing their potential bitter and astringent sensations. Reaction with saliva proteins partially explains why the first sample is usually less bitter and astringent than subsequent samples. The first taste more closely simulates the perception generated when wine is taken with a meal. If this is an important aspect of the tasting, it is essential that the tasting progress slowly. This permits stimulated salivary production to compensate for its dilution during tasting.

Odor – retronasal

To enhance the in-mouth detection of fragrance, tasters frequently aspirate the wine. This involves tightening the jaws, contracting the cheek muscles (to pull the

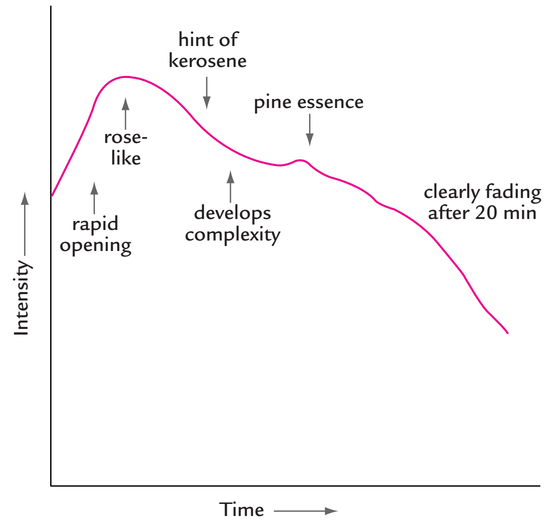

Figure 1.7 Graphic representation of the development of a wine's fragrance during a tasting. Specific observations can be applied directly to the point on the graph where the perception was detected.

lips slightly ajar), and slowly drawing air through the wine. Alternatively, some tasters purse the lips before drawing air through the wine. Either procedure increases volatilization—analogous to swirling wine in a glass. Although less effective, vigorous agitation of the wine in the mouth has a similar effect. The liberated aromatic compounds flow up into the nasal passages, producing what is called **retronasal olfaction**. The combination of retronasal olfaction with taste and mouth-feel generates the sensation of **flavor**. The perceptions observed should be recorded quickly, as they can change unpredictably. The significance of retronasal olfaction to flavor detection is easily demonstrated by clamping the nose. This limits the movement of aromatics from the oral cavity up into the nasal passages.

Some tasters complete their assessment of the wine's fragrance with a prolonged aspiration. Following inhalation, the wine is swallowed, and the vapors slowly exhaled through the nose. Any aromatic sensations detected are called the **after-smell**. While occasionally informative, it is typically of value only with highly aromatic wines, such as ports.

Following assessment, the wine is either swallowed or expectorated. In wine appreciation courses, wine societies, and the like, the samples are typically consumed. Because the number of wines being tasted is often small, and assessment not critical, consumption is unlikely to seriously affect tasting skill. However, twenty or more wines may be sampled in wine competitions or technical tastings. Consequently, consumption is assiduously avoided. Scholten (1987) has shown that expectoration avoids significant amounts of alcohol accumulating in the blood. Nevertheless, sufficient tannic material may be consumed to induce a headache.

One of the occupational hazards of wine tasting can be headaches. This appears to be especially so in individuals producing low levels of platelet-bound phenolsulfotransferase (PST) (Alam *et al.*, 1997). PST inactivates the action of biogenic amines and catacholamines that dilate small blood vessels in the brain, possibly through the release of prostaglandins. In some people (including the author), headache development is often prevented by the prior consumption of prostaglandin synthesis inhibitors, such as acetylsalicylic acid (e.g., aspirin), acetaminophen (e.g., Tylenol®), and ibuprofen (e.g., Advil®) (Kaufman, 1992). Large polymeric tannins, such as those that form during aging, are unable to enter the bloodstream through the intestinal wall. This probably explains why aged red wines induce fewer headaches and suppress the action of PST than their younger counterparts.

Finish

Finish refers to the aromatic and sapid sensations that linger following swallowing or expectoration. It is the vinous equivalent of a sunset—typically, the longer the finish, the more highly rated the wine. Some tasters consider its duration a major indicator of quality. Fruity–floral essences, associated with refreshing acidity, epitomize most superior white wines; while complex berry fragrances combined with flavorful tannins exemplify the best red wines. Fortified wines, possessing more intense flavors, have a very long finish. Exceptions to the generally desirable nature of a protracted finish are features such as a persistent metallic aspect, or excessively acidic, bitter and astringent sensations.

Overall quality

After the sensory aspects have been studied individually, attention shifts to integrating the various sensations. This may involve aspects of conformity with, and distinctiveness within, regional standards;[2] the development, duration, and complexity of the fragrance; the duration and character of the finish; and the uniqueness of the tasting experience.

Many of the terms used for overall quality have been borrowed from the world of art. Relative to wine, the term **complexity** refers to the presence of many, distinctive, aromatic elements, rather than one or a few easily recognizable odors. **Balance** (harmony) denotes the perceptive equilibrium of all olfactory and sapid sensations, where individual perceptions do not dominate. The complex interaction of sensory perceptions in the origin of balance is evident in the reduced fruitiness of red wines possessing excessive astringency, or the imbalance of a sweet wine lacking sufficient fragrance. Balance may appear to be simpler to achieve in white wines because of their low phenolic content. White wines are also typically less aromatically complex. Nonetheless, balance in white wines is no easier to achieve than in red wines. Occasionally, individual aspects may be sufficiently intense to give the impression that balance is on the brink of collapse. In

[2] Like grammar, traditional quality standards are the result of historical precedent. The attributes considered appropriate for a particular wine have evolved through the cyclical interaction of winemakers and discriminating consumers.

this situation, the balance has an element of **nervousness** that can be particularly fascinating. **Development** designates changes in the aromatic character that occur throughout the sampling period. Ideally, these changes maintain interest and keep drawing one's attention back to its latest transformation. **Duration** refers to how long the fragrance retains a unique character, before losing its individuality, and becoming just vinous. **Interest** is the combined influence of the previous factors on retaining the taster's attention. Implied, but not often specifically stated, is the requirement for both **power** and **elegance** in the wine's sensory characteristics. Without these attributes, attractiveness is short-lived. If the overall sensation is sufficiently remarkable, the experience becomes unforgettable, an attribute Amerine and Roessler (1983) call **memorableness**.

Most European authorities feel that quality should be assessed only within regional appellations, counseling against comparative tastings among regions or grape varieties. Although these restrictions make tastings simpler, they negate much of their value in promoting quality improvement. When tasting concentrates on artistic quality, rather than stylistic purity, comparative tasting can be especially revealing. Comparative tastings are more popular in the UK and the New World, where artistic merit tends to be considered more highly than compliance with regional styles.

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Visual perceptions

2

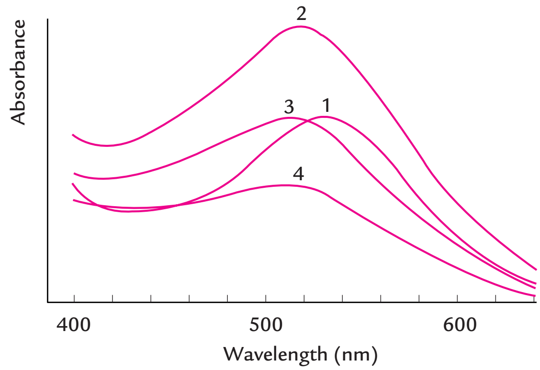
As noted in Chapter 1, wine appearance can provide useful indicators of quality, style, and varietal origin. Unfortunately, it can also provide false clues and prejudice assessment. In this chapter, the nature, origin, and significance of the visual aspects of wines are discussed.

Color

Color perception and measurement

The visual characteristics of a wine depend on how its chemical and particulate nature transmit, absorb, and reflect visible radiation. For example, the pigments in a red wine reflect (and absorb) specific wavelengths of visible radiation. These induce reactions in the retina of the eye that generate the impression of red. The color intensity depends on the amount and chemical state of the pigments present, and correspondingly the quantity and quality of light reflected. The purity of the color depends on the relative absorptive properties of the pigments across the visible spectrum. The broader the spectrum, the less pure the perceived color (indicated by a higher "tint" value; Fig. 2.1).

Although such characteristics can be accurately measured with a spectrophotometer (Fig. 2.1), the relevance of the data to human color perception is far from simple. Spectrophotometric measurements assess the intensity of individual wavelengths, whereas human perception combines the responses from many neurons (cones and rods) in the retina. Each cone responds to a relatively narrow range of wavelengths, with peak sensitivity in either the blue-violet (437 nm), green (533 nm) or yellow (564 nm) regions. The green- and yellow-absorbing cone pigments show considerable overlap. In contrast, the rods react nonspecifically to low-intensity light. Color perception results from the combined impulses from the three types of cones, while brightness and clarity are the prerogative of the rods. In addition, the eye possesses additional receptor cells (P and M) that help coordinate the stimuli from the rods and differentiate contrast. Finally, color perception involves a comparison of the nerve responses at the boundary where color changes. This probably is the origin



No.	Age (mo)	λ_{max} (nm)	A_{max}	Color density	Tint
1	0	531	8.05	12.20	0.52
2	4	520	11.80	18.60	0.58
3	16	515	7.95	13.45	0.69
4	28	515	5.20	9.40	0.81

Figure 2.1 Absorbance scans of a single cultivar port (*Touriga Nacional*, 1981) at different ages (from Bakker and Timberlake, 1986, reproduced by permission).

of the color constancy that occurs under most daily changes in sunlight spectral quality (Brou *et al*., 1986; Fig. 5.1). Thus, color perception of natural objects is a complex collation of responses, not a simple reaction to individual wavelengths or their respective intensities.

There is no generally accepted classification of wine color. It is also notoriously difficult to adequately represent the color of wine on photographic paper or film. Although people can differentiate thousands of color gradations by direct comparison, they tend to consistently differentiate comparatively few by name (Fig. 2.2). Many terms are used synonymously (Chapanis, 1965). Therefore, the number of color terms generally used for wine colors should be limited and kept simple to aid consistent use. Color terms should incorporate aspects of hue (wavelength purity), saturation (greyness) and brightness (capacity to reflect or transmit light). Their combination reflects the difficulty people have in differentiating these aspects of

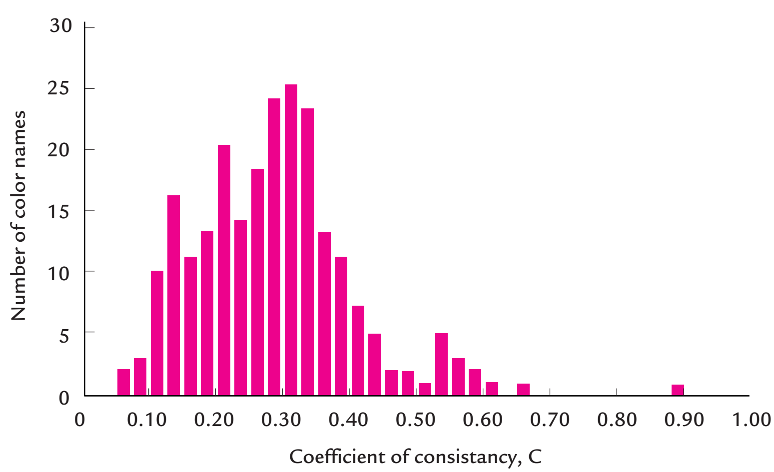


Figure 2.2 Coefficients of consistency for the selections made to 233 color names (from Chapanis, 1965).

color. For example, both yellow–red and brown commonly would be described as hues. Technically, however, yellow–red is a hue (precise region along the visible spectrum), whereas brown is an impure yellow–red (combining yellow–red and blue spectral elements). Equally, moderate pink is partially saturated light red. Figure 2.3 illustrates the three fundamental characteristics of color—hue, saturation and brightness.

A readily available standard of wine colors would increase the value of color in sensory evaluation. The Munsell color notation (Munsell, 1980) has a long history of use in the food industry and scientific investigation. However, its expense and unfamiliar color designation system (e.g., 5 YR 4/6—a moderate orange–brown) has precluded its more general adoption. Genetic variability in color perception also limits the applicability of a standard. Color blindness is the best-known example, but more subtle deficiencies are widespread. Color perception also changes with age. Yellow pigment accumulates in the lens and retina, resulting in a slow loss in blue sensitivity.

While difficulties remain in correlating spectral absorbance to perceived color, simple techniques can yield valuable data. One technique measures the absorbance of undiluted samples of red wine at 420 nm and 520 nm (Somers and Evans, 1977).

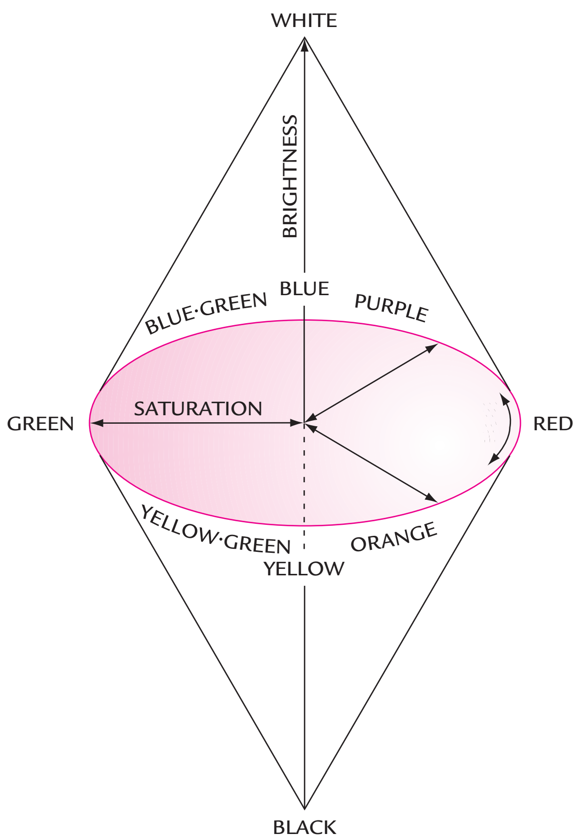


Figure 2.3 Schematic representation of the psychological dimensions of color space (from Chapanis, 1965).

The sum of these values is a measure of color depth, while their ratio estimates tint. Absorbance at 420 nm provides an indicator of a brown cast, while absorbance at 520 nm assesses redness. As red wines age, the level of yellowish polymeric pigments increases, and the impact of monomeric red anthocyanins decreases. Besides the resulting shift toward brown, there is also pigment loss and reduction in color depth. In white wines, absorbance at 420 nm is an indicator of browning (Peng *et al*., 1999).

Although useful, absorbance at 420 and 520 nm is too crude to adequately reflect small differences in color. Additional data, such as the proportion of colored (ionized) monomeric anthocyanins, total anthocyanin and phenol contents, and the proportion of anthocyanins complexed to various phenolic polymers, may be derived from acidification with hydrochloric acid, decolorization with metabisulfite, and subsequent recoloration with acetaldehyde, respectively (Somers and Evans, 1977). Because the proportion of complexed anthocyanins increases with age, it has been described as the wine's "chemical age." Several studies have shown a strong correlation between the amount of colored (ionized) anthocyanins and the perceived quality of young red wines (Somers and Evans, 1974; Somers, 1998).

Another means of objectively assessing wine color employs tristimulus colorimetry. It involves taking three separate intensity measurements of light transmitted through wine, using red, green and blue filters. This approximates the response of the human eye. Appropriate measurements may be obtained with a spectrophotometer, but these require complicated mathematical transformations. Tristimulus colorimeters directly correlate the values with color vision. Estimates of brightness (clarity), chroma (saturation) and hue angle (shade) are generated. These are the three parameters normally used in defining color.

Another means of estimating color response involves the CIE (Commission Internationale de l'Eclairage) system. The CIE system involves measuring light transmission at three wavelengths (445, 550, and 625 nm), and occasionally at 495 nm. These data can be used to derive values for *L* (relative lightness), *a* (relative redness) and *b* (relative yellowness). These can be used either in the Hunter L*a*b* or CIELAB measurements. These scales have been used to measure wine color, though several researchers have proposed changes to make the values more applicable to wine (Negueruela *et al*., 1995; Ayala *et al*., 1997). The information is particularly suited to determining color differences. This information can improve the blending of wines to a predetermined color (Negueruela *et al*., 1990), but it has found little use in wine assessment.

Significance in tasting

Color often affects quality perception (Williams *et al*., 1984a; Fig. 2.4; Fig. 2.5), as well as taste perception (Maga, 1974; Clydesdale *et al*., 1992). For red wines, flavor intensity (and wine quality) has often been correlated with color density (Iland and Marquis, 1993) and hue (the proportion of red "ionized" anthocyanins) (Somers and Evans, 1974; Bucelli and Gigliotti, 1993). Wine flavors, located primarily in the skins, are likely to be extracted under the same conditions that promote pigment extraction. Color depth is also considered an indicator of aging potential.

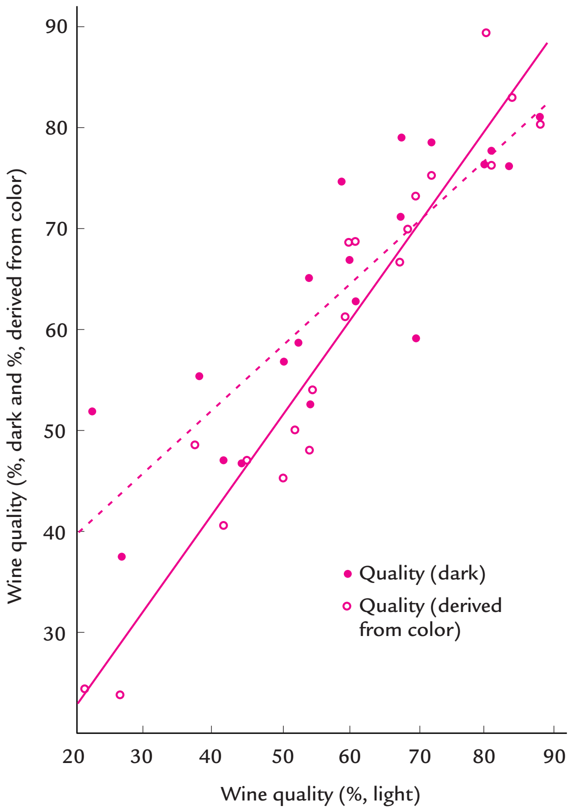


Figure 2.4 Illustration of the relationship between wine quality assessed by smell and taste (in darkness) and by sight alone (from color) compared with quality assessed by all three senses (light) (from Tromp and van Wyk, 1977, reproduced by permission).

Occasionally, wines are sampled in black wine glasses, or under red light, to negate color biases.

Often tasters associate particular colors with certain wines. Young, dry, white wines generally range from nearly colorless to pale straw colored. A more obvious yellow tint may suggest long maceration or maturation in oak cooperage. Sweet white wines may vary from a pale straw to yellow–gold. Sherries vary from pale straw to dark golden-brown, depending on the style. Rosé wines are expected to be pale to light pinkish or rosé, without shades of blue. Hints of brown, purple, or orange usually indicate oxidation. Red wines vary from deep purple to pale tawny red. Initially, most red wines have a purplish-red hue, especially noticeable at the edge of the wine. Red ports, depending on the style, may be deep red, ruby, or tawny colored.

Because wines eventually take on brownish hues, brownness is often used as an indicator of age. This feature is indicated by a lowering of the A_{420}/A_{520} spectrophotometric ratio (Somers and Evans, 1977). However, a brownish cast may equally indicate oxidation or heating. Therefore, wine age, type, and style must be known before

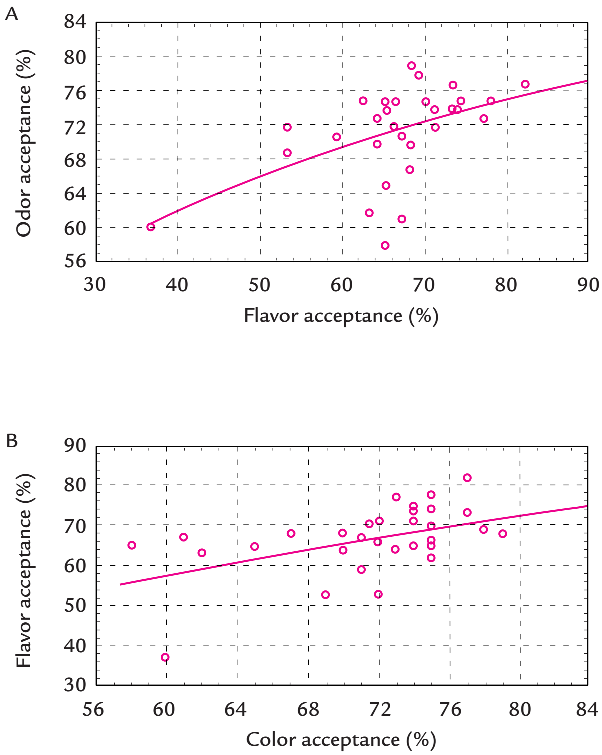


Figure 2.5 Relation between flavor and odor acceptance (A) and color and flavor acceptance (B) (from Pokorný *et al.*, 1998, reproduced by permission).

interpreting the meaning and significance of a brownish hue. Brown shades are acceptable only if associated with the development of a desirable processing or aged bouquet. The heating of madeira, which gives the wine its brown coloration and baked bouquet, is an example of process-produced browning. Because most wines fail to develop a desirable aged bouquet, brown casts often mean that the wine is "over the hill."

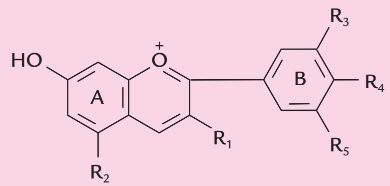
Most of the data suggest that color influences are learned associations (see Clydesdale *et al.*, 1992), although results from Pangborn *et al.* (1963) indicate that other explanations may be possible. Regardless of origin, the effects probably arise from visual, taste and olfactory messages interacting in the orbitofrontal cortex (Fig. 3.8).

Origin

Red wines

Anthocyanins are the primary determinants of color in red grapes and wine. In grapes, anthocyanins occur predominantly as glucosides. These are conjugates with one or more glucose molecules. The complex both increases chemical stability and water solubility. The glucoside may also associate with acetic, coumaric, or caffeic acids.

Table 2.1 Anthocyanins occurring in wine[a]



Specific name	R_3	R_4	R_5
Cyanidin	OH	OH	
Peonidin	OCH_3	OH	
Delphinidin	OH	OH	OH
Petunidin	OCH_3	OH	OH
Malvidin	OCH_3	OH	OCH_3

Derivatives	Structure
Monoglucoside	R_1 = glucose (bound at the glucose 1-position)
Diglucoside	R_1 and R_2 = glucose (bound at the glucose 1-position)

[a]After *Methods for Analysis of Musts and Wines*, MA Amerine and CS Ough, Copyright 1980 John Wiley and Sons, Inc. Reprinted by permission of John Wiley and Sons, Inc.

Five classes of anthocyanins occur in grapes—the cyanins, delphinins, malvins, peonins, and petunins. They are differentiated relative to the number of hydroxyl and methyl groups on the B ring of the anthocyanidin molecule (Table 2.1). The content and relative amounts of each class vary considerably among cultivars and with growing conditions (Wenzel *et al*., 1987). The hydroxylation pattern of the anthocyanidin B ring primarily controls both the hue and color stability. Free hydroxyl groups enhance blueness, whereas methylation augments redness. In addition, the presence of two hydroxyl groups next to each other on the B ring (*o*-diphenols) markedly enhances their potential to oxidize. Therefore, wine with a high proportion of malvin or peonin, neither of which possess *o*-diphenols, significantly enhances color stability. Resistance to oxidation is also a function of conjugation of the anthocyanin with sugar and other compounds (Robinson *et al*., 1966). In most red grapes, malvin is the predominant anthocyanin. Because it is the reddest of anthocyanins, the red hue of most young red wine comes from this compound.

Besides the five main types of anthocyanins, each type occurs in a dynamic equilibrium among five major molecular states in wine. Four are free forms and one is bound to sulfur dioxide (Fig. 2.6). Most are colorless within the pH range of wine. Those that exist in the flavylium state generate a red hue, while those in the quinoidal state give a bluish tint. The proportion of each state depends primarily on the pH and free sulfur dioxide content of the wine. Low pH enhances redness (favors the flavylium state), whereas high pH generates a blue–violet cast (by favoring the quinoidal state). Color density is also affected. Bleaching of anthocyanins by sulfur

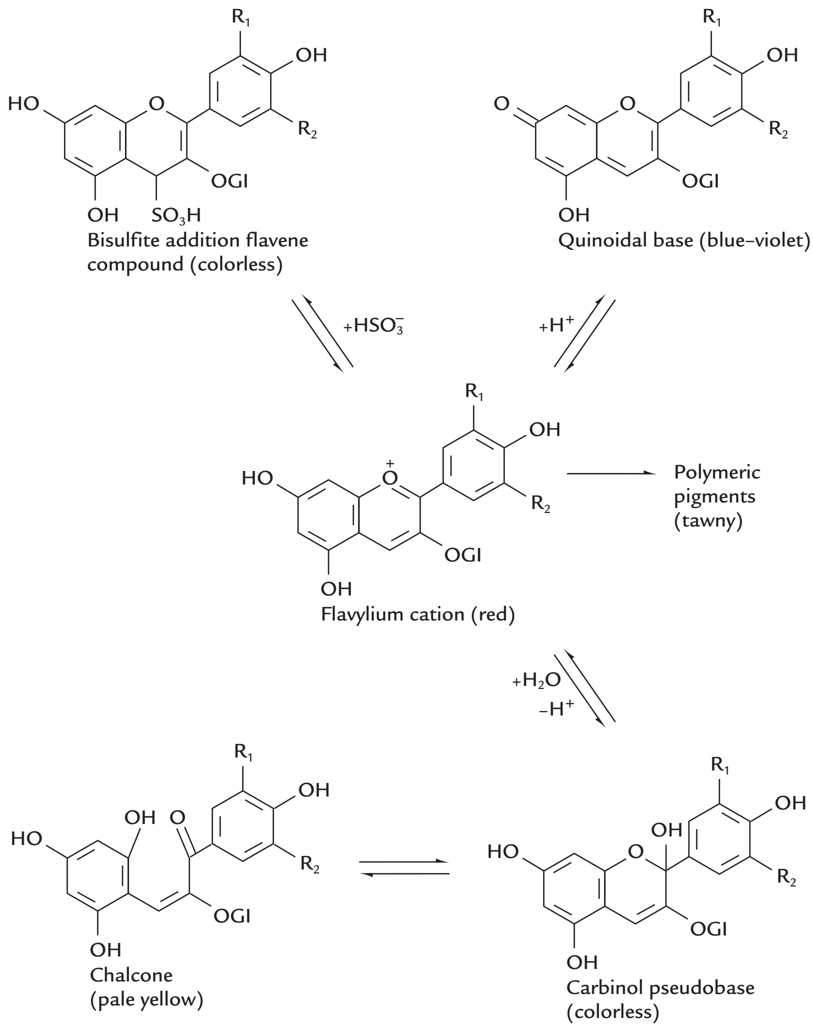


Figure 2.6 Equilibria among the major molecular states of anthocyanins in wine: Gl, glucose (from Jackson, 2000, reproduced by permission).

dioxide (either an additive, or produced by yeasts during fermentation) can further diminish color depth.

In grapes, anthocyanins exist primarily in stacked conglomerates, induced by processes called self-association and copigmentation. Hydrophobic interactions between individual anthocyanidins (self-association) or between anthocyanidins and other phenolic compounds (co-pigmentation) hold the aggregates together. Both complexes increase light absorbency and color density. During vinification and maturation, these conglomerates tend to disassociate. Anthocyanin molecules freed into the acidic wine environment lose their bluish color. In addition, disassociation also results in reduced light absorption and loss in color depth. Typical losses in color density can vary from two- to five-fold, depending on the pH, ethanol, and tannin contents of the wine. Nevertheless, sufficient self-association complexes seem to survive to generate the purple tint characteristic of most young red wines. These color changes occur without a reduction in the absolute anthocyanin content.

During maturation, not only do anthocyanin aggregates disassociate, but individual anthocyanin molecules tend to lose their sugar and acyl (acetate, caffeate, or coumarate) constituents. This makes them more susceptible to both irreversible oxidation (browning), and to conversion of the colored flavylium state to colorless hemiacetals. To limit these events, it is important that the wine contains significant quantities of catechins and procyanidins (tannin subunits). They combine with free anthocyanins to form stable polymers. The polymers also extend light absorption into the blue region. This explains most the brownish shift that occurs during the aging of red wines.

The concurrent extraction of tannins with anthocyanins during fermentation is critical to long-term color stability in red wines. These compounds begin to polymerize with free anthocyanins almost immediately. By the end of fermentation, some 25% of the anthocyanins may exist polymerized with tannins. This can rise to about 40% within 1 year in oak cooperage (Somers, 1982). Subsequently, polymerization continues more slowly, and it may approach 100% within several years (Fig. 2.7). Thus, red color not only reflects the amount, nature, and states of the anthocyanin content of a wine, but also the types and amounts of tannin subunits extracted and retained during and after vinification (McCloskey and Yengoyan, 1981). The poor color stability of most red muscadine wines appears to involve the absence of appropriate tannins and acylated anthocyanins in muscadine grapes (Sims and Morris, 1986).

Polymerization protects the anthocyanin molecule from oxidation or other chemical modifications. Incidently, polymerization also increases solubility, minimizing tannin and pigment loss by precipitation. In addition, more anthocyanin molecules are colored in tannin complexes, because of increases in the proportion of both the flavylium and quinoidal states. For example, about 60% of anthocyanin–tannin polymers are colored at pH 3.4, whereas 20% of equivalent free anthocyanins are colored

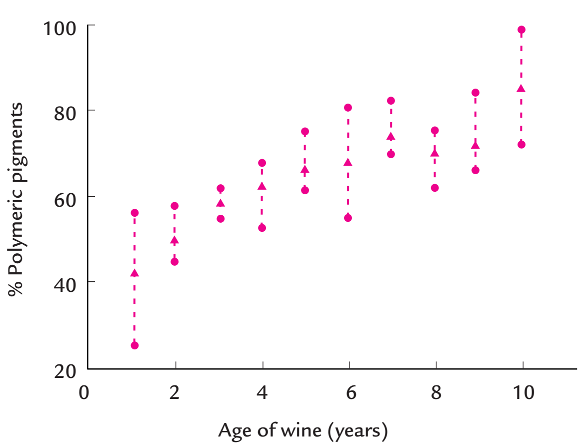


Figure 2.7 Increase in the contribution of polymeric pigments to wine color density during the aging of *Shiraz* wines: ▲, mean values: ●, extremes (from Somers, 1982, reproduced by permission).

(Fig. 2.8). The yellow-brown flavylium and quinoidal anthocyanin–tannin polymers generate the age-related brickish shades.

Polymerization of anthocyanins with procyanidins occurs slowly in the absence of oxygen. Nevertheless, polymerization is promoted by the oxygen inadvertently absorbed during racking. The small amounts of peroxide generated, as oxygen reacts with tannins, oxidizes ethanol to acetaldehyde. The subsequent reaction of acetaldehyde with anthocyanins promotes their polymerization with procyanidins (tannin subunits). The initially small anthocyanin–acetaldehyde–procyanidin polymers are thought to accentuate the violet shift so typical of young red wines (Dallas *et al.*, 1996). Acetaldehyde also reacts with sulfur dioxide, removing it from anthocyanins. This not only reverses the bleaching action of sulfur dioxide, but also liberates the anthocyanin for polymerization with procyanidins.

Other mechanisms suspected in color stabilization involve various yeast metabolites, notably pyruvic acid. It can react with anthocyanins (Fulcrand *et al.*, 1998), generating a tawny red color. Monoglucosides and coumaroyl monoglucosides of malvin, the predominant anthocyanin in grapes, also may complex with 4-vinylphenol, generating red–orange pigments (Fulcrand *et al.*, 1997).

As red wine ages, its color reflects the increasing proportion of anthocyanin–tannin polymers. Table 2.2 illustrates the various forms producing yellow, yellow–red, yellow–brown, red, and violet shades. The reduction in color density that also accompanies aging may result from oxidation, structural changes in anthocyanin–tannin polymers, and polymer precipitation with tartrate salts or soluble proteins.

Red wines can vary from deep red-purple to pale tawny red. The purplish-red hue of young red wines may be a result of the continuing presence of anthocyanin

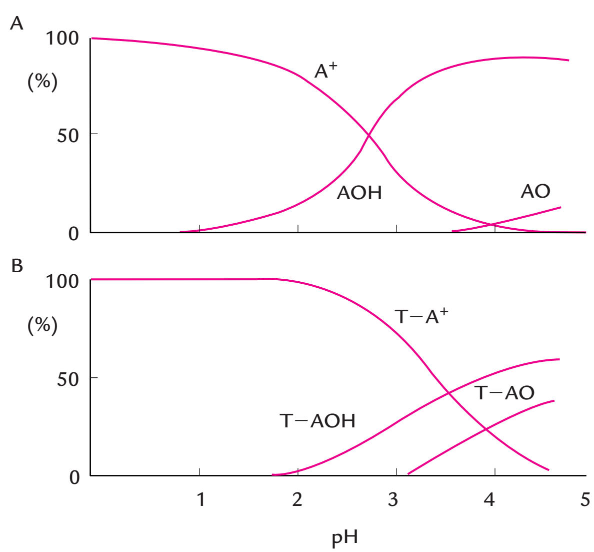


Figure 2.8 Equilibria among different forms of A free anthocyanins (A) and B combined anthocyanins (T-A) extracted from wine. +, red flavylium cation; OH, colorless carbinol pseudobase; O, blue–violet quinoidal base (from Ribéreau-Gayon and Glories, 1987, reproduced by permission).

Table 2.2 Color and molecular weight of some wine phenols[a]

Name[b]	Color	Molecular weight (kDa)
A^+	Red	500
AOH	Noncolored	
AO	Violet	
$AHSO_3$	Noncolored	
P	Noncolored	600
T	Yellow	1000–2000
$T\text{-}A^+$	Red	1000–2000
T-AOH	Noncolored	
T-AO	Violet	
$T\text{-}AHSO_3$	Noncolored	
TC	Yellow-red	2000–3000
TtC	Yellow-brown	3000–5000
TP	Yellow	5000

[a]From Ribéreau-Gayon and Glories (1987), reproduced by permission.
[b]A, Anthocyanin; P, procyanidin; T, tannin; TC, condensed tannin; TtC, very condensed tannin; TP, tannin condensed with polysaccharides; OH, carbinol pseudobase; O, quinoidal base; HSO_3, bisulfite addition compound.

complexes or anthocyanin–acetaldehyde–tannin polymers, but it may also indicate that the pH of the wine is undesirably high (>3.8). A light color may indicate grape immaturity or poor winemaking practices. However, certain cultivars, such as *Gamay* and *Pinot noir*, seldom yield wines with deep colors. *Spätburgunder* wines from Germany are typically so pale colored as to often resemble a dark rosé. Cool climatic conditions are also not conducive to the production of dark-colored red wines. In these situations, the varietal origin must be known to avoid unduly penalizing the wine.

More intensely pigmented varieties, such as *Nebbiolo* and *Cabernet Sauvignon*, may remain deep red for decades. Dark shades often correlate with rich flavors. These are probably extracted along with anthocyanins from the skins. Standard vinification procedures favor the uptake of high levels of tannins. These generate the bitter and astringent sensations that take prolonged aging to soften. However, use of rotary fermentors favors the early extraction of berry flavors and intense coloration, before tannin uptake reaches high levels.

Most red wines begin to take on a noticeable brickish red cast within a few years, especially when long aged in oak cooperage (Fig. 2.1). Brickish red or tawny red colors are acceptable only if linked to the development of a favorable aged bouquet. In most standard red wines, these hues indicate only that the wine has lost the fruitiness it might have had. In young red wines, brick shades may suggest overheating (as in a warehouse where it would be associated with a baked odor), or a faulty closure (and an associated oxidized odor).

Rosé wines

Rosé wines are expected to be pale pink, cherry, or raspberry colored, without shades of blue. The actual shade depends on the amount and type of anthocyanins found in the cultivar(s) used. An orangish cast is generally undesirable, but this is characteristic of rosés made predominantly from *Grenache*. Otherwise, hints of orange usually suggest oxidation. Purplish hints often signify that the wine is too high in pH and may taste flat.

White wines

In comparison with red wines, little is known about the chemical nature and development of color in white wine. The small phenolic content of white wines consists mostly of hydroxycinnamates, such as caftaric acid and related derivatives. On crushing, these readily oxidize and form *S*-glutathionyl complexes. These generally do not turn brown. Thus, it is believed that most of the yellowish pigmentation in young white wine is derived from the extraction and oxidation of flavonols, such as quercetin and kaempferol. Nonflavonoids and lignins extracted from oak cooperage during wine maturation can add significantly to the color of white wines. The deepening yellow–gold of older white wines probably comes from the oxidation of phenols or galacturonic acid. However, gold shades may also develop following the formation of melanoidin compounds by Maillard reactions, or the caramelization of sugars. Occasionally, a pinkish cast is detectable in wines made from *Gewürztraminer*. This comes from trace amounts of anthocyanins extracted from the skins of this pinkish cultivar. The coloration in some so-called white wines made from red varieties also comes from the extraction of anthocyanins from skins. In fortified sweet wines, much of the color comes from either oxidation of phenolics in the wine, or from melanoid pigments, formed during heat concentration of grape juice used for sweetening.

Typically, young, dry, white wines range from nearly colorless to pale straw colored. A more obvious yellow tint may be considered suspicious, unless associated with extended skin contact (maceration), or maturation in oak cooperage. The wine takes on deeper hues with aging. If associated with the development of an appreciated aged bouquet, it is desirable. If associated with accidental oxidation, and the presence of an aldehyde odor, it is unacceptable. In contrast, unusually pale colors may suggest the use of unripe grapes (absence of typical coloration, high acidity, little varietal character), removal of the juice from the skins without maceration (extraction of few phenolics and minimal varietal flavor), or the excessive use of sulfur dioxide (which has a bleaching action). Sweet white wines generally are more intensely colored, being straw-yellow to yellow-gold. This probably results from the in-berry oxidation of grape constituents during over-ripening. Sherries vary from pale straw to golden-brown, depending on the particular style (fino to oloroso), and the degree to which they are sweetened. Madeiras are always amber colored (unless decolorized) because of the heat processing they undergo. Although white wines typically darken with age, some fortified white wine may lighten (e.g., Marsala). This results from the precipitation of melanoid pigments.

Clarity

In contrast to the complexity of interpreting the significance of color, haziness is always considered a fault. With modern techniques of clarification, wine consumers now expect a clear product with long shelf-life. Consequently, considerable effort is expended in producing wines stable in terms of clarity.

Crystals

Young wines remain supersaturated with tartrate salts after fermentation. During maturation, isomerization of these salts reduces solubility. Consequently, storage under cool conditions often leads to crystallization. Crusty, flake-like crystals are usually potassium bitartrate (cream of tartar), whereas fine crystals are typically calcium tartrate.

As the alcohol content rises during fermentation, the solubility of bitartrate decreases. This induces the slow precipitation of potassium bitartrate. Given sufficient time, the salt crystals usually precipitate spontaneously. In northern regions, the low temperatures found in unheated cellars may induce adequately rapid precipitation. Where spontaneous precipitation is inadequate, refrigeration often achieves rapid and satisfactory bitartrate stability.

Because bitartrate crystallization is concentration dependent, mildly unstable wines may be insufficiently stabilized by cold treatment. Protective colloids, such as yeast mannoproteins, may retard crystallization by masking positively charged sites on bitartrate crystals (Lubbers *et al.*, 1993). The interaction between tannins, tartrate and potassium ions also retards crystallization.

Occasionally, crystals of calcium oxalate form in wine. If crystallization occurs, it develops primarily in older wines because of the slow oxidation of ferrous oxalate to the unstable ferric form. After dissociation from the metal, oxalic acid may react with calcium, forming calcium oxalate crystals.

Other potential troublesome sources of crystals are saccharic and mucic acids. Both are produced by the pathogen *Botrytis cinerea* and both may form insoluble calcium salts. Calcium mucate is often the source of yellowish particles occasionally found in bottles of Sauternes.

Although comparatively rare, the presence of salt crystals is not a legitimate cause for consumer rejection. The crystals are tasteless and usually remain in the bottle with any sediment. Alternatively, they adhere to the cork. Because white wines are transparent and sold in pale to colorless bottles, crystals are more obvious in white than red wine. In addition, white wines are typically chilled or stored cool, accentuating crystal formation. Some producers mention their possible occurrence by the euphemistic term "wine diamonds." Consumers may unwittingly mistake elongated tartrate crystals for glass slivers.

Sediment

Resuspension of sediment is probably the most frequent source of clouding in older red wine. Sediment typically consists of complexes of polymerized anthocyanins, tannins, proteins, and tartrate crystals. Depending on their chemical composition, sediment may have a bitter or chalky taste. To some wine critics, the presence of sediment is considered a sign of quality. Excessive and unnecessary clarification can remove flavorants, but its avoidance does not guarantee a finer or more flavorful wine.

Proteinaceous haze

Although a less common cause of wine rejection than crystal formation, protein haze can still cause considerable economic loss in bottle returns. Protein haze results from the clumping of dissolved proteins into light-dispersing particles. Heating accelerates the process, as does reaction with tannins and trace contamination with metals. Two proteins of importance in haze production in white wine are pathogenesis-related (PR) proteins—chitinase and an acid-stable thaumatin-like protein (Waters *et al*., 1996b). They occur in infected grapes and are also produced rapidly in grapes damaged during harvesting (Pocock and Waters, 1998). Although many yeast mannoproteins and grape arabinogalactan–protein complexes may promote heat-induced protein haze, specific ones can reduce haze formation (Pellerin *et al*., 1994).

Phenolic haze

Excessive use of oak-chips in wine maturation, or the accidental incorporation of leaf material from the grape crush (Somers and Ziemelis, 1985) can occasionally induce rare forms of haze. The first situation results in the excessive extraction of ellagic acid, leading to the formation of fine, off-white to fawn-colored crystals. In the second situation, fine, yellow, quercetin crystals, extracted from leaf material during crushing, can induce a flavonol haze in white wines bottled before the crystals have had a chance to settle (Somers and Ziemelis, 1985). The excessive use of sulfur dioxide has also been associated with cases of phenolic haze in red wines.

Casse

Several insoluble metal salts generate haziness in bottled wine (*casse*). The most important are induced by iron (Fe^{3+} and Fe^{2+}) and copper (Cu^{2+} and Cu^{+}). The primary source of troublesome concentrations of these metal ions comes from corroded winery equipment.

Two forms of ferric *casse* are known. White wines may be affected by a white haze that forms as soluble ferrous phosphate oxidizes to insoluble ferric phosphate. The haze results either from particles of ferric phosphate alone, or from a complex formed between ferric phosphate and soluble proteins. In red wine, oxidation of ferrous to ferric ions can generate a blue *casse*. In this instance, ferric ions form insoluble particles with anthocyanins and tannins.

In contrast to iron-induced haziness, copper *casse* forms only under reduced (anaerobic) conditions. The *casse* develops as a fine, reddish-brown deposit when the redox potential of bottled wine falls during aging. Exposure to light speeds the reaction. The particles consist of cupric and cuprous sulfides, or their complexes with proteins. Copper *casse* is primarily a problem in white wines, but it can occur in rosé wines.

Deposits on bottle surfaces

Occasionally, sediment adheres tightly to glass. This can generate an elongated, elliptical deposit on the lower side of the bottle. Less frequently, a lacquer-like deposit may coat the interior surfaces of bottles of red wine. It consists of a film-like tannin–anthocyanin–protein complex (Waters *et al*., 1996a). Champagne bottles may also develop a thin, film-like deposit on their inner surfaces. This phenomenon, called *masque*, results from the deposition of a complex between albumin (used as a fining agent) and fatty acids (probably derived from autolysing yeast cells) (Maujean *et al*., 1978).

Microbial spoilage

Haze can also result from the action of spoilage organisms (yeasts and bacteria). The most important spoilage yeasts in bottled wine are species of *Zygosaccharomyces* and *Brettanomyces*. Three groups of bacteria may be involved, lactic acid bacteria, acetic acid bacteria, and *Bacillus* species.

Zygosaccharomyces bailii can generate both flocculant and granular deposits (Rankine and Pilone, 1973), notably in white and rosé wines. Contamination usually results from growth in improperly cleaned and sterilized bottling equipment. In contrast, *Brettanomyces* spp. induces a distinct haziness. It may become evident at less than 10^2 cells/ml (Edelényi, 1966). With other yeasts, noticeable cloudiness begins only at concentrations above 10^5 cells/ml. Yeast-induced haziness may occur without spoilage, but frequently it is associated with vinegary (*Z. bailii*) or mousy (*Brettanomyces*) off-odors. Other fungi can cause clouding or pellicle formation, but only under aerobic conditions—a situation not found in properly sealed bottled wine.

Certain lactic acid bacteria generate a cloudy, viscous deposit in red wines, in a situation called *tourne*. The affected wine also turns a dull red-brown, develops a sauerkrauty or mousy taint, and may show spritz if carbon dioxide accumulates. Other strains may synthesize profuse amounts of mucilaginous polysaccharides (β-1,3-glucans). These polysaccharides hold the bacteria together in long silky chains. The filaments often appear as floating threads, generating the condition called *ropiness*. When dispersed, the polysaccharides give the wine an oily look and viscous texture. Although visually unappealing, ropiness is not consistently associated with taints.

Acetic acid bacteria have long been associated with wine spoilage. For years, molecular oxygen was thought essential for their growth. It is now known that quinones (oxidized phenolics) can substitute for oxygen (Aldercreutz, 1986). Thus, acetic acid bacteria may grow in bottled wine if acceptable electron acceptors are present. If they multiply in wine, they can form a haziness associated with the development of marked vinegary odors and tastes. Lactic acid bacteria can induce a diversity of spoilage problems, usually in wine at high pH values (>3.7). If this occurs in bottled wine, their growth can lead to the development of a slight haziness.

Viscosity

The viscosity of wine is largely a function of its sugar, ethanol, glycerol, and soluble polysaccharide contents. Usually, though, visually perceptible differences in wine viscosity are uncommon. If they occur, they tend to result from high sugar and/or alcohol contents; glycerol contents ≥25 g/l (as in botrytized wines); or the presence of mucopolysaccharides produced by bacteria (in cases of wines showing *ropiness* or *tourne*).

Spritz

Still wines may retain sufficient carbon dioxide after fermentation to form bubbles along the sides and bottom of the glass. This usually occurs if wine is bottled early, before the supersaturated carbon dioxide has escaped. Much of the excess, weakly bound carbon dioxide is soon liberated, and can form bubbles when the bottle is opened.

Bubbles may also come from carbon dioxide produced by bacterial metabolism. This may develop as a consequence of malolactic fermentation occurring after bottling. It may also result from the action of spoilage bacteria, as in the case of wine showing *tourne*.

In most instances, effervescence occurs intentionally. The size, association, and duration of bubbling is an important quality feature in sparkling wines. Slow effervescence is favored by prolonged contact between yeasts (which produce the carbon dioxide) and the wine. After several months, the yeasts autolyze (self-digest), releasing cell wall constituents (colloidal mannoproteins) into the wine. The weak bonds formed between carbon dioxide and these proteins are essential to the production of a steady stream of bubbles following opening.

Many factors affect the solubility of carbon dioxide. Primary among these are temperature and the wine's sugar and ethanol contents. Increasing these factors decreases gas solubility. Once poured, atmospheric pressure becomes the critical factor promoting bubble formation. Pressure on the wine drops from 6 atm (in the bottle) to 1 atm (ambient). This reduces carbon dioxide solubility from about 14 g/l to 2 g/l. This initiates the release of approximately 5 l of gas (from a 750 ml bottle). In the absence of agitation, there is insufficient free energy for the CO_2 to escape immediately. It enters a metastable state from which it is slowly liberated.

Carbon dioxide escapes from the wine by several mechanisms (Fig. 2.9). The initial foaming associated with pouring is activated by free energy liberated by the

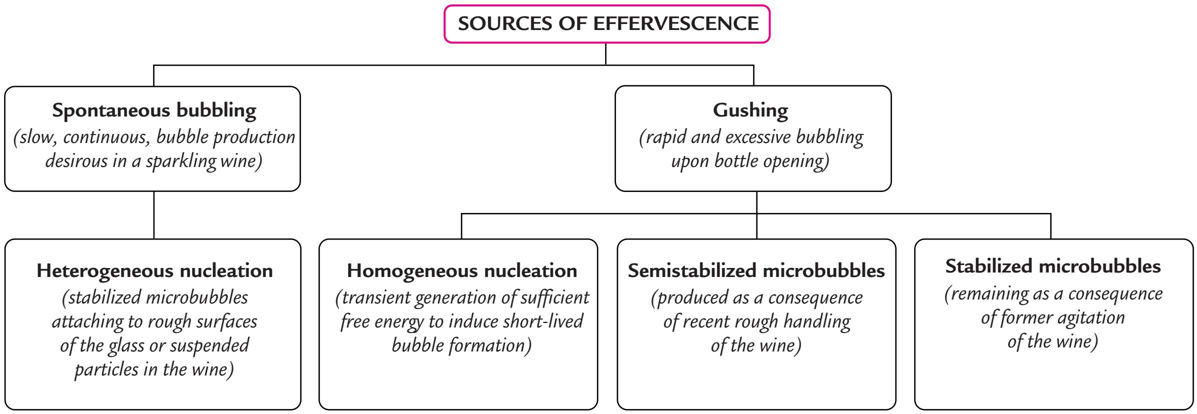


Figure 2.9 Mechanisms of effervescence (CO_2 escape) from sparkling wine (from Jackson, 2000, reproduced by permission).

falling wine. Pouring also generates microbubbles that slowly escape. However, the continuous chains of bubbles, so desired in sparkling wine, are produced by heterogenous nucleation. The gas nuclei start to form on rough surfaces of the glass and suspended particles in the wine. Heterogenous nucleation accounts for about 60% of the CO_2 released over an hour. In contrast, gushing, the sudden to explosive release of carbon dioxide, results from a number of separate processes. Mechanical shock waves or rapid pouring provides sufficient energy to weaken the bonds between water and carbon dioxide. As the bubbles reach a critical size, they incorporate more CO_2 than they lose, and enlarge as they rise. In addition, semistabilized to stabilized microbubbles, previously generated in the bottle, are ready to enlarge explosively if sufficient free energy is provided.

Another important feature in assessing the quality of sparkling wines is the accumulation of a small mound of bubbles in the center of the glass (*mousse*), and a ring of bubbles (*cordon de mousse*) along the meniscus at the air–wine–glass interface. Prolonged duration of the mousse, as in the head on beer, is undesirable. The durability of these formations is largely dependent on the nature of surfactants, which decrease surface tension (such as soluble proteins, polyphenols, and polysaccharides). They originate as degradation products of yeast autolysis. Their concentration in the wine increases two to three times within the first year of maturation, following the second CO_2-producing fermentation. Gravity removes fluid from between the bubbles, causing them to fuse with one another and take on angular shapes. As their size increases so does their tendency to break.

Tears

After swirling, droplets form and slide down the sides of the glass (Fig. 2.10). These have variously been termed *tears*, *legs*, or *rivulets*. They form when alcohol evaporates

Figure 2.10
Illustration of the flow of wine up a wine glass (lower arrows) and the formation of "tears." These begin to flow down the sides as ethanol escapes from the thin film of wine adhering to the glass, (upper arrows) that results in an increase of surface tension of the remaining water.

from the film of wine coating the inner surfaces of the glass. Because ethanol evaporates more rapidly than other constituents, the surface tension of the film increases. This increases the tendancy of water molecules to pull together, inducing droplets to form. As the mass of these droplets increases, they start to sag, producing *arches*. Finally, the drops slide down, forming the tears. On reaching the surface of the wine, fluid is lost and the drop may pull back. Without repeated swirling, the rim of the film descends, eventually reaching the level of the meniscus around the sides of the glass.

Once formed, the increased surface tension created by alcohol evaporation may pull wine up the sides of the glass (Neogi, 1985). Cooling produced by alcohol evaporation activates the generation of convection currents that facilitate drawing wine up the glass. The duration of tear formation depends on factors affecting the rate of evaporation, such as temperature, alcohol content, and the liquid/air interface. Contrary to popular belief, glycerol neither significantly affects nor is required for tear formation. Movement of wine up the sides of the glass can be demonstrated by adding a drop of food coloring, or nonwettable powder, to wine after tears have formed.

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Olfactory system

3

Olfactory system

Nasal passages

The olfactory region consists of two small patches in the upper portion of the nasal passages (Fig. 3.1). Volatile compounds reach the olfactory epithelium either directly, via the nostrils (orthonasal), or indirectly, from the back of the throat (retronasal). The latter route is especially important in the generation of what is termed flavor.

The nasal passages are bilaterally divided by a central septum into right and left halves. The receptors in each patch send signals to corresponding halves of the olfactory bulb, located directly above, at the base of the brain. Some experiments suggest that the right hemisphere may possess greater odor discrimination than the left hemisphere (Zucco and Tressoldi, 1988). This may explain the greater discriminatory skill occasionally attributed to the right nostril (Zatorre and Jones-Gotman, 1990).

Each nasal passage is further incompletely subdivided transversely by three outgrowths—the turbinate bones. These increase contact between the epithelial lining of the nasal passages and incoming air. The baffle-like bones induce turbulence,

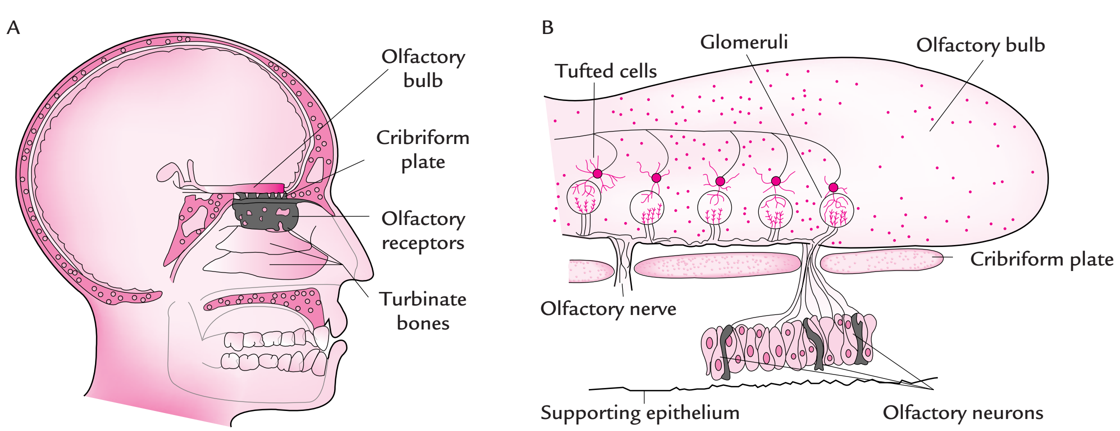

Figure 3.1 Olfactory system. (A) Location of the olfactory region in the nasal cavity and (B) an enlarged section (not to scale) showing the olfactory neurons (receptors) and their connections to the olfactory bulb (from Jackson, 2000, reproduced by permission).

warming, and cleaning of the air, but they restrict air flow to the olfactory regions. It is estimated that in ordinary breathing, only about 5 to 10% of inhaled air passes the olfactory patches (de Vries and Stuiver, 1961). Even at high rates of air intake, the value may increase to only 20%. Although higher flow rates may enhance odor perception (Sobel *et al*., 2000), the duration (Fig. 3.2), number, or interval between sniffs (Fig 3.3) apparently does not greatly affect perceived odor intensity. The usual recommendation to take short, swift, sniffs probably has more to do with avoiding odor adaptation than enhancing odor perception.

In several mammals, lateral nasal glands in the nose discharge an odor-binding protein (olfactomedin) into the stream of air passing into the nose (Snyder *et al*., 1991). The protein binds nonspecifically to volatile compounds, and it is carried with the air stream into the nasal passages. The binding protein is lipophilic and it may promote the deposition and absorption of aromatic compounds onto the olfactory epithelium. The protein is also synthesized by glands associated with the olfactory epithelium. This may partially explain the concentration of odorant molecules (10^3 to 10^4-fold) in the nasal mucus versus the inflowing air stream (Senf *et al*., 1980). It is uncertain whether this occurs in humans.

Only a fraction of the aromatic molecules that reach the olfactory patches are absorbed by the mucus that coats the epithelium. Of these molecules, only a proportion probably diffuse through the mucus and reach reactive sites on the olfactory receptor neurons. In some animals, high concentrations of cytochrome-dependent oxygenases accumulate in the olfactory mucus (Dahl, 1988). These enzymes catalyze a wide range of reactions, and may increase the hydrophilic properties of odorants, or facilitate their release from the mucous coating of the olfactory epithelium. The mucous layer is replaced about every 10 min.

Olfactory epithelium, receptor neurons, and connections with the brain

The olfactory epithelium consists of a thin layer of tissue covering an area of about 2.5 cm^2 on each side of the nasal septum. Each region contains about 10 million receptor neurons, and associated supporting and basal cells (Fig. 3.4). Receptor

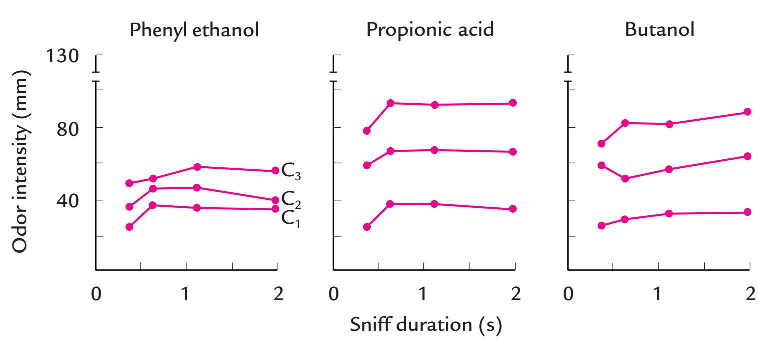

Figure 3.2 The perceived intensities (expressed as mm along a scale) of three concentrations (C_1, C_2 and C_3) of each of three odorants plotted as a function of the duration of a sniff (from Laing, 1986, reproduced by permission).

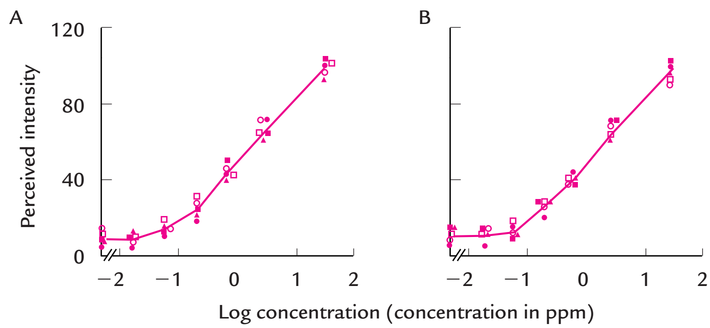

Figure 3.3 Arithmetic means of estimates of the perceived odor intensity of different concentration of pentyl acetate. These were obtained by having subjects use (A) their natural sniffing technique (●) or one (■), three (□), five (△), or seven (○) natural sniffs; (B) natural sniffing (●) or three natural sniffs separated by intervals of 0.25 s (■), 0.5 s (□), 1.0 s (○), and 2.0 s (△) (from Laing, D. G. (1983). Natural sniffing gives optimum odour perception for humans. *Perception* **12**, 99–117, Pion Limited, London. reproduced by permission).

neurons are specialized nerve cells that respond to aromatic compounds. Supporting cells (and the glands underlying the epithelium) produce a special mucus and several classes of odorant-binding proteins (Hérent *et al*., 1995; Garibotti *et al.*, 1997). Basal cells differentiate into receptor neurons and replace them as they degenerate. Receptor neurons remain active for an indefinite period, averaging about 60 days, but possibly functioning for up to 1 year. Differentiating basal cells produce extensions that grow through openings in the skull (cribriform plate) to connect with the olfactory bulb. These nonmyelinated extensions (axons) associate into bundles as they pass through the cribriform plate. In humans, olfactory and gustatory neurons are the only nerve cells known to regenerate regularly[1]. Supporting cells electrically isolate adjacent receptor cells and help maintain normal function.

Olfactory neurons show a common cellular structure. Therefore, odor quality, the unique perceived characteristics of an odorant, is not associated with obvious cellular differentiation of receptor neurons. Recognition is believed to occur on the dendritic extensions (cilia) that develop on the surface of receptor cells (Fig. 3.5A). The receptor cell forms a swelling called the olfactory knob (Fig. 3.5B). From it project up to twenty 1–2 μm-long, hair-like cilia. These markedly increase the surface area over which odorants can react with the odor-binding proteins on the receptor membrane.

Odor quality is thought to arise from the differential sensitivity of receptor neurons to aromatic compounds. Sensitivity appears to reflect the presence of a unique family of proteins (odor-binding or G-proteins[2]) produced by the olfactory epithelium (Buck and Axel, 1991). About a thousand unique G-proteins are produced, but only one is synthesized by any one type of receptor cell. The olfactory receptor gene cluster constitutes the largest known gene family in mammals (Fuchs *et al*., 2001), and it may constitute about 1 to 2% of the human genome (Buck, 1996). The

[1] Evidence is accumulating that nerve growth occurs in the adult human brain.

[2] GTP-regulated proteins.

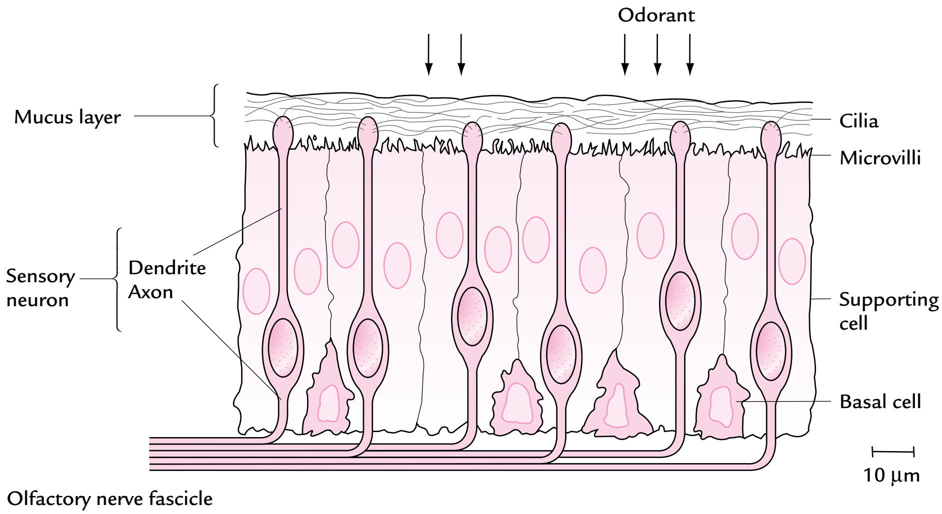

Figure 3.4 Drawing of the olfactory neuroepithelial layer (from Lancet, 1986. With permission from the *Annual Review of Neuroscience,* Volume 9. © 1986 by Annual Reviews www.AnnualReviews.org).

proteins possess seven domains, each of which spans the cell membrane. Their presence on the olfactory cilia ideally positions them to associate with odorants in a receptor–odorant complex. Each of these odor-binding proteins bears several variable regions, each of which may bind a different odorant. Thus, individual receptor proteins (and their associated neurons) can bind with several odorants. Equally,

A

B

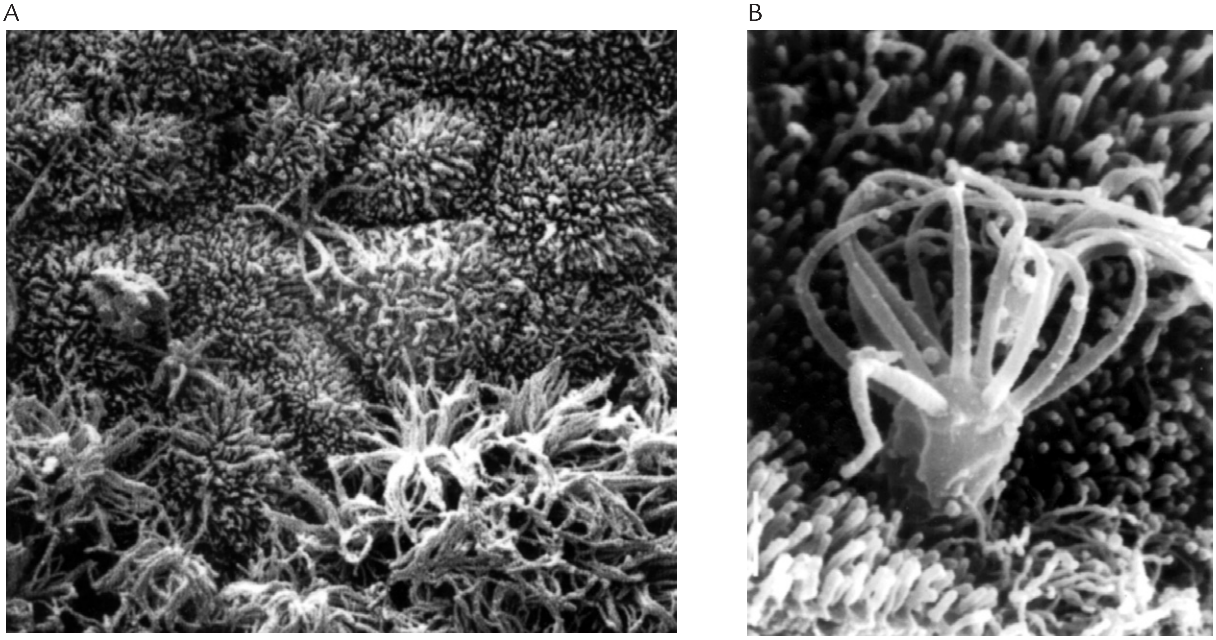

Figure 3.5 Scanning electron micrographs of (A) the human olfactory mucosal surface and (B) olfactory dendritic knobs and cilia (photos courtesy of Drs Richard M. Costanzo and Edward E. Morrison, Virginia Commonwealth University).

most odorants probably activate sites on more than a single type of receptor protein (Fig. 3.6). Odor identity appears to depend on the specific combination of stimuli activated by several receptor proteins on distinct receptor cells (Fig. 3.7). This is analogous to the production of a musical chord on a piano. In addition, different concentrations of a compound may activate a different range of receptor proteins. This may clarify why the perceived aromatic character of a compound may change with its concentration. Reaction between an olfactory receptor G-protein and an odorant induces an influx of calcium, typical of most nerve stimulation (Murrell and Hunter, 1999). A further level of sophistication in the olfactory response involves inhibitory circuits. This modulation of nerve response may elucidate why odor mixtures occasionally generate reactions not predicted from the response of their individual components (Christensen *et al*., 2000).

There is evidence suggesting that cells showing similar sensitivities to odorants have unique spacial distributions on the olfactory epithelium (Scott and Brierley, 1999). Selective reproduction of specialized subclasses of basal cells, producing one or a few selective G-protein(s), may account for the increased sensitivity to an odorant on repeat exposure to it (Wysocki *et al*., 1989).

On stimulation, an electrical impulse rapidly moves along the filamentous extensions (axons) of the receptor neuron, toward the olfactory bulb. Olfactory receptor cells are the only sensory neurons that directly synapse with the forebrain, without initially passing via the thalamus. In the olfactory bulb, bundles of receptor axons terminate in spherical regions called glomeruli. Each glomerulus is enervated by about 25,000 receptor neurons. The axons associated with a particular glomerulus

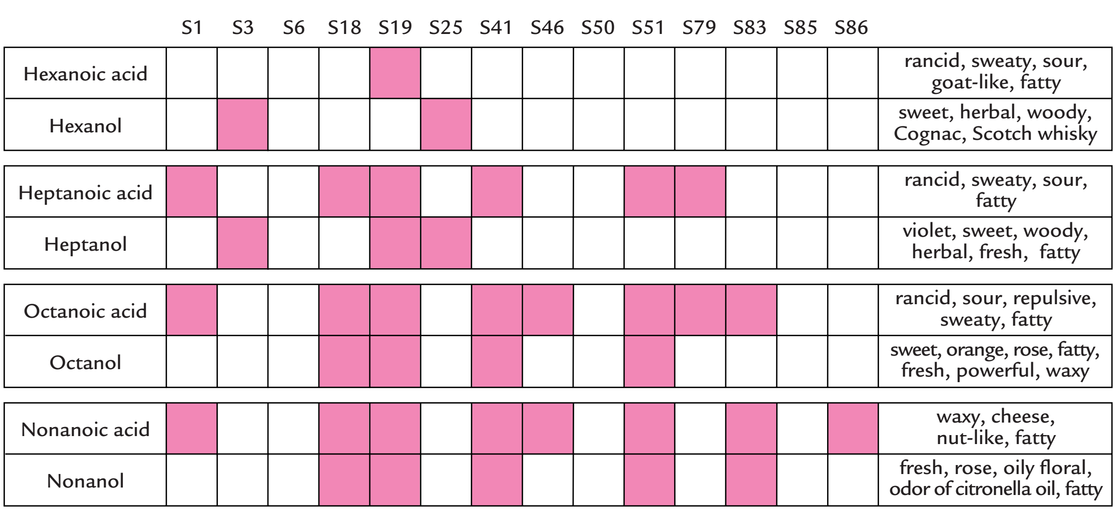

Figure 3.6 Comparison of the receptor codes for odorants that have similar structures but different odors. Aliphatic acids and alcohols with the same carbon chains are recognized by different combinations of olfactory receptors (S1–S86), thus providing a potential explanation for why they are perceived as having strikingly different odors. Perceived odor qualities shown on the right were obtained from Arctander (1969), The good Scents Company (http:///www.execpc.com/~goodscnt/Index.html), and The Chemfinder Web Server (http://chenfinder.camsoft.com) (Reprinted from *Cell*, **96**, Malnic, B., Hirono, J., Sato, T., and Buck, L. B. (2000). Combinatorial receptor codes for odors. 713–723. With permission from Elsevier Science).

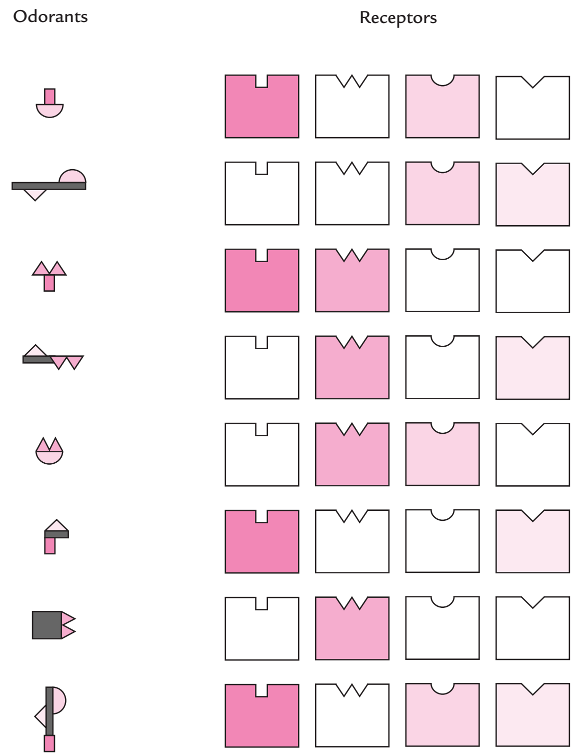

Figure 3.7 Model for the combinatorial receptor codes for odorants. The receptors shown in color are those that recognize the odorant on the left. The identities of different odorants are encoded by different combinations of receptors. However, each olfactory receptor can serve as one component of the combinatorial receptor codes for many odorants. Given the immense number of possible combinations of olfactory receptors, this scheme could allow for the discrimination of an almost unlimited number and variety of different odorants. (Reprinted from *Cell*, **96**, Malnic, B., Hirono, J., Sato, T., and Buck, L. B. (2000). Combinatorial receptor codes for odors. 713–723. With permission from Elsevier Science).

come from olfactory receptor cells responding to the same odorant(s) (Buck, 1996; Mori *et al*., 1999). Within the glomeruli, the axons synapse with one or more of several types of nerve cells (mitral and tufted cells) in the olfactory bulb.

The olfactory bulb is a small bilaterally lobed portion of the brain that collects and edits the information received from receptor cells in the nose. From here, impulses are sent via the lateral olfactory tract to the hypothalamus and other centers of the limbic system. Subsequently, signals pass on to the thalamus and higher centers in the brain, notably the orbitofrontal cortex. It is in the orbitofrontal cortex that neurons from the taste, odor and visual centers of the brain intermingle (Fig. 3.8). It is hypothesized that the orbitofrontal cortex is the origin of the complex perception called flavor.

In may be in the orbitofrontal cortex that learned associations elicit the perceived sweetness of some aromatic compounds. Stevenson *et al.* (1999) have shown that odorants with the strongest connection with sweetness had the greatest influence on enhancing the sweet taste of sugars. The same aromatics also had the greatest

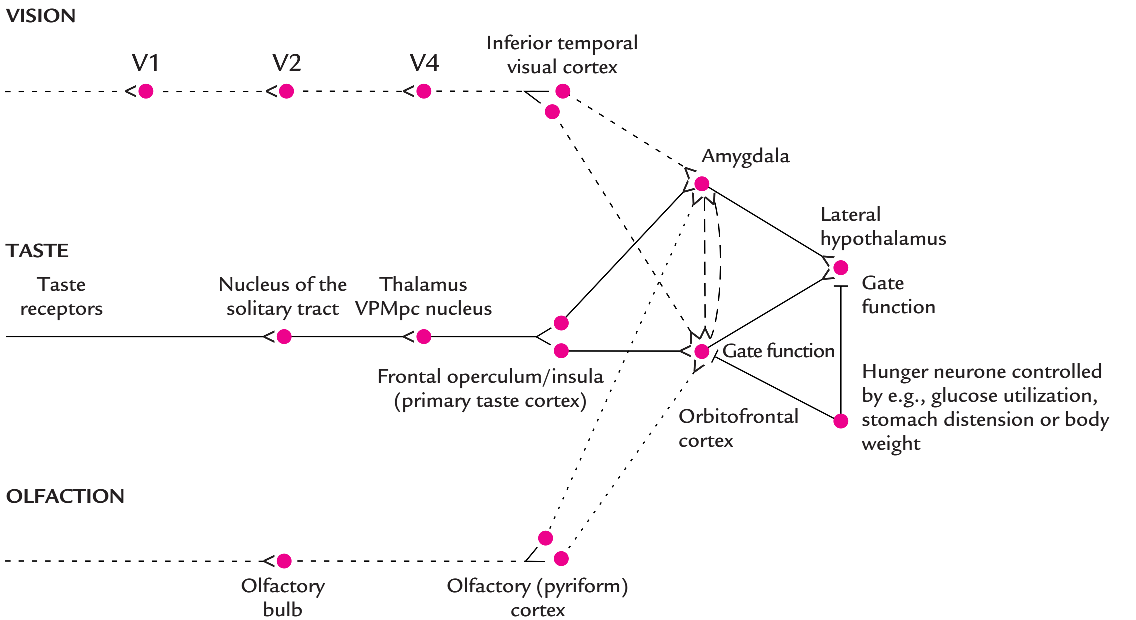

Figure 3.8 Schematic diagram of the taste pathways in primates showing how they converge with olfactory and visual pathways. The gate functions shown refer to the finding that the responses of taster neurons in the orbitofrontal cortex and the lateral hypothalamus are modulated by hunger. VPMpc, ventral posteromedial thalamic nucleus: V1, V2, V4 visual cortical areas (Reprinted from Rolls, E. T. (1995). Central taste anatomy and neurophysiology. *In*: "Handbook of Olfaction and Gustation" (R. L. Doty, ed.), pp. 549–573. Marcel Dekker Inc., N.Y., by courtesy of Marcel Dekker Inc).

influence on reducing the sourness of citric acid. Figure 3.9 shows the effect of strawberry odor on sweetness.

Odorants and olfactory stimulation

There is no precise definition of what constitutes an olfactory compound. Based on human perception, there are thousands of olfactory substances, involving many chemical groups. For air-breathing animals, an odorant must be volatile (pass into a gaseous phase at normal temperatures). Although this places an upper limit on molecular size (≤300 daltons), low molecular weight implies neither volatility nor aromaticity. Most aromatic compounds have strong hydrophobic (fat-soluble) and weak polar (water-soluble) sites. They also tend to bind weakly to cellular constituents and dissociate readily.

It appears that several molecular properties are involved in olfactory stimulation (Ohloff, 1986). These include electrostatic attraction, hydrophobic bonds, van der Waals forces, hydrogen bonding, and dipole–dipole interactions. Small structural modifications, such as those found in stereoisomers, can markedly affect the relative intensity and perceived quality of related odorants. For example, D- and L-carvone

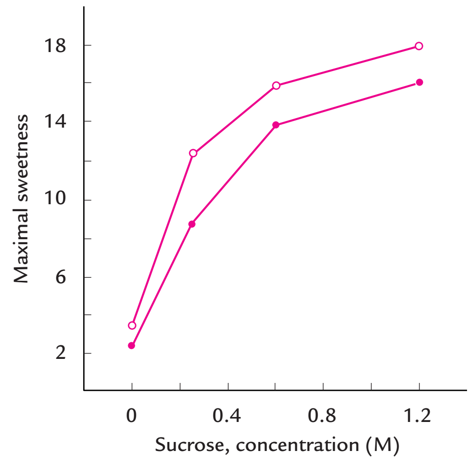

Figure 3.9 Perceived sweetness as affected by the presence or absence of fragrance (●, no odour; ○, strawberry odor) (from Frank, R. A. and Bryam, J. (1988). Taste–smell interactions are tastant and odorant dependent. *Chem. Senses* **13**, 445–455. Reproduced by permission of Oxford University Press).

stereoisomers possess spearmint-like and caraway-like qualities, respectively. In a few cases, sensitivity to a series of chemically related odorants (e.g., pyrazines) correlates with their ability to bind to proteins of the olfactory epithelium (Pevsner *et al.*, 1985).

Compounds possessing similar odors, and belonging to the same chemical group, appear to show competitive inhibition. This phenomenon, called cross-adaptation, results in suppressed detection of an odorant by prior exposure to a related odorant. Mixtures of different odorant groups usually retain their odor qualities, but at reduced intensities. However, at low concentrations, they may act synergistically and enhance mutual detection (Fig. 3.10). This can benefit detection of desirable aromatics, but it can also enhance the perception of off-odors (Selfridge and Amerine, 1978). Occasionally, a mixture of aromatic compounds generates an odor quality seemingly unrelated to those of its components (Laing and Panhuber, 1978). These reactions, combined with human variability in sensitivity, partially explain why people differ so frequently in their responses to wines.

Chemical groups involved

The major chemical constituents in wine generate gustatory rather than olfactory influences. In contrast, minor or trace constituents produce a wine's distinctive aromatic characteristics. For example, most wine phenolics (e.g., tannins) induce gustatory sensations, whereas trace phenolics (e.g., vinyl phenols, syringaldehyde) are often aromatic. The primary exception is ethanol. Although principally inducing mouth-feel sensations, ethanol also possesses a mild but distinctive odor.

Volatility, an essential attribute of an odorant, is influenced by many factors. One of the more important of these involves nonvolatile wine constituents. For example,

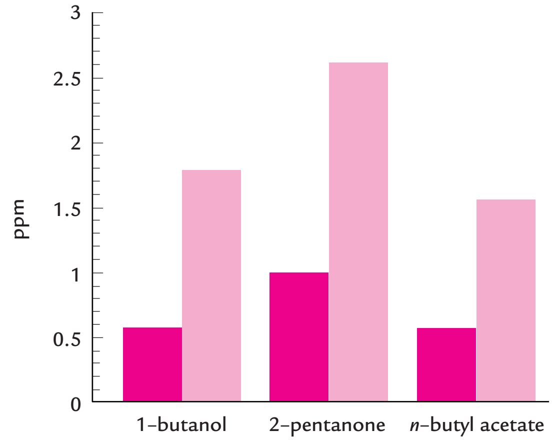

Figure 3.10 Mean thresholds of detection for 1-butanol, 2-pentanone, and *n*-butyl acetate alone (■) and in a mixture of all three compounds (■). Data from 40 subjects (from Patterson, M. Q., Stevens, J. C., Cain, W. S., and Cometto-Muñiz, J. E. (1993). Detection thresholds for an olfactory mixture and its three constituent compounds. *Chem. Senses* **18**, 723–734. Reproduced by permission of Oxford University Press).

mannoproteins bind important flavorants such as β-ionone, ethyl hexanoate, and octanal, as well as enhance the volatility of others such as ethyl octanoate and ethyl decanoate (Lubbers *et al*., 1994). Sugars (Sorrentino *et al*., 1986) and ethanol content (Williams and Rosser, 1981) can also influence volatility.

Acids

The most significant volatile acid, acetic acid, is also the most common. Other volatile acids, such as formic, butyric, and propionic acids occur, but seldom at above threshold levels. All of these acids have marked odors—acetic acid being vinegary; formic acid having a strong pungent odor; propionic acid possessing a fatty smell; butyric acid resembling rancid butter; and C_6 to C_{10} carboxylic acids possessing a goaty odor. Correspondingly, volatile acids are typically associated with off-odors. A partial exception is acetic acid. It can add complexity to the bouquet at threshold levels, but above its recognition threshold (300 mg/l), it becomes a major fault.

The major wine acids, notably tartaric and malic, are nonvolatile. Lactic acid has a mild odor but it is seldom of sensory significance. These acids may indirectly play a role in wine fragrance via their participation in the formation of aromatic esters.

Alcohols

The mild fragrance of ethanol has already been noted. Nevertheless, the most significant aromatic alcohols are higher alcohols. These are chemically related to ethanol, but have carbon chains three to six carbons long. Examples such as 1-propanol, 2-methyl-1-propanol (isobutyl alcohol), 2-methyl-1-butanol, and 3-methyl-1-butanol (isoamyl alcohol) tend to have fusel odors, whereas hexanols possess a herbaceous scent. The major phenol-derived alcohol, 2-phenylethanol (phenethyl alcohol), has a rose-like aspect.

The higher alcohols most commonly found in wine have a strong pungent odor. At low concentrations (~0.3 g/l or less), they add complexity to the bouquet. At higher levels, they increasingly dominate the fragrance. It is only in port that a fusel character is considered a positive quality attribute. This property comes from the fortifying brandy added during its production. (In distilled beverages, such as brandies and whiskeys, fusel alcohols give the beverage much of its distinctive fragrance.) Although most higher alcohols are yeast by-products, *Botrytis cinerea* produces an important mushroom alcohol (1-octen-3-ol) (Rapp and Güntert, 1986).

Aldehydes and ketones

Acetaldehyde is the major vinous aldehyde. It often constitutes more than 90% of the wine's aldehyde content. Above threshold values, acetaldehyde is considered an off-odor. Combined with other oxidized compounds, it contributes to the traditional bouquet of sherries and other oxidized wines. Furfural and 5-(hydroxymethyl)-2-furaldehyde are other aldehydes having a vinous sensory impact. Their caramel-like aspects are most evident in baked wines.

Phenolic aldehydes, such as cinnamaldehyde and vanillin, may accumulate in wines matured in oak. Other phenolic aldehydes, such as benzaldehyde, may have diverse origins. Its bitter-almond odor is considered characteristic of certain wines, for example, those from *Gamay* grapes.

Although not having a direct sensory effect, hydroxypropanedial (triose reductone) characteristically occurs in botrytized wines (Guillou *et al.*, 1997). It exists in a tautomeric equilibrium between 3-hydroxy-2-oxopropanal and 3-hydroxy-2-hydroxypro-2-enal. Reductones, such as hydroxypropanedial, can play a role in preserving a wine's fragrance by fixing (slowing volatile loss of) its aromatic constituents.

Many ketones are produced during fermentation, but few appear to have sensory significance. The major exception is diacetyl (biacetyl, or 2,3-butanedione). At low concentrations, diacetyl donates a buttery, nutty, or toasty flavor. However, at much above its sensory threshold, diacetyl generates a buttery, lactic off-odor. This commonly occurs in association with spoilage induced by certain strains of lactic acid bacteria.

Acetals

Acetals form when an aldehyde reacts with the hydroxyl groups of two alcohols. They generally possess vegetal odors. Because they form primarily during oxidative aging and distillation, they tend to occur only in wines like sherry, or in brandies.

Esters

Over 160 esters have been isolated from wine. Because most esters occur only in trace amounts, and they have either low volatility or mild odors, their importance to wine fragrance is negligible. However, the more common esters occur at or above their sensory threshold. Because some of these have fruity aspects, they can be an important factor in the bouquet of young wines.

The most significant esters found in wine are formed between ethanol and short-chain fatty acids; acetic acid and various short-chain alcohols; and nonvolatile acids and ethanol. Several other ester groupings occur, but in most instances they have no sensory significance.

Ethyl acetate, formed by a dehydration reaction between ethanol and acetic acid, is the most significant. In sound wines, its concentration is generally below 50 to 100 mg/l. At low levels (<50 mg/l), it may add to a wine's complexity. At levels above 150 mg/l, ethyl acetate generates an acetone-like off-odor (Amerine and Roessler, 1983).

Other than ethyl acetate, the major ethanol-based esters are those formed with higher alcohols, such as isoamyl and isobutyl alcohols. These lower-molecular-weight esters are often termed "fruit" esters because of their fruit-like fragrances. For example, isoamyl acetate (3-methylbutyl acetate) has a banana-like scent, whereas benzyl acetate has an apple-like aspect. They play a significant role in the bouquet of young wines (Vernin *et al.*, 1986). As the length of the hydrocarbon chain increases, the odor shifts from being fruity to soap-like and, finally, lard-like with C_{16} and C_{18} fatty acids. The presence of certain of these esters, for example, hexyl acetate and ethyl octanoate, have occasionally been considered indicators of red wine quality (Marais *et al.*, 1979).

Esters of the major fixed acids in wine (tartaric, malic and lactic acids) form slowly during aging. Nevertheless, because of their weak odors, they are seldom of sensory significance. In contrast, the formation of the methanolic and ethanolic esters of succinic acid appears to contribute to the aroma of muscadine wines (Lamikanra *et al.*, 1996).

Occasionally, other esters of significance are found in grapes. The phenolic ester, methyl anthranilate, is a prime example. It contributes to the grapy essence of most *Vitis labrusca* varieties. Another is ethyl 9-hydroxynonanoate, synthesized by *B. cinerea.* It may contribute to the distinctive aroma of botrytized wines (Masuda *et al.*, 1984).

Hydrogen sulfide and organosulfur compounds

Hydrogen sulfide (H_2S) and sulfur-containing organics generally occur only in trace amounts in bottled wine—thankfully so, because they usually have unpleasant to nauseating odors. However, because their sensory thresholds are typically low (often in parts per trillion), they occasionally generate off-odors.

Hydrogen sulfide is a common by-product of yeast sulfur metabolism. At near-threshold levels, hydrogen sulfide is part of the yeasty odor of newly fermented wines. Above threshold levels it generates a putrid, rotten egg off-odor.

The simplest organosulfur compounds found in wine are the mercaptans. A significant member is ethanethiol (ethyl mercaptan). It produces a rotten onion, burnt-rubber odor at threshold levels. At higher levels, it has a skunky, fecal odor. Related thiols, such as 2-mercaptoethanol, methanethiol, and ethanedithiol, have barnyard, rotten cabbage and sulfur–rubber off-odors, respectively. 2-Mercaptoethyl acetate and 3-mercaptopropyl acetate generate the grilled, roasted meat odor occasionally associated with *Sauvignon blanc* and *Sémillon* wines (Lavigne *et al.*, 1998).

Light exposure can stimulate the reductive synthesis of organosulfur compounds in bottled wine. An example is the cooked-cabbage, shrimp-like off-odor generated by dimethyl sulfide in the *goût de lumière* taint of champagne (Charpentier and Maujean, 1981).

Although most organosulfur compounds generate off-odors, a few contribute to varietal aromas. 4-Mercapto-4-methylpentan-2-ol and 3-mercaptohexan-1-ol, for example, produce odors reminiscent of citrus zest and grapefruit, respectively. Both are important impact compounds in *Sauvignon blanc* wines (Tominaga *et al.*, 1998), whereas the first is an important odorant in *Scheurebe* (Guth, 1997). In addition, 4-mercapto-4-methylpentan-2-one plus 3-mercaptohexyl acetate contribute to the box-tree aroma of some *Sauvignon blanc* wines (Tominaga *et al*., 1996). 3-Mercapto-3-methylbutan-1-ol may also contribute an odor of cooked leeks in *Sauvignon blanc* wines.

Hydrocarbons derivatives

Several hydrocarbons in grapes generate important volatile degradation products in wine. Examples are β-damascenone (floral-like), α- and β-ionone (violet-like), and vitispirane (eucalyptus–camphor-like). Several are derived from the hydrolytic degradation of carotenoids.

Possibly the most significant hydrocarbon derivative is the norisoprenoid, 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN). After several years of in-bottle aging, the concentration of TDN can rise to about 40 parts per billion (ppb) (Rapp and Güntert, 1986). At above 20 ppb it donates a smoky, kerosene, bottle-aged fragrance.

A cyclic hydrocarbon occasionally found in wine is styrene. It can produces a taint in wine stored in plastic cooperage or transport containers (Hamatschek, 1982). Additional hydrocarbon taints may come from methyl tetrahydronaphthalene, implicated in some types of corky off-odors (Dubois and Rigaud, 1981).

Lactones and other oxygen heterocycles

Lactones are cyclic esters formed by internal esterification between carboxyl and hydroxyl groups. Those coming from grapes seldom contribute to varietal odors. However, one exception is 2-vinyl-2-methyltetrahydrofuran-5-one. It is probably associated with the distinctive aroma of *Riesling* and *Muscat* varieties (Schreier and Drawert, 1974). Because lactone formation is enhanced during heating, some of the raisined character of sunburned grapes may come from lactones such as 2-pentenoic acid-γ-lactone. Sotolon (4,5-dimethyl-tetrahydro-2,3-furandione) is characteristic of *Botrytis*-infected wine (Masuda *et al*., 1984), as well as sherries (Martin *et al*., 1992). It has a nutty, sweet, burnt odor.

Lactones in wine may form during fermentation or aging, but the most common are extracted from oak. The most important of these are the oak lactones (isomers of β-methyl-γ-octalactone). Yeasts may also synthesize small amounts of these compounds. They possess oaky, coconut-like odors.

Among other heterocyclic compounds, vitispirane appears to be the most significant (Etiévant, 1991). Vitispirane forms slowly during aging, reaching concentrations of 20 to 100 ppb. Its two isomers have different odors. The *cis*-isomer has a chrysanthemum flower–fruity odor, whereas *trans*-vitispirane has a heavier, exotic, fruit-like scent.

Terpenes and oxygenated derivatives

Terpenes provide the characteristic fragrance of many flowers, fruits, seeds, leaves, woods, and roots. Chemically, terpenes are composed of two or more basic five-carbon isoprene units. Unlike many other wine aromatics, terpenes are primarily derived from grapes (Strauss *et al*., 1986). Only those that occur free (unbound to sugars) contribute to wine fragrance.

Terpenes contribute to the varietal character of several important grape varieties, most notably members of the *Muscat* and *Riesling* families. Other cultivars produce terpenes, but they appear to play little role in their varietal distinctiveness (Strauss *et al*., 1987).

Although terpenes are unaffected by fermentation, grape infection by *B. cinerea* both reduces and modifies their terpene content. This undoubtedly plays a major role in the loss of varietal character in most botrytized wines (Bock *et al*., 1988).

During aging, the types and proportions of terpenes found in wines change significantly (Rapp and Güntert, 1986). Although some increase results from the breakdown of glycosidic bonds, losses caused by oxidation are more common. In the latter reactions, most monoterpene alcohols are replaced by terpene oxides. These have sensory thresholds approximately 10 times higher than their precursors. In addition, these changes usually affect odor quality. For example, the muscaty, iris-like odor of linalool is progressively replaced by the musty, pine-like scent of α-terpineol. Other changes can modify the structure of wine terpenes. Some terpenes become cyclic and form lactones, for example, 2-vinyl-2-methyltetrahydrofuran-5-one (from linalool oxides). Other terpenes may transform into ketones, such as α- and β-ionone, or spiroethers such as vitispirane.

Although most terpenes have pleasant odors, some produce off-odors. A prime example is the musky-smelling sesquiterpenes produced by *Penicillium roquefortii* in cork (Heimann *et al.*, 1983). *Streptomyces* species may also synthesize earthy-smelling sesquiterpenes in cork or cooperage wood.

Phenolics

The most important grape-derived volatile phenolic is methyl anthranilate. It is an important aroma component of most *V. labrusca* varieties. Another significant volatile phenolic is 2-phenylethanol, which produces the rose-like fragrance typical of some *V. rotundifolia* cultivars.

Although several phenolics may contribute to the varietal aroma of a few cultivars, the most significant are the hydroxycinnamic esters generated during fermentation or from oak cooperage. Hydroxycinnamates can also be metabolized to volatile phenols by spoilage microbes. Their derivatives, vinylphenols (4-vinylguaiacol and 4-vinylphenol) and ethylphenols (4-ethylphenol and 4-ethylguaiacol) can donate spicy, pharmaceutical, clove-like odors and smoky, phenolic, animal, stable-like notes, respectively. Off-odors are frequently detected when ethylphenol contents exceed 400 μg/l, or 725 μg/l for vinylphenols. Eugenol, another clove-like derivative, can also occur in wine. At usual concentrations, eugenol generally adds only a spicy note. Another derivative, guaiacol, has a sweet, smoky odor. It is the source of some cork-derived off-odors.

Oak cooperage is the source of several volatile phenolic acids and aldehydes. Benzaldehyde is particularly prominent and possesses an almond-like odor. Its occurrence in sherries may participate in their nut-like bouquet. Other important phenolic aldehydes are vanillin and syringaldehyde, both of which possess vanilla-like fragrances. They form during the breakdown of wood lignins. The toasting of oak staves during barrel construction is another source of volatile phenolic aldehydes, notably furfural and related compounds.

Pyrazines and other nitrogen heterocyclics

Pyrazines are cyclic nitrogen-containing compounds that contribute significantly to the flavor of many natural and baked foods. They also are important to the varietal aroma of several grape cultivars. 2-Methoxy-3-isobutylpyrazine plays a major role in the green-pepper odor often detectable in *Cabernet Sauvignon* and related cultivars, such as *Sauvignon blanc* and *Merlot*. At concentrations of about 8–20 ng/l, methoxybutylpyrazine may be desirable, but, above these values, it generates an overpowering vegetative, herbaceous aroma. Related pyrazines are present, but these generally occur at concentrations at or below their detection thresholds (Allen *et al.,* 1996).

Pyridines are another group of aromatic cyclic nitrogen compounds periodically isolated from wine. Thus far, their involvement in wine flavor appears to be restricted to the production of mousy off-odors. This odor has been associated with 2-acetyltetrahydropyridines (Heresztyn, 1986).

Sensations from the trigeminal nerve

Unlike the concentration of olfactory receptors, free nerve endings of the trigeminal nerve occur scattered throughout the nasal epithelium (excepting the olfactory patches). The nerve endings respond to low concentrations of a wide range of pungent and irritant chemicals. At higher concentrations, the receptors respond to all odorant molecules. They are less susceptible to adaptation than olfactory receptors (Cain, 1976). Because of their general responsiveness to chemicals, the trigeminal nerve engenders what is called the common chemical sense.

Most pungent chemicals react nonspecifically with sulfhydryl groups (-SH) or disulfide bridges (-S-S-) of proteins (Cain, 1985). The reversible structural changes induced in membrane proteins probably stimulate the firing of free nerve endings. Most pungent compounds also tend to have a net positive charge. In contrast, putrid compounds commonly possess a net negative charge (Amoore *et al*., 1964).

As noted, most aromatic compounds can stimulate trigeminal nerve fibers. Their stimulation induces sensations such as irritation, burning, stinging, tingling, and freshness. Volatile compounds that are strongly hydrophobic may dissolve into the lipid component of the cell membrane, disrupting cell permeability and inducing nerve firing (Cain, 1985). Stimulation of free nerve endings can also modify the perceived quality of an odorant. For example, small amounts of sulfur dioxide can be pleasing, but at high concentrations it becomes strongly irritant. Similarly, hydrogen sulfide contributes to a yeasty bouquet and fruitiness at low concentrations (~1 μg/l; MacRostie, 1974), but at slightly higher concentrations, its putrid rotten-egg odor becomes overpowering.

Vomeronasal organ

The vomeronasal organ consists of a pair of small tubular cavities lined by chemoreceptive cells, near the opening of the nose (Moran *et al.*, 1994). They respond to vomeropherins—volatile compounds that play important roles in animal social interaction. In humans, these structures appear to be vestigial, occurring infrequently and appearing to be nonfunctional (Trotier *et al*., 2000). Therefore, it seems unlikely that the vomeronasal organ plays a role in wine perception.

Odor perception

Differences in odorant perception between individuals have long been known; what is now realized is the extent of this variation (Pangborn, 1981). Variation can affect a person's ability to detect, identify, and sense odor intensity, as well as their emotional or hedonic response.

The detection threshold is defined as the concentration at which the presence of a substance just becomes noticeable. Human sensitivity to odorants varies over 10 orders of magnitude, from ethane at about 2×10^{-2} M to between 10^{-10} and 10^{-12} M for mercaptans. Even sensitivity to the same (Fig. 3.11), or chemically related compounds, may show tremendous variation. For example, the detection thresholds of trichloroanisole (TCA) and pyrazines span 4 and 9 orders of magnitude (Seifert *et al*., 1970). Threshold values also depend on the solution in which the compound is dissolved.

When the detection threshold of an individual is markedly below normal, the condition is called anosmia. Anosmia can be general, or affect only a small range of related compounds (Amoore, 1977). The occurrence of specific anosmias varies widely in the population. For example, it is estimated that about 3% of the human population is anosmic to isovalerate (sweaty), whereas 47% is anosmic to 5α-androst-

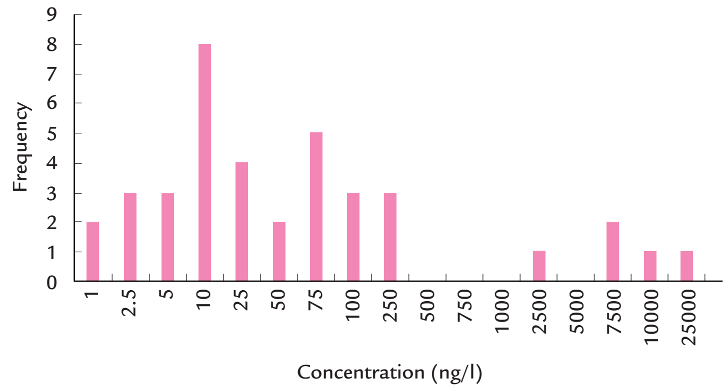

Figure 3.11 Frequency distribution for individual 2,4,6-trichloroanisole detection thresholds in *Sauvignon blanc* wine (from Suprenant and Butzke, 1996, reproduced by permission).

16-en-3-one (urinous). The genetic–neurological nature of most specific anosmias is unknown.

Hyperosmia, the detection of odors at abnormally low concentrations, is little understood. One of the most intriguing accounts of hyperosmia relates to a 3-week experience of a medical student suddenly being able to recognize people and objects by their odors (Sachs, 1985). Hyperosmia may also occur in people treated with L-dopa (a synthetic neurotransmitter), as well as in some individuals with Tourette's syndrome.

The origin of the normally limited olfactory skills of humans is unknown. It may arise from the small size of the human olfactory epithelium and olfactory bulbs. For example, dogs possess an olfactory epithelium up to 150 cm^2 in surface area (containing about 200 million receptor cells), whereas the olfactory patches in humans cover about 5 cm^2 (and possesses 6 to 10 million receptors). Comparative measurements of the odor thresholds in dogs and humans indicate that dogs possess thresholds about 100 times lower than humans (Moulton *et al.*, 1960). This may partially account for our generally poor skill at distinguishing among similar odors. In addition, there is evidence of decline in the number of functional genes coding for olfactory receptor proteins in humans (Sharon *et al.*, 1999). This may have had selective advantage in the evolution of the human nuclear family and our gregarious life-style (Stoddart, 1986). Loss of olfactory acuity, and its association with recognizing kin, territory, and sexual receptiveness, could have reduced social aggression. Feedback suppression from higher centers of the brain could also explain reduced odor sensitivity.

Detection thresholds can be affected by the presence of other volatile compounds. Compounds may act synergistically at subthreshold concentrations, mutually decreasing their respective thresholds of detection. Solvents, by affecting volatility, can also influence threshold values. Figure 3.12 illustrates how the concentration of ethanol can affect the volatility of several esters. Because enhanced volatility is greatest at low alcohol contents, its significance is largely limited to the finish and in-mouth sensations. At this point, the alcohol content may have fallen sufficiently

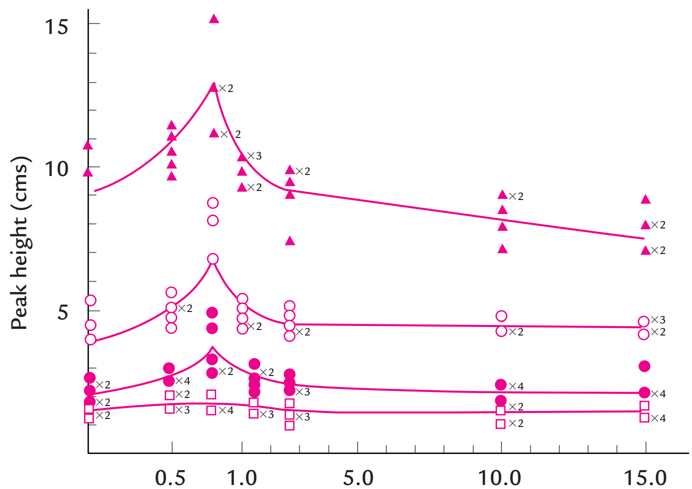

Figure 3.12 Effect of ethanol on the headspace composition (measured as peak height for each constituent) of a synthetic mixture. ●, Ethyl acetate; ○, ethyl butrate; ▲, 3-methylbutyl acetate; □, 2-methylbutanol. (from A. A. Williams and P. R. Rosser (1981). Aroma enhancing effect of ethanol. *Chem. Senses* **6**, 149–153. Reproduced by permission of Oxford University Press).

to increase volatility. Evaporation of alcohol from wine coating the sides of the glass, following swirling, also may favor the release of other odorants.

Two other olfactory thresholds are generally recognized—recognition and differentiation thresholds. The recognition threshold refers to the minimum concentration at which an aromatic compound can be correctly identified. The recognition threshold is typically higher than the detection threshold. The differentiation threshold is the concentration difference between samples required for sensory discrimination.

It is generally recognized that people have considerable difficulty identifying odors correctly, especially without visual or contextual clues (Engen, 1987). Nevertheless, it is often thought that expert tasters and perfumers have superior identification skills. Although probably true, the evidence is largely anecdotal and unquantified. In addition, such skill has little relevance to consumers unable to detect such differences. Even winemakers frequently fail to recognize their own wine in blind tastings, and experienced wine tasters frequently misidentify the varietal and geographical origin of wines (Noble *et al.*, 1984). This is easy to comprehend, in the face of the marked variability that exists within regional and varietal wines (Fig. 3.13). What is surprising is the comparative success they have. Some experienced tasters in the Department of Viticulture and Enology, Davis, CA achieved success rates of over 40% (Winton *et al.*, 1975). As expected, the most easily recognized wines were those from cultivars with pronounced aromas (e.g., *Cabernet Sauvignon*, *Petit Sirah*, *Zinfandel*, *Muscat*, *Gewürztraminer*, and *Riesling*). Peynaud (1987) notes that identifying regional styles is considerably more difficult than recognizing varietal origin.

The problems of identification become compounded when odorants occur in mixtures (Jinks and Laing, 2001). In most tests of odor recall, the sample contains a single compound or, if a mixture, the task is simply to name its source (e.g., a

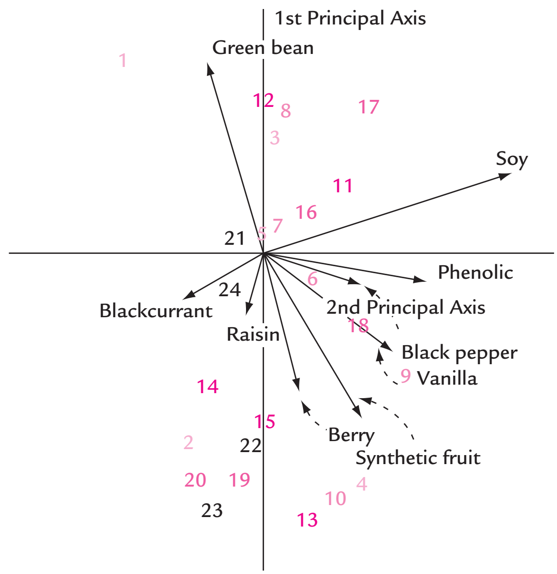

Figure 3.13 Plot of principal component scores of 24 Bordeaux wines based on nine aroma attributes: 1–5, St. Estèphe; 6–10, St. Julien; 11–15, Margaux; 16–20, St. Émilion; 21,22, Haut Médoc; 23, Médoc; 24, Bordeaux. Note the considerable dispersion in sensory attributes of these regional wines (Williams *et al.*, 1984, reproduced with permission).

particular fruit). Studies of identification ability of the individual components of a mixture are rare. Figure 3.14 illustrates the difficulty of the task. Training and expertise help, but successful identification rapidly declines as the number of components increases. Therefore, it is easy to understand why most people have difficulty correctly identifying the constituents of a wine's fragrance. Even recognizing off-odors in wine can be a severe challenge (Fig. 3.15).

Odors are often grouped by origin (e.g., floral, vegetal, smoky), or related to specific events (e.g., Christmas, springtime, location). Thus, odor terms typically are concrete, referring to an object or experience, and not to the olfactory perception itself—the more significant the event, the more intense and stable the memory. Engen (1987) views this memory pattern as equivalent to how young children associate words. Children tend to categorize objects and events functionally, rather than conceptually. For example, a hat is something one wears rather than an article of clothing. This may partially clarify why it is so difficult to use unfamiliar terms (e.g., chemical names) for familiar odors. The difficulty of correctly naming odors may arise from the localization of linguistic and olfactory processing in different hemispheres of the brain (Herz *et al.*, 1999). Humans also have difficulty in envisaging odor sensations in the mind, as we can imagine visual and aural perceptions. Verbal or contextual clues improve identification (de Wijk and Cain, 1994), but they can bias or modify opinions during a tasting. Suggesting the name of a cultivar often induces tasters to detect its odor, even in its absence. Suggestion seems to reorganize

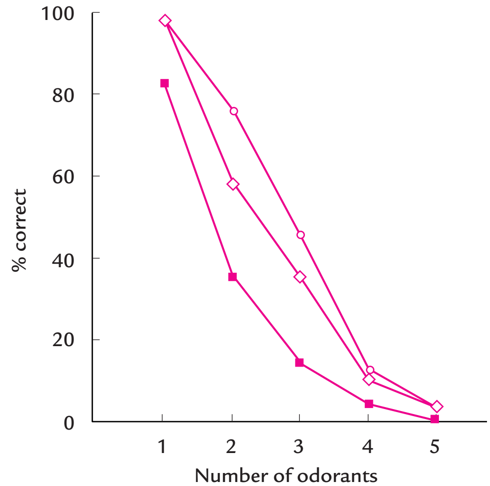

Figure 3.14 Percent correct identification of the constituents of mixtures containing up to five odorous chemicals by untrained (■), trained (◇), and expert (○) subjects (Reproduced from Laing, D. G. (1995). Perception of Odor Mixtures. *In*: "Handbook of Olfaction and Gustation" (R. L. Doty, ed.), pp. 283–297. Marcel Dekker Inc., N.Y., courtesy of Marcel Dekker Inc).

odor perception in a similar manner to that in which it reforms visual clues (Murphy, 1995). Although supplying verbal, visual, or contextual clues facilitates the identification of most odors, those learned without additional clues (e.g., the smell of toast or frying bacon) are easily recognized by odor alone.

Odor terms derived from personal experience are generally more easily recalled than those generated by others (Lehrner *et al.*, 1999a). It is important that wine tasters develop an extensive odor vocabulary to accurately express their perceptions (Gardiner *et al.*, 1996; Herz and Engen, 1996). In contrast, the terms most consumers use to describe a wine express more their emotional response to the wine than its sensory attributes (Lehrer, 1975; Dürr, 1985).

As with other attributes, perceived intensity often varies considerably. Compounds such as hydrogen sulfide or mercaptans seem intense, even at their recognition thresholds. Detectable differences in intensity vary markedly among odorants. For example, a 3-fold increase in perceived intensity was correlated with a 25-fold increase in the concentration of propanol, but a 100-fold increase in the concentration of amyl butyrate (Cain, 1978).

Sources of variation in olfactory perception

Small sex-related differences have been detected in olfactory acuity. Women are generally more sensitive to, and more skilled at identifying odors (Fig. 3.16). The types of odors identified may also show sex- (or experience-) related differences. Women generally identify floral and food odors better than men, whereas men tend to do better at identifying petroleum odors. In addition, women experience modulation in

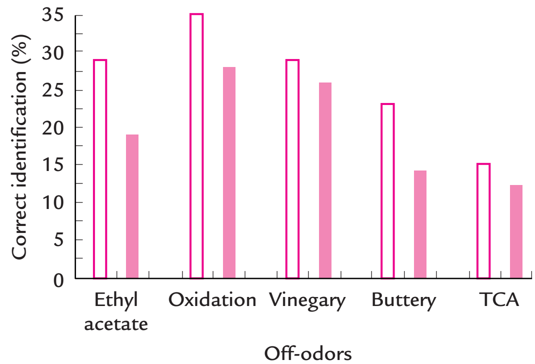

Figure 3.15 Detection of off-odors in different wines: □, white wine; ■, red wine; ethyl acetate (60 mg/l); oxidation (acetaldehyde; 67 mg/l); vinegary (acetic acid; 0.5 g/l); buttery (diacetyl; 24 mg/l); TCA (2,4,6-trichloroanisole; 15 μg/l). Based on results from 42 subjects.

olfactory discrimination, correlated with cyclical hormonal changes (see Doty, 1986).

Age also influences olfactory acuity. This expresses itself in increased detection, identification, and discrimination thresholds (Stevens *et al.*, 1984; Cowart, 1989; Lehrner *et al.*, 1999a). There is also a reduction in short-term odor memory (Lehrner *et al.*, 1999b). This seems to arise both from increased thresholds and greater difficulty in retrieving verbal labels. For example, identification skill declines by about 50% between 20 and 70 years of age (Murphy, 1995). Nevertheless, there is considerable individual diversity in all age groups (Doty *et al.*, 1984).

Reduction in the regeneration of receptor neurons probably explains much age-related olfactory loss (Doty and Snow, 1988). However, neuronal degeneration of the olfactory bulb and connections to the rhinencephalon (olfactory cortex) may be equally important. Olfactory regions frequently experience earlier degeneration than other parts of the brain (Schiffman *et al.*, 1979). This accounts for smell often being the first of the chemical senses to show age-related loss. In addition, it is clear that cognitive functions tend to decline with age. This is often particularly marked in terms of memory, such as learning odor names (Davis, 1977; Cain *et al.*, 1995). Although wine judging ability may decline with age, experience and mental concentration may compensate for sensory loss.

Nasal and sinus infection can accelerate certain degenerative changes, producing long-term acuity loss. Short-term effects involve massive increases in mucus secretion. Infection can block air access to the olfactory regions (Fig. 3.17) and diffusion to receptor neurons. The significance of the retronasal aspect of olfaction is evident in Figs 3.18 and 3.19.

Loss in olfactory ability may be associated with several major diseases, such as polio, meningitis, and osteomyelitis. Destruction of the olfactory nerve can cause total anosmia. In addition, some genetic diseases are associated with generalized anosmia, notably Kallmann's syndrome. Many medications and drugs affect smell (Schiffman, 1983). Cocaine, for example, disrupts the olfactory epithelium.

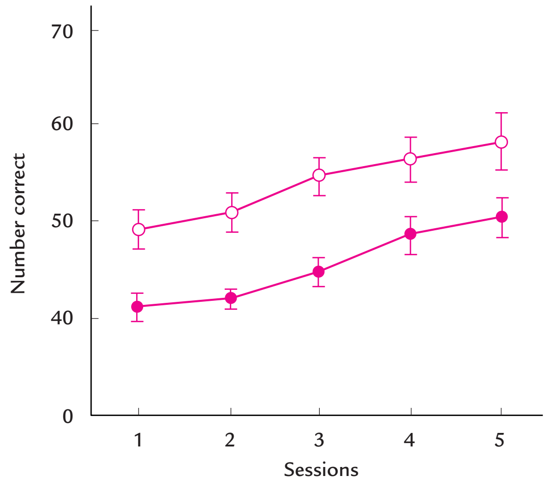

Figure 3.16 Mean number of correct odor identifications (± 1SEM) by males (●) and females (○) over the course of five sessions (from Cain, W. S. (1982). Odor identification by males and females: Predictions and performance. *Chem. Senses* **7**, 129–141. Reproduced by permission of Oxford University Press).

It is commonly believed that hunger increases olfactory acuity and, conversely, that satiation lowers it. This view is supported by a report that both hunger and thirst increase the general reactiveness of the olfactory bulb and cerebral cortex (Freeman, 1991).

Smoking produces both short- and long-term impairment of olfactory skills (Fig. 3.20). Therefore, smoking is not permitted in tasting rooms. Nonetheless, smoking has not prevented some individuals from becoming highly skilled winemakers and cellar masters.

Adaptation is an additional source of altered olfactory perception (Fig. 3.21). Adaptation can result from temporary loss in receptor excitability, reduced sensitivity in the brain, or both (Zufall and Leinders-Zufall, 2000). Generally, the more intense the odor, the longer it takes for adaptation to develop.

Because adaptation occurs rapidly (occasionally within a few seconds), the perceived fragrance of a wine may change quickly. Wine tasters are usually counseled to take only short sniffs. Normal acuity usually takes 30 s to 1 min to reestablish. Recovery frequently follows a curve similar to, but the inverse of, adaptation (Ekman *et al.*, 1967). However, with aromatically complex wines, such as vintage ports, it can be beneficial to smell the wine over an extended period. Progressive adaptation can successively reveal different components of a wine's fragrance. This view is supported by one of the few studies on adaptation in odorant mixtures (de Wijk, 1989).

The additive effect of dilute odor mixtures on decreasing sensory threshold has already been noted. For this, the odorants need not be chemically related (Fig. 3.10). This probably has considerable importance in wine, where hundreds of compounds occur at or below their respective detection thresholds. Probably of equal importance, but little investigated, is the role of odor masking (reduced perception of one odorant in the presence of another), and cross-adaptation (reduced perception of an

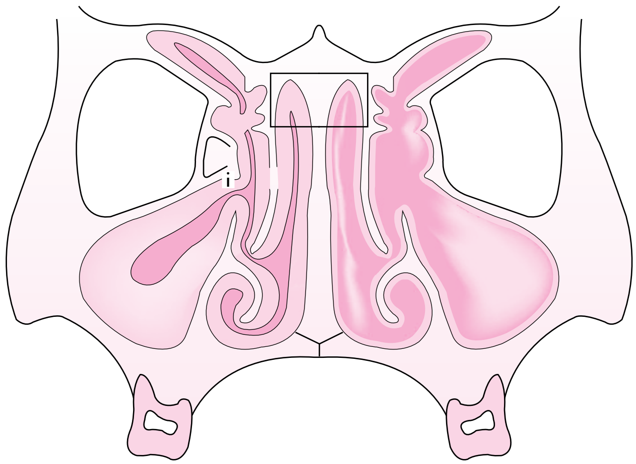

Figure 3.17 Schematic drawing (coronal) of the nasal cavity and paranasal sinuses. The left side is typical of chronic rhinitis, illustrating restricted airflow to the olfactory epithelium caused by congestion of the ostiomeatal complex. The right side resembles typical airflow. (From Smith, D. V., and Duncan, H. J. (1992). Primary olfactory disorders: Anosmia, hyperosmia, and dysosmia. *In*: "Science of Olfaction." (M. J. Serby and K. L. Chobor, eds.) pp. 439–466. Copyright Springer-Verlag, reproduced by permission).

odorant by prior exposure to another). Whether these phenomena account for the rapid decline in odor identification as the number of components increase (seen in Fig. 3.14) is unknown.

The origin of odor preferences has been little studied. Nevertheless, it appears that threshold intensity is not particularly important (Trant and Pangborn, 1983). Odor preferences tend to mature most noticeably between the ages of 6 and 12 years (Garb and Stunkard, 1974), with further significant changes occurring as one ages (Moncreiff, 1967). There are also significant age-related changes in wine partiality

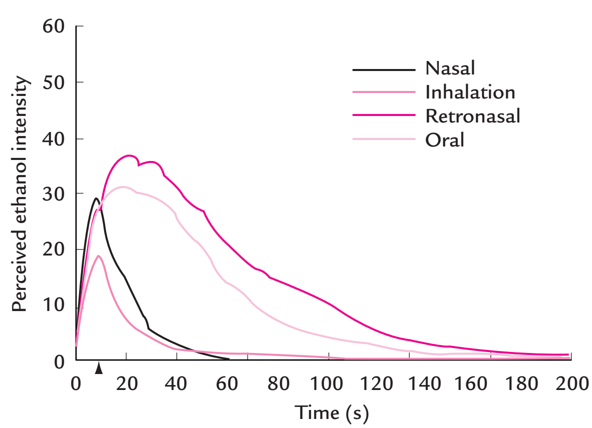

Figure 3.18 Average time–intensity curves for nasal (sniff), inhalation (inhale), retronasal (sip), and oral (sip, nose plugged) response for ethanol intensity of 10% v/v ethanol (from Lee, 1989, reproduced by permission).

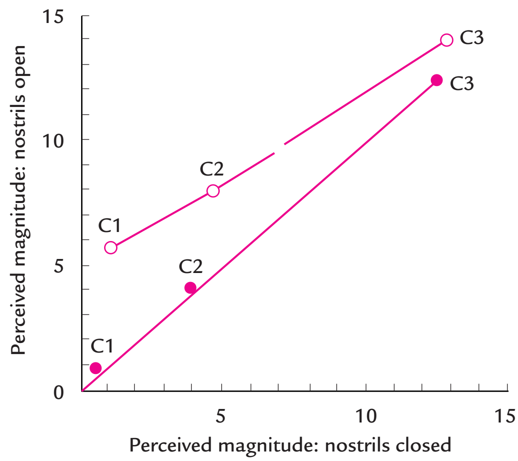

Figure 3.19 Perceived sweetness intensity of sodium saccharin (c1, 7.20×10^{-4} m; c2, 1.68×10^{-4} m; c3 3.95×10^{-4} m) in the presence (○) or absence (●) of ethyl butryate (3.70×10^{-2} % by volume) when sipped with the nostrils either open or closed (modified from Murphy *et al.*, 1977, reproduced by permission).

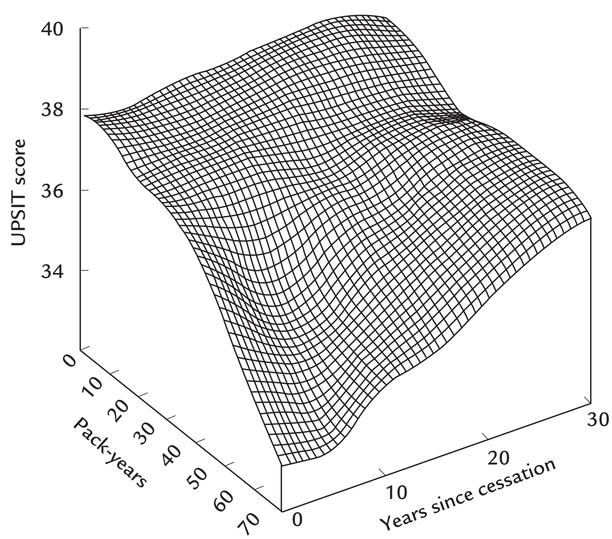

Figure 3.20 Effect of cumulative smoking dose and years since cessation from smoking for previous smokers. The individual data were fit to a distance weighted least-squares regression to derive the surface plot. Although a few subjects evidenced a smoking dose greater than 70 pack-years, the pack-year scale was limited for clarity of surface illustration. UPSIT, University of Pennsylvania Smell Identification Test (from Frye, R. E., Schwartz, B. S., and Doty, R. L. (1990). Dose-related effects of cigarette smoking on olfactory function. *J. Am. Med. Assoc.* **263**: 1233–1236. Copyrighted *(*1990*) American Medical Association*, reproduced by permission).

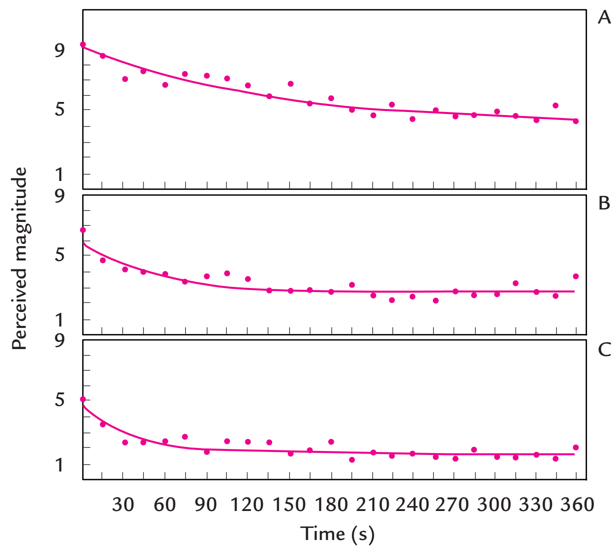

Figure 3.21 Adaptation in perceived magnitude of *n*-butyl acetate at (A) 18.6 mg/l, (B) 2.7 mg/l, and (C) 0.8 mg/l (from Cain, 1974, reproduced by permission).

(Williams *et al.*, 1982). However, these changes may relate more to experience than age itself.

Although environmental conditions significantly affect the hedonic response to odors (and wines), genetic differences in odor responsiveness are presumably involved. For example, androsterone elicits a variety of responses. People generally fall into one of three classes—those detecting androsterone at low concentration consider it extremely unpleasant (urine-like); those less sensitive often detect a sandalwood odor; whereas those insensitive express no reaction. Twin studies indicate a genetic component, with identical twins showing similar responses, whereas fraternal twins often differ. Hormonal (or genetic) factors are also probably involved in the higher proportion of women detecting androsterone than men.

Psychological factors play an important role in odor response. Knowledge of the prestige and origin of a wine often biases one's opinion. Comments from tasters, especially those with established reputations, can have a profound influence on the views of others. If these psychological influences enhance the appreciation of wine, they may be beneficial. However, they have no role in critical wine assessment.

Odor assessment in wine tasting

Assessment of wine fragrance is one of the most difficult and discriminative aspects of wine tasting. Olfaction generates the most diverse and complex perceptions found in wine. The distinctive varietal, stylistic, and aging characteristics of wines are almost exclusively aromatic. This property may be obscured in tasting sheets and score cards, where aspects of fragrance are often submerged under the term flavor. Nevertheless, it is fragrance that gives wine the majority of its consumer and market appeal.

In wine tasting, humans are primarily interested in the positive, pleasure-giving aspects of a wine's fragrance. Regrettably, little progress has been made in describing varietal, regional, or stylistic features in a format meaningful to others. Figure 1.3 provides a range of wine descriptive terms. Regrettably, the samples are a nuisance to prepare, maintain, and standardize. Even pure chemicals can contain contaminants that alter odor quality. "Scratch-and-sniff" strips would be ideal and efficient but they are commercially unavailable. In most cases, only a few descriptors are usually necessary to differentiate among particular types of wine (Lawless, 1984).

Wine fragrance is commonly subdivided into two categories, aroma and bouquet; their differentiation being based on origin. Aroma refers to odorants, or their precursors, derived from grapes. Although usually applied to compounds giving grape varieties their distinctive fragrance, aroma also includes odorants derived from grape sunburn, over-ripening, raisining, or disease. Currently, there is no evidence supporting the common belief that grapes derive specific flavors from the soil. Terms such as *flinty* and *goût de terroir* may have meaning, but they do not refer to sensory attributes coming from flint or soil, respectively.

The other major category, bouquet, refers to scents that develop during fermentation, processing, and aging. Fermentative bouquets include aromatics derived from yeast (alcoholic) or bacterial (malolactic) fermentation. Processing bouquets refer to odors derived from procedures such as the addition of brandy (port), baking (madeira), fractional blending (sherry), yeast autolysis (sparkling wines), maturation in oak cooperage, and *sur lies* maturation. Aging bouquets refer to the fragrant elements that develop during in-bottle aging.

Although the subdivision of wine fragrance into aroma and bouquet is common, it is difficult to use precisely. Similar or identical aromatics may be derived from grapes, yeast, or bacterial metabolism, or by abiotic chemical reactions. In addition, it is only with long experience that aroma and bouquet aspects can be distinguished.

Off-odors

In the absence of clear definitions of quality, it is not surprising that more is known about the chemical nature of wine faults than wines' positive attributes. This section briefly summarizes the characteristics of several important wine off-odors. Appendix 5.3 gives directions to preparing faulty wine samples for training purposes.

Quick and accurate identification of off-odors is advantageous for winemaker and wine merchant alike. For the winemaker, early remedial action can often correct the problem, before the fault becomes more serious or irreversible. For the wine merchant, avoiding losses associated with faulty wines improves the profit margin.

Consumers should also know more about wine faults. Rejection should be based only on genuine faults—not unfamiliarity, the presence of bitartrate crystals, or dryness (often incorrectly termed vinegary).

No precise definition of what makes a wine faulty exists, human perception is too variable. Nevertheless, aromatic faults destroy (mask) the wine's fragrance. The same compounds that produce faults are often desirable at or near their detection threshold. At such concentrations, they may add to the prized complexity of fine wines. In addition, when aromatically intricate, they may be an essential element in certain wines. Examples are the oxidized bouquets of sherries and the fusel odor of port. In other instances, off-odors such as barnyardy may be considered part of the *goût de terroir* of certain wines. Finally, there is personal preference. Noticeable oakiness is a fault to some, for others, it is a highly prized asset.

Oxidation

Presence of an obvious oxidized aspect is now comparatively rare in commercial table wine. Oxidation produces a flat, acetaldehyde off-odor, associated with increased color depth in white wines, or a brickish tint in red wines. In bottled wine, it can ensue from the use of faulty corks, or improper cork insertion. Rapid temperature changes can also put sufficient pressure on the cork to loosen the seal, permitting oxygen to gain access to the wine. However, the major source of premature oxidation in bottled wine is positioning the bottle upright. Ingress of oxygen follows drying and shrinkage of the cork. Even under seemingly acceptable storage conditions, most white wines may begin to show obvious oxidation after 4 to 5 years. In contrast, wine placed in bag-in-box packages often oxidizes within a year. This results from the slow infiltration of air around or through faulty spigots.

A mild form of oxidation develops within several hours of bottle opening. The same phenomenon in recently bottled wine is called "bottle sickness." It usually dissipates within several weeks. The acetaldehyde generated following oxygen uptake reacts with other wine constituents, such as flavonoids and sulfur dioxide. When the acetaldehyde content falls below its recognition threshold, the wine loses its oxidized taint.

Ethyl acetate

Wines spoilt by the presence of ethyl acetate are far less common than in the past (Sudraud, 1978). Concentrations below 50 mg/l can add a subtle fragrance. Above about 150 mg/l, it generates an acetone-like off-odor. Threshold values vary with the type and intensity of the wine's fragrance. Spoilage microbes are the most common source of ethyl acetate off-odors.

Acetic acid

Accumulation of acetic acid to detectable levels usually results from the action of acetic acid bacteria. Detection and recognition thresholds are about 100 times higher than those of ethyl acetate. Vinegary wines typically are sharply acidic, with an irritating odor derived from the combined effects of acetic acid and ethyl acetate. Ethyl acetate can accumulate from the abiotic esterification of acetic acid with ethanol. Acetic acid concentrations in wine should not exceed 0.7 g/l.

Sulfur odor

Sulfur dioxide is typically added at one or more points during winemaking or maturation. It may also be produced by wine yeasts. Nevertheless, reduced use means that sulfur dioxide seldom occurs at concentrations sufficient to produce an irritating, burnt-match odor. Even above threshold levels, a sulfur dioxide odor usually dissipates quickly as the wine is swirled.

Reduced sulfur odors

Hydrogen sulfide and several reduced sulfur organics may be produced at various stages in wine production and maturation. The putrid odor of hydrogen sulfide can usually be eliminated by mild aeration. This does not occur with off-odors generated by organic sulfide compounds. Mercaptans impart off-odors reminiscent of farmyard manure or rotten onions, whereas disulfides generate cooked-cabbage to shrimp-like odors. Related compounds, such as 2-mercaptoethanol and 4-(methylthio)butanol, produce intense barnyardy and chive–garlic odors, respectively. These compounds may be produced by spoilage microbes, but more commonly form abiotically in lees under highly reducing conditions.

Light struck

Light-struck (*goût de lumière*) refers to a reduced-sulfur odor that can develop in wine during light exposure. In champagne, it results from the combined odors of dimethyl sulfide, methyl mercaptan, and dimethyl disulfide. This fault is but one of several undesirable consequences of the exposure of wine to light.

Geranium

A geranium-like odor occasionally tainted wine in the past, because of the use of sorbate as a wine preservative. Metabolism of sorbate by certain lactic acid bacteria converted it to 2-ethoxyhexa-3,5-diene. This compound has a sharp, penetrating off-odor. As a consequence, sorbate is rarely used in wine preservation now.

Fusel

During fermentation, yeasts produce limited amounts of higher (fusel) alcohols. At concentrations close to their detection thresholds, they can add to the complexity of a wine's fragrance. If these alcohols accumulate to levels greater than about 300 mg/l, they become a negative quality factor. Nevertheless, presence of a fusel note is characteristic and expected in Portuguese ports (*porto*). It comes from the concentration of fusel alcohols during the production of the largely unrectified wine spirits used to fortify port.

Buttery

Diacetyl usually is found in wine at low concentrations as a result of yeast and bacterial metabolism. It may also be an oxidative by-product of maturation in oak barrels. Although typically considered butter-like, diacetyl is a negative quality factor above its recognition threshold. For some individuals (the author included), contaminants generated along with diacetyl give it a crushed earthworm (decomposing hemoglobin) odor.

Corky/moldy

Wines may gain corky or moldy odors from a variety of compounds. One of the most common is 2,4,6-trichloroanisole (2,4,6-TCA). It usually develops as a consequence of fungal growth on or in cork, following the use of PCP (a pentachlorophenol fungicide) on cork trees, or the bleaching of stoppers with chlorine. It produces a distinctive, musty, chlorophenol odor at a few parts per trillion. Other off-odors in cork can form following the production of sesquiterpenes by filamentous bacteria such as *Streptomyces*. Additional moldy odors in cork can result from the production of guaiacol by fungi such as *Penicillium* and *Aspergillus*. Although most moldy (corky) taints come from cork, oak cooperage can also be a source of similar off-odors.

Baked

Fortified wines, such as madeira, are purposely heated to over 45°C. Under such conditions, the wine develops a distinctive, baked, caramelized odor. Although characteristic and expected in wines such as madeira, a baked odor is a negative feature in table wines. In table wines, a baked odor is usually indicative of exposure to high temperatures during transit or storage. A baked essence can develop within a few weeks at above 35°C.

Vegetative odors

Several herbaceous off-odors have been detected in wines. The best known is that associated with the presence of "leaf" (C_6) aldehydes and alcohols. Additional sources of vegetative off-odors come from the presence of several pyrazines, notably those that characterize poor examples of *Cabernet Sauvignon* and *Sauvignon blanc* wines.

Mousy

Several *Lactobacillus* and *Brettanomyces* species generate a **mousy** taint. The odor is caused by the synthesis of several tetrahydropyridines.

Atypical aging flavor (untypischen Alterungsnote)

This off-odor possess a naphthalene-like aspect resulting from the synthesis of 2-aminoacetophenone in wine, a breakdown product of tryptophan or its byproduct IAA. Its synthesis appears to be related to unfavorable seasonal growing conditions, not microbial action.

Additional recognized off-odors include **raisined** (use of sun-dried grapes), **cooked** (wines fermented at high temperatures), **stemmy** (presence of green grape stems during fermentation), and **rancio** (old oxidized red wines). Off-odors of unknown identities or origins are **rubbery, weedy,** and **earthy**.

Chemical nature of varietal aromas

The presence of a distinctive varietal aroma is one of a wine's premium quality features. Unfortunately, aroma characteristics are not consistently expressed. They vary with the clone, environmental (Fig. 3.22), and viticultural conditions, as well as the production skills of the winemaker.

For several cultivars, specific aroma descriptors tend to epitomize the essential varietal character of the cultivar (Tables 7.1 and 7.2). In a few cases, these can be correlated with the presence of a single compound. With other cultivars, the varietal aroma is associated with the presence of several volatile compounds. In most instances, though, no particular compound, or group of compounds, has signal importance. This may be because there are no unique aroma compounds, or because we have yet to discover them.

Determination of the chemical nature of a varietal aroma is fraught with difficulties. Not only must the compounds exist in forms not modified by present-day extraction techniques, but they must occur in concentrations that make isolation and identification feasible. Isolation is easier when the compounds exist in volatile forms in both fresh grapes and the wine. Unfortunately, aroma compounds often exist in grapes as nonvolatile conjugates. These may be released only on crushing, through yeast activity, or during aging.

Even with the highly sophisticated analytical tools presently available, great difficulty can be encountered in the detection of certain groups of aromatic compounds (e.g., aldehydes bound to sulfur dioxide). The situation is even more demanding when impact compounds are labile, or occur in trace amounts.

For comparative purposes, volatile ingredients are often grouped into impact, contributing, or insignificant categories. Impact compounds induce distinctive, often varietal, fragrances. Contributing compounds add complexity, but they are not by themselves varietally unique. The acetate esters of higher alcohols that impart the fruity odor to most young white wines are examples (Ferreira *et al.*, 1995). Components of an aged bouquet would also be considered contributing compounds. Insignificant compounds constitute the vast majority of volatile wine constituents. They occur at concentrations insufficient to affect the aroma or bouquet.

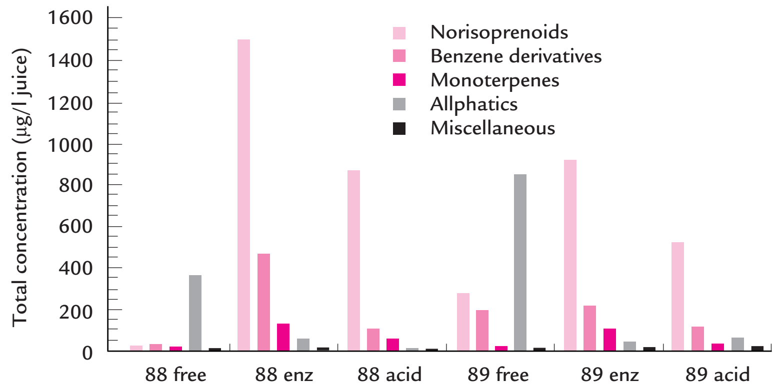

Figure 3.22 Concentration of five categories of volatiles, observed as free compounds (free) or after release by either glycosidase enzyme (enz) or acid hydrolysis (acid) of precursor fractions from the 1988 and 1989 *Chardonnay* juices (from Sefton *et al.*, 1993, reproduced by permission).

Most grape varieties do not possess varietal aromas, or their presence is as yet to be widely recognized. This may be because so few varieties have been studied sufficiently to know whether they have a distinctive aroma. For example, if the fame of *Pinot noir* were not already established, few growers or winemakers would spend the time and effort to occasionally produce a wine that shows the cultivar's potential. Nevertheless, there is a growing list of cultivars in which impact compounds have been found. The following summarizes some of what is presently known.

Several *V. labrusca* cultivars show a foxy character. This has been variously ascribed to ethyl 3-mercaptopropionate (Kolor, 1983), N-(N-hydroxy-N-methyl-γ-aminobutyryl)glycin (Boison and Tomlinson, 1988), or 2-aminoacetophenone (Acree *et al.*, 1990). Other *V. labrusca* cultivars possess a strawberry odor, probably induced by furaneol (2,5-dimethyl-4-hydroxy-2,3-dihydro-3-furanone) and its methoxy derivative (Schreier and Paroschy, 1981), or from methyl anthranilate and β-damascenone (Acree *et al.*, 1981).

The bell-pepper character of some *Cabernet Sauvignon* (Boison and Tomlinson, 1990) and *Sauvignon blanc* (Lacey *et al.*, 1991) wines is primarily a result of the presence of 2-methoxy-3-isobutylpyrazine. Isopropyl and sec-butyl methoxypyrazines are also present in *Sauvignon blanc* wines, but at lower concentrations. The source of the desirable blackcurrant fragrance of some *Cabernet Sauvignon* wines is unknown. Several thiols are potentially involved in the varietal aroma of *Merlot* and *Cabernet Sauvignon* wines (Bouchilloux *et al.*, 1998).

The spicy character of *Gewürztraminer* wines has been associated with the presence of 4-vinyl guaiacol, along with several terpenes (Versini, 1985), and *cis*-rose oxide, several lactones, and esters (Guth, 1997; Ong and Acree, 1999). Interestingly, the same compounds that give litchis their aroma are found in *Gewürztraminer* wines, giving credence to the presence of a litchi-like fragrance.

Most reduced sulfur organics have distinctly undesirable odors. Nevertheless, a few are important varietal impact compounds. For example, the fragrance of *Colombard* wines has been attributed to the presence of the mercaptan, 4-methyl-4-pantan-2-one (du Plessis and Augustyn, 1981). Other varietally distinctive thiols are 4-mercapto-4-methylpentan-2-one, 3-mercaptohexyl acetate, 4-mercapto-4- methylpentan-2-ol and 3-mercaptohexan-1-ol. They are found in *Sauvignon blanc* wines (Darriet *et al*., 1995; Tominaga *et al*., 1998). The first two donate a box-tree odor, whereas the last two may give citrus zest–grapefruit and passion fruit–grapefruit essences, respectively. 4-Mercapto-4-methylpentan-2-one is also crucial to the aroma characteristics of *Scheurebe* (Guth, 1997).

Muscat varieties are distinguished by the prominence of monoterpene alcohols in their varietal aromas. Similar monoterpene alcohols are important, but occur at lower concentrations in *Riesling* and related cultivars. The relative and absolute concentrations of these compounds, and their respective sensory thresholds, distinguish the varieties in each group.

In some instances, compounds that are varietally distinctive also occur as by-products of fermentation. An example is 2-phenylethanol, an important impact compound in muscadine wines (Lamikanra *et al.*, 1996). Isoamyl acetate, a distinctive flavorant of *Pinotage* wines, may also be derived from yeast action (van Wyk *et al*., 1979).

Several well-known, aromatically distinctive cultivars, such as *Chardonnay* (Le Fur *et al*., 1996) and *Pinot noir* (Brander *et al*., 1980) do not appear to produce distinctive impact compounds. In many cultivars, varietal distinctiveness may arise from quantitative, rather than qualitative, aromatic differences (Le Fur *et al*., 1996; Ferreira *et al*., 1998). These may be grape-derived, produced by yeast metabolism, or formed during maturation. In addition, several oak constituents are similar to grape flavorants. This may explain the observation that the varietal expression of some cultivars is enhanced by maturation in oak (Sefton *et al*., 1993).

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4 Taste and mouth-feel

Two sets of chemoreceptors in the mouth produce the perceptions of taste and mouth-feel. Specialized receptor neurons, grouped in cavities within taste buds, generate **taste** (gustatory) perceptions, notably *sweet*, *sour*, *salt*, and *bitter*. Free nerve endings scattered throughout the oral cavity generate the **mouth-feel** (tactile) perceptions of *astringency*, *touch, viscosity, burning*, *temperature*, *body*, *prickling* and *pain*. Combination of these sensations with those from the nose produces the perception called **flavor**. The olfactory component comes from volatile compounds that enter the nasal passages via the nose (orthonasal) and back of the mouth (retronasal).

By themselves, taste and mouth-feel sensations are comparatively monolithic. Their bland character is evident when a head cold clogs the nasal passages. Because odorants cannot reach the olfactory patches, food loses its usual sensory appeal. Nevertheless, balancing the oral sensations of a wine is one of the most demanding tasks for a winemaker. A distinguishing feature of superior wines is the harmony achieved among these seemingly simple sensations. Imbalances created by excessive acidity, astringency, bitterness, etc. are often the first deficiencies noted by a judge. Thus, although sensorially elementary, gustatory sensations are critical to the perception of wine quality.

In contrast to olfactory sensations (Ch. 3), taste and mouth-feel are responses to the major chemical constituents in wine—sugars, acids, alcohol, and phenolics. Tastants usually occur in the order of parts per thousand, whereas odorants may be detected down to parts per trillion.

Taste

Taste is detected by nerve-like receptors collected into flask-shaped depressions called taste buds. Specialized supporting cells line the taste buds, each of which contains up to 50 slender, columnar, receptor cells and associated neuroepithelial cells (Fig. 4.1). The latter are variously differentiating or degenerating receptor cells. Cranial nerve fibers enter the base of the taste bud and synapse with one or more receptor cells. About two thirds of the taste buds are located on the tongue, where they

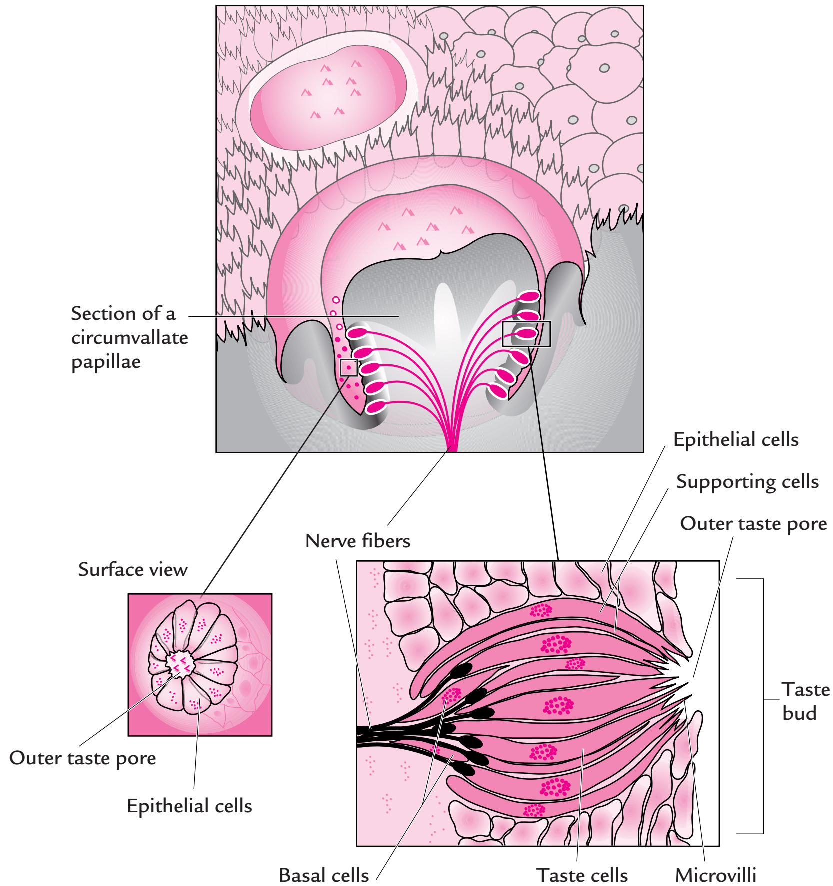


Figure 4.1 Schematic drawing of a taste bud within a circumvallate papillae. The top portion of the figure shows the location of the taste buds within the papillae, while the bottom figures show the taste bud itself (from Levine and Shefner, 1991, reproduced by permission).

are found on the sides of raised growths called papillae. The remainder occur primarily on the soft palate and epiglottis. A few may also be located on the pharynx, larynx, and upper portion of the esophagus.

Taste buds are associated with three of the four classes of papillae (Fig. 4.2). Fungiform papillae occur primarily on the front two-thirds of the tongue. These papillae are so central to gustation that their density has been directly correlated with taste acuity (Zuniga *et al*., 1993). A few, large, circumvallate papillae develop along a V-shaped zone across the back of the tongue. Foliate papillae are restricted to ridges between folds along posterior margins of the tongue. Filiform papillae are the most common class, but these contain no taste buds. Their tapering, fibrous extensions give the tongue its characteristic rough texture.

Receptor (gustatory) cells often remain active for only a few days, being replaced by differentiating adjacent neuroepithelial cells. Each receptor neuron culminates in a receptive dendrite or many fine extensions (microvilli). These project into the saliva

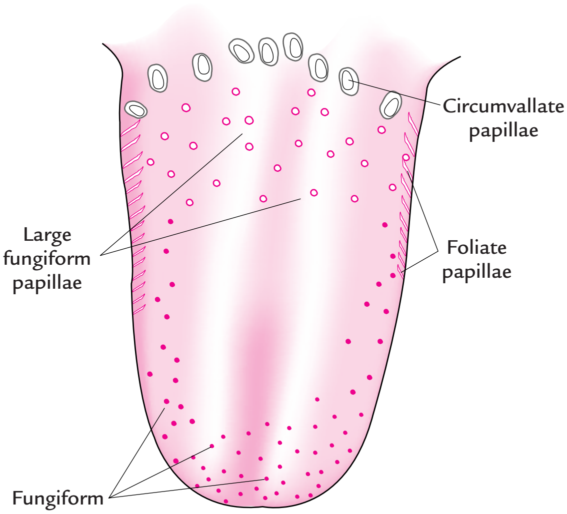


Figure 4.2 Schematic drawing of the tongue indicating the location of the major types of papillae (from Jackson, 2000, reproduced by permission).

coating the oral cavity. The endings possess multiple copies of several related receptor proteins. When sufficient tastant reacts with these proteins, a series of events change the cell's membrane potential. Activation of the membrane induces the release of neurotransmitters from the base of the cell body (Nagai *et al.*, 1996). After diffusion across the synapse, the neurotransmitters incite the depolarization of associated afferent nerve cells and the generation of an action potential. Each afferent nerve cell may synapse with many receptor cells, in several adjacent taste buds. Nerve stimulation not only generates the impulses sent to the brain, but also maintains the integrity of the taste buds. The distribution pattern of cranial nerves in the tongue partially reflects the differential sensitivity of separate areas of the tongue to taste (sapid) substances (Fig. 4.3).

The neurons that enervate the taste buds originate from one of three cranial nerves. The geniculate ganglion (chorda tympani) of the facial nerve (cranial nerve VII) supplies neurons to taste buds of the fungiform papillae on the anterior tongue, whereas other branches contact taste buds in the frontal region of the soft palate. The petrous ganglion of the glossopharyngeal nerve (cranial nerve IX) services taste buds of the foliate and circumvallate papillae, tonsils, fauces, and posterior portions of the palate. Finally, the nodose ganglion of the vagus nerve (cranial nerve X) branches into the taste buds of the epiglottis, larynx and upper reaches of the esophagus.

Impulses from the afferent nerves pass initially to the solitary nucleus in the brain stem (Fig. 4.4). Subsequently, most impulses pass to the thalamus and taste centers in the cortex. Additional neurons transmit signals to the hypothalamus, evoking emotional responses to the stimuli.

As noted, four taste perceptions are usually recognized: sweet, sour, salty, and bitter. Some researchers have proposed expansion of the list to recognize two types

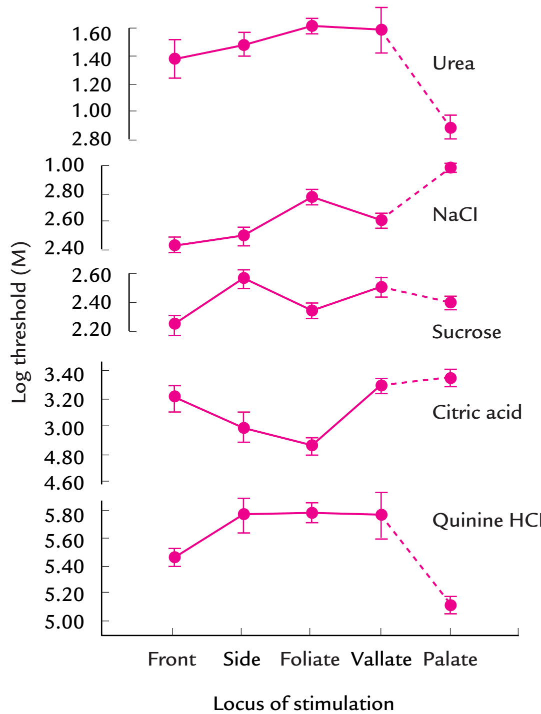


Figure 4.3 Threshold of five compounds as a function of locus on the tongue and soft palate (from Collings, 1974, reproduced by permission).

each of sweetness and bitterness, and additional sensations such as **umami** (response to glutamate and 5′-nucleotides; Rolls *et al.*, 1998), the taste of free fatty acids (Gilbertson *et al.*, 1997), and a metallic sensation (Table 4.1). Nevertheless, others have suggested that distinct tastes are artificial—created out of a continuum of

Table 4.1 Summary of Human Taste Sensation (Modified from Boudreau, J.C., Oravec, J., Hoang, N.K., and White, T.D. (1979). Taste and the taste of foods. *In* "Food Taste Chemistry" ACS Symposium Series No. 115. pp. 1–30. Copyright (1979) American Chemical Society)

Sensation	Locus	Stimuli (examples)	Receptors	Ganglion	Alternative location
Salty	Anterior tongue	NaC1, KC1	Taste Buds	Geniculate	Palate
Sour	Anterior tongue	Malic Acid	Taste Buds	Geniculate	Palate
$Sweet_1$	Anterior tongue	Fructose, Alanine	Taste Buds	Geniculate	Palate
$Sweet_2$	Posterior tongue	Dihydrochalone	Taste Buds	Petrous	Palate
$Bitter_1$	Anterior tongue	Alkaloids, Tryptophan	Taste Buds	Geniculate	Palate
$Bitter_2$	Posterior tongue	Phenolics, $MgSO_4$	Taste Buds	Petrous	
$Umami_1$	Anterior tongue	Glutamate, Lactones	Taste Buds	Geniculate	
$Umami_2$	Anterior tongue	IMP, GMP[a]	Taste Buds	Geniculate	Palate
Metallic	Tongue	Silver nitrate	Taste Buds (?)		

[a]IMP, inositol monophosphate; GMP, guanosine monophosphate.

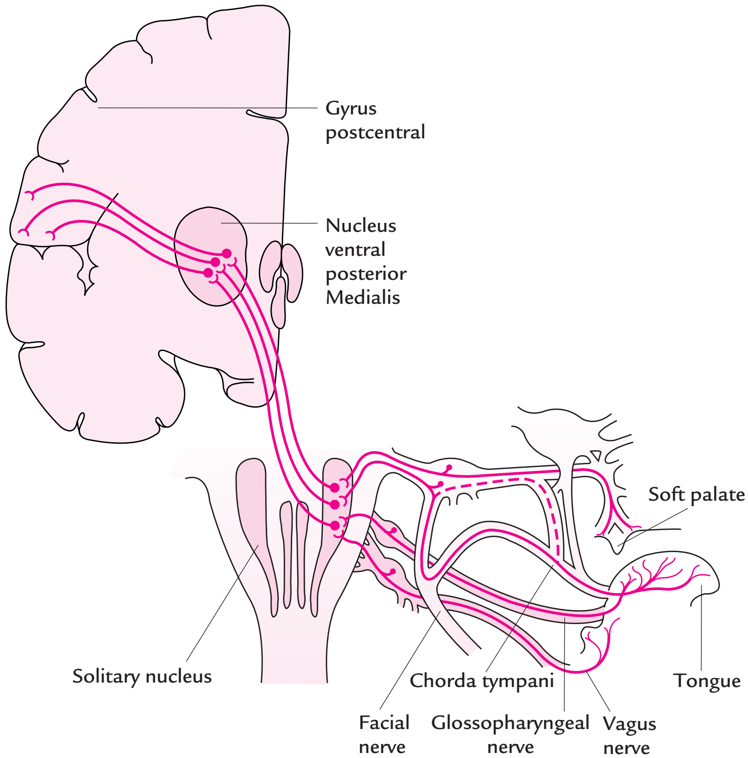


Figure 4.4 Diagram of the neuroanatomical pathway of taste fibers. Heavy lines show the paths most commonly taken. Most fibers travel from the chorda tympani to the facial nerve: other fibers travel in the vagus and glossopharyngeal nerves (from Neurological anatomy in relation to clinical medicine, third edition by Alf Brodal, copyright 1969, 1981 by Oxford University Press, Inc. Used by permission of Oxford University Press, Inc.).

perceptions (Erickson, 1985). Still others note that sensations such as metallic perceptions may be unrecognized odors (Hettinger *et al.*, 1990).

Genetic analysis of specific taste deficits (**ageusia**) has shown that some deficiencies are associated with recessive genes, for example, the bitter aspects of phenylthiocarbamide (Kalmus, 1971) and saccharin (Bartoshuk, 1979). This is considered evidence for the association of specific receptor molecules for particular tastants. A protein produced by von Ebner's gland, often associated with taste buds, may play a role in promoting taste reception (Schmale *et al.*, 1990).

Some studies have noted that receptors of similar sensitivity tend to be grouped together (Scott and Giza, 1987). Nevertheless, individual receptor neurons may react differentially to more than one sapid compound (Scott and Chang, 1984). Therefore, it is not surprising that individual taste buds typically respond to several tastant categories (Beidler and Tonosaki, 1985). These factors may partially account for poor taste localization with complex solutions such as wine.

Taste acuity is correlated with the number of taste pores on the tongue. Average tasters have about 70 fungiform papillae per cm^2 on the front of the tongue, whereas hypertasters[1] possess more than 100/cm^2, and hypotasters have about 50/cm^2 (Bartoshuk *et al.*, 1994). This approximates to about 350, 670, and 120 taste pores per cm^2 for standard, hypertaster and hypotaster categories, respectively. The fungiform papillae of hypertasters are smaller, but have more taste pores than those of hypotasters.

Hypertasters, as the name suggests, are especially sensitive to taste and touch sensations (Bartoshuk *et al.*, 1994), often preferring foods with more subtle tastes. In contrast, hypotasters are relatively insensitive to most sapid substances, and tend to prefer foods or beverages with more intense flavors. The genetic basis of taste sensitivity is primarily controlled by a single gene. Hypertasters are homozygous (TT) for a tasting gene (both allelic copies being functional), medium tasters are heterozygous (Tt), possessing one each of the functional and nonfunctional alleles, whereas hypotasters are homozygous (tt) for the non-functional allele. Environmental factors probably account for much of the variability in expression of the gene (number of papillae and taste pores). Nevertheless, additional genetic factors are presumably involved since women tend to have more papillae (Fig. 4.5A) and taste buds (Fig. 4.5B) than men.

Because hypertasters are more sensitive than the majority of tasters, it is a moot point whether they are the best wine tasters. Being especially sensitive to sapid substances, they may object to wines marginally too sour, bitter, or sweet. The same issue applies to those especially sensitive to odors. The relevance of taster sensitivity depends primarily on the purpose of the tasting. If the intention is more analytic and scientific, then those hypersensitive to sapid and olfactory sensations are probably preferable. However, if data relative to average consumer acceptance is needed, then tasters reflecting the norm of human sensitivity would be more appropriate. At present, there is no clear evidence that gustatory sensitivity is related to olfactory acuity.

Sweet and bitter tastes

Although the perceptions of sweetness and bitterness appear unrelated, they have similar modes of activation. Both sensations depend partially on the formation of van der Waals attractions or hydrogen bonds with protein sites on receptor neurons (Beidler and Tonosaki, 1985). Specific receptor proteins bind to gustducin, a guanine-nucleotide-binding (G-) protein that spans the cell membrane (Walters, 1996). Reaction with an appropriate tastant results in gustducin releasing one of its components, changing the level of cytoplasmic transducers in the cell. These cytoplasmic transducers modify ion flow across the cell membrane, causing depolarization. Membrane depolarization subsequently permits the influx of calcium ions (or release from intracellular storage) that activates the release of neurotransmitters from the cell. There is evidence for at least two alternative activation systems. For example, natural sweeteners activate via a cyclic AMP route, whereas many artificial sweeteners and amino acids employ an inositol triphosphate (IP_3) activation route

[1] The terms *hypertaster* and *hypotaster* are used in lieu of the more frequent but less accurate *supertaster* and *non-taster* categories.

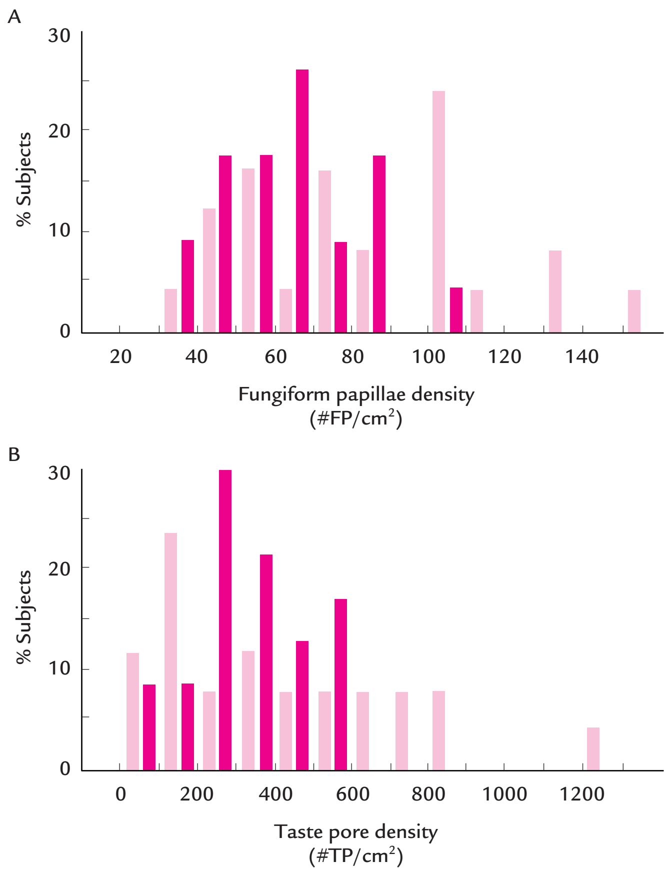


Figure 4.5 Distribution of (A) fungiform papillae (FP) density, and (B) taste pore (TP) density on the anterior tongue. Frequencies are expressed as percent of each sex: ■ female; ■ male. (*Physiol. Behavior* **56**, 1165–1171. Bartoshuk, L. M., Duffy, V. B., and Miller, I. J., PTC/PROP tasting: Anatomy, psychophysics and sex effects. Copyright (1994), with permission from Elsevier Science).

(Herness and Gilbertson, 1999; Fig. 4.6). Slight structural changes in many sweet- and bitter-tasting compounds can change their taste quality from sweet to bitter, or vice versa. Also, bitter- and sweet-tasting compounds are well known to mask each others perception.

About 40 to 80 related gustatory receptor proteins have been identified (Adler *et al.*, 2000). The receptor proteins are synthesized only in taste receptor cells, of which any individual cell expresses many related forms (Chandrashekar *et al.*, 2000). The presence of multiple versions in individual receptor cells may explain why many chemically unrelated compounds induce the same basic taste perception.

Glucose and fructose are the primary sources of sweet sensations in wine, with fructose being sweeter. The perception of sweetness may be enhanced by the presence of glycerol and ethanol.

Flavonoid phenolics are the primary bitter compounds in wines, with tannin monomers (catechins) being relatively more bitter than their polymers (condensed

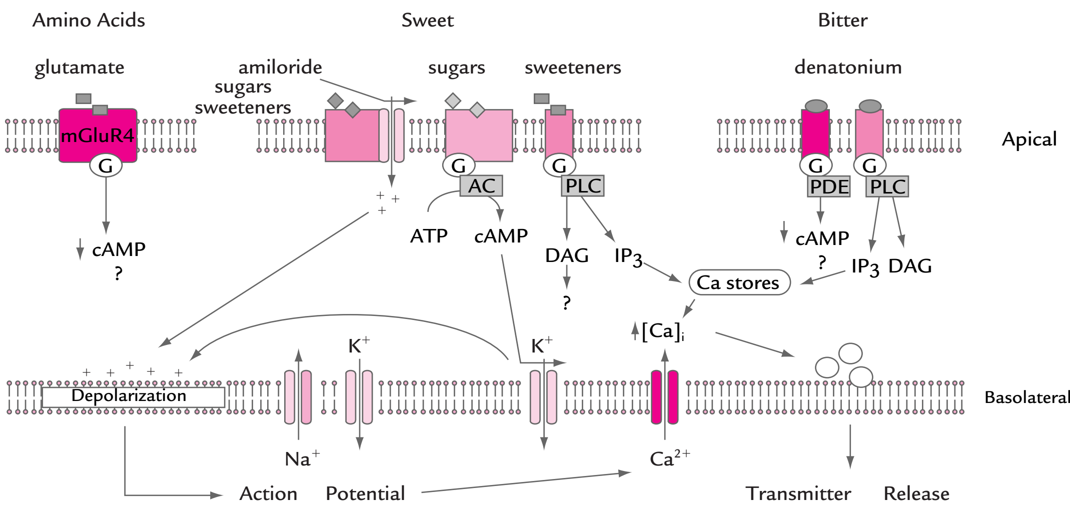


Figure 4.6 Receptor-mediated transduction mechanisms. Glutamate is thought to bind to the metabotropic glutamate receptor (mGluR4), but the steps subsequent to receptor binding are not known. Three different mechanisms may be involved in sweet transduction. Sugars are believed to bind to receptors coupled to adenylyl cyclase, leading to an increase in cAMP. The cAMP blocks K^+ channels to depolarize taste cells. Synthetic sweeteners likely bind to receptors coupled to phospholipase C, resulting in generation of IP_3 and diacylglycerol (DAG). The IP_3 causes release of Ca^{2+} from intracellular stores, but additional steps in the transduction cascade are likely because sweeteners depolarize taste cells. The third mechanism involves a ligand-gated cation channel on the apical membrane. Bitter transduction also involves multiple mechanisms. In one scheme, bitter stimuli bind to receptors coupled to phospholipase C, with results in an IP_3-mediated release of Ca^{2+} from intracellular stores. In the other scheme of bitter transduction, bitter stimuli activate phosphodiesterase (PDE) via a transducin-like G protein. It is not known how a decrease in cAMP results in taste cell depolarization. Increases in intracellular Ca^{2+} can result from a depolarization-mediated Ca^{2+} influx or from release from intracellular stores. (Reprinted from *Food Qual. Pref.* **7**, 153–160. Kinnamon, S. C. Taste transduction: Linkage between molecular mechanism and psychophysics. Copyright (1996), with permission from Elsevier Science).

tannins) (Robichaud and Noble, 1990). In tannic red wines, the bitterness of tannins is often confused with the astringent aspects of tannins (Lee and Lawless, 1991), or potentially masked by them (Arnold and Noble, 1978). During aging, wine often develops a smoother (less astringent) taste, as tannins polymerize and precipitate. Both processes can reduce perceived bitterness and astringency. However, if smaller phenolics remain in solution, or larger tannins hydrolyze to their monomers, perceived bitterness may increase with age.

Several glycosides, terpenes, and alkaloids may occasionally induce bitter sensations. Examples include the bitter terpene glycosides found in *Muscat* wines (Noble *et al.*, 1988), and the bitter glycoside, naringin, found in *Riesling* wines. Additional bitter compounds may come from pine resin (added to *retsina*), or herbs and barks, as used in flavoring vermouth.

Sour and salty tastes

Sourness and saltiness are commonly called the *electrolytic* tastes. In both instances, small soluble inorganic cations (positively charged ions) are the active components (Fig. 4.7). For acids, free H^+ ions are selectively transported across the cell membrane (via ion channels) of receptive cells. For salts, it is primarily free metal and metalloid cations, notably Na^+ ions, that are transported across the receptor cell membrane. In both cases, the influx of ions induces a membrane depolarization that triggers the release of neurotransmitters. Since related ion channels are involved in both instances, it is not surprising that acids frequently express some saltiness, and some salts show a mild sour aspect (Ossebaard *et al.*, 1997).

The tendency of acids to dissociate into ions is influenced by the anionic (negatively charged) component of the molecule and the pH. Thus, both factors significantly affect wine sourness. Although undissociated acid molecules are relatively inactive in stimulating receptor neurons, they do have an effect on perceived acidity (Ganzevles and Kroeze, 1987). The major acids affecting sourness in wine are tartaric, malic, and lactic acids. These acids can also induce astringency, presumably by denaturing saliva proteins (Sowalsky and Noble, 1998). Additional acids occur in wine, but, with the exception of acetic acid, they do not occur in amounts sufficient to affect perceived acidity.

Salts also dissociate into positively and negatively charged ions. Salt cations are typically a metal ion, for example, K^+ and Ca^{2+}, whereas the anion component may be either inorganic or organic, such as Cl^- and bitartrate, respectively. As with sourness, salt perception is not solely influenced by the activating salt cation. The tendency of a salt to ionize affects perceived saltiness. For example, large organic anions suppress the sensation of saltiness by limiting dissociation. Because the major salts

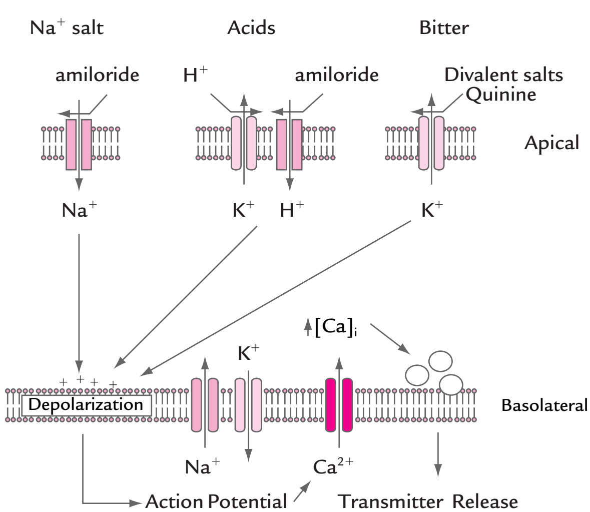


Figure 4.7 Taste transduction: linkage between molecular mechanism and psychophysics. Apical ion channels in transduction. Na^+ and H^+ permeate amiloride-sensitive Na^+ channels to depolarize taste cells. H^+, as well as some bitter molecules block apically located K^+ channels to depolarize taste cells. Depolarization activates voltage dependent Na^+ and K^+ channels to elicit action potentials, which cause influx of Ca^{2+} through voltage-gated Ca^{2+} channels. An increase in intracellular Ca^{2+} mediates transmitter release. (Reprinted from *Food Qual. Pref.* **7**, 153–160. Kinnamon, S. C. Taste transduction: Linkage between molecular mechanism and psychophysics. Copyright (1996), with permission from Elsevier Science).

in wine possess large organic anions (e.g., tartrates and bitartrates), that dissociate weakly at wine pH values, their common cations (K^+ and Ca^{2+}) do not stimulate salt receptors. In addition, it is atypical for the principal salty-tasting cation (Na^+) to occur in wine in perceptible amounts. Correspondingly, saltiness is rarely perceived in wine. If detected, it is probably a result of the action of H^+ ions activating salt receptors.

Other taste sensations

Many amino acids possess slightly sweet tastes, but they occur in wine at concentrations unlikely to have any perceptible influence. In addition, glutamate has its own unique receptor and sensation—*umami* (Rolls *et al.,* 1998). It generates a "pleasant" sensation, as well as enhancing the flavor of other compounds. Nevertheless, the amount of glutamine in wine is insufficient to have a sensory impact. Fatty acids also activate particular receptors cells, but, as with amino acids, they occur at contents below detectable levels in wine.

Factors influencing taste perception

Many factors affect the ability to detect and identify taste sensations. These may be conveniently divided into four categories: physical, chemical, biological, and psychological.

Physical

After a century of investigation, the role of temperature in taste perception is still unclear. The general view is that perception is optimal at normal mouth temperature. For example, cooling reduces the sweetness of sugars (Fig. 4.8) and the bitterness of alkaloids (Green and Frankmann, 1987). However, the bitterness (and astringency) of tannins is well known to be greater at cool temperatures. This apparent anomaly may relate to the different receptors involved in tannin and alkaloid bitterness (see Table 4.1). Bitter alkaloids occur in wine only when specifically added, as in vermouth.

Another important physicochemical factor affecting taste perception is pH. This occurs both directly, by influencing the ionization of salts and acids, and indirectly by affecting the shape and biological activity of proteins. Structural modification of receptor proteins on gustatory neurons could significantly affect taste responsiveness.

Chemical

Sapid substances not only directly stimulate receptor neurons, but they also influence the perception of other tastants. For example, mixtures of different sugars suppress the perceived intensity of sweetness, especially at high concentrations (McBride and

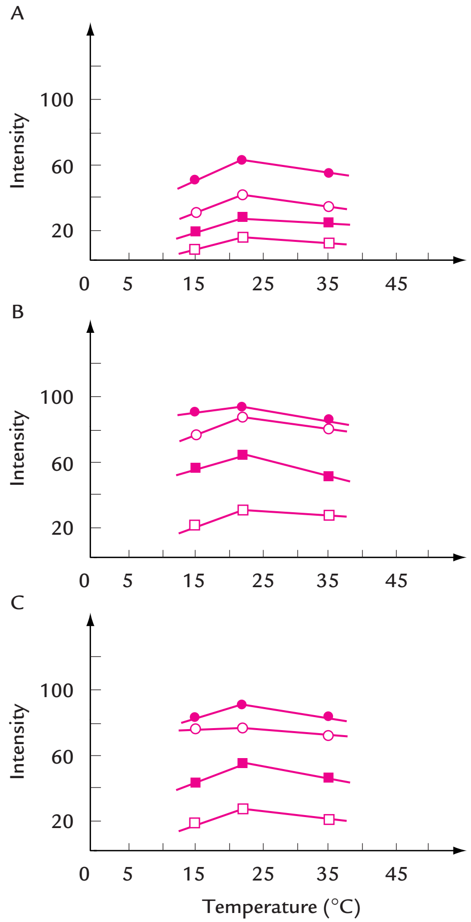


Figure 4.8 Variation in the sweetness intensity of (A) D-glucose, (B) D-fructose, and (C) sucrose as a function of temperature and concentration (●, 9.2 g/ml; ○ 6.9 g/ml; ■ 4.6/g/ml; □ 2.3 g/ml). (Reprinted from *Food Chem.* **44**, 83–92. Portmann, M.-O., Serghat, S., and Mathlouthi, M. Study of some factors affecting intensity/time characteristics of sweetness. 83–92. Copyright (1992), with permission for Elsevier Science.)

Finlay, 1990). In addition, members of one group of sapid substances can affect the perception of another, as in the suppression of bitterness, astringency and sourness by sugars. The saltiness of some cheeses can suppress the bitterness of red wines. These influences may affect response time, duration, and maximum perceived intensity (Figs 4.9 and 4.10). Although suppression of perception is common, ethanol enhances the sweetness of sugars and the bitterness of flavonoids, while suppressing astringency and the sourness of some acids.

Sapid substances may also influence other sensations (Voilley *et al.*, 1991). Of particular interest is the influence of sugar on the volatility of aromatic compounds. At low concentrations (1%), fructose has been shown to decrease the volatility (and detection) of acetaldehyde (Maier, 1970), whereas it enhances the volatility of ethyl

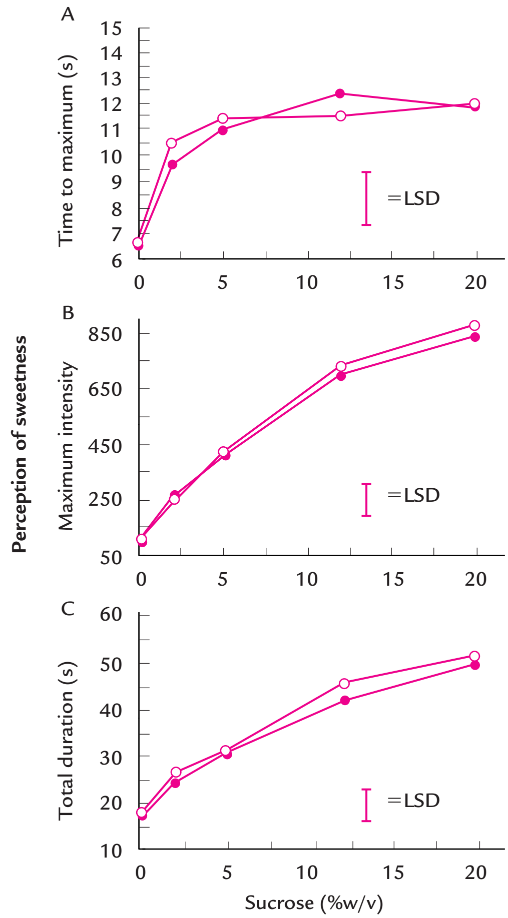


Figure 4.9 Effect of the astringency of tannins (○ low, 1300 GAE; ● high, 1800 GAE) on sweetness perception (A) time to maximum intensity, (B) maximum intensity, and (C) total duration. (GAE, gallic acid equivalents) (Reprinted from *Food Qual. Pref.* **6**, 27–34. Ishikawa, T., and Noble, A. C. Temporal perception of astringency and sweetness in red wine. Copyright (1995), with permission of Elsevier Science).

acetate and ethanol (Nawar, 1971). Modification of the equilibrium between solubility and volatility may be the source of these effects.

Sapid substances often have more than one sensory quality. For example, tannins may be both bitter and astringent, as well as possess fragrance; glucose can be sweet and mildly tart; acids show both sour and astringent properties; potassium salts are salty and bitter; and alcohol possesses a sweet taste, as well as generating the mouth-feel perceptions of burning and weight. In mixtures, these side-tastes can significantly affect overall taste perception (Kroeze, 1982). The perceived intensity of a mixture generally reflects the intensity of the dominant component, not a summation of the intensities of its individual components (McBride and Finlay, 1990). The origin of these interactions may be various and complex (Avenet and Lindemann, 1989).

The interaction of sapid compounds is further complicated by the changing chemical nature of wine in the mouth. Wine stimulates salivary flow (Fig. 4.11), which

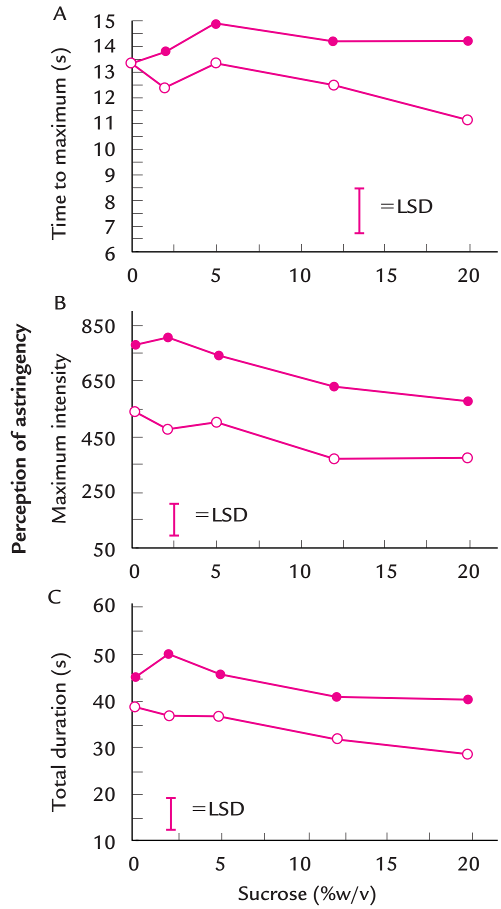


Figure 4.10 Effect of sweetness on the perception of astringency (A) time to maximum intensity, (B) maximum intensity and (C) total duration (○ low, 1300 GAE; ● high, 1800 GAE) (Reprinted from *Food Qual. Pref.* **6**, 27–34. Ishikawa, T., and Noble, A. C. Temporal perception of astringency and sweetness in red wine. Copyright (1995), with permission of Elsevier Science).

both dilutes and modifies wine chemistry. The proline-rich proteins of saliva, which make up about 70% of saliva proteins, effectively bind tannin. Not only does this affect the generation of an astringent mouth-feel, but it also reduces the number of tannin molecules that can react with bitter-sensing neurons. Because saliva chemistry can change throughout the day, and often differs between individuals, it is difficult to predict the specific effects saliva has on taste perception.

Biological

Several studies have noted a loss in sensory acuity with age (Bartoshuk *et al*., 1986; Stevens and Cain, 1993). The number of both taste buds and sensory receptors per taste bud decline past middle age. Nevertheless, age-related sensory loss is not known to seriously limit wine tasting ability. Certain medications also reduce taste sensitivity

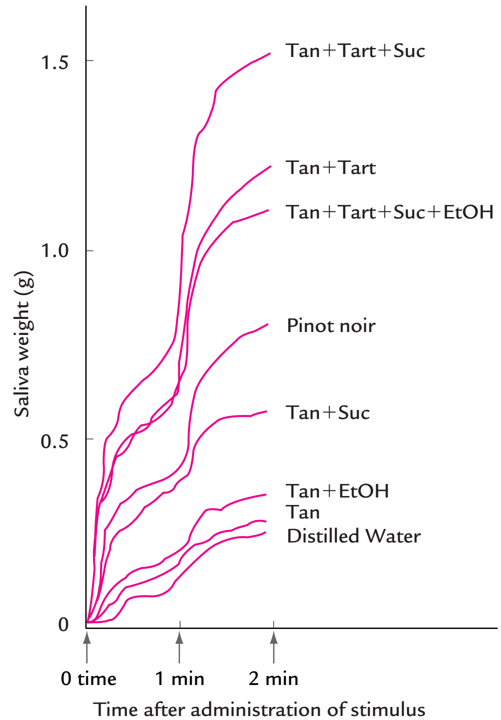


Figure 4.11 Amount of parotid saliva secreted in response to tasting *Pinot noir* wine and selected constituents of the wine, singly and in combination. EtOH, ethanol; Suc, sucrose; Tan, tannin; Tart, tartaric acid (from Hyde and Pangborn, 1978, reproduced by permission).

(see Schiffman, 1983). In addition, taste perception can be disrupted by various household chemicals. A familiar example is the disruption of taste perception by sodium lauryl sulfate (sodium dodecyl sulfate), a common toothpaste ingredient (DeSimone *et al*., 1980).

Acuity loss is generally measured as an increase in the detection threshold—the lowest concentration at which a substance can be detected. Chronic oral and dental ailments may create lingering mouth tastes, complicating discrimination at low concentrations (Bartoshuk *et al*., 1986). This could explain why detection thresholds are usually higher in elderly people with natural dentation than with dentures. Acuity loss also reduces identification of sapid substances in mixtures (Stevens and Cain, 1993).

Although recessive genetic traits produce specific taste deficiencies, subtle individual variations in taste acuity are more common (Fig. 4.12). These differences undoubtedly account for some of the dissension usually expressed at tastings concerning the relative merits of different wines. Acuity can also vary temporally. Sensitivity to phenylthiocarbamide (a bitter-tasting compound commonly used in sensory studies) has been found to vary by a factor of 100 over several days (Blakeslee and Salmon, 1935).

Short-term loss in acuity associated with extended exposure to a tastant is termed adaptation. At moderate concentrations, adaptation to a tastant can become

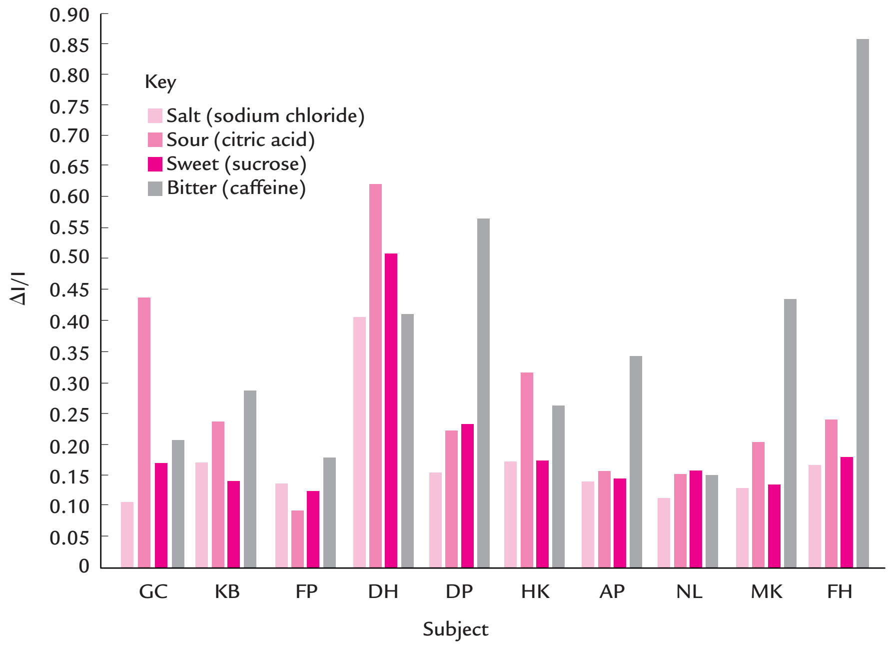


Figure 4.12 Illustration of the variability in the differential sensitivity (△I/I) the principal taste qualities in each of 10 subjects (from Schutz and Pilgrim, 1957, reproduced with permission).

complete. Correspondingly, it is usually recommended that wine tasters cleanse the palate between samples with water or unsalted white bread.

Cross-adaptation refers to the effect of adaptation to one compound on sensitivity to another. Some of the effects are inherently easy to comprehend, for example, the apparently sweet sensation of sampling water after tasting bitter or acidic solutions. Others, however, seem beyond simple explanation, such as the sweetness of water tasted after consuming artichoke, which is not apparently bitter (McBurney and Bartoshuk, 1973).

Psychological

Color influences taste perception (Maga, 1974), as well as the evaluation of food (Clydesdale *et al.*, 1992; Francis, 1995) and wine (Tromp and van Wyk, 1977). Most studies suggest that these influences are learned associations (see Clydesdale *et al.*, 1992), although results from Pangborn *et al.* (1963) suggest otherwise.

Several aromatic compounds have been noted to possess a taste component (Murphy *et al.*, 1977; Enns and Hornung, 1985). For example, several ethyl esters and furanones are commonly described as possessing a sweet aspect. Whether this results from stimulation of taste buds on the back of the epiglottis, from enhanced sweetness perception (Frank and Byram, 1988), or integration of taste and gustatory inputs in the orbitofrontal cortex (Rolls *et al.*, 1998) is unknown. In general, aromatics added to a food or beverage contribute more to its perceived flavor than its smell (Sekuler and Blake, 1994).

Cultural and family upbringing also affect sensory perception, or at least the development of preferences (Barker, 1982). For example, the frequently mentioned affinity between regional cuisines and local wines is probably just the embodiment of habituation, or the pleasure of being on vacation in a charming locale.

Mouth-feel

Mouth-feel refers to sapid sensations activated by free nerve endings of the trigeminal nerve. Trigeminal fibers surround taste buds (Whitehead *et al*., 1985) and they are also randomly distributed throughout the oral cavity. This accounts for the diffuse, poorly localized, mouth-feel sensations in the mouth. In wine, mouth-feel involves the perceptions of astringency, temperature, prickling, body, and burning. They derive from the stimulation of one or more of the types of trigeminal receptors—of which there are at least four. These are categorized as mechanoreceptors (touch), thermoreceptors (heat and cold), nocioreceptors (pain), and proprioreceptors (movement and position).

Astringency

Astringency is a complex sensation inducing a dry, puckery, rough, dust-in-the-mouth perception typically found in red wines (Lawless *et al*., 1994). The sensation is induced primarily by phenolic compounds extracted from the seeds and skins of grapes. Maturation in oak cooperage can also donate sufficient tannins to add to a wine's astringency. White wines generally show little astringency because of their low phenolic content.

Although astringency may be confused with bitterness (Lee and Lawless, 1991), and both may be induced by the same compounds, they are distinct sensations. Adding to the potential confusion is the similar nature of their response curves—both perceptions develop comparatively slowly and possess lingering aftertastes (Figs 4.13 and 4.14). The strong astringency of condensed tannins may partially mask their bitterness (Arnold and Noble, 1978). When demanded, trained tasters differentiate between these sensations. How well they succeed is a moot point. Figure 4.15 illustrates the relative intensities for astringency vs bitterness of several phenolics found in wine.

Astringency typically accrues from the binding and precipitation of proline-rich salivary proteins and glycoproteins with phenolic compounds (Haslam and Lilley, 1988). The two major phenolic groups involved are flavonoid and nonflavonoid tannins (Table 4.2). The main reaction between tannins and proteins involves -NH_2 and -SH groups of proteins with *o*-quinone groups of tannins (Haslam *et al*., 1992). Other tannin-protein reactions are known (see Guinard *et al*., 1986b), but they are apparently of little significance in wine. In the binding of tannins to proteins, their mass, shape, and electrical properties change, and this can result in precipitation.

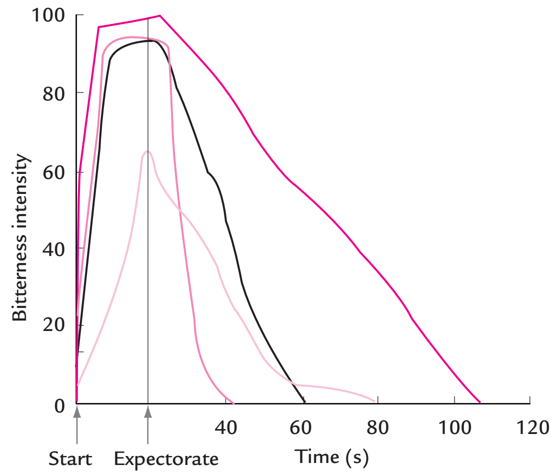


Figure 4.13 Individual time–intensity curves for four judges in response to bitterness of 15 ppm quinine in distilled water (from Leach, E. J. and Noble, A.C. (1986). Comparison of bitterness of caffeine and quinine by a time-intensity procedure. *Chem. Senses* **11**, 339–345. Reproduced by permission of Oxford University Press).

An important factor influencing astringency is pH (Fig. 4.16). The hydrogen ion concentration affects protein hydration, and both phenol and protein ionization. In excessively acidic wines, the low pH can independently induce sufficient salivary glycoprotein precipitation (Dawes, 1964) to elicit the sensation of astringency (Thomas and Lawless, 1995).

As tannins react with proline-rich salivary proteins, salivary viscosity is reduced and friction increases. Both factors reduce the lubricating properties of the saliva

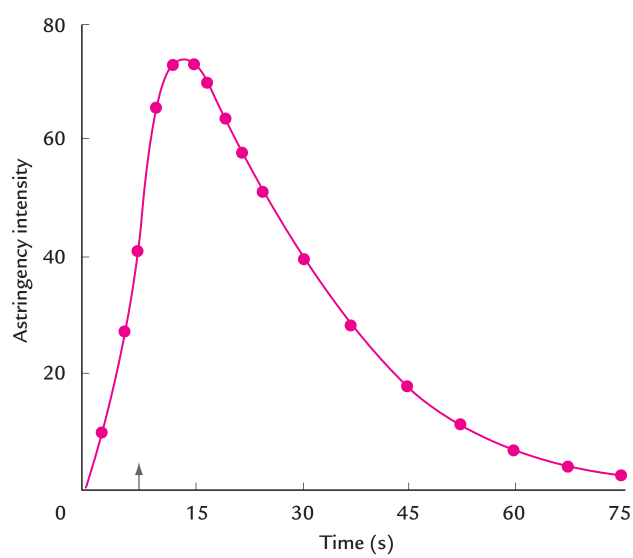


Figure 4.14 Average time–intensity curve for astringency of 5 mg/l tannic acid in white wine. The sample was held in the mouth for 5 s (↑) before expectorated (from Guinard *et al.*, 1986a, reproduced by permission).

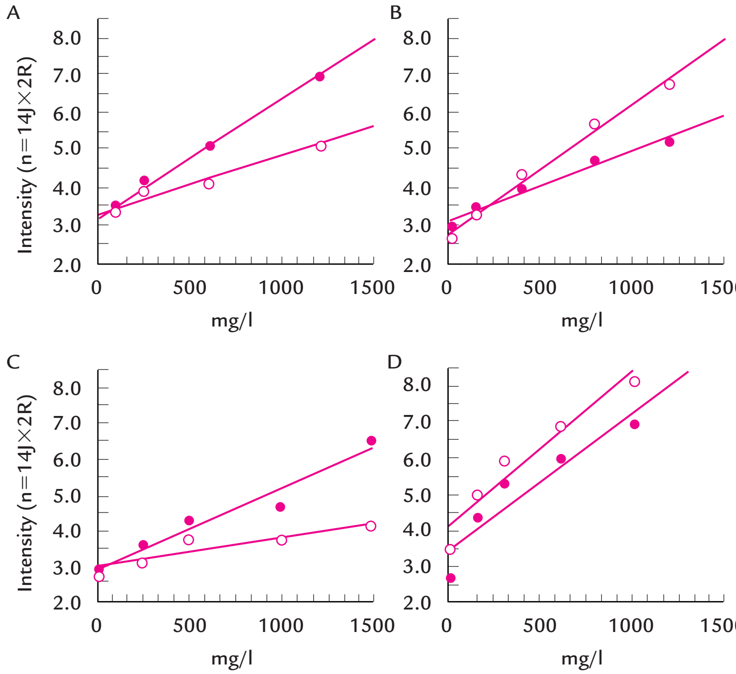


Figure 4.15 Mean intensity rating for bitterness (●) and astringency (○) as a function of concentration for (A) Carechin, (B) grape seed tannin, (C) gallic acid, and (D) tannic acid (from Robichaud, J. L., and Noble, A. C. (1990). Astringency and bitterness of selected phenolics in wine. *J. Sci. Food Agric*. **53**, 343–353. Copyright Society of Chemical Industry. Reproduced with permission. Permission is granted by John Wiley & Sons Ltd on behalf of the SCI).

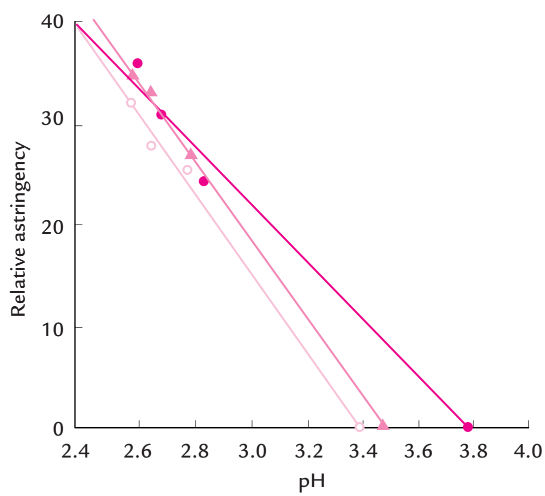


Figure 4.16 Effect of pH on perceived intensity of astringency in model wine solutions at three tannic acid concentrations: ●, 0.5 g/l; ▲, 1 g/l; ○, 2 g/l (from Guinard, J., Pangborn, R. M., and Lewis, M. J. (1986b). Preliminary studies on acidity–astringency interactions in model solutions and wines. *J. Sci. Food Agric*. **37**, 811–817. Copyright Society of Chemical Industry. Reproduced with permission. Permission is granted by John Wiley & Sons Ltd on behalf of the SCI).

(Prinz and Lucas, 2000). The precipitation of protein–tannin complexes on the surface of the epithelial lining of the mouth forces water away from the cell surface, simulating dryness. Precipitated salivary proteins also coat the teeth, producing the characteristic rough texture associated with astringency. Reactions between tannins and cell-membrane glycoproteins and phospholipids of the mucous epithelium may be even more important than those with salivary proteins. Malfunctioning of the cell membrane, such as disruption of catechol amine methylation, may play a role in the perception of astringency. In addition, the relatedness of certain tannin constituents to adrenaline and noradrenaline could stimulate localized blood vessel constriction, further enhancing the dry, puckery, sensation. Repeated exposure to tannins, and the associated removal of salivary proteins, increases the perception of astringency (Guinard *et al.*, 1986a).

Astringency is one of the slowest in-mouth sensations to develop. Depending on the concentration and types of tannins present, astringency can take up to 15 s before reaching maximal intensity (Fig. 4.14). The decline in perceived intensity occurs even more slowly. Different tasters have similar but unique response curves to specific tannins.

The intensity and duration of an astringent response often increases with repeat sampling. This phenomenon is less likely to occur when wine is consumed with food, owing to reactions between tannins and proteins in the food. However, the increase in apparent astringency could produce sequence errors in tastings where wines are sampled in quick succession without adequate palate cleansing. Sequence errors are differences in perception owing to the order in which objects are sampled. Although tannins stimulate the secretion of saliva (Fig. 4.11), production is usually insufficient to limit the increase in perceived astringency.

One of the more important factors known to influence tannin-induced astringency is molecular size. Polymerization is correlated with increased astringency, up to the point where the polymers precipitate or no longer bind to proteins. The specific role of individual tannins in these reactions is unknown. This partially results from the extreme structural complexity of tannins, and their modification during aging. The flavonoid and nonflavonoid monomers can polymerize (forming dimers, trimers and tetramers), as well as associate with anthocyanins, acetaldehyde, pyruvic acid derivatives, and various sugars. How these relate to the so-called "soft" and "hard" tannins of the skins and seeds, respectively, remains to be clarified.

Although tannins and organic acids are the main inducers of astringency in wine, other compounds may evoke astringency, for example, high concentrations of ethanol. However, at the concentrations typically found in wine, ethanol tends to limit salivary protein precipitation by condensed tannins (Lea and Arnold, 1978; Yokotsuka and Singleton, 1987). This feature, combined with the viscosity of high sugar contents may account for the low perceived astringency of port wines.

Burning

High ethanol content produces a burning sensation in the mouth, especially noticeable at the back of the throat. This perception results from the activation of receptors that respond to heat. Wines particularly high in sugar content (e.g., eisweins and Tokaji Eszencia) may possess a sensation described as a sugar "burn." Whether this sensation is similar to the burning sensations of alcohol and condiments, such as chili peppers, is unknown.

Temperature

The cool mouth-feel produced by chilled white and sparkling wine adds to the interest and pleasure of wines of subtle flavor. Cool temperatures enhance the prickling sensation (Fig. 4.17) and prolong the effervescence of sparkling wines. Cool temperatures also diminish perceived sweetness (Green and Frankmann, 1988), but augment the perception of bitterness and astringency. Red wines are usually served at between 18 and 22°C. Within this range, volatility is promoted, increasing the perception of the wine's fragrance. Nevertheless, preferred serving temperature probably also reflects habituation. This could explain what now seems the odd preference for serving red wines at cool temperatures during the 1800s (Saintsbury, 1920).

Prickling

Bubbles bursting in the mouth produce a prickling, tingling, occasionally painful burning sensation. The feeling is elicited in wines containing more than 3 to 5‰ carbon dioxide, and it is affected by bubble size and temperature. In addition to its mouth-feel, dissolved carbon dioxide has a slightly sour taste (from the formation of carbonic acid), with bitter and salty side-tastes (Cowart, 1998).

Carbon dioxide modifies the perception of sapid compounds (Cowart, 1998), notably those with sweet, sour, and salty qualities. It reduces the sensation of sweetness, but it enhances saltiness. Its effect on wine sourness is more complex. Carbon dioxide increases sourness in the presence of sugar, but it decreases the perceived

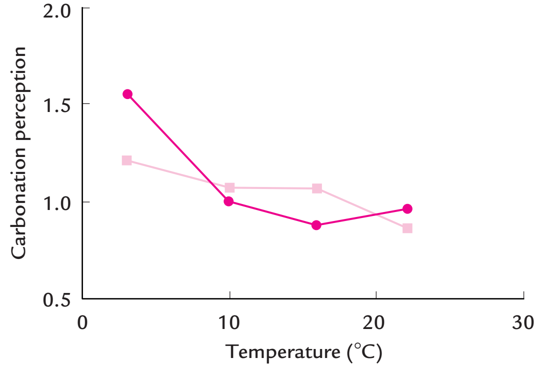


Figure 4.17 Temperature versus carbonation perception for 2.4 volume for swallowing from the trained (■) and naive (●) panels. Y axis: rescaled magnitude estimates of response (from Yau, N. J. N. and McDaniel, M. R. (1991). The effect of temperature on carbonation perception. *Chem. Senses* **16**, 337–348. Reproduced by permission of Oxford University Press).

sourness of acids. In addition, carbonation significantly augments the perception of coldness in the mouth (Green, 1992).

Although carbon dioxide promotes the evaporation of some volatile compounds, it also suppresses the detection of other aromatics (Cain and Murphy, 1980). This presumably explains the reduced "foxy" aspect of sparkling wines produced from *Concord* grapes.

Body (weight)

Despite the importance of body to the overall quality of wines, its precise origin remains unclear. In sweet wines, body is roughly correlated with sugar content. In dry wines, it has often been associated with alcohol content. This view has recently been challenged (Pickering *et al.*, 1998). Glycerol appears to increase the perception of body, whereas acidity reduces it. Tannins are likely involved in most red wines. The intensity of the wine's fragrance also appears to enhance the perception of body.

Metallic

A metallic sensation is occasionally found in dry wines, notably in the aftertaste in sparkling wines. The origin of the sensation is unknown. Iron and copper ions can generate a metallic taste, but at concentrations at or above those normally found in wine (>20 and 2 mg/l, respectively). Detection of the metallic aspect of Cu^{2+} is apparently augmented by tannins (Moncrieff, 1964).

Aromatic compounds, such as oct-1-en-3-one, have been associated with a metallic sensation in dairy products. Acetamides are also reported to have a metallic aspect (Rapp, 1987). It has been suggested that, because metals often catalyze lipid breakdown, they may be responsible for the formation of oct-1-en-3-one from lipids in the mouth (Forss, 1969). This type of reaction may explain why ferrous sulfate generates a metallic "taste" in the mouth only when the nostrils are open (Hettinger *et al.*, 1990).

Chemical compounds involved

Sugars

Sweetness in wines is primarily due to the presence of sugars, notably glucose and fructose. Concentrations above 0.2% are generally required to generate perceptible sweetness. Because most table wines have residual sugar contents less than this, they generally appear dry. When sweetness is detected in dry wines, it usually comes from the presence of aromatic compounds, combined with the mild sweet tastes of ethanol and glycerol. The induction of perceived sweetness by some aromatic compounds probably originates in the orbitofrontal cortex (Fig. 3.8).

At concentrations above 0.2%, sugars begin to exhibit a sweet taste and they increasingly contribute to the sensation of body. At high concentrations, sugars can generate a cloying sensation, as well as a burning mouth-feel. Sugars can diminish the harsh aspects of wines that are excessively acidic, bitter, or astringent.

Alcohols

Several alcohols occur in wine, but only ethanol occurs in sufficient quantities to produce gustatory sensations. Although ethanol possesses a sweet aspect, the acidity of wine diminishes its sensory significance. Ethanol does, however, detectably enhance the sweetness of sugars. Ethanol also reduces the perception of acidity, making acidic wines appear less sour and more balanced. At high concentrations (above 14%), alcohol increasingly generates a burning sensation and it may contribute to the feeling of weight or body, especially in dry wines. Ethanol also can augment the perceived intensity of bitter phenolic compounds, while decreasing the sensation of tannin-induced astringency (Lea and Arnold, 1978).

Glycerol is the most prominent wine polyol. In dry wine, it can also be the most abundant compound, after water and ethanol. Consequently, glycerol has often been assumed to be important in generating a smooth mouth-feel and the perception of viscosity. Nevertheless, glycerol rarely reaches a concentration that perceptibly affects viscosity (≥26 g/l) (Noble and Bursick, 1984). It may, however, still be sufficient to play a minor role in suppressing the perception of acidity, bitterness, and astringency. The slightly sweet taste of glycerol may also play a minor role in dry wines, in which the concentration of glycerol often surpasses its sensory threshold for sweetness (≥5 g/l). However, it is unlikely to contribute detectably to the sweetness of dessert wines.

Several sugar alcohols, such as alditol, arabitol, erythritol, mannitol, *myo*-inositol, and sorbitol, occur in wine. Combined, their small individual effects may influence the sensation of body.

Acids

As a group, carboxylic acids are as essential to the sensory attributes of wines as alcohol. Acids generate a refreshing taste (or sourness, if in excess), affect wine color (and its stability), and modify the perception of other sapid compounds. This is especially noticeable in diminished sweetness. In addition, the release of acids from cell vacuoles during crushing initiates an acid-induced hydrolytic release of aromatics in the fruit (Winterhalter *et al*., 1990). Several important aroma compounds, such as monoterpenes, phenolics, C_{13} norisoprenoids, benzyl alcohol, and 2-phenylethanol often occur in grapes as acid-labile nonvolatile glycosides (Strauss *et al*., 1987a).

By maintaining a low pH, acids are crucial to the color stability of red wines. As the pH rises, anthocyanins decolorize and they may eventually turn blue. Acidity also affects ionization of phenolic compounds. The ionized (phenolate) phenolics are more readily oxidized than their nonionized forms. Accordingly, wines of high pH (≥3.9) are especially susceptible to oxidization and loss of their fresh aroma and young color (Singleton, 1987).

These influences depend mainly on the potential of the acids to deionize in wine—a complex function of the acid's structure, wine pH, and the concentration of various metal and metalloid anions (notably K^+ and Ca^{2+}). Because of the partial nonspecificity of gustatory receptors, it is not surprising that people respond idiosyncratically to wine acidity, and that perceived acidity cannot easily be predicted from pH and acid content.

Phenolics

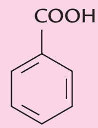
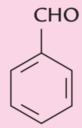
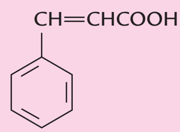
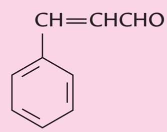
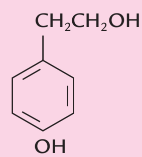
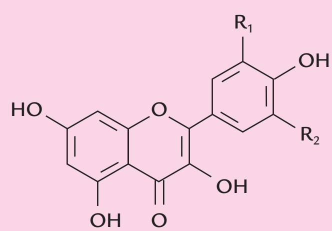
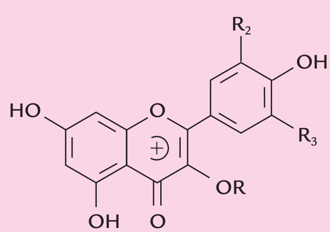
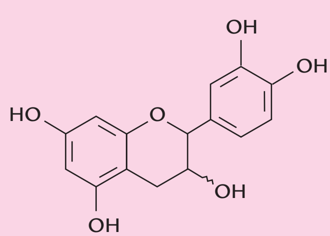
The phenolic compounds in wine consist primarily of flavonoid and nonflavonoid monomers. Table 4.2 illustrates the differences between flavonoid phenolics (a group of phenylpropanoids possessing two phenol groups joined by a pyran ring) and nonflavonoids (a group of phenyl compounds possessing a single phenolic group). Both groups exert a marked influence on taste and mouth-feel. Alone, or in combination, they generate a very large group of polymers called tannins. In wine, they induce bitter and astringent sensations, as well as contributing to its color, body, and flavor. Their individual influences depend on the constituent phenolics, their oxidation, ionization, and polymerization with themselves, proteins, acetaldehyde, sulfur dioxide, or other compounds. Flavonoid tannins constitute the major phenolic compounds in red wines, whereas nonflavonoids constitute the major phenolic group in white wine. Nonflavonoids, derived from oak cooperage, also generate woody, vanilla, coconut, and smoky scents. The particular flavors donated depend on the type of oak, its seasoning, the degree of toasting, repeat use, and the duration of contact (see Oak, Ch. 8).

Flavonoids are derived primarily from the skins and seeds of the fruit, and less frequently from the stems. Flavonols, such as quercetin and anthocyanins commonly collect in cellular vacuoles of the skin. Flavonols also may be deposited in stem tissue. In contrast, flavan-3-ol production occurs primarily in the stems and seeds of grapes. These tannins consist primarily of catechin, epicatechin, and epigallocatechin subunits. Those tannins that occur in the skin are characterized by a higher degree of polymerization and greater epigallocatechin contents.

Catechins and their polymers (procyanidins and condensed tannins) generate the majority of bitter and astringent sensations in red wines. Catechins and procyanidins tend to be primarily bitter; mid-sized condensed tannins are both bitter and astringent; whereas large tannins are predominantly astringent. The largest tannin polymers are too massive to react effectively with taste receptors or saliva proteins. Because these tasteless polymers form slowly during aging, they explain the progressive reduction in the roughness of tannic red wines. If they precipitate, the sediment generated affects mouth-feel only when resuspended by agitation. Tannin interaction with soluble proteins promotes joint precipitation.

Although flavonoids seldom detectably influence the taste or flavor of white wines, there are a few exceptions. In cultivars such as *Riesling* and *Silvaner*, the flavanone glycoside, naringin, contributes to the slight bitterness of their wines (Drawert, 1970). In addition, the nonflavonoid ester, caffeoyl tartrate (caftaric acid), may confer mild bitterness (Ong and Nagel, 1978). Finally, small amounts of catechins and

Table 4.2 Phenolic and related substances in grapes and wine[a] (from Jackson 2000, reproduced by permission)

General type	General structure	Examples	Major source[b]
Nonflavonoids			
Benzoic acid		Benzoic acid Vanillic acid Gallic acid Protocatechuic acid Hydrolyzable tannins	G, O O G, O G, O G
Benzaldehyde		Benzaldehyde Vanillin Syringaldehyde	G, O, Y O O
Cinnamic acid		*p*-Coumaric acid Ferulic acid Chlorogenic acid Caffeic acid	G, O G, O G G
Cinnamaldehyde		Coniferaldehyde Sinapaldehyde	O O
Tyrosol		Tyrosol	Y
Flavonoids			
Flavonols		Quercetin Kaempferol Myricetin	G G G
Anthocyanins		Cyanin Delphinin Petunin Peonin Malvin	G G G G G
Flavan-3-ols		Catechin Epicatechin Gallocatechin Procyanidins Condensed tannins	G G G G G

[a] Data from Amerine and Ough (1980) and Ribéreau-Gayon (1964).
[b] G, grape; O, oak; Y, yeast.

leucoanthocyanins may donate part of the wine's body. The classification of German wines, customarily based on fruit ripeness, has been correlated with increased flavonoid content (Dittrich *et al*., 1974). Nevertheless, their role in browning and bitterness (which occurs at >40 mg/l) places upper limits on their desirability.

The primary nonflavonoids found in wines, not matured in oak, are derivatives of hydroxycinnamic and hydroxybenzoic acids. They are easily extracted from cell vacuoles during crushing. The most numerous, and variable in composition, are the hydroxycinnamic acid derivatives—notably caftaric, coutaric, and fertaric acids. Individually, they occur at concentrations below their detection thresholds (Singleton and Noble, 1976). In combination, though, they may bestow a bitter note. This potential increases as the alcohol content of the wine rises.

Elevated levels of hydroxybenzoic acid derivatives, notably ellagic acid, occur frequently in wines aged in oak cooperage. Ellagic acid comes from the breakdown of hydrolyzable tannins (ellagitannins). Castalagin and vescalagin (polymers of three ellagic acids) are the forms most frequently found in wine. Degradation of oak lignins liberates various cinnamaldehyde and benzaldehyde derivatives.

Hydrolyzable tannins seldom play a significant role in the sensory quality of wine (Pocock *et al*., 1994). Although more astringent than condensed tannins, their low concentration and early degradation generally limits their sensory impact. Occasionally, though, sufficient derivatives of hydroxycinnamic acid may be liberated via hydrolysis of esters with tartaric acid to contribute to the bitterness of white wines (Ong and Nagel, 1978). Slow breakdown of hydrolyzable tannins extracted during prolonged maturation in oak cooperage may indicate why some red wines never lose their bitterness with aging.

Tyrosol production by yeast metabolism can also contribute to wine bitterness. This is particularly noticeable in sparkling wines. Tyrosol level increases considerably during the second in-bottle fermentation, characteristic of most sparkling wines. Even in still white wines, tyrosol can donate bitterness at typical concentrations (~25 mg/l).

Phenolics such as 2-phenylethanol and methyl anthranilate may contribute to the peppery sensation characteristic of certain grape varieties. Additional phenol derivatives can generate pungency or reinforce varietal aroma.

In addition to direct influences on bitterness and astringency, phenols influence the perception of sweetness and acidity. They also have direct impacts on the perception of body and balance.

Nucleic acids

During extended contact with autolysing yeast cells, such as during *sur lies* maturation or sparkling wine maturation, there is the release of nucleotides from the dead and dying cells. This release is most marked during early autolysis. Because of the potent flavor enhancement of several nucleotides (*umami*), there is interest in their sensory significance in wine (Courtis *et al*., 1998).

Taste and mouth-feel sensations in wine tasting

To distinguish between taste and mouth-feel sensations, tasters may concentrate sequentially on the sensations of sweetness, sourness, bitterness, and astringency. Their temporal response curves can be useful in confirming identification (Kuznicki and Turner, 1986). Response localization in the mouth, or on the tongue, can also be useful in affirming taste characterization. Balance is a summary perception, derived from the interaction of sapid and mouth-feel sensations, probably associated with retronasal fragrance.

Sweetness is probably the most rapidly detected taste sensation. Sensitivity to sweetness is optimal at the tip of the tongue, but it also occurs elsewhere (Fig. 4.3). Possibly because sugar content is typically low, sweetness tends to be the first taste sensation to show adaptation. Its perception is reduced by the presence of acids and wine phenolics. These influences are important in avoiding a cloying sensation in sweet wines.

Sourness is also rapidly detected. The rate of adaptation is usually slower than for sugar, and it may represent the primary aftertaste in dry white wines. Acid detection is commonly strongest along the sides of the tongue, but this varies considerably among individuals. Some people detect sourness more distinctly on the insides of the cheeks or lips. Strongly acidic wines induce astringency, giving the teeth a rough feel. Both the sour and astringent aspects of acidic wine may be mollified by the presence of perceptible viscosity.

Perception of bitterness usually follows, if present, taking several seconds for detection to commence. Peak intensity may not be reached for 10 to 15 s (Fig. 4.13). On expectoration, the sensation declines gradually and it may linger for several minutes. Most bitter-tasting phenolic compounds are detected at the back central portion of the tongue. In contrast, the bitterness of some alkaloids is perceived on the soft palate and front of the tongue (Boudreau *et al.*, 1979). This aspect of bitterness is rarely detected in wine because perception of phenolics at the back of the tongue develops more rapidly (McBurney, 1978). Also few alkaloids occur in wine. Wine bitterness is more difficult to assess when the wine is equally astringent. High levels of astringency may diminish the perception of bitterness. Sugar reduces bitterness (Schiffman *et al.*, 1994), whereas alcohol enhances it (Noble, 1994).

The perception of astringency is slow to develop, often being the last principal sapid sensation to be detected. On expectoration, the perception slowly declines over a period of several minutes. Astringency is poorly localized because of the relatively random distribution of free nerve endings throughout the mouth. Because perceived intensity and duration increase with repeat sampling, some judges recommend that astringency be based on the first taste. This would give a perception more closely approximating the sensation detected on consuming the wine with food. Others consider that judging astringency should occur only after several samplings, when the modifying effects of saliva have been minimized.

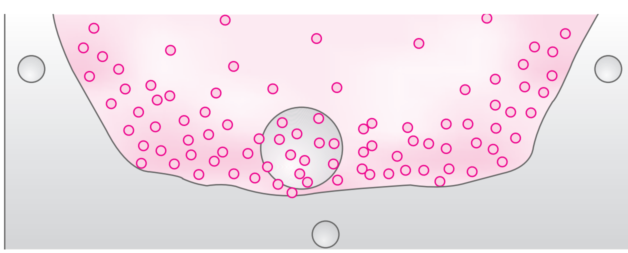
The increase in perceived astringency when tasting wines (Guinard *et al.*, 1986a) can significantly affect assessment, notably red wines—the first wine often appearing smoother and more harmonious. A similar situation can arise when a series of dry acidic wines, or very sweet wines, are tasted. The effect of such sequence errors can be partially offset by presenting the wines in a different, but random, order to each taster. Lingering taste effects can be further minimized by assuring adequate palate cleansing between samples.

Appendix 4.1

Measuring taste bud density

A simple measure of taste sensitivity can be obtained by counting the number of fungiform papillae on the tip of the tongue. The technique given below was developed by Linda Bartoshuk, Yale University.

Subjects swab the tip of their tongue with a Q-tip dipped in a dilute solution of methylene blue (or blue food coloring). Rinsing away the excess dye reveals the unstained fungiform papillae as pink circles against a blue background. Placing the tongue in a tongue holder flattens the tongue, making the fungiform papillae easier to view. The tongue holder consists of two plastic microscope slides held together by three small nutted screws (see diagram below). For convenience and standardization, only fungiform papillae in the central tip region are counted. This can be achieved with the use of a small piece of wax paper containing a hole in the center (using a hole punch). Counting is facilitated with the use of a 10× hand lens. The average number of fungiform papillae per cm^2 is obtained by dividing the number of papillae counted by the surface area (πr^2) of the observation hole.



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5

Quantitative (technical) wine assessment

Quantitative wine assessment usually entails one of two components—evaluation or analysis. Evaluation involves the differentiation and ranking of wines. It can vary from large consumer tastings to small laboratory panels. This is the aspect that most people equate with wine tasting. Occasionally, panels of experts may go further, in assigning a monetary value to the characteristics detected. In contrast, wine analysis involves detailed investigation of a wine's sensory attributes. Its intent is to obtain relatively objective data on aspects such as the sensory differences between wines, the features that lead to preference, and the nature and dynamics of sensory perception. Alternatively, it may function as a quality control procedure. Sensory evaluation may or may not use trained panels, whereas sensory analysis typically uses panels specifically trained for each task. Because sensory analysis is a research–developmental tool, it is essential that it be conducted in a quiet, neutral environment, devoid of taster interaction or prior knowledge of the samples' origin.

Selection and training of tasters

Basic requirements

Possibly the most critical requirement for membership in a tasting panel is motivation. Motivation is essential for both learning and dependable attendance. Without a genuine interest in wine, it is unlikely that members will retain the dedication needed for the often arduous concentration that can occur periodically for weeks, months, or years. For consistency, it is desirable to retain a common nucleus of members. Therefore, selection includes many more candidates than required. Often no more than 60% of candidates possess the requisite sensory skill.

To maintain enthusiasm and attendance, a clear indication of the importance of the panel's work is essential. Providing a comfortable, dedicated, tasting room is a major sign of importance. Educational sessions or periodic demonstration of how their work is used can be valuable. Feedback on panelist effectiveness (presented privately) can be encouraging. Finally, depending on legality and appropriateness, presentation of vouchers for wine is another tangible expression of worth.

Besides interest and dedication, panelists must be consistent in their assessment, or soon develop this property. Consistency can be assessed using one of several statistical tools. For example, insignificant variance in ranking repeat samples, or term use, are indicators of consistency. Analysis of variance data can also establish whether panel members are individually or collectively using a score sheet uniformly. Although tasters show fluctuations in sensory skill, this must be minimal if subtle differences are to be detected. Panelists are frequently used as a substitute for analytic sensory instruments. Correspondingly, panelist reactions to the features studied must be highly uniform. Whether this property is equally desirable when assessing wine quality (an integrative property) is a moot point. If the experimenter wants to distinguish minute differences, then small inter-member variation is essential. In contrast, if the intent is to know whether consumers might differentiate among particular wines, panel variation should be representative of the target group. The latter assumes that the nature of the sensory variation in the target group is known.

Another attribute often required of professional tasters is extensive experience with traditionally accepted norms. This is especially important when rating varietal or stylistic expression. Professional tasters must also judge independently of their personal preferences, and describe wine attributes precisely. This requires both training and considerable experience.

As noted, sensitivity to particular characteristics can influence panelist suitability. In descriptive sensory analysis, high acuity to particular attributes may be required. In most situations, though, panel members need only possess standard sensitivity to sensory attributes. For example, a panel composed of individuals hypersensitive to bitterness and astringency may unduly downgrade young red wines. Typically, the ability to learn and consistently use sensory terms is more important. For quality evaluation, appropriate use of integrative quality terms, such as complexity, development, balance, body, and finish, may be the central requirement.

In situations where specific marks are assigned to particular attributes, panelists sufficiently confident and skilled in scoring are clearly essential. Inexperienced tasters tend to unduly concentrate marks in the mid-range (central tendency). This can make separation among similar but distinct wines impossible.

Because the features preferred by trained tasters (and most afficionados) typically differ from those of the average wine consumer, panel rankings rarely reflect consumer preference (Table 5.1). However, consumers are themselves not a homogeneous group. This is clearly indicated by the preference differences shown by those in different age groups or possessing distinct drinking habits (Tables 5.2 and 5.3). Therefore, if taste panels are used in marketing studies, careful selection of members representative of the target group is essential.

Table 5.1 Correlation between overall acceptability and hedonic scores for general wine attributes (from Williams *et al.*, 1982, reproduced by permission)

	General public	Master of wine: As commercial product	Master of wine: As wine of specific type	Trained panelists
Appearance	–	–	–	−0.01
Color	0.54	0.56	0.74	0.39
Aroma	0.40	0.96	0.95	0.78
Flavor by mouth	0.91	0.92	0.89	0.96

Table 5.2 Correlation between overall acceptability and hedonic scores for general wine attributes within population subsets (from Williams *et al.*, 1982, reproduced by permission)

	Age			
	18–24	25–34	35–44	45–64
Color	0.40	0.43	0.45	0.59
Aroma	0.17	0.32	0.73	0.46
Mouth flavor	0.90	0.82	0.90	0.82

Table 5.3 Correlation between overall acceptability and hedonic scores for general wine attributes within wine price categories and frequency of wine consumption (from Williams *et al.*, 1982, reproduced by permission)

	Red wine: Drinking habits			
	<£2 per bottle		>£2 per bottle	
	Frequent drinkers	Infrequent drinkers	Frequent drinkers	Infrequent drinkers
Color	0.42	0.57	0.56	0.48
Aroma	0.63	0.36	0.73	0.47
Mouth flavor	0.88	0.94	0.84	0.96

Identification of potential wine panelists

No series of tests can infallibly identify those superior in tasting proficiency. This reflects as much the different skills that may be required as it does the efficacy of testing. Nevertheless, aspects of tasting capacity, such as sensory acuity, discrimination, recognition, memory, and scoring consistency, can be measured. They function as indicators of the skills that tasters should possess or develop, for example, excellent short-term memory for direct comparisons, and long-term memory for assessing compatibility with stylistic norms. It is exceptional memory rather than phenomenal perceptual acuteness that tends to distinguish great tasters.

The tests noted below are designed for selection. The skills measured indicate aptitude for sensory analysis, as well as demonstrating individual strengths and weaknesses. The degree of proficiency required in these tests depends on the skills required. Wine assessment is distinctly different from measuring the quality of manufactured goods. There, quality standards are usually precise and easily measured objectively.

Ideally, testing should be conducted over several weeks. This reduces stress and, therefore, improves the likelihood of valid assessment (Ough *et al.*, 1964). However, in commercial situations, multiple wines may need to be sampled in rapid succession. Therefore, concentrating the testing within a short period may provide the stress that highlights those best able to rapidly discern subtle differences.

In preparing the tests, it is important that wine samples be free of fault, and truly representative of variety and type. Repute or previous acceptability is no substitute for prior sampling. Price should not be a condition for either selection or exclusion.

Taster training and testing

As noted, extraordinary olfactory acuity is rarely required. In addition, initial skill in recognizing odors is of little significance, as it usually only reflects previous exposure (Cain, 1979). Although repeat exposure does not necessarily improve detection (Stevens and O'Connell, 1995), it frequently improves verbal recognition (Clapperton and Piggott, 1978). Therefore, measures of learning ability can be valuable in screening tasters (Stahl and Einstein, 1973). The mental concentration required during training may enhance discriminatory skills by activating latent ability. Humans can differentiate thousands of odorants (compared side-by-side), but easily recognize few without visual or contextual clues. Even perfumers may recognize only 100 to 200 odors by smell alone (Jones, 1968). Sensory skill is probably like the intellect—training increases the knowledge base without necessarily modifying intrinsic intelligence. Practice and concentration hone the effective use of our modest gustatory and olfactory potential.

Testing can function both as a learning experience and as a selection tool. For example, olfactory testing both assesses and develops odor memories for wine fragrances and off-odors. If warranted, standards for inappropriate taste, mouth-feel, and visual attributes may be developed. Because they are rarely deemed of significance, they have not been included here.

Although testing helps to develop relevant odor memories and promote appropriate term use, periodic re-exposure is necessary to solidly embed these memories in the brain. This is required as they do not have the support of the visual and contextual clues that typically contribute to our odor memory.

It is normally required that panelists recognize the attributes that characterize quality. Therefore, beyond determining basic tasting aptitude, training may include extensive training in the norms for varietal, regional, and stylistic wine expressions. This is particularly important in evaluative tastings. For this, samples should express fully the range ordinarily to be expected. Depending on the importance of this skill, training continues until candidates show the level of proficiency and consistency deemed necessary, or they are eliminated. For descriptive sensory analysis, training concentrates on the appropriate and consistent use of a descriptive language. In the process, candidates showing insufficient skill are removed.

In the past, wine evaluation was conducted primarily by winemakers or wine merchants. Their training tended to focus on recognizing accepted regional (varietal) norms. However, most individuals possess biases and sensory deficiencies. To offset individual weaknesses, most wine evaluation and assessment is now conducted by teams of tasters. This has required the training of more tasters than generated by the older, informal, in-house experience approach. It has also led to a more general and rigorous training of tasters. There is also the realization that instruction and assessment of sensory skills need to be standardized.

For economy and convenience, aspects of grape varietal aromas may be simulated by producing odor samples (see Appendix 5.2). These have the advantage of being continuously available for reference. Standards may be prepared in a neutral or artificial wine base, or stored under paraffin in sample bottles (Williams, 1975 and 1978). Because pure compounds may contain trace impurities that can modify odor quality, it may be necessary to conduct initial purification before use (Meilgaard *et al.*, 1982).

In addition to recognizing wine odors, identification of odor faults is a vital component of training. In the past, faulty samples were obtained from wineries, but samples prepared in the laboratory can be standardized and readily available. In addition, they can be presented in any wine and at any desired intensity (see Appendix 5.3).

Training also includes taste samples, prepared either in water or wine. As with odor training, testing discloses personal idiosyncrasies in sensitivity and perception.

Basic selection tests[1]

Taste recognition

As noted, fine discrimination of taste sensations is seldom a criterion for wine tasting. This does not imply insignificance, but merely the lack of clear standards of acceptance. Thus, the tests mentioned are primarily for the benefit of the participants—to give them an opportunity to discover their own taste idiosyncracies. They also gain insight into human sensory variability.

Taste acuity For the initial assessment, prepare the samples in water. This simplifies detection and identification, each chemical being isolated from the complex chemistry of wine. Subsequent samples are prepared in white and red wine. Table 5.4 provides an example of preparing such a series.

Pour the samples into 750 ml water (Session 1), or wine (Sessions 2 and 3) about an hour before use. Stir adequately to assure complete dissolution. For the samples prepared in wine, allow participants to taste the base wine in advance to become familiar with its attributes.

Present the samples (glasses containing 30 ml) in random order. For each sample, participants note all detected taste and mouth-feel sensations (Appendix 5.1),

[1] Based on those outlined by Jackson (1994, 2000).

Table 5.4 Standards for testing recognition of taste and mouth-feel sensations

Sample (solution)	Amount (per 750 ml water or wine)	Sensations
Sugar	15 g sucrose	sweet
Acid	2 g tartaric acid	sour
Bitter	10 mg quinine sulfate	bitter
Astringent	1 g tannic acid	astringent, woody
Alcohol	48 ml ethanol	sweet, hot, body, alcoholic odor

as well as record the intensity of the most dominant sensation along the line supplied.

Participants should note where each sensation occurs most prominently, especially with the aqueous samples. This permits individual localization of the distribution of sensitivity throughout the mouth. Subsequent samples examine ability to recognize taste and mouth-feel stimuli in the context of a white and a red wine. These abilities often differ significantly from those found in water.

Figure 5.1 illustrates the diversity of perceived intensity in the series of aqueous samples noted in Table 5.4. Table 5.5 reveals the diversity of perceptions elicited by the samples. The perceptions noted for the water sample may reflect either lingering sensations from the previous sample, or the belief that some sensation must be present. Participants were not instructed to expect a water blank. Figure 5.2 demonstrates how the solute (water or wine) can influence response to a tastant.

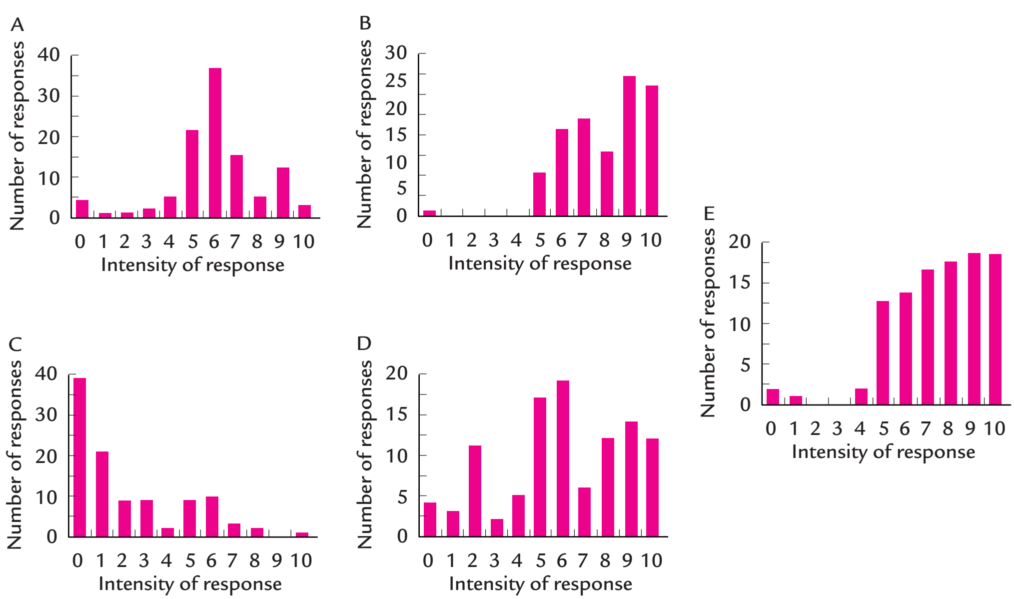


Figure 5.1 Intensity response of 105 people to several taste solutions: (A) sucrose (15 g/l), (B) tartaric acid (2 g/l), (C) quinine sulfate (10 mg/l), (D) tannic acid (1g/l) and (E) ethanol (48 ml/l).

Table 5.5 The variation in responses of 27 people to taste sensations in water: Sucrose (15 g/l), tartaric acid (2 g/l), quinine sulfate (10 mg/l), tannic acid (1 g/l) and ethanol (48 ml/l)

	Percent of Responses							
Solution	**Sweet**	**Sour**	**Bitter**	**Astringent**	**Alcoholic**	**Dry**	**Salty**	**Nothing**
Sucrose	94	6	0	0	3	0	0	0
Tartaric acid	3	47	17	12	3	0	22	0
Quinine	0	15	40	15	0	4	0	34
Tannic acid	0	16	25	47	0	7	7	0
Ethanol	7	6	12	1	74	0	1	0
Water	7	15	7	14	0	0	0	57

Relative sensitivity (sweetness) To assess relative sweetness, dissolve sucrose in separate wine samples at 3, 6, 12, and 24 g/l. Provide white bread or water as palate cleansers. Have participants familiarize themselves with the base wine. They can keep the sample as a reference in the subsequent test.

Each person receives five randomly numbered samples to rank in order of relative sweetness. The test is conducted on several occasions with different wines. Table 5.6 presents the setup for an example of three sessions with different wines.

Similar tests of sensitivity for acid, bitter and astringent compounds may be provided by using citric or tartaric acids for sourness (5, 10, 20, 40 g/l), quinine for bitterness (2.5, 5, 10, 20 mg/l), and tannic acid for bitterness and astringency (5, 10, 20, 40 g/l). To present astringency without bitterness, alum (aluminum potassium sulfate) can be used (2.5, 5, 10, 20 g/l).

Threshold assessment Establishing the taste thresholds of panelists is seldom conducted. However, if desired, the simple procedure outlined below is adequate.

A series of concentrations are usually prepared in water. This permits absolute thresholds to be determined, in contrast to relative thresholds obtained if wine were used. The number of concentrations employed should be sufficient to adequately cover the known range for the compound. For example, concentrations of 0, 1, 2, 3, 4, 5, 6, and 7 g/l glucose, or 0.03, 0.07, 0.10, and 0.15 g/l tartaric acid might be used for sweetness and acidity, respectively. If more precision is desired, once the rough range has been established, additional sets can more precisely bracket the threshold.

Table 5.6 Sweetness sensitivity test

Session 1 Chardonnay	**Session 2 Valpolicella**	**Session 3 Riesling**
#5[a] (A[b])	#5 (E)	#1 (E)
#3 (B)	#3 (D)	#4 (D)
#2 (D)	#4 (C)	#2 (C)
#1 (C)	#2 (B)	#3 (A)
#4 (E)	#1 (A)	#5 (B)

[a] # 1–5 Label identifying the sample.
[b] A, control (0 g/l sucrose); B, 3 g/l; C, 6 g/l; D, 12 g/l; E, 24 g/l.

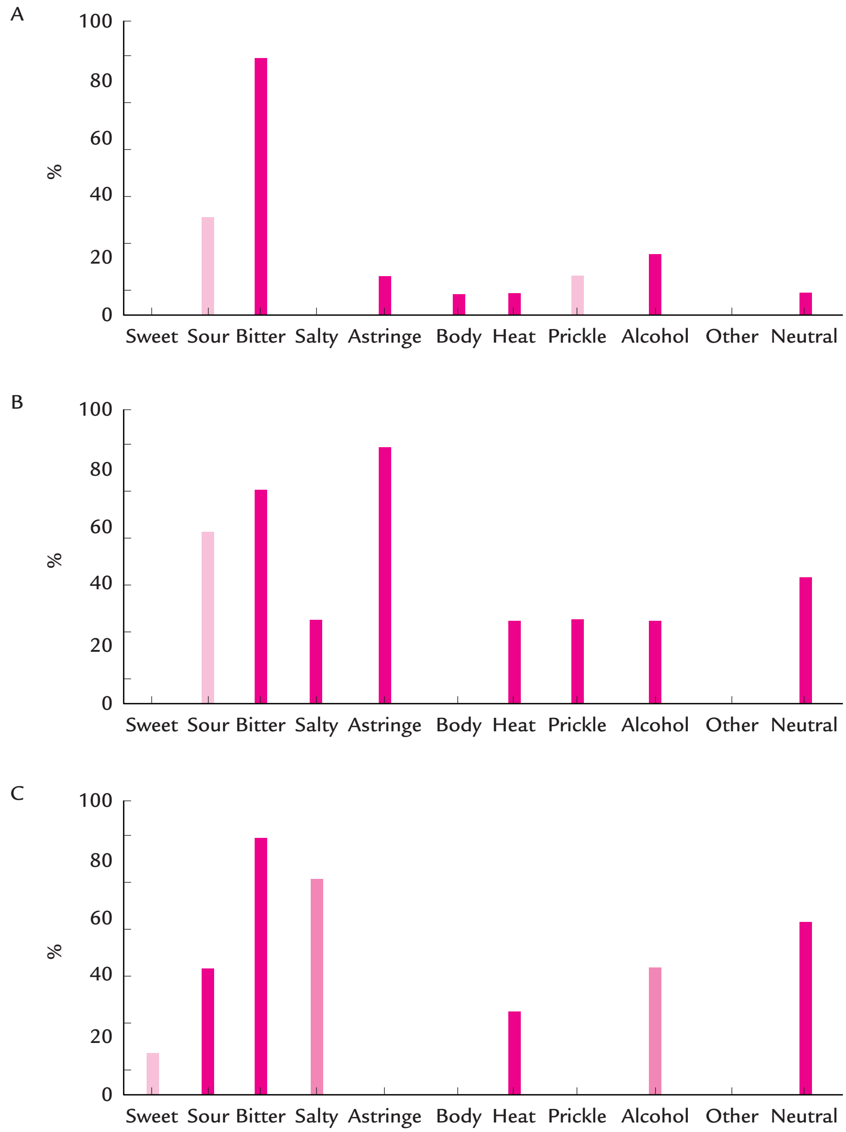


Figure 5.2 Variety of responses of 15 people to the presence of quinine sulfate (10 mg/l) in (A), water; (B), *Cabernet Sauvigon* wine; (C), *Sémillon/Chardonnay* wine.

For example, if the rough threshold were between 4 and 5 g/l glucose, concentrations such as 4.0, 4.2, 4.4, 4.6, 4.8, and 5.0 g/l would be appropriate.

Each sample concentration is paired with a water blank (control). The samples are arranged and marked so that the control sample is tasted first, followed by the tastant or another water blank. Participants note whether the second sample is the same or different from the control. This procedure is called an A–not-A test. Each concentration pair should appear at random at least six times. Chance alone should produce about 50% correct responses. Detection of a legitimate differentiation among samples requires a correct response rate of ≥75% (50% more than chance).

In the example given in Table 5.7, the participant would have a detection threshold of between 0.4% and 0.5% glucose.

Odor recognition

Fragrance (aroma and bouquet) This test measures identification of several characteristic wine fragrances. Appendix 5.2 gives an example of preparation of odor samples. Because learning is a component of the test, present the samples for study at least several hours before each test. Cover the mouths of the glasses with tight-fitting covers (e.g., 60 mm plastic petri dish bottoms) to permit vigorous swirling. Encourage the participants to take notes on the aromatic features they think may help them recognize the samples and the unmodified base wine (control). Samples are only smelled (tasting is not intended).

For the test, present the samples in dark glasses (or under red light) to negate visual clues as to origin (the appearance of some samples is unavoidably affected in preparation). Substitute some odors samples with control samples in each test session. This helps to minimize identification by elimination.

The answer sheet lists all samples plus provides space for recording an unidentified number of controls. Descriptor terms are provided because identification is being assessed, not word recall. For simplicity, participants mark the sample number opposite the appropriate term, or record the sample as a control.

After the test, encourage the participants to reassess misidentified samples as an additional learning experience. Three training–testing sessions are usually adequate to assess ability to learn and identify fragrance samples.

Figure 5.3 illustrates a typical response for this type of test by 15 participants. When participants misidentify samples, they frequently (but not consistently) choose a term in the same category of odors, for example bell pepper for herbaceous.

Off-odors: basic test The test assesses ability to learn and identify several characteristic odor faults. Appendix 5.3 gives an example of preparation of off-odor samples. Training sessions with the samples should be held at least several hours before the test. During training, encourage the participants to record their impressions to help them recognize the off-odors. They can use these notes in the subsequent test periods.

The answer sheet lists all fault names, plus space for several controls. Participants smell each sample and mark the sample number opposite the appropriate term, or as a control. The samples are covered (petri dish bottoms) when not in use to minimize

Table 5.7 Responses to an A–not-A test for determining the detection threshold to glucose

	Sample (% glucose)						
	Control	0.2%	0.3%	0.4%	0.5%	0.7%	0.9%
Correct responses[a]	3	4	3	4	5	5	5
Percent correct	50	66.7	50	66.7	83.3	83.3	83.3

[a]Total number of responses = 6.

odor contamination of the surroundings. Present the samples in dark-colored wine-tasting glasses (or under red light).

Three training–testing sessions are usually adequate to assess off-odor recognition. Additional training sessions should be provided periodically to maintain proficiency. Figure 5.4 illustrates a typical set of responses from 15 participants. When misidentified, they are frequently confused selectively, notably baked and oxidized; mercaptan and *goût de lumière*; guaiacol and trichloroanisole; and ethyl acetate with acetic acid, fusel alcohols, and plastic.

Off-odors in different wines The previous test presents off-odors at a single concentration, and in a relatively neutral-flavored wine. To provide a more realistic indication of identification ability, this test presents the faults at two concentrations (closer to those that might occur naturally), and in both white and red wine. Wine type can affect both perception and recognition of off-odors (Martineau *et al.*, 1995).

In the test design given in Appendix 5.4, only a selection of the more important and easily prepared faults are used. Participants sample the undoctored (control) wines for familiarization before performing the test.

In the test, arrange the faulty and control samples randomly. List all off-odor names on the answer sheet, even though only some are presented. Leave space for an undisclosed number of controls. Participants smell each sample and mark the number of the sample opposite the appropriate fault or in the space for the controls.

Figure 3.15 illustrates results from this type of test. Off-odors are more readily detected in white than red wines, presumably because of the less intense fragrance of white wines. Intriguingly, almost half of the control samples are identified as having

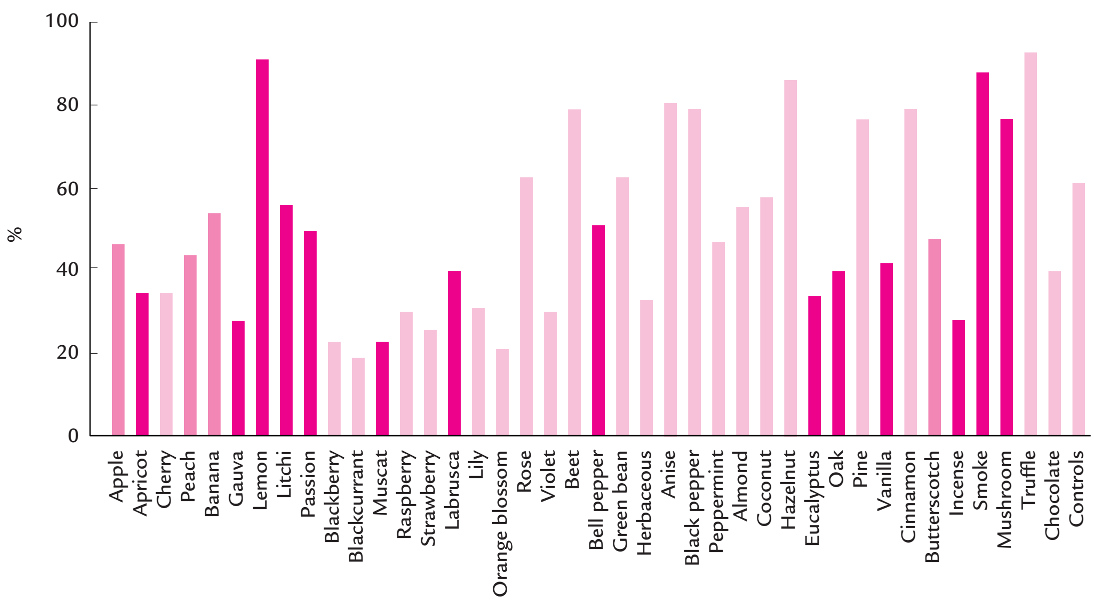


Figure 5.3 Success rate (%) of identifying several aroma samples (Appendix 5.2) in a neutral base wine (15 participants).

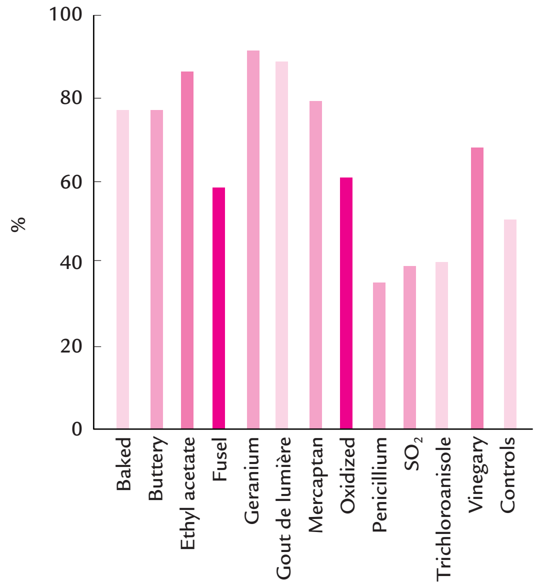


Figure 5.4 Success rate (%) of identifying several off-odor (Appendix 5.3) in a neutral base wine (15 participants).

an off-odor, even though participants sampled the base wines before the test. This is probably an example of how suggestion can influence perception.

Discrimination tests

Varietal dilution The Varietal Dilution test measures discrimination among subtle differences in wine samples. Wines possessing a varietally distinctive aroma are diluted with neutral-flavored wine of similar color. If appropriate wines of similar color are unavailable, the samples should be artificially colored, presented in dark glasses, or tested under red light. The dilution series can be at any level desired, but dilutions of 4, 8, 16, and 32% provide a reasonable range for discrimination.

Five sets of three glasses at each dilution is the minimum requirement. Pour one glass of diluted wine and one glass of the undiluted wine (control). The remaining glass holds either the undiluted or diluted sample, so that each triplet has one different sample, but not consistently the diluted or undiluted wine. This testing procedure is called the triangle test.[2] Arrange the sets at random. Table 5.8 illustrates an example of a setup for this type of test.

Participants move past each set of glasses, remove the covers, and smell each sample. They note the *most different* sample on the answer form. Requesting identification of the most different sample is more appropriate because it does not also require recognition of which two samples are identical. Because the "identical"

[2] Other test procedures, such as the pair and duo–trio tests, are equally applicable, but are less economic in wine use. In addition, the triangle test tends to be more rigorous, requiring increased concentration.

Table 5.8 Example of a setup for a varietal dilution test

					Sample sequence number in session:		
Dilution fraction[a]	**green**	**yellow**	**purple**	***most different*[b] sample**	**#1**[c]	**#2**	**#3**
4%	c[d]	x	c	y	1	15	13
4%	x	c	c	g	8	18	9
4%	c	c	x	p	13	5	19
4%	x	c	x	y	6	12	18
4%	c	c	x	p	19	1	8
8%	c	x	c	y	12	20	4
8%	c	x	x	g	17	13	14
8%	x	c	x	y	5	4	15
8%	x	c	c	g	18	7	1
8%	c	x	c	y	9	3	7
16%	c	c	x	p	11	11	2
16%	x	c	x	y	2	16	10
16%	c	x	x	g	10	9	5
16%	c	c	x	p	16	2	3
16%	c	x	c	y	14	6	6
32%	c	x	x	g	4	19	12
32%	c	c	x	p	7	10	20
32%	c	x	c	y	15	14	17
32%	c	x	x	g	3	17	11
32%	x	c	x	y	20	8	16

[a] Needs 4 bottles of each wine plus a bottle for dilution; 4 empty bottles for diluted samples
To dilute samples: 4% = 384 ml wine + 16 ml diluting wine
8% = 368 ″ ″ + 32 ″ ″
16% = 336 ″ ″ + 64 ″ ″
32% = 272 ″ ″ + 128 ″ ″

[b] The base of each glass is marked with a colored sticker (g, green; p, purple; y, yellow). The participants identify the most different sample by noting the color of the sample on the test sheet.

[c] Sessions #1: Cabernet Sauvignon, #2: Zinfandel, #3: Chardonnay.

[d] c, control (undiluted) sample; x, diluted sample.

samples may have come from separate bottles, they may not be as equivalent as one might desire. It also avoids the problem that adaptation may result in identical samples not being perceived as duplicates. If participants are not certain which is the *most different,* they are required to guess. The statistical test assumes that some correct responses will be guesses.

Probability tables provided in Appendix 5.5 indicate the level at which participants begin to distinguish differences among samples. Under the conditions used in Appendix 5.5 (five replicates), participants must correctly identify four out of five replicates to accept differentiation.

Although the test is designed to distinguish the sensory skills of individuals, group results are intriguing. All levels of dilution are generally distinguished from the undiluted control. However, the success rate differs markedly among wines, but rarely exceeds 60%. Success at differentiation surprisingly does not increase significantly with higher rates of dilution.

Varietal differentiation This test assesses ability to distinguish between similar varietal wines. As in the previous test, the triangle procedure is used.

Choose distinctive pairs of three varietal wines. For each pair, prepare 10 sets of glasses. Two glasses contain one of the wines, whereas the third contains the other. Use dark-colored glasses or red illumination if the wines are noticeably different in color. Alternatively, adjusting the color with food dyes may eliminate the color differences. Random positioning of the sets minimizes the likelihood of identical pairs occurring in sequence (Table 5.9). With 10 replicates of each set of wines, the participant must obtain seven correct responses to signify identification ($p = 0.05$) (see Appendix 5.5).

Participants should assess each of the pairs of wines before the test. This removes experience from being an important factor in differentiation. This is equally important if participants are asked to identify the varietal origin of each set of wines.

The test is particularly important in assessing tasting ability. Tasters are required to recognize the subtle differences that distinguish similar wines. Correspondingly, samples must be chosen carefully to demonstrate the characteristics expected to be distinguished on a regular basis, for example, samples should be differentiable by the preparers of the test.

Figure 5.5 illustrates the type of group results one might expect. For example, participants had more difficulty separating the two Beaujolais (*Gamay noir*) than recognizing that they were Beaujolais. In contrast, the group found it easier to separate the two *Chardonnay* samples than to recognize that they were *Chardonnay* wines. Individually, participants varied from recognizing 33 to 90% of varietal origin, and from 33 to 70% in differentiating between sample pairs.

Short-term wine memory The wine memory test is particularly significant as it measures ability to recognize wines sampled previously. This skill is essential for fair assessment of wines sampled, as usual, in groups.

In preparation for the test, each participant tastes a set of five wines. Each wine should be sufficiently unique to permit clear differentiation. Dark-colored glasses, or dim red lighting, can be used to eliminate color as a distinguishing criterion. A number or letter code identifies each wine.

Participants assess each wine for odor, taste, and flavor, using a standard detailed score card. They retain their sheet as a reference during the test.

The test consists of sets of glasses containing seven wines. Participants are told that among the seven are the five wines sampled earlier. They are also informed that among the seven glasses are two that are either repeats of one or two of the wines previously sampled, or contain wines different from those previously tasted. Participants taste the samples, identifying them as one of the previously sampled wines or as a new sample.

Table 5.9 Example of the arrangement of samples in a wine differentiation test

	Green (g)	Yellow (y)	Purple (p)	*Most different** Sample	Position#
Sangiovese	1	2	1	y	1
	2	1	1	g	5
(1, Melini Chianti;	2	2	1	p	7
2, Ruffino Chianti)	1	2	1	y	11
	1	2	2	g	15
	1	1	2	p	18
	1	2	2	g	21
	2	2	1	p	23
	1	2	1	y	26
	1	2	2	y	28
Cabernet Sauvignon	2	1	2	y	2
	1	2	2	g	4
(1, Santa Rita;	1	1	2	p	8
2, Santa Carolina)	2	1	1	g	10
	2	1	1	g	13
	2	1	2	y	17
	1	2	1	y	20
	1	1	2	p	24
	2	1	2	y	27
	1	1	2	p	29
Pinot noir	1	2	2	g	3
	2	1	2	y	6
(1, Drouhin;	2	1	2	y	9
2, Pedauque)	1	2	1	y	12
	2	1	1	g	14
	1	1	2	p	16
	2	2	1	p	19
	1	1	2	p	22
	2	1	2	y	25
	1	2	1	y	30

* The base of each glass is marked with a colored sticker. The participants identify the *most different* sample on the test sheet.

Assessing functional tasting skill

Brien *et al*. (1987) have summarized many of the statistical measures researchers have used for measuring panelist accuracy. They have also proposed additional indicators, such as discrimination (the ability to distinguish among wines of distinct character), stability (reproducibility of scoring results of similar wines from tasting to tasting), reliability (reproducibility of score differences between replicate sets of the same wines), variability (range of scores between replicate wine samples), and agreement (scoring differences among tasters). Of these measures of consistency, two require that identical wines be sampled repeatedly, either on one occasion (reliability), or on separate occasions (variability). Additional reviews of statistical measures are given by Cliff and King (1997), and Stone and Sidel (1992).

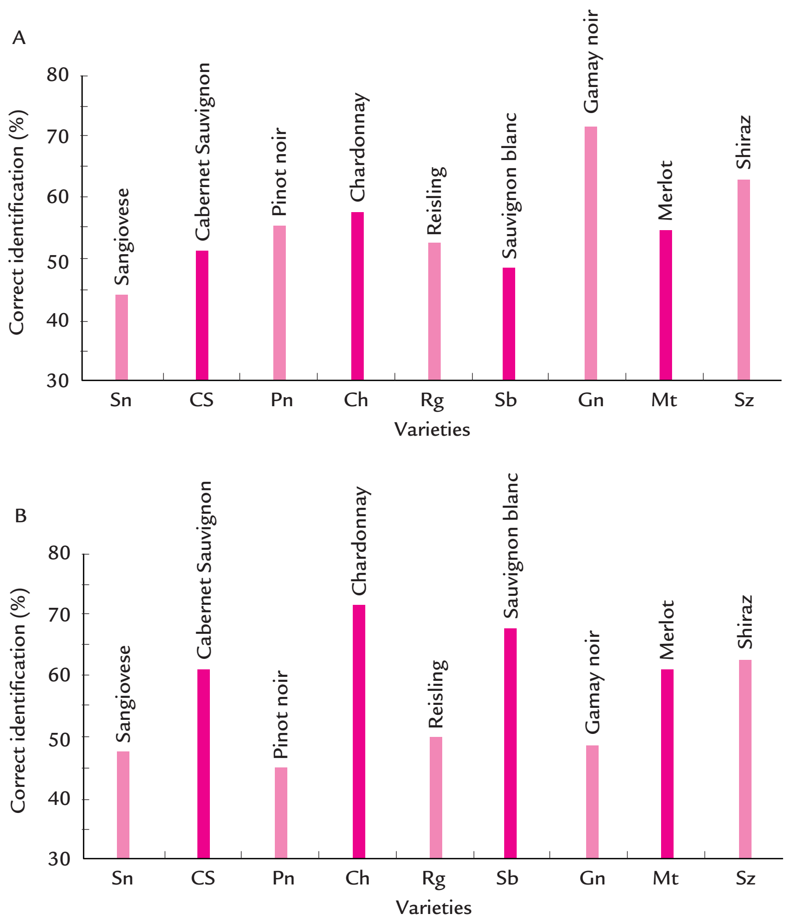


Figure 5.5 Success rate of 15 participants (%) of recognizing (A) varietal origin and (B) different samples of the same variety in the wine differentiation test (Sn, *Sangiovese*; CS *Cabernet Sauvignon*; Pn, *Pinot noir*; Ch, *Chardonnay*; Rg, *Reisling*; Sb, *Sauvignon blanc*; Gn, *Gamay noir*; Mt, *Merlot*; Sz, *Shiraz*).

Because of the complexities of making these assessments, they are seldom performed. In addition, there is the issue of what is the minimum acceptable level for performance. For most purposes, analysis of variance of tasting results usually provides adequate information. In general, consistency and score variability are the measures of most concern to those conducting tastings.

Consistency in all aspects of critical tasting is essential. In descriptive sensory analysis homogeneous use of descriptive terms is obligatory. Continuous monitoring of term use during training can be analyzed to determine if there is low taster X term variance. For evaluation-type tasting, random repeat tasting of a few wines over several weeks or months can provide similar data. Variance that is insignificant suggests taster consistency. In the latter assessment, it is important that the wines given repeatedly not be unique. If particularly distinctive, tasters will soon detect this, realize why the same wines are appearing frequently, and modulate their scores accordingly.

With the ready availability of computer statistical packages, use of analysis of variance has become the standard means of assessing aspects of consistency. Because these packages incorporate *F*-distribution and *t*-distribution tables, they have not been reproduced here. If required, they can be found in any modern set of statistical tables. Even without dedicated statistical software, spreadsheet programs in Office software packages can be readily setup to perform analyses of variance.

Table 5.10A presents hypothetical tasting results, from which data are used to assess taster consistency. In this example, scoring data on two different wines, randomly presented twice during five separate tastings, are compiled. From the analysis of variance table (Table 5.10B), the least significant difference (LSD) can be derived from the formula:

$$\mathrm{LSD} = t_\alpha \sqrt{2v/n} \qquad \text{Eq.1}$$

Table 5.10 A. Scoring of two wines (A and B) by a single taster on two separate occasions during a tasting. Replicates of this event occurring during five independent tastings

Tasting occasion	Wines A_1	A_2	B_1	B_2	Total
1	9	10	6	5	30
2	10	8	7	6	31
3	7	9	5	7	28
4	8	9	6	5	28
5	9	8	7	6	30
Total	43	44	31	29	
Mean	8.6	8.8	6.2	5.8	

$G = \Sigma$ Totals = (43 + 44 + 31 + 29) = (30 + 31 + 28 + 28 + 30) = 147

$C = G^2/n = (147)^2/20 = 1080.45$

Total SS = Σ (individual scores)^2 − C = ($9^2 + 10^2 + 7^2 + 8^2 +$ ....6^2) − C = 1131−1080.45 = 50.55

Wine SS = Σ (wine total)^2/n − C = ($43^2 + 44^2 + 31^2 + 29^2$)/5 − C = 1117.4 − 1080.45 = 36.95

Replicates SS = Σ (replicate totals)^2/n − C = ($30^2 + 31^2 + 28^2 + 28^2 + 30^2$)/5 − C = 1082.25 − 1080.45 = 1.8

Error SS = Σ (individual scores)^2 − Σ (wine total)^2/n − Σ (replicate totals)^2/n = 50.55 − 36.95 − 1.8 = 11.8

df (degrees of freedom): Total (# scores −1) = (20−1) = 19; Wine (# wines −1) = (4−1) = 3; Replicate (# replicates −1) = (5−1) = 4; Error (total *df* − Wine *df* − Replicates *df*) = 19 − 3 − 4 = 12

ms: Wines (Wine SS ÷ Wine *df*) = 36.95/3 = 12.32; Replicates (Replicate SS ÷ Replicate *df*) = 1.79/4 = 0.45; Error (Error SS ÷ error *df*) = 11.8/12 = 0.98

F: Wines (Wine *ms* ÷ error *ms*) = 12.32/0.98 = 12.52; Replicates (Replicates *ms* ÷ Error *ms*) = 0.46/0.98 = 0.46

B. Analysis of variance table

Source	*SS*	*df*	*ms*	*F*	$F^*_{.05}$	$F_{.01}$	$F_{.001}$
Total	50.55	19					
Wines	36.95	3	12.32	12.52	3.49	5.95	10.8
Replicates	1.79	4	0.45	0.46	3.26	5.41	9.36
Error	11.8	12	0.98				

**F* - distribution values are available in all standard statistical tables.

where t_α is the t value with error degrees of freedom (available from standard statistics charts), at a specific significance level (α); v is the error variance (ms); and n is the number of scores on which each mean is based. At a 0.1% level of significance, the formula for data from Table 5.10 becomes:

$$\text{LSD} = 3.055\sqrt{2(0.983)/5} = 1.916 \qquad \text{Eq.2}$$

For significance, the difference between any two means must exceed the calculated LSD-value (1.916). The difference between the mean scores for both wines (A and B) clearly indicate that there is no significant difference between the ranking of either wine. For wine A, the mean difference was 0.2 (8.8 − 8.6), and for wine B, the mean difference was 0.4 (6.2 − 5.8). Both values are well below the LSD-values needed for significance—1.916. Equally, the results show that the two wines were well distinguished by the taster. All combinations of the mean differences between replicates of wines A and B were greater than the LSD-value (1.916):

$$A_1 - B_1 = 8.6 - 6.2 = 2.4 \qquad \text{Eq.3}$$

$$A_1 - B_2 = 8.6 - 5.8 = 2.8 \qquad \text{Eq.4}$$

$$A_2 - B_1 = 8.8 - 6.2 = 2.6 \qquad \text{Eq.5}$$

$$A_2 - B_2 = 8.8 - 5.8 = 3.0 \qquad \text{Eq.6}$$

Score variability

A high level of agreement among tasters is necessary when the experimenters are interested in whether wines of similar character can be differentiated. However, agreement may also indicate lack of skill, or an inadequate reflection of human variability. For example, inexperienced tasters may show lower score variability in tasting than experienced tasters, possibly because experience permits confidence in use of the full range of a marking scheme. Tasters with consistent, but differing views on wine quality will also increase score variability. Acceptance of this variability, and the consequential reduction in potential for differentiation, will depend on the purpose of the tasting. As noted, absence of accepted standards for wine quality makes it difficult to decide whether score variability results from divergence in perceptive ability, experience, concepts of quality, or other factors.

In the absence of quality standards, the best that can be done is to measure panel score variability. If tasters have been shown to be consistent, then significant variance among panelists scores for single wines probably reflects differences in perception. However, significant difference among score averages for several wines probably indicates real differences among the wines. Table 5.11A provides data on the ranking of four wines assessed by five tasters.

In this example, analysis of variance (Table 5.11B) shows that panelists clearly demonstrated the ability to distinguish among the four wines. The calculated F value (21.2) is greater than F statistics up to the 0.1% level of significance (10.8). However, no significant difference appeared among the scores of the five tasters—the calculated F value (1.17) is less than the $F_{.05}$ statistic (3.26). This indicates group scoring consistency.

Analysis of variance can also show whether a panel is showing a common concept of quality. Table 5.12A provides data where the wines cannot be considered significantly different, but the individual scores show significant difference. The analysis of variance table (Table 5.12B) generates an F value of 2.23 for variance among wines. Because this is less than the $F_{.05}$ statistic (2.78), this indicates that no significant difference (p <0.05) was detected among the wines. In contrast, the calculated F value of 3.35 for variance among tasters is greater then the $F_{.05}$ statistic for tasters (2.51). This suggests that panel members probably did not have a common view of wine quality. Removing data generated by panelists who are unfamiliar with the wine, inconsistent in scoring, or who possess aberrant views of wine quality, might show that the wines were differentiable, and the remaining panelists consistent in their perception of quality (at least for those wines).

Assessment of panelist consistency, both of individuals and groups should be based on many tastings. Individuals have off-days and views of quality often vary between wines, being more consistent for some wines than others.

Pre-tasting organization

Tasting area

Indirect natural lighting is often considered ideal for assessing wine color, presumably because diffuse sunlight is thought to be spectrally uniform. This assumption is mistaken (Fig. 5.6). Even if skylight were spectrally constant, it is rarely possible

Table 5.11 A Data on the scores for four wines tasted by five tasters

	Wines					
Tasters	W_1	W_2	W_3	W_4	Sum	Mean
1	15	9	15	12	51	12.8
2	16	10	12	13	51	12.8
3	18	10	13	11	52	13
4	19	11	14	12	56	14
5	17	12	13	15	57	14.3
Sum	85	52	67	63		
Mean	17	10.4	13.4	12.6		

B Analysis of variance table

Source	SS	*df*	*ms*	*F*	$F_{.05}$	$F_{.01}$	$F_{.001}$
Total	142.55	19					
Wines	112.95	3	37.65	21.21	3.49	5.95	10.8
Tasters	8.30	4	2.08	1.17	3.26	5.41	9.36
Error	21.30	12	1.77				

Table 5.12 A Scoring results of seven tasters for five *Riesling* wines

Tasters	Wines W_1	W_2	W_3	W_4	W_5	Sum	Mean
1	3	5	4	7	7	26	5.2
2	5	6	5	6	9	31	6.2
3	9	3	2	4	5	23	4.6
4	7	2	8	8	6	31	6.2
5	6	5	4	5	6	26	5.2
6	7	8	5	8	7	35	7
7	3	4	7	8	9	31	6.2
Sum	40	33	35	46	49	203	
Mean	5.7	4.71	5	6.6	7		

B Analysis of variance table

Source	*SS*	*df*	*ms*	*F*	$F_{.05}$
Total	56.6	34			
Wines	9.5	4	2.38	2.23	2.78
Tasters	21.5	6	3.58	3.35	2.51
Error	25.7	24	1.07		

to provide such illumination under tasting conditions. Most tasting rooms possess only artificial lighting, with little if any natural illumination. Of light sources, flourescent tubes provide more uniform illumination. If lighting must resemble diffuse natural illumination, special daylight tubes can be used. In most instances, though, cool-white fluorescent tubes are adequate. The mind adjusts color perception to a wide range of daily spectral and intensity changes (Brou *et al.*, 1986). If tasting is done in the same room, tasters quickly adapt to the color characteristics of most forms of standard illumination. Within typical ranges, the intensity and diffuse nature of flourescent illumination is more important than its spectral qualities. Alternately, recessed or track halogen lights from the ceiling can provide individual, brilliant, full-spectrum or low-intensity red illumination of each station. In contrast, standard incandescent lighting is rarely uniform and it has an excessively high yellow component. Color distortion can be further minimized by having tasting rooms painted in bright neutral colors and having counters or table tops matte-white.

When the influence of color on perception must be avoided, low-intensity red light is often used. This so distorts color differentiation that clues it might provide are negated. Use of wine glasses painted black has the same effect.

Tasting rooms should be air-conditioned, not only for the comfort of the tasters, but also to prevent odor accumulation. Positive air pressure assures excellent ventilation and prevents the entrance of extraneous odors. Tasters may become accustomed to mild background odors, but it is preferable to avoid any potential sources of olfactory distortion. When air-conditioning is not available, air purifiers can help

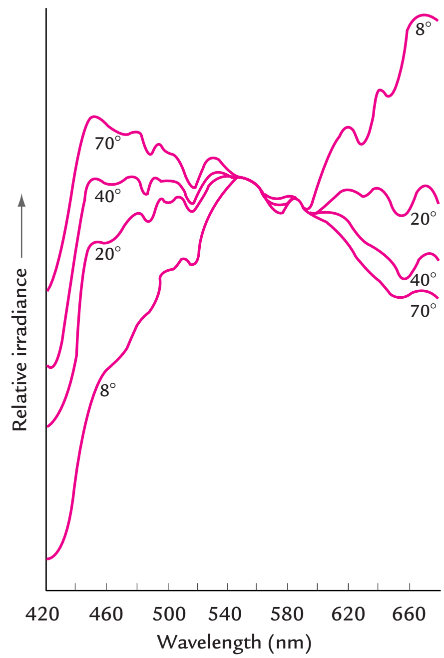


Figure 5.6 Daily spectral variability in diffuse skylight. When the sun is high in the sky (70° above the horizon), the peak radiation is in the blue section. This shifts as the sun begins to set to a point where it is in the red by half an hour before sunset (8° above the horizon). (Adapted from Henderson, 1977, reproduced by permission.)

provide an aromatically neutral tasting environment. Tasting rooms equally need to be free of annoying sounds that could disrupt concentration.

Tasting stations should be physically isolated to prevent taster interaction (Fig. 5.7). Even with silence, facial expressions can be very communicative. If tasting locations cannot be compartmentalized, separate and random sequence of wine presentation for each taster can reduce the likelihood of significant taster interaction.

Chairs or stools should be adjustable as well as comfortable. Panel members may be spending hours concentrated on the difficult tasks of identification, differentiation, or evaluation. Every effort must be made to make this work as pleasant as possible.

Rooms specifically designed for tasting should possess dentist-like cuspidors at each station. They are both hygienic and prevent odor build-up. Because most tasting environments are not so well equipped, 1 l opaque plastic buckets can act as substitutes. These need to be voided frequently, or possess a cover to limit odor contamination of the surroundings. Covers over the mouths of the glasses can further limit odor dispersion throughout the tasting area.

Pitchers of water, or samples of dry, unsalted, white bread should typically be available for palate cleansing. As noted, the extent to which palate cleansing is desirable is under dispute. Because bread and water remove saliva, as well as residual wine, they can affect oral perception. Peynaud (1987) speculates that palate cleansing disrupts acclimation of the oral surfaces to the basic characteristics of wine. In

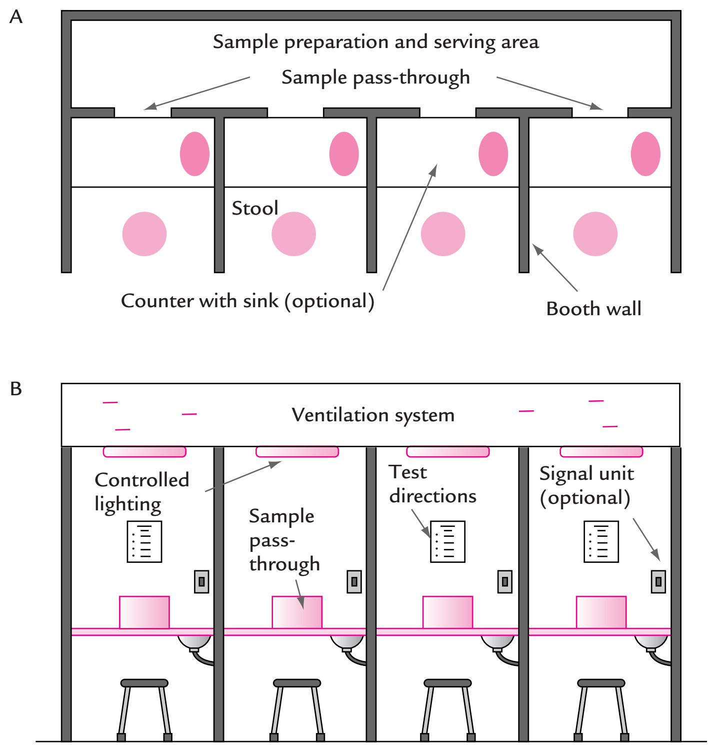


Figure 5.7 Diagram of the booth area in a sensory-evaluation facility (not drawn to scale) (A) Floor Plan. (B) Front elevation. (From Stone and Sidel, 1992, reproduced by permission.)

situations where very similar wines are being sampled, Peynaud's view seems reasonable. However, in almost every other situation, cleansing the palate before and between each sample is probably essential to limit sequence errors from affecting perception.

Computer terminals positioned at each booth or tasting station greatly facilitate data collection. Rapid analysis permits almost instantaneous feedback during training, while samples are still present for reassessment. The presence of a touch screen monitor, incorporating the tasting sheet, frees the tasting surface of the clutter of writing materials. If notation demands more than just checking items, a keyboard on a slide rail under the counter could be installed. It eliminates problems that frequently arise from illegible handwriting.

Industrial dish washers are indispensable for the rapid, efficient, and sanitary cleaning of the large amount of glassware involved in most tastings. Odorless cleaners, combined with proper rinsing, provide glassware that is crystal clear, as well as odor- and detergent-free. Storage in odor-free cabinets is equally essential.

Number of samples

There is no generally accepted number of samples appropriate for a tasting. If the samples are similar, only a few should be sampled jointly. For accurate evaluation, the taster must be able to simultaneously remember the attributes of each sample—no easy task. Also, because ratings tend to be relative, the more detailed the tasting, the fewer the samples that can be adequately evaluated concurrently.

If the samples are markedly different, relatively large numbers of wines can often be evaluated. Nevertheless, six wines tends to be the limit that can be jointly compared adequately. In contrast, wine tasters are often expected to sample over 30 wines within a few hours. Obviously, these assessments can be only quick and simple, even when sampled in groups. Serious consideration of the development or duration of the wine's fragrance is not possible. Typically, the wines are judged on an overall quality ranking. Although rapid, it does potential injustice to several of the wines' more valued qualities.

Replicates

In most tastings, replicate samples are unavailable, primarily for economic reasons. If the tasters are skilled and consistent, there is little need for replication. However, if taster consistency is unknown, the incorporation of some replicates can assess taster reliability. Replicates are also useful if substitutes are needed to replace faulty samples.

Temperature

White wines are typically considered to be best served at cool temperatures, whereas red wines are presented at "room" temperature. Rosé wines are served at a temperature in-between those deemed optimal for white and red wines. Besides these general guidelines, there is little precise agreement among authorities.

The recommended *cool* for white wines can vary from 8 to 12°C, with the upper end of the range being more frequent. In the author's experience, anywhere within this range is appropriate. What is more important, though, is that all wines be served at the same temperature. As with other aspects of tasting, it is essential that wines be sampled under identical conditions. Sweet (dessert) white wines often show best at the lower end of the range, whereas dry white wines are more preferred at the upper end of the scale. Dry white wines can even show well at 20°C. This should not be surprising because wine soon reaches and surpasses 20°C in the mouth. Some aspects of wine development may result from increased volatility as the wine warms.

Red wines are generally recommended to be tasted at between 18 and 22°C. This range enhances the fragrance and diminishes perceived bitterness and astringency. Only light, fruity red wines, such as carbonic maceration wines (e.g., Beaujolais), are taken somewhat cooler, at between 15 and 18°C. Rosé wines are typically served around 15°C.

Sparkling wines have an optimal serving temperature between 4 and 8°C. This range enhances the expression of the toasty aspect so desired in most dry sparkling wines. In addition, it slows the release of carbon dioxide and the effervescence it generates. Cold temperatures also enhance the prickling sensation of sparkling wines (see Green, 1992). Finally, the cool feel gives the wine part of its refreshing sensation. Unfortunately, cold temperatures can also increase the metallic sensation occasionally found in some sparkling wines.

Sherries are generally taken cool to cold. This mellows their intense bouquet. It also decreases the sweetness of cream sherries and the burning influence of their high alcohol content. In contrast, it is generally recommended that port be taken at temperatures near the lower range for red wines.

Although temperature preferences partially reflect habituation, they also embody empirical observations on the effects of temperature on volatility and gustatory sensitivity.

Although aromatic compounds become more volatile as the temperature rises, this glosses over important differences in the response of individual compounds to temperature change. Because temperature's effect on volatility varies with the compound, the relative proportion of aromatics in a wine's fragrance varies with the temperature. Consequently, temperature change can either increase or decrease the detection of particular aromatics. This may explain why some white wines seem more pleasingly aromatic at cooler than warmer temperatures. In addition, temperature changes will be particularly significant in the thin film of wine that adheres to the sides of a glass after swirling. The alcohol content of this fraction also falls rapidly, further altering the relative volatility of its aromatics.

Temperature has marked effects on taste and mouth-feel. Cool temperatures reduce sensitivity to sugars, but enhance receptiveness to acids. These phenomena partially account for dessert wines appearing more balanced at cooler temperatures. Coolness can also generate a pleasant freshness. This gives rosé wines part of their appeal as sipping wines in the summer. In contrast, reduced bitterness and astringency helps clarify why red wines are typically served at or above 18°C.

Wines are ideally brought to the desired temperature several hours before tasting. In most commercial situations, this occurs in specifically designed refrigerated units. Some of these are subdivided to maintain wines at different temperatures. Alternatively, wines may be immersed in water at the desired temperature, or stored in a room or refrigerator until the desired temperature is reached. Figure 5.8 provides examples of the rates of temperature change in 750 ml wine bottles in air and water, respectively. Temperature adjustment is about ten times faster in water than in air: equilibration often being reached within minutes rather than hours. Once the desired temperature has been reached, the wine can be kept at this value for several hours in well-insulted containers, or for short periods in individual wine jackets.

Because the wine begins to warm after pouring, it is better to serve the wine at the lower limit of suitable temperatures. Thus, the wine will remain within the desirable range for the longest period. This is particularly important if features such as duration and development of a wine's fragrance are assessed. Unfortunately, most tastings occur so rapidly that these noteworthy properties are missed.

Cork removal

No corkscrew is fully adequate in all situations. For general use, those with a helical coil are adequate. The waiter's corkscrew is a classic example, but needs considerable

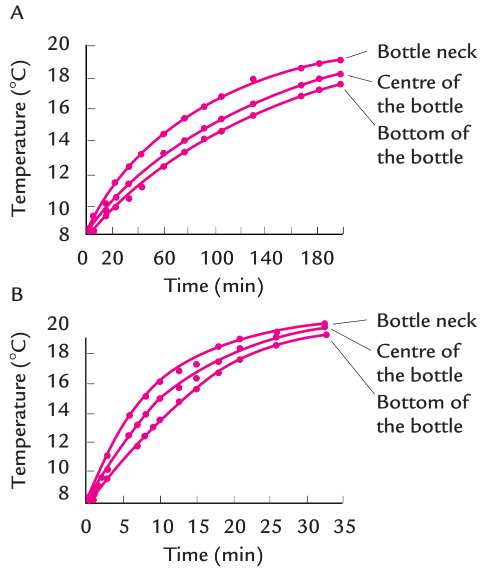


Figure 5.8 Distribution and change in the temperature of wine in a 750 ml bottle placed (A) at 21°C in air or (B) in water at 20°C (from Gyllensköld, 1967).

force for cork extraction. Double action models are preferable. They both sink the screw into the cork as well as subsequently remove the cork. A lever model of the Screwpull® is available for commercial use. Regardless of design, most corkscrews have difficulty removing old corks. With time, cork loses its resiliency and tends to crumble on removal. In this situation, the two-prong U-shaped Ah-So, or a hand pump connected to a long hollow needle can prove invaluable. If corrosion occurs on the lip of the neck, it should be removed with a damp cloth.

Decanting

Decanting is valuable when sampling wines that have developed sediment. It also permits early detection of off-odors. In the process, though, the wine is inadvertently exposed to oxygen. This is of little concern if the wine is tasted shortly after opening. For old wines, however, tasting should occur immediately if the wine is decanted. These wines rapidly lose whatever fragrance they still possess. Covering the mouth of the decanter with a watch glass or petri dish top can limit aromatic loss. Because most modern wines are sufficiently stabilized to prevent sediment formation, they rarely need decanting.

Changes in the equilibrium between volatile and loosely fixed non-volatile complexes may explain anecdotes concerning the aromatic benefits of decanting. Whatever the explanation, phenomena such as "opening" of the fragrance is much more likely to occur when the wine is poured into a glass and swirled (see Decanting and "Breathing," Ch. 6). In addition, if sensory benefits accrue from decanting, the taster should experience them.

Sample volume

The volume of each wine sample should be identical. Depending on the purpose of the tasting, this can range from 35 to 70 ml. Where only simple evaluation is required, volumes in the 35 ml range are fully adequate. If a more detailed or prolonged assessment is required, volumes in the 50 to 60 ml range are typical. With volumes in the 50 ml range, a 750 ml bottle can serve 12 to 14 tasters.

Dispensers

Wine dispensers are refrigerated units holding up to sixteen 750 ml bottles of wine. They can keep both red and white wines in adjacent compartments at separate but constant temperatures. Each bottle is separately connected to a nitrogen gas cylinder. It supplies the pressure to dispense wine when the spigot is pushed. Originally designed for commercial wine bars, they have particular value in training sessions. Wines can be economically sampled over several days or weeks, without oxidation or other forms of deterioration. If refrigeration is less important, almost any number of samples can be supplied with spigots connected to a common nitrogen cylinder. This is especially useful where aroma or off-odor samples are employed. Because these samples are used irregularly over an extended period, they remain instantly available, but stable for months.

Representative samples

When dealing with bottled wine, a single bottle is generally assumed to exemplify the characteristics of the wine they represent. For relatively young wines, this is probably true. With older wines, having been exposed to different aging conditions, it is less likely. With tank or barrel samples, obtaining representative samples can be difficult.

In large cooperage, such as tanks, wine has the potential to become stratified, with disparate zones experiencing different maturation conditions. Bottom samples are likely to be cloudy and tainted with hydrogen sulfide or mercaptans, because of the low redox potential that can develop in the collected sediment. Regions next to oak may have high concentrations of wood extractives. Therefore, samples taken from the middle of the tank are preferable. Several liters may have to be drained before obtaining a representative sample.

Variation throughout a barrel is less marked than in tanks, because of their smaller size. Nevertheless, barrel-to-barrel differences can be even greater than those that arise in large tanks. These variations can develop because of differences in cooperage manufacture, conditioning, and prior use, as well as nonuniform cellar conditions. Barrels from several regions in the cellar usually need to be tapped if a representative sample is to be obtained. Frequently, though, a representative sample is not required. Tastings may be used only as a check for faults, or to follow the development of the wine.

In either case, the samples should be placed in sealable containers and transported immediately to a tasting room for analysis—cellars are notoriously poor areas in which to taste wine. If sampling must be delayed, the storage containers should be flushed with nitrogen or carbon dioxide before use. This helps minimize oxidation before testing.

Glasses

Wine glasses must possess specific characteristics to be appropriate for critical wine tasting. The glass needs to be crystal clear and uncolored. These properties are essential for accurate observation of the wine's appearance. The bowl should have sufficient capacity and shape to permit vigorous swirling of between 35 to 60 ml of wine. The glass should also be wider at the base than the top, to concentrate the aromatics released from the wine. In addition, the stem needs to be adequate for convenient holding and vigorous swirling. These features have been incorporated into the International Standard Organization (ISO) Wine Tasting glass (Fig. 1.2). The broad base and sloped sides facilitate viewing and vigorous swirling, whereas the narrow mouth (giving the glass its tulip shape) concentrates aromatics released by the wine. The latter is particularly useful in detecting subtle fragrances.

Most ISO glasses are slim crystal. Although enhancing elegance, they are too fragile for regular cleaning in commercial dishwashers. Therefore, thicker versions (such as available from Durand) are preferable. Their Wine Tasting Glass comes in 210 and 310 ml capacities. A less expensive but adequate substitute is the Libby Citation #8470. Where they are used solely for in-house tastings, a circular line may be etched[3] around the glass to denote an adequate fill level.

For sparkling wines, tall, slender, flute-shaped glasses are typically used. The shape permits detailed assessment of the wine's effervescence. This includes the size, persistence, and nature of the chain of bubbles; the mounding of bubbles on the wine (*mousse*), and the ring of bubbles around the edge of the glass (*cordon de mousse*).

Industrial dishwashers not only effectively clean but also sterilize the glasses. Extensive rinsing removes detergent and odor residues.

Once glasses have been cleaned and dried, they should be stored upright in a dust- and odor-free environment. The upright position helps limit aromatic contaminants collecting on the inside of the glass. This is especially critical if the glassware must be stored in cardboard boxes. Hanging stem ware upside down may be acceptable in restaurants, where they are used frequently, but it is ill-advised in wood or painted cabinetry.

Number of tasters

In theory, the larger the number of tasters, the greater the probability of obtaining clear data, or that the data will be indicative of the consumers for whom tasters may be considered representatives. Typically, though, as few tasters as possible are used. The number chosen often reflects the nature of the tasting and the need for accuracy. Use of skilled, consistent tasters improves the confidence level, while keeping costs to a minimum. In practice, a nucleus of 15 to 20 trained tasters is usually adequate,

[3] Most stores that do engraving will etch glasses for a nominal fee.

especially for wine analysis. This should provide a minimum of 12 tasters for any one tasting. For wine evaluation, six or seven skilled tasters are probably sufficient.

Because tasters are occasionally "out-of-form," continuous monitoring of taster function would be ideal. However, designing a simple, and effective test for sensory adequacy has proven impossible. It is usually more effective, and polite, to request panel members excuse themselves if they are not feeling "up-to-par."

For quality control work, the number of tasters may go as low as one (the winemaker). Nevertheless, it is preferable that several people be involved. Daily variation in perception is often too marked to leave decisions up to a single person, no matter how skilled.

Because individual tasters perceive tastes and odors differently, they probably also assess wine quality differently. Therefore, the number of tasters should be sufficient to buffer these idiosyncrasies, or the tasters must be trained and selected for consistent assessment of the sensory attributes required. Which approach is preferred will depend on the intent and nature of the tasting. For example, members showing the diversity of a particular subcategory of consumers may be desirable in wine evaluation, but be unacceptable for descriptive sensory analysis.

In major wine competitions, the number of tasters usually needs to be large. However, the number used to evaluate any particular category is usually small. Individual tasters can taste only a limited number of wines accurately, and they must be asked to assess only those wines within their range of experience. For example, tasters possessing little experience with dry sherries cannot be expected to evaluate these wines fairly or adequately. In situations where the experience of the tasters is not known, this information should be requested to avoid inappropriate assignment. Ideally, a qualifying sensory skill test should be administered well in advance of the tasting. In practice, this is seldom done. Typically, selection is based on availability and reported tasting experience, without evidence of skill, accuracy, or consistency being required. In such instances, statistical analysis of the results is particularly essential. Otherwise, it is impossible to distinguish between valid rankings and those derived by chance. Although it may be discouraging for tasters (and organizers) to discover that their rankings are insignificant, it is better to acknowledge reality than accept unsupportable conclusions. Of more general importance is the recognition that appropriate qualification of tasters is essential for confidence in tasting results. If tasters possessing clear, consistent, and appropriate[4] views of wine quality are available, statistical analysis is less essential.

For preference studies, adequate representation of consumer diversity requires large numbers of individuals. For example, less-affluent social groups and infrequent wine drinkers consider sweetness and freedom from bitterness and astringency of particular importance (Williams, 1982). They also tend to dislike oakiness or spiciness, whereas most wine experts appreciate these attributes. The importance of color and aroma to general acceptability increases with consumer age and the frequency

[4] What is *appropriate* depends on the group of wine consumers, traditions, or concepts tasters are supposed to exemplify.

of wine consumption. Not surprisingly, experience also influences the words people use to describe wine (Dürr, 1984; Solomon, 1990).

Tasting design

Information provided

Wines assessed critically must have their specific identity withheld. Nevertheless, providing general information may be useful or essential. For example, if measuring conformity with some particular varietal or regional norm is important, then the tasters must know this in advance. In other situations, it is debatable whether the rationale for the tasting should be revealed. For example, a request to check for faults may result in an exaggeration of their presence. However, avoiding any mention of this aspect may lead to under recording of their presence.

Prepouring in marked glasses or carafes effectively obscures wine identity. This has several advantages, in addition to concealing identity. It removes any sediment that might have developed, and permits prior detection and substitution of unrepresentative samples. Prepouring into dark glasses can have the added benefit of masking the wine's color. This is especially useful when panelists are being trained to recognize age-related changes in bouquet (devoid of their associated color effects).

If the wines are prepoured or decanted, this should occur just prior to tasting, to minimize aroma loss. If prepouring is impractical, placing the bottles in paper bags is a common alternative. Although successful in concealing the label, bottle color and neck design remain evident. Both can give clues to potential origin. Residual corroded material on the neck may also provide hints as to wine age. Bottle shape may also suggest wine origin. Having the wine poured by nonparticipants can remove this source of information.

Presentation sequence and sources of perceptive error

Without appropriate precaution, sequence errors can invalidate tasting results. Sequence errors distort perception based on the order in which the wines are presented. A common type of sequence error can occur when all tasters sample wines in the same order. For example, the first in a series of red wines is often ranked more highly than would be expected by chance. This probably results from the removal of tannins by precipitation with saliva proteins, making the first wine appear smoother. An analogous sequence error can result from taste adaption, notably sweetness—the first in a series appearing the sweetest. Equally, a wine tasted after a faulty sample will probably be perceived better than it would have had it followed a superior wine. Similar effects can occur whenever markedly different wines are presented in the same sequence. Grouping wines by category is a standard technique to minimize the influence of sequence errors.

The effect of sequence errors on group data can be reduced by allowing sufficient time (at least 2 min) between each sample, and adequate palate cleansing between wines. However, this may not be practical, or possible, in most situations. Therefore, it is preferable to present the wines to each taster in a different sequence. A method used of assuring order differentiation is the Latin Square (Table 5.13), or its modifications.

Subliminal numerical bias can be minimized by giving each wine a two-digit code. Amerine and Roessler (1983) suggest the random use of numbers between 14 and 99. These numbers are less likely to be associated with psychological prejudice than those between 1 and 13.

Other problems can be avoided (or arise), as noted above, depending on information provided. Stating that identical samples might be present could be useful to condition tasters not to exaggerate differences. However, the same information may induce tasters to ignore legitimate differences. Because both supplied and withheld information can influence human perception, it is essential that much forethought goes into the design of critical tastings. The potential effect of observing facial reactions has already been noted. The more difficult the tasting, the more likely tasters are to be swayed by suggestion. Panel members should be aware of these effects, so that they can guard against their influence.

The standard serving recommendations of white before red, dry before sweet, and young before old are appropriate. If conditions permit, each set of wines should differ. This helps maintain interest and minimize sensory fatigue.

Typically, only similar wines are tasted together, for example regional or varietal wines. Wines may also be subgrouped, based on price or hierarchical classification. Such arrangements are necessary if expression of regional or varietal characteristics is central to the tasting. Unfortunately, tasting within narrow categories does little to encourage change or improvement. Cross-regional and cross-varietal comparisons are excellent means of identifying where improvements could, or should, be made.

Timing

Tastings are commonly held in the late morning, when people are generally at their most alert. Alternately, late afternoon or mid-evening timings are selected. Organizing tastings two to three hours after eating correlates with improved sensory skills. Reduced acuity associated with satiety, results from suppression of central nervous system activity (see Rolls, 1995), not from diminished receptor sensitivity.

Table 5.13 Example of randomization of wine order using a Latin Square for six wines and six tasters

	Order of tasting					
Taster	1st	2nd	3rd	4th	5th	6th
A	1	3	6	4	2	5
B	2	4	1	5	3	6
C	3	5	2	6	4	1
D	4	6	3	1	5	2
E	5	1	4	2	6	3
F	6	2	5	3	1	4

Wine terminology

The language of wine is often colorful, poetic, and evocative. It also poorly articulates actual sensory perceptions, especially those of odor. Typically, impressions are funneled through the language of taste and mouth-feel. Flavor, if mentioned, often involves illusions of size or shape (e.g., big, round), power (e.g., robust, slight), or weight (e.g., heavy, watery). The rest of the vocabulary tends to elicit general emotional reactions (e.g., pleasant, unctuous, vivacious). Increased experience produces a language that is more florid (e.g., honey, cherries, truffles, tar) and metaphoric (e.g., heavenly, voluptuous, feminine, nervous). The preference bias in wine language usage is obvious when comparing the frequency of descriptive terms chosen by wine consumers (e.g., fruits and flowers) versus teetotalers (e.g., pungent, vinegary, alcoholic) (Fig. 5.9).

For critical analysis, communication must be clear and precise. Taste and touch sensations are easier to describe because our language possesses terms used exclusively for these sensations. It is with odors that humans have the greatest problem. Our lexicon of olfactory terms is extremely short, and limited largely to negative responses—especially those from the trigeminal nerve (pungent, acrid, putrid). For positive olfactory impressions, we depend almost totally on reference to objects or situations associated with a particular odor. These may be grouped into categories (fruity, floral), but precision requires specificity (e.g., dried litchis, canned green beans, "Granny Smith" apples).

Although availability of a universal, precise, language of wine would be desirable, it has proven difficult to develop. In addition, people have great difficulty correctly using terms, even for common odors. Figure 5.10 illustrates this imprecision. Even personal categorization of odors is variable, and may change from day to day (Ishii *et al.*, 1997). This may explain some of the difficulty people have in recognizing wines using descriptions they have themselves prepared (Lawless, 1984; Duerr, 1988). That terminology often reflects specific personal experience helps explain why people vary so much in how they describe wines.

Other terms commonly used, especially when ranking wines, denote aspects of intensity or temporal development. Terms such as finish, development, duration, and memorability may also incorporate the integration of several independent sensations. Additional terms specifically relate to the interaction of perceptions, notably balance, body, complexity, and flavor. Such abstract terms are essential but impossible to define precisely. The absence of reference samples for these impressions makes measurement of their consistent use suspect.

For wine evaluation, terms are usually provided on a prepared tasting sheet. Nevertheless, consistency of use is usually superior when self-generated. In addition, if the terms provided do not permit adequate representation of impressions, there is a strong likelihood that existent terms will be expropriated (misused) for their expression. For wine assessment (sensory evaluation), terms are often generated by the tasters in the course of their training.

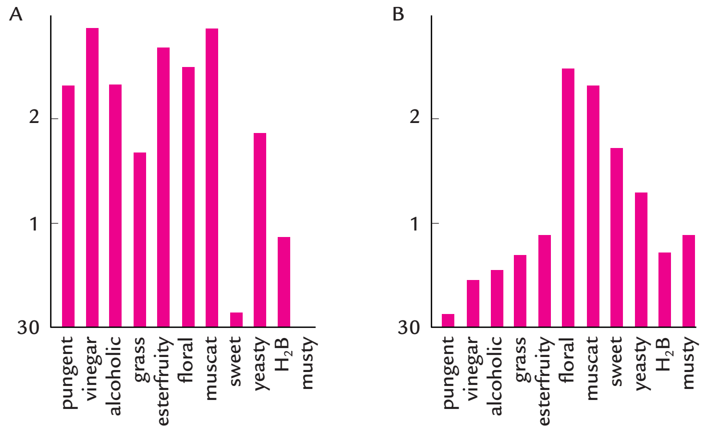


Figure 5.9 The relative choice of terms used to describe wine by (A) wine abstainers and (B) wine consumers (from Duerr, 1984, reproduced by permission).

Wine evaluation

Score sheets

Wine tasting has a multiplicity of functions. They span the spectrum from purely academic investigations, such as sensory function or the influence of production techniques, to the very prosaic tasks of maintaining constancy of a proprietary blend, or recommending the "best buy" in some category. Also involved are public and comparative tastings that only rank wines. Ranking may be based on aesthetic principles, with or without weighting of particular attributes. Even here, the data may be used to develop a perception profile of the tasters, or study those features most influential in their ranking.

Because tasting serves so many purposes, tasting sheets are equally diverse. For preference rating, sheets recording ordinal divisions may be sufficient (Fig. 5.11). For this function, they can be as effective as detailed assessments (Lawless *et al*., 1997). In contrast, most tasting sheets rank particular attributes (Fig. 5.12), or provide ample space for detailed comments. The categories focus attention on the important traits that give wines their distinctive characteristics. These may stress specific sensory attributes pertinent to a particular category of wines (Fig. 5.13), or emphasize integrated impressions (Fig. 5.14). Detailed score sheets are particularly useful in identifying specific strengths and defects. Where most score sheets are deficient is in adequately rating intensity characteristics or gauging the negative influences of faults. Finally, tasting sheets may be designed specifically for descriptive sensory analysis (see Figs 5.19 and 5.20), which attempt to quantitatively measure the attributes that discriminate among similar wines.

Few tasting sheets have been studied to determine how quickly or effectively they are used. Relevance of the data derived from the sheets will, of course,

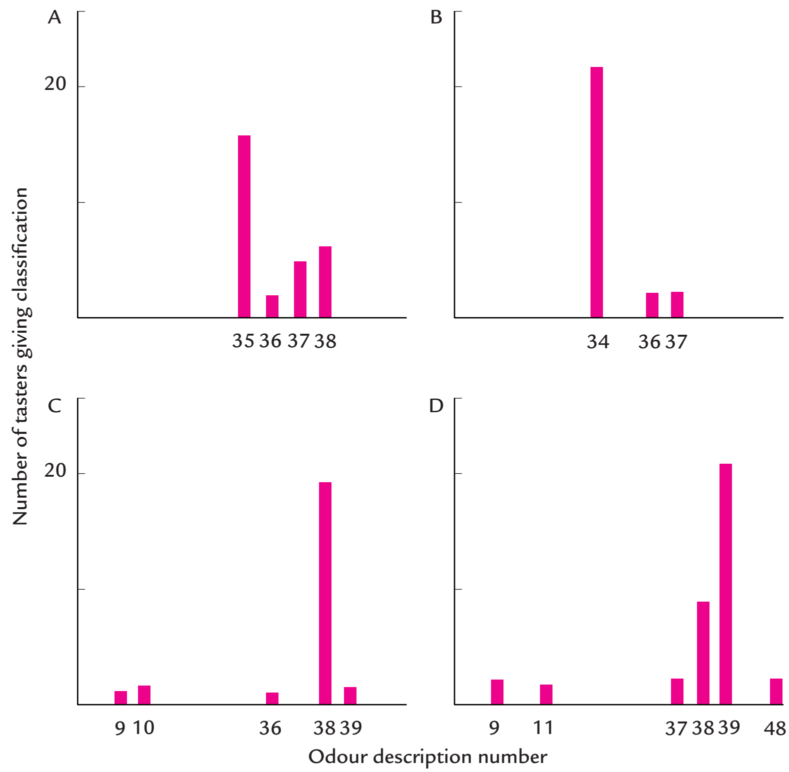


Figure 5.10 Percent allocation of four fragrances (A) banana (B) strawberry (C) peardrop and (D) apple to particular descriptors: 9, fusel alcohol-like; 10, ethyl acetate-like; 11, acetaldehyde-like; 34, strawberry-like; 35, banana-like; 36, pineapple-like; 37, pear-like; 38, peardrop-like; 39, apple-like; 48, spicy (from Williams, A. A. (1975). The development of a vocabulary and profile assessment method for evaluating the flavour contribution of cider and perry aroma constituents. *J. Sci. Food Agric.* **26**, 567–582. Copyright Society of Chemical Industry. Reproduced with permission. Permission is granted by John Wiley & Sons Ltd on behalf of the SCI).

depend on how accurately and consistently tasters use the forms. Generally, the more detailed the score sheet, the longer it takes tasters to use them consistently (Ough and Winton, 1976). If too complex, features may be disregarded and ranking based on preexisting quality concepts (Amerine and Roessler, 1983). Conversely, insufficient choice may result in *halo-dumping*—the use of unrelated terms

Ranking: Name of wine

First: ______________________
Second: ______________________
Third: ______________________
Fourth: ______________________
Fifth: ______________________
Sixth: ______________________

Figure 5.11 Hedonic scorecard (hierarchical ranking).

Wine: ______________________ Date: ______________________

Feature	Description	Score
Appearance and color		
0	POOR – Dull or slightly off-color	
1	GOOD – Bright with characteristic color	
2	SUPERIOR – Brilliant with characteristic color	
Aroma and bouquet		
0	FAULTY – Clear expression of an off-odor	
1	OFF CHARACTER – Marginal expression of an off-odor	
2	ACCEPTABLE – No characteristic varietal–regional–stylistic fragrance or aged bouquet	
3	PLEASANT – Mild varietal–regional–stylistic fragrance or aged bouquet	
4	GOOD – Standard presence of a varietal–regional–stylistic fragrance or aged bouquet	
5	SUPERIOR – Varietal–regional–stylistic fragrance or aged bouquet distinct and complex	
6	EXCEPTIONAL – Varietal–regional–stylistic fragrance or aged bouquet rich, complex, refined	
Acidity		
0	POOR – Acidity either too high (sharp) or too low (flat)	
1	GOOD – Acidity appropriate for the wine style	
Balance		
0	POOR – Acid/sweetness ratio inharmonious; excessively bitter and astringent	
1	GOOD – Acid/sweetness ratio adequate; moderate bitterness and astringency	
2	EXCEPTIONAL – Acid/sweetness balance invigorating; smooth mouth-feel	
Body		
0	POOR – Watery or excessively alcoholic	
1	GOOD – Typical feeling of weight (substance)in mouth	
Flavor		
0	FAULTY – Off-tastes or off-odors so marked as to make the wine distinctly unpleasant	
1	POOR – Absence of varietal, regional, or stylistic flavor characteristics in the mouth	
2	GOOD – Presence of typical varietal, regional, or stylistic flavor characteristics	
3	EXCEPTIONAL – Superior expression of varietal, regional, or stylistic flavor characteristics	
Finish		
0	POOR – Little lingering flavor in the mouth; excessive astringency and bitterness	
1	GOOD – Moderate lingering flavor in the mouth, pleasant aftertaste	
2	EXCEPTIONAL – Prolonged flavor in the mouth (>10 to 15 s), delicate and refined aftertaste	
Overall quality		
0	UNACCEPTABLE – Distinctly off-character	
1	GOOD – Acceptable representation of traditional aspects of the wine type	
2	SUPERIOR – Clearly better than the majority of the wines of the type	
3	EXCEPTIONAL – So nearly perfect in all sensory qualities as to be memorable	

Figure 5.12 General score sheet based on the Davis model.

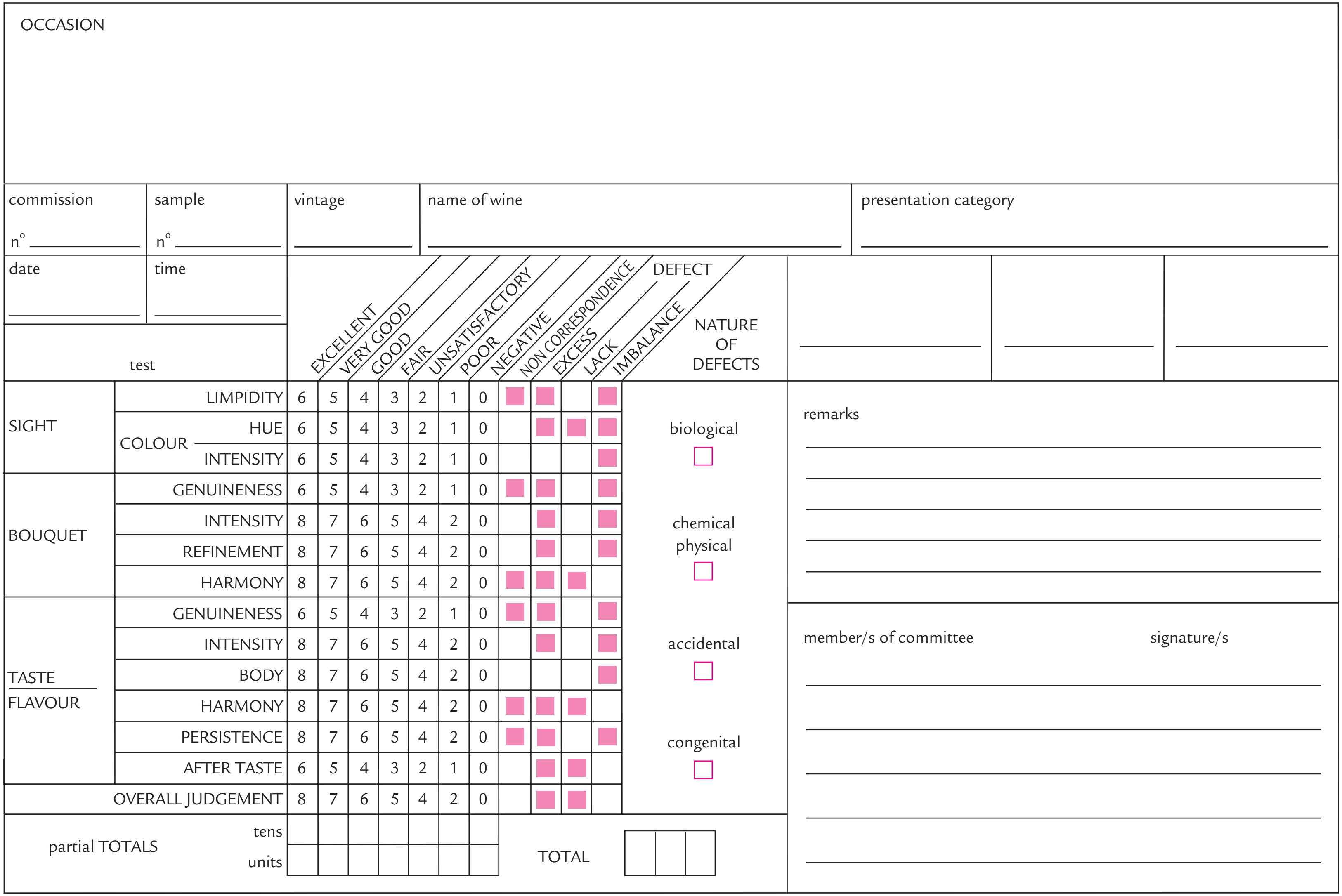
Wine: ______________________ Date: ______________________

Feature	Description	Score
Appearance and color		
0	POOR – Dull or slightly off-color	
1	GOOD – Bright with characteristic color	
2	SUPERIOR – Brilliant with rich color	
Effervescence		
0	POOR – Few, large bubbles in loose chains, short duration	
1	GOOD – Many mid-sized bubbles in long chains, long duration, no *mousse**	
2	SUPERIOR – Many fine bubbles in long continuous chains, long duration, *mousse* present	
3	EXCELLENT – Multiple long chains of fine, compact bubbles, *mousse* traits fully developed	
Aroma and bouquet		
0	FAULTY – Clear expression of an off-odor	
1	OFF-CHARACTER – Marginal expression of an off-odor	
2	STANDARD – Mild varietal fragrances and process† bouquet	
3	SUPERIOR – Subtle varietal fragrances with complex, toasty, process bouquet	
4	EXCELLENT – Complex, subtly rich aromas and refined toasty bouquet, long duration	
Acidity		
0	POOR – Acidity either too high (sharp) or too low (flat)	
1	GOOD – Acidity fresh and invigorating	
Balance		
0	POOR – Watery, acid/sweetness inharmonious, overly bitter, metallic tasting	
1	GOOD – Standard acid/sweetness balance, smooth mouth-feel, no metallic sensation	
2	SUPERIOR – Fresh dynamic acid/sweetness balance, rich mouth-feel, harmonious	
Flavor		
0	FAULTY – Off-tastes or off-odors so marked as to make the wine distinctly unpleasant	
1	POOR – Absence of traditional flavor characteristics, soapy effervescence	
2	GOOD – Presence of traditional subtle flavors, prickling effervescence sensation	
3	EXCEPTIONAL – Rich traditional flavors and vibrant mouth-feel from the effervescence	
Finish		
0	POOR – Little lingering flavor in the mouth; excessive astringency and bitterness	
1	GOOD – Moderate lingering flavor in the mouth, pleasant aftertaste	
2	EXCEPTIONAL – Prolonged flavor in the mouth (>10 to 15 s), delicate and refined aftertaste	
Overall quality		
0	UNACCEPTABLE – Distinctly off-character	
1	GOOD – Standard representation of traditional aspects of type	
2	SUPERIOR – Clearly better than the majority of sparkling wines	
3	EXCEPTIONAL – So nearly perfect in all sensory perceptions truly remarkable	

* collection of fine bubbles on the wine's surface in the center of the glass and as a ring around the outer edges of the glass

† attributes derived from treatments given after fermentation is complete.

Figure 5.13 Sparkling wine score sheet.



OCCASION

commission n°	sample n°	vintage	name of wine	presentation category
date	time			

test			EXCELLENT	VERY GOOD	GOOD	FAIR	UNSATISFACTORY	POOR	NEGATIVE	DEFECT: NON CORRESPONDENCE	EXCESS	LACK	IMBALANCE	NATURE OF DEFECTS
SIGHT		LIMPIDITY	6	5	4	3	2	1	0	■	■		■	biological ☐
	COLOUR	HUE	6	5	4	3	2	1	0		■	■	■	
		INTENSITY	6	5	4	3	2	1	0				■	
BOUQUET		GENUINENESS	6	5	4	3	2	1	0	■	■		■	
		INTENSITY	8	7	6	5	4	2	0		■		■	chemical physical ☐
		REFINEMENT	8	7	6	5	4	2	0		■		■	
		HARMONY	8	7	6	5	4	2	0	■	■	■		
TASTE FLAVOUR		GENUINENESS	6	5	4	3	2	1	0	■	■		■	
		INTENSITY	8	7	6	5	4	2	0		■		■	accidental ☐
		BODY	8	7	6	5	4	2	0				■	
		HARMONY	8	7	6	5	4	2	0	■	■	■		
		PERSISTENCE	8	7	6	5	4	2	0	■	■		■	congenital ☐
		AFTER TASTE	6	5	4	3	2	1	0		■	■		
OVERALL JUDGEMENT			8	7	6	5	4	2	0		■	■		
partial TOTALS		tens								TOTAL				
		units												

remarks

member/s of committee | signature/s

Figure 5.14 Sensorial analysis tasting sheet for wine judging competitions (Method of the "Union Internationale des Oenologues"; from Anonymous, 1994, reproduced by permission).

to register perceptions not present on the sheet (Lawless and Clark, 1992; Clark and Lawless, 1994).

Possibly the most widely used scoring sheet is the Davis scorecard. Because it was developed as a tool to identify wine production defects, it is not fully applicable to wines of equal or high quality (Winiarski *et al.*, 1996). In addition, the card may rate aspects that are inappropriate to certain wines (e.g., astringency in white wines), or lack features central to a particular style (e.g., effervescence characteristics of sparkling wines). Evaluation forms designed for sparkling wines incorporate a special section on effervescence attributes (Fig. 5.13; Anonymous, 1994). Style-specific forms may be equally valuable for particular varietal or regional wines, or when wines are rated on integrated quality attributes (Figs 5.14 and 5.15). Therefore, choice of a score sheet must reflect the purposes for which it is intended. It should also be simple (rapid and easy to use), precise (absence of confusion or redundancy), and be consistently and accurately used.

The total point range used should be no greater than that which can be used effectively and consistently. In 10-point (decimal) systems, half-points are often permitted, to increase the range to the maximum that can be used effectively. It also increases breadth in the mid range—most tasters avoid the extremes (Ough and Baker, 1961). Typically, ends of a range are used only when fixed to specific quality designations (e.g., Figs 5.12 and 5.16).

Assuming that wines show a normal distribution of quality, scores should equally show a normal distribution. While generally true, scores are skewed to the right (Fig. 5.17), reflecting the infrequent appearance of faulty wines. When tasters use the full range, scoring distribution tends to be non-normal (Fig. 5.18). Tasters showing non-normal distributions using the Davis 20-point card demonstrated standard distributions when using fixed-point scales (Ough and Winston, 1976).

A point range spanning 1 to 100 seems unjustified. There is no evidence that tasters distinguish this degree of subtlety. This is confirmed by the typical range of 80 to 100 in popular 100-point rankings.

An alternative procedure is to ask tasters to assign any number they want. In this instance there is no upper limit and the taster's ratings are not constrained. Procrustes analyses are used to interpret the data. They are based on the assumption that people measure the same attributes, even if they use different terms and scales. Procrustes procedures search for common trends, and shrink, expand or rotate the scales to develop the best matching of the data.

Most professional scoring sheets numerically weigh the various sensory categories of wine with surprising uniformity (Table 5.14). They differ primarily when overall impressions are combined with taste/flavor.

If both ranking and detailed sensory analyses are desired, independent scoring systems should be used. Not only does this simplify assessment, but it can avoid the *halo effect*—the situation where one assessment prejudices another (McBride and Finlay, 1990; Lawless and Clark, 1992). For example, astringent bitter wines may be scored poorly on overall quality and drinkability, but be rated more leniently when the wine's sensory aspects are assessed independently.

Wine: ______________________ Date: ______________________

Feature	Description	Score
Appearance and color		
0	POOR – Dull or slightly off-color	
1	GOOD – Bright with characteristic color	
2	SUPERIOR – Brilliant with characteristic color	
Aroma and bouquet		
0	FAULTY – Clear expression of an off-odor	
1	OFF CHARACTER – Marginal expression of an off-odor	
2	ACCEPTABLE – Absence of characteristic varietal-regional stylistic fragrance or bouquet	
3	GOOD – Mild to standard varietal-regional stylistic fragrance or aged bouquet	
4	SUPERIOR – Varietal-regional-stylistic fragrance or aged bouquet distinct and complex	
5	EXCEPTIONAL – Rich, complex traditional fragrance or refined lingering aged bouquet	
Taste and flavor		
0	FAULTY – Off-tastes or off-odors so marked as to make the wine distinctly unpleasant	
1	POOR – Absence of varietal, regional or stylistic taste and flavor characteristics	
2	GOOD – Presence of distinctive varietal, regional, or stylistic taste and flavor characteristics	
3	EXCEPTIONAL – Superior varietal, regional or stylistic taste and flavor characteristics	
Balance		
0	POOR – Acid/sweetness ratio inharmonious; excessively bitter and astringent	
1	GOOD – Acid/sweetness ratio adequate; moderate bitterness and astringency	
2	EXCEPTIONAL – Acid/sweetness balance invigorating; smooth mouth-feel	
Development/duration		
0	POOR – Fragrance simple, does not develop, of short duration	
1	STANDARD – Fragrance typical, develops in complexity, does not fade during tasting	
2	SUPERIOR – Fragrance improves in intensity and/or character, lasts throughout tasting	
3	EXCEPTIONAL – Rich fragrance, improves in intensity and character, long lasting	
Finish		
0	POOR – Little lingering flavor in the mouth; excessive astringency and bitterness	
1	GOOD – Moderate lingering flavor in the mouth, fresh aftertaste	
2	EXCEPTIONAL – Prolonged flavor in the mouth (>10 to 15 s), subtle, refined after-sensations	
Overall quality		
0	UNACCEPTABLE – Distinctly off-character	
1	GOOD – Acceptable representation of traditional aspects of the type	
2	SUPERIOR – Clearly better than the majority of the wine type	
3	EXCEPTIONAL – Memorable experience	

Figure 5.15 Score sheet assessing esthetic wine quality.

Letter-grading score sheet

Wine #	Verbal description:	Letter grade
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____

Rank	Subcategories*			Characteristics	Proportion(%)**
A	A^+	A	A^-	exceptionally fine for its class	5
B	B^+	B	B^-	clearly better than average for class	25
C	C^+	C	C^-	average for class	40
D	D			below average	25
E	E			faulty	5

* The A, B, and C categories are subdivided into grouping of below average, average and superior representation within each grade level. The subdivisions are more likely to be skewed to the left, with more in the '−' level than in the '+' grouping since excellence is a rare phenomenon in any aspect of human endeavor. If desired, each of the categories could be substituted by a number to achieve a numerical comparison of a series of wines.

** Assuming a random quality distribution among wines.

Figure 5.16 Letter-grade wine score sheet.

Statistical analysis

Statistical analysis assesses the potential validity of interpretations of experimental data. Ideally, statistical analysis provides only mathematical confirmation for what is self-evident from observing the data. Statistics is most useful when significance is in doubt. It may either confirm the doubt (without proving it), or provide a level of confidence in differences detected. This is particularly valuable when many factors are involved and direct comparison of the data is difficult. Principle Component Analysis, for example, helps identify those factors leading to differences.

Table 5.14 Comparison of score sheets showing the percentage weighting given each sensory category

Score sheet	Appearance	Smell	Taste/flavor	Overall/typicity
Associazione Enotecnici Italiani (1975)	16	32	36	12
Davis scorecard (1983)	20	30	40	10
O. I. V. tasting sheet (1994)	18	30	44	8

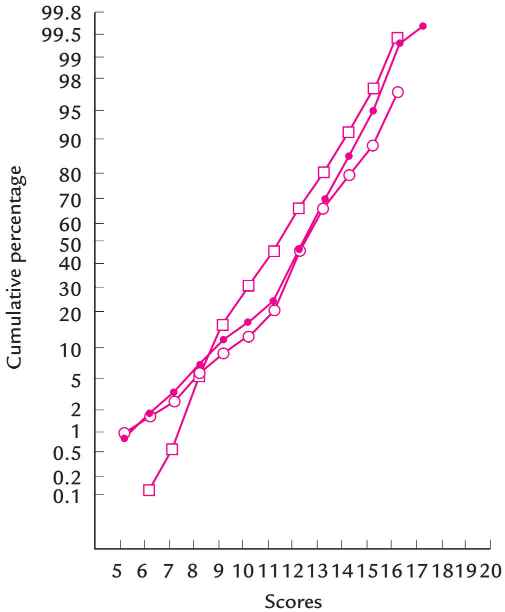


Figure 5.17 Cumulative percentage distribution of scoring for a particular taster (XII) for three different years using the Davis 20-point scorecard: ○ 1964; ● 1965; □ 1971 (from Ough and Winton, 1976, reproduced by permission).

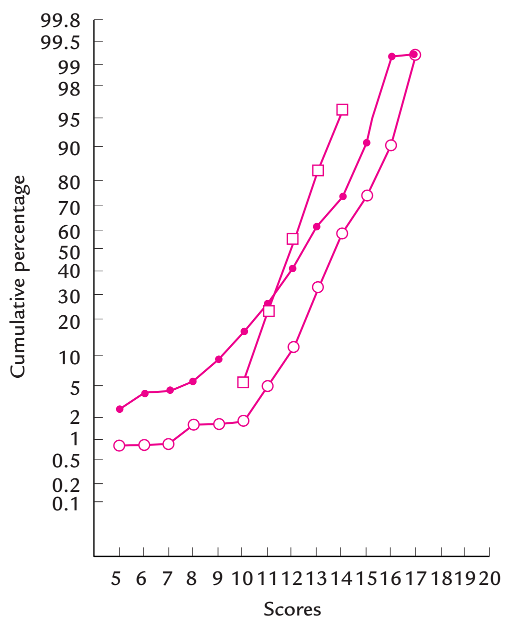


Figure 5.18 Cumulative percent distribution of scoring for a particular taster (XI) for three different years using the Davis 20-point scorecard: ○ 1960; ● 1965; □ 1968 (from Ough and Winton, 1976, reproduced by permission).

Demonstration of significance generally leads to further experimentation, designed to provide additional clarification.

One of the problems for nonstatisticians is the difficulty of intuitively confirming conclusions derived from complicated statistical analysis. Except for those with extensive statistical training, it is desirable to seek professional help in choosing the most appropriate analytic method and its interpretation. It is far too easy to be dazzled by the impressive graphic representation of complex data analysis. Conclusions can be no better than the validity of data on which they are based—derived from the proper use of experimental design, adequate replication, use of competent tasters, and compliance with the conditions required by the statistical test. Because an adequate discussion of multivariate procedures is the prerogative of statistical tests, only illustrations of relatively simple statistical tests are provided. More complex statistical tests are noted only relative to their potential use in wine analysis.

At its simplest, statistical analysis can be used to determine whether a particular group of individuals can detect differences among a set of wines. In addition, the data can often be used to identify which wines were distinguishable, or whether panelists scored the wines similarly (see Tables 5.10, 5.11 and 5.12). Taster consistency is particularly important because inclusion of data from panelists with poor scoring skills can potentially negate the significance of differentiation by skilled panelists. What statistics cannot answer is whether differences detected are of pragmatic significance. Establishment of a detectable difference does not confirm that there is an equivalent preference difference, any more than distinguishing between apples and oranges implies that a preference exists. Equally, clear preferences may exist, but the scores may be identical.

In most instances, simple statistical tests adequately determine if wines can be differentiated. The results can be obtained rapidly, and without complex computation necessitating calculators or computers.

Simple tests

Table 5.15A presents hypothetical results from a ranking of six wines by five tasters. A cursory look at the data suggests that differences exist among the wines. However, statistical analysis (Appendices 5.6 and 5.7) indicates that distinction is not accepted at a 5% level of significance. For significance, rank totals would have to fall outside the range of 9 to 26. The actual rank total range was from 9 to 24. Lack of differentiation results from individual rankings being too variable.

In many instances, increasing the number of tasters can improve panel discrimination. In Table 5.15B, the number of tasters is increased to ten, but their scoring pattern is replicated. Appendix 5.6 indicates that differentiation at the 5% level requires that rank totals exceed the range of 22 to 48. The actual range was 18 to 48. Thus, with ten tasters, wine A is now shown to be significantly different from the other wines. In the same manner, were there 15 tasters of the same skill used, both wines A and E would be differentiated (the highest and lowest ranked wines). Even a few tasters inconsistent in their scoring, or possessing different concepts of quality can negate differentiation.

Table 5.15 shows one of the limitations of simple ranking. Wines may be differentiated, but only into hierarchical categories. The degree of difference on which separation occurs is unknown. Ranking wines, based on scoring individual attributes, rectifies the problem. This is illustrated in Table 5.16, where five wines are ranked by seven tasters. For separation, the range in wine scores must be greater than the statistic given in Appendix 5.8. These values are multiplied by the sum of the score ranges for individual wines.

In Table 5.16A, the pertinent statistic for seven tasters and five wines is 0.58 ($p > 0.5$). Differentiation requires that the range of total scores for wines be greater than the product of 0.58 and the sum of score ranges for wines (24)—in this instance, 13.9. Because the range of total scores for wines (26) is greater than the calculated product (13.9), one can conclude that the tasters could distinguish among the wines. Which wines are distinguishable can be determined with the second (lower) statistic in Appendix 5.8 (0.54). It is multiplied by the sum of score ranges for wines, producing the product 13. When the difference between the total scores of any pair of wines is greater than the calculated product (13), the wines may be considered significantly different. Table 5.16B shows that significant differences ($p > 0.5$) occur

Table 5.15 Hierarchical ranking of six wines

A Five tasters

Taster	Wines					
	A	B	C	D	E	F
1	1	3	6	4	5	2
2	2	1	4	5	3	6
3	3	6	2	5	4	1
4	1	4	5	3	6	2
5	2	5	3	4	6	1
Rank total	9	19	20	21	24	12
Overall rank	6	4	3	2	1	5

B Ten tasters

Taster	Wines					
	A	B	C	D	E	F
1	1	3	6	4	5	2
2	2	1	4	5	3	6
3	3	6	2	5	4	1
4	1	4	5	3	6	2
5	2	5	3	4	6	1
6	1	3	6	4	5	2
7	2	1	4	5	3	6
8	3	6	2	5	4	1
9	1	4	5	3	6	2
10	2	5	3	4	6	1
Rank total	18	38	40	42	48	24
Overall rank	6	4	3	2	1	5

between wines A & B, A & E, B & C, B & D, and D & E. This can be illustrated visually as follows, where a line joining wines indicates insignificance between the wines:

$$\underline{E \quad B} \quad A \quad \underline{C \quad D} \qquad \text{Eq.7}$$

Table 5.16 Five wines scored by seven tasters (maximum 20)

A Wine scoring data

Taster	Wines						
	A	B	C	D	E	Total	Range
1	14	20	12	13	14	73	8
2	17	15	14	13	18	77	5
3	18	18	15	13	17	82	5
4	15	18	17	14	18	82	4
5	12	16	15	12	19	74	7
6	13	14	13	14	17	71	4
7	15	17	13	14	16	75	4
Mean	15	16.9	14.1	13.3	17		
Total	104	118	99	93	119		
Range	6	6	5	2	5		

Sum of score ranges: (Wines) = (6+6+5+2+5) = 24 (Tasters) = (8+5+5+4+7+4+4) = 37
Range of total scores (Wines) = (119 − 93) = 26 (Tasters) = (82 − 71) = 11

Appendix 5.8 provides two statistics for 5 wines and 7 tasters: 0.58 (upper) and 0.54 (lower)

For significance, differences among wine totals must exceed Sum of wine score ranges (24) multiplied by the upper statistic (0.58) = 13.9

For significance, differences among taster totals must exceed Sum of taster score ranges (37) multiplied by the upper statistic (0.58) = 20.0

For significance, differences between pairs of samples differences among totals must exceed 24 (0.54) = 13. Table B represents the difference in total scores between pairs of wines.

B Difference among the sum of scores for pairs of wines

	Wine A	Wine B	Wine C	Wine D	Wine E
Wine A	–				
Wine B	14*	–			
Wine C	6	19*	–		
Wine D	12	25*	6	–	
Wine E	14*	1	10	25*	–

*significance at the 5% level.

C Analysis of variance table

Source	*SS*	*df*	*ms*	*F*	$F_{.05}$	$F_{.01}$	$F_{.001}$
Total	164.2	34					
Wines	76.2	4	19.0	6.74	2.78	4.22	6.59**
Tasters	20.2	6	3.4	1.19	2.51		
Error	67.8	24	2.8				

**significance at the 0.1% level.

To determine if differences exist between tasters, multiply the upper statistic (0.58) by the sum of taster score ranges (37). Because the product (20) exceeds the difference between their score totals (11), the tasters appear to taste similarly. Thus, obviating the need for the second calculation to determine which tasters scored differently.

Table 5.16C shows the analysis of variance table using the same data. It confirms significant differences between wines, but no differentiation between tasters.

Analysis of variance

For a detailed evaluation of tasting results, analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) are typically used. For example, it permits appraisal of the interaction among various factors in the tasting. Although these techniques are more complicated, computers have made them available to essentially all those requiring their use. Direct electronic incorporation of data further eases the analysis of large sets of data. This has developed to the point that computer programs have been developed specifically for the food and beverage industries (i.e, Compusense *five*®). They can be adjusted to suit the special needs of the user.

Pertinence of tasting results

Most of this chapter is based on the assumption that training and selection of tasters provides not only more consistent results, but more inherently valid data. Nevertheless, there are those who consider that the artificial conditions required for these benefits make the results irrelevant. That a wine consumed with a meal will appear different than when sampled in the lab, or in a competitive tasting, is beyond doubt. Equally, wine perception changes depending on the accompanying food, or the same food on separate days or in different premises. It is because environmental and psychological influences so affect perception that wines can be impartially compared only under the admittedly artificial conditions of critical tasting. In addition, the data obtained are only comparative, not absolute. It is naturally hoped that conclusions derived from such tastings have relevance to real-life situations, but the degree to which this exists has yet to be established.

Sensory analysis

Sensory analysis involves a series of techniques designed to study wine attributes, how they are perceived, and how they relate to features such as chemical, varietal, regional, or stylistic origin. That is, they are primarily research tools. These procedures include techniques such as descriptive sensory analysis, time–intensity analysis, and charm analysis.

Descriptive sensory analysis

Descriptive sensory analysis quantitatively describes the sensory attributes of a food or beverage. It developed out of procedures used to generate a complete flavor profile. However, flavor profile development is very time consuming, and it usually involves features unessential to determining the source of wine differentiation, or the effects of changing product formulation.

Descriptive sensory analysis usually concentrates on the sensory features that distinguish similar products—information crucial in developing products designed for particular consumer groups. In this role, it has seen little use in wine production. Producers and consumers alike want wines to be viewed as natural products, not processed-food items. Therefore, descriptive sensory analysis has been used primarily in studying or validating features thought to distinguish wines made from particular varieties (Guinard and Cliff, 1987), produced in specific regions (Williams *et al*., 1982), or made in distinctive styles. Sensory analysis has also been used in investigating the climatic features of a region that make it appropriate for producing particular wine styles (Falcetti and Scienza, 1992). It can also study the effects of changing viticultural or enological procedures. In so doing, it is essential that all other factors be as equivalent as possible. In combination with chemical analysis, sensory analysis can help to identify compounds responsible for specific sensations. Although not directly involved in assessing quality, sensory analysis can clarify those attributes or chemicals most critical in quality perception. Finally, the technique can be combined with preference studies in exploring commonly held views on consumer preferences. For example, Williams *et al*. (1982) confirmed the relative importance of sweetness, low acidity, and minimal bitterness and astringency to infrequent wine drinkers.

In most forms of descriptive analysis, members of the taste panel are specifically trained to use sensory terms in a common and consistent manner. To obtain a complete sensory profile, all pertinent sensory attributes are quantified. For wine, this includes visual, gustatory and olfactory traits. Typically, though, only aspects of the aroma or flavor are studied. Attributes need not adequately describe the wine's flavor, only consistently differentiate among the wines. Quantification involves scoring intensity. Quality aspects of the attributes are not assessed because their subjectivity precludes precise measurement.

There are many forms of descriptive sensory analysis. Only the three most common examples are noted. These are Quantitative Descriptive Analysis, Spectrum Analysis, and Free-choice Profiling.

Prospective members usually undergo screening to eliminate those without the prerequisite skills. This also familiarizes candidates with the characteristics of the wines to be studied. Screening is always category-specific, as is subsequent training. In contrast, panel members for Free-choice Profiling seldom undergo screening, nor are measures of sensory variability determined.

Once trained, members can usually adapt quickly to evaluating other wines, and they do not need additional screening. This does not guarantee, however, that members will stay qualified. Nor does it imply that additional training may not be required. Monitoring performance before each test is advisable, especially if only a few replicates of each test are possible. Although high sensory acuity is generally not a requirement, each member must perceive all the essential differences at better than chance.

Once screening is complete, training begins. This typically involves considerable attention to the language used to describe wine attributes. How the language is developed partially differentiates quantitative descriptive analysis from spectrum analysis.

In addition, sensory features are grouped into related categories, definitions developed for each attribute, reference samples prepared, and members trained in how to score intensity. Abstract terms, such as body, balance, and development, are not employed. Precise definition of these terms is impossible and adequate references unattainable.

With Quantitative Descriptive Analysis, members work toward a consensus on descriptors that adequately represent the wine's distinctive attributes. This occurs under the supervision of a leader who both guides and arbitrates the discussion, attempting to avoid the inclination to polarize around initially stated opinions (Meyers and Lamm, 1975). The panel leader does not directly participate in term development or in the tastings. Otherwise, prior knowledge might bias the features chosen and the terms used. The leader's responsibility is limited to encouraging fruitful discussion, organizing the tests, and analyzing the results. Training is usually shorter if members use their own terms rather than unfamiliar technical terms. Subsequently, panelists assess wines using these descriptors to determine their efficacy (lack of confusion or redundancy) and they learn which terms are the most discriminatory. This typically involves analysis of tasting results after several trials with identical wines. Only then can the number of attributes be reduced to the minimum needed. Analysis also permits members' use of terms to be measured. At this stage inconsistent tasters can be confidently removed from the panel. Earlier elimination is inappropriate because the members are still in the training phase.

Data in Table 5.17 illustrate some of these aspects. Significant judge–wine ($J \times W$) interaction (among mint/eucalyptus, earthy, and berry-by-mouth ratings) indicates an unacceptable level of variation in term usage. Thus, these attributes were eliminated from subsequent analyses. High levels of individual judge–wine interaction can indicate those tasters who are using terms inconsistently.

Term redundancy is often detected by significance in correlation matrices. Table 5.18 illustrates that attributes such as fresh berry and berry jam; leather and smoke; and astringency and bitterness showed highly significant correlation. However, it is well known that astringency and bitterness are distinct sensations, induced by similar if not identical compounds. Therefore, in this instance, significant correlation does not indicate term redundancy. Data from sensory analysis must be interpreted critically, and only in association with other information.

Spectrum Analysis provides panelists with preselected attributes to measure, reference standards, and established intensity scales. In situations where the discriminatory attributes are known, and the wines are unlikely to present new sensory variability, training time can be reduced. Spectrum analysis is also appropriate where the experimenter has interest in only specific wine attributes. However, this runs the risk that panel members may expropriate terms to represent properties not present in the designated terminology (halo-dumping). Training in term use is similar to that of quantitative descriptive analysis.

Despite training and selection, both Quantitative Descriptive and Spectrum methods may experience problems associated with inconsistent term use. In addition, some researchers have pondered about problems associated with polarization during term development, idiosyncratic term use, and even whether "correct" sets of

Table 5.17 Analyses of variance of attribute ratings (7 judges) for *Pinot noir* wines: df, degrees of freedom; MSE, error mean squares (from Guinard and Cliff, 1987, reproduced by permission)

	F ratios						
	Judges (J)	Reps (R)	Wines (W)	J × R	J × W	R × W	MSE
Red color	30.74***	0.02	61.17***	0.90	1.12	1.97**	94.87
Fresh berry	37.30***	0.08	2.61***	0.59	1.17	1.15	198.73
Berry jam	70.34***	2.20	2.90***	0.28	1.32*	0.85	150.17
Cherry	71.91***	0.35	2.71***	0.39	1.42*	0.83	130.65
Prune	72.46***	0.23	1.39	0.66	1.21	1.38	147.57
Spicy	130.64***	1.17	1.78*	1.82	1.28	0.99	89.32
Mint/eucalyptus	121.27***	0.90	2.32***	0.55	2.10***	1.40	105.02
Earthy	121.47***	1.33	5.28***	1.03	1.64***	1.93**	125.67
Leather	56.59***	0.63	2.39***	0.98	1.17	0.85	181.54
Vegetal	103.28***	0.01	4.74***	2.64*	1.38*	0.77	130.74
Smoke/tar	110.38***	0.07	4.02***	2.81*	1.19	1.22	129.90
Berry by mouth	36.05***	3.67	2.21**	1.79	1.55**	0.92	171.75
Bitterness	111.21***	5.72*	3.83***	2.22*	1.19	1.06	134.94
Astringency	128.78***	0.29	5.05***	1.45	1.24	1.65	146.91
df	6	1	27	6	162	27	162

*, **, ***, significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

descriptors are possible (Solomon, 1991). These aspects prompted development of Free-choice Profiling, in which tasters are allowed to use their own vocabulary to describe wine attributes. Although training is minimal, time is still required to gain experience with the wines, develop their own terminology, and become familiar with intensity scale use. Similar numbers of terms makes analysis simpler, but this is not necessary. It is assumed members experience identical sensations, even though term and intensity scale use differ.

One of the problems with Free-choice Profiling arises from the complex mathematical adjustment involved. In generalized Procrustes analysis (Oreskovich *et al.*,

Table 5.18 Correlation matrix among the descriptive terms (df = 26) used for differentiation of *Pinot noir* wines

Term	1	2	3	4	5	6	7	8	9	10	11
1. Red color	1.00										
2. Fresh berry	−0.05	1.00									
3. Berry jam	0.01	0.60***	1.00								
4. Cherry	0.13	0.71***	0.42*	1.00							
5. Prune	−0.22	−0.22	0.04	−0.19	1.00						
6. Spicy	0.32	0.29	0.27	0.47*	−0.25	1.00					
7. Leather	0.18	−0.50**	−0.45*	−0.28	0.14	0.16	1.00				
8. Vegetal	−0.46*	−0.57**	−0.27	−0.61***	0.51**	−0.54**	0.11	1.00			
9. Smoke/tar	0.46*	−0.66***	−0.41*	−0.35	0.04	0.20	0.70***	0.15	1.00		
10. Bitterness	0.09	−0.14	−0.14	−0.08	0.35	0.04	0.35	0.10	0.27	1.00	
11. Astringency	0.57**	0.00	0.00	−0.02	−0.04	0.23	0.23	−0.27	0.36	0.61***	1.00

*, **, ***, significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

1991; Dijksterhuis, 1996), rotation, stretching and shrinking of the data are used to search for common trends. Thus, the possibility exists that relationships may be generated where none exist. In addition, relating the generated axes to specific sensory attributes can be difficult. This often requires combination of these data with data derived from sensory profiling or chemical analysis. Nevertheless, Free-choice Profiling is especially valuable when using consumer panels. Part of its advantage arises from its economy—saving considerably on the time required to develop a discriminative terminology, train members in its use, and select those that use the terms consistently. Consistent and uniform use is particularly essential if differences among the samples are small.

All sensory analysis procedures attempt to minimize panel variation, either by member selection or with a multidimensional mathematical model such as Procrustes analysis. In the process, they can remove important subgroups with different perceptions. Although a legitimate problem, this is an unavoidable consequence of using humans as substitute analytic instruments.

For Quantitative Sensory and Spectrum Analyses, reference standards are developed for every term, where possible. They permit panel members to refer to the standard when they have difficulty detecting or employing terms during tastings. Although preferred, absence of an acceptable reference standard does not necessarily exclude the term. Where present, standards should demonstrate only the property intended, without confusing tasters with additional attributes. They also should be sufficiently subtle to avoid sensory interaction or fatigue. It is equally important that standards remain stable over the experimental period. If they need to be replaced, the panel should be questioned about acceptability. When not in use, standards are usually refrigerated and stored in the absence of oxygen. Using nitrogen as a headspace gas helps, as does incorporation of a small amount of antioxidant, such as sulfur dioxide (~30 mg/l).

Reference standards are particularly useful when new panel members are incorporated. They permit the new member to quickly gain experience in appropriate term usage. Reference standards are particularly important in training members for Spectrum Analysis, where members are not involved in term development.

An essential element in most descriptive analyses is intensity scoring. In Quantitative Descriptive Analysis, panelists note intensity on a line scale. Traditionally, this involves a line 15 cm long with two vertical lines placed 1.27 cm from each end. Above each vertical line is an expression denoting the intensity and direction. For effective use, panel members must be given sufficient time to become proficient in scale use. It is equally important that representative examples of the polar extremes be provided. Although individual panel members may use different regions of the scale, this is of minor concern because of repeat sampling. It is more important that each member use the scale consistently. In Spectrum Analysis, however, several types of scales may be employed. Specific numerical anchors are often provided for particular sensory characteristics. In Free-choice Profiling, a single type of line scale is used. In all procedures, intensity indications are converted to numerical values for analysis.

Examples of tasting sheets applicable to descriptive sensory analysis are given in Figures 5.19 and 5.20. Figure 5.19 illustrates the use of intensity scales for several sensory attributes. Figure 5.20 involves a simplification for categorizing large numbers of wines—more than can easily be assessed by traditional sensory analysis procedures. Panel members select terms from a list, giving the five attributes that most characterize individual wines.

All methods incorporate replicate trials—four to six replicates generally being considered adequate. Most panels consist of between 10 and 20 members.

Data generated from these procedures are often visualized as **polar** ("spider web") **plots**. The distance from the center represents the mean intensity value for each attribute (Fig. 5.21). Additional information can be shown if correlation coefficients are used to define the angles between the lines connecting the intensity values (Fig. 5.22). This presentation works well for up to five comparisons (especially when presented in color), but it becomes visually too cluttered and confusing with additional comparisons. In such situations, statistical methods are used to reduce the number of points involved in each comparison. Multivariate analysis becomes invaluable, and only legitimate, when dealing with large data sets (Meilgaard *et al*., 1999). Each sensory attribute can be considered as a point in multidimensional space, the coordinates of which are the magnitude of the component attributes. Multivariate analysis helps highlight the most discriminant attributes.

Principal component analysis is particularly effective in visualizing correlations between attributes. For example, Figure 5.23 shows that the peach, floral, and citrus notes of *Chardonnay* wines are closely correlated (perceived similarly), but negatively correlated (rarely associated) with pepper notes (1st principal component). The 2nd principal component illustrates an independent relationship between sweet and vanilla notes that is inversely correlated with the presence of obvious bitterness. These associations can be detected in conventional histograms, but they are less visually obvious. Histograms also do not present quantitative indicators of correlation. Combination of average data with that of individual wines can demonstrate whether particular wines cluster with specific flavor characteristics (Fig. 5.24). Principal component analysis can also be used to suggest which attributes are insufficiently discriminatory and might be eliminated. This can improve analysis by limiting the detail demanded of the tasters. If tasting becomes too onerous, maintenance of member enthusiasm may wain, resulting in deterioration of the data. However, if too may attributes are eliminated, panelists may receive a negative message, suggesting that the considerable effort expended in preparing the attribute list was unnecessary. It might imply that some "hidden" list was expected.

Cluster analysis is another statistical technique used to highlight quantitative relationships between factors. These often resemble the branching of a tree. Connections between the branches indicate the degree of correlation. Because this type of information is rarely of relevance to sensory analysis, it has seen little use.

To date, descriptive sensory analysis has been used primarily to distinguish or characterize groups of wines. This limitation is regrettable, especially in relation to the time and effort involved. For example, investigation of the reasons for the association of specific fragrances noted in Figure 5.23 could have been particularly

Wine: ______________________ Date: ______________________

Attribute	**Relative intensity scale***
Flavor	Low — High
Berry	
Blackcurrant	
Green bean	
Herbaceous	
Black pepper	
Bell pepper	
Tannic	
Oaky	
Vanilla	
Leather	
Cigar Box	
Taste/Mouth-feel	
Sourness	
Bitterness	
Astringency	
Body	
Balance	

* Place a vertical line across the horizontal line at the point which best illustrates how you rate the intensity of the attribute.

Figure 5.19 Example of a descriptive sensory analysis tasting form adjusted for Bordeaux wines.

Name: ______________________ Date: ______________________

Wine # : ________ Attributes:* ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

Wine # : ________ Attributes: ________, ________, ________, ________, ________

* Describe each wine sample with the use of two to five of the set of listed terms, examples are given for two grape varieties:

Chardonnay wines: apple, citrus, muscat, fruit, buttery, honey, caramel, oak, herbaceous, neutral
Semillion wines: floral, lime, pineapple, honey, nutty, grassy, toasty, tobacco, smoky, oak

Figure 5.20 Multi-wine descriptive analysis scorecard.

informative. Was it because of term redundancy, related chemicals, varietal origin, or a unifying winemaking procedure? Equally revealing would be an understanding of why certain attributes were inversely correlated. The potential of descriptive sensory analysis is illustrated in the work of Williams *et al*. (1982) and Williams (1984), where preference data are correlated with particular aromatic and sapid substances. Relating wine chemistry to consumer preferences would facilitate producing wines designed for particular consumers. This may not fit the romantic image of wine-

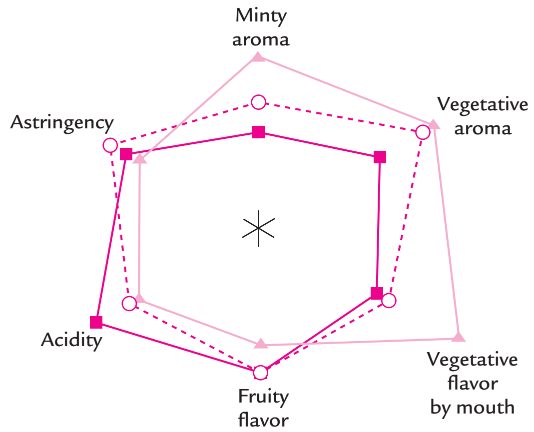


Figure 5.21 Comparison of descriptive profiles of *Cabernet Sauvignon* wines from Napa Valley (■), Monterey (▲), and Mendocino (○) (Reproduced from Noble, A. C. (1988). Analysis of wine sensory properties. *In* "Wine Analysis" (H. F. Linskens and J. F. Jackson, eds.), pp. 9–28. Copyright Springer-Verlag).

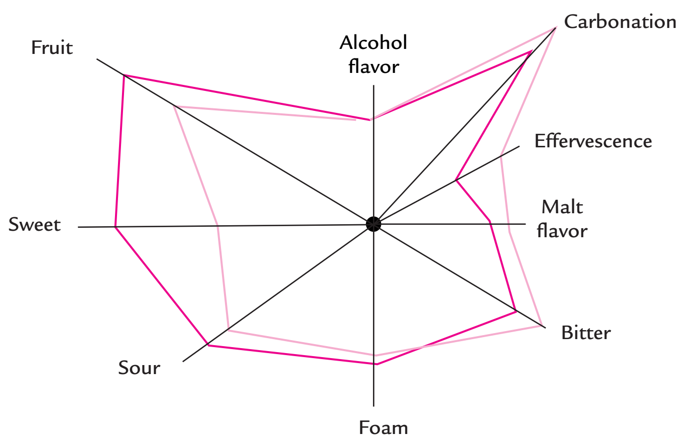


Figure 5.22 Quantitative descriptive analysis of two competitive products: the distance from the center is the mean value for that attribute, and the angles between the outer lines are derived from the correlation coefficients (from Stone *et al.*, 1974, reproduced by permission).

making, as the expression of artisan winemakers, but can be highly remunerative. The success of wine coolers is a clear example.

Another, incidental use of sensory analysis is in the training of winemakers. Winemakers must develop astute sensory skills. For example, preparing blends requires the individual evaluation of each of the wine's sensory properties. This is a prerequisite for assembling the wines to enhance their positive qualities and minimize any defects. The intense concentration and scrutiny required in descriptive sensory analysis is a wonderful learning experience for young and seasoned winemakers alike.

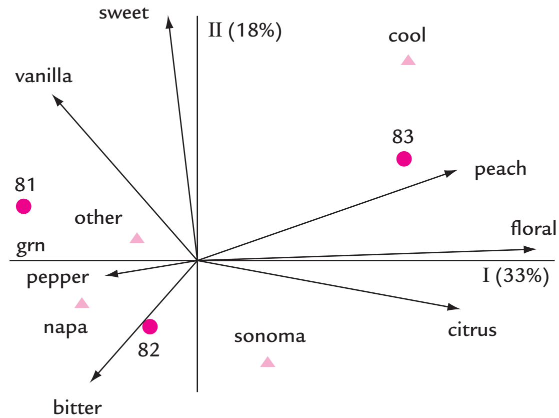


Figure 5.23 Principal component analysis of *Chardonnay* wines. Projection of sensory data on principal components I and II. Attribute loadings (vectors) and mean factor scores for wines from 1981, 1982, and 1983 (●) and from Napa Valley, Sonoma Valley, cool regions and "other" locations (▲) (Reproduced from Noble, A. C. (1988). Analysis of wine sensory properties. *In* "Wine Analysis" (H. F. Linskens and J. F. Jackson, eds.), pp. 9–28. Copyright Springer-Verlag).

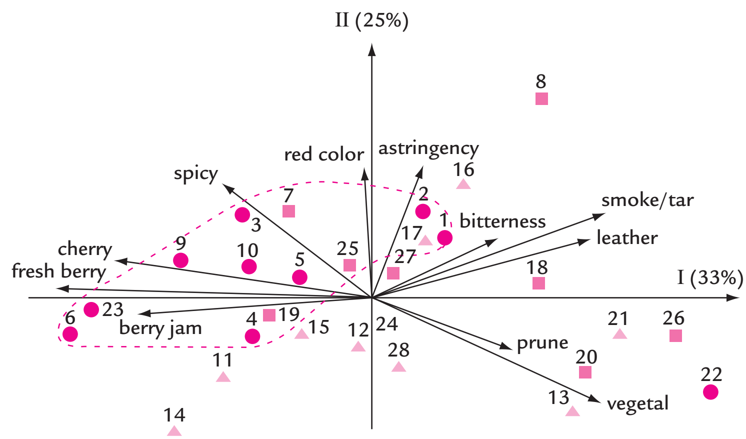


Figure 5.24 Principal component analysis of the mean ratings of 28 *Pinot noir* wines from three regions: Carneros (●), Napa (□), and Somoma (△) (from Guinard and Cliff, 1987, reproduced by permission).

Time–intensity analysis

Time–intensity analysis records the temporal dynamics of oral sensations (Overbosch *et al.*, 1986; Lawless and Clark, 1992). The technique requires participants to continuously record their perceptions of a particular taste, mouth-feel, or flavor sensation. The procedure has little applicability to purely aromatic sensations because they develop and vanish almost instantaneously. The only exception is retronasal olfactory sensations (Fig. 3.18), such as those of a wine's finish. Regrettably, this important feature has not been investigated by time–intensity analysis.

Measurements are most easily recorded in real time on a computer using one of several software packages (e.g., CompuSense *five*®). Formerly, it was recorded on moving strips of perforated chart paper.

As illustrated in Figure 5.25, four basic aspects of perception can be distinguished. These include the time taken to reach maximum intensity; the maximum perceived intensity; the duration of the perception; and the temporal dynamics of perception. These features vary from person to person, but they remain relatively constant for an individual. The sample is usually expectorated shortly after tasting.

The technique has been particularly useful in quantifying the dynamics of individual and group reactions to particular tastants, either in water, simulated wine solutions, or wine. It has clarified the differences between the dynamics of sweet, sour, bitter and astringent perceptions. Concentration has little effect on the time taken to reach maximum perceived intensity, although it affects the duration of the sensation. Because the sample is normally expelled shortly after tasting, the procedure must be modified to study adaptation. It has shown that increased concentration delays the onset of adaption (Fig. 5.26). The timing of expectoration must also be changed to study the effect of repeat exposure on features such as astringency (Fig. 5.27). To date, the procedure has been little used to investigate the interaction between sapid substances, or the joint influences of sapid and olfactory compounds on flavor perception.

Although providing valuable data on the nature of perception, it is not directly used in wine tasting. In an imprecise form, though, it has long been employed as a rapid and visual means of representing dynamic changes in wine fragrance and flavor (Fig. 1.7; Vandyke Price, 1975).

Charm analysis

Charm analysis assesses the olfactory significance of compounds isolated from wines by procedures such as gas chromatography (Acree and Cottrell, 1985). Gas

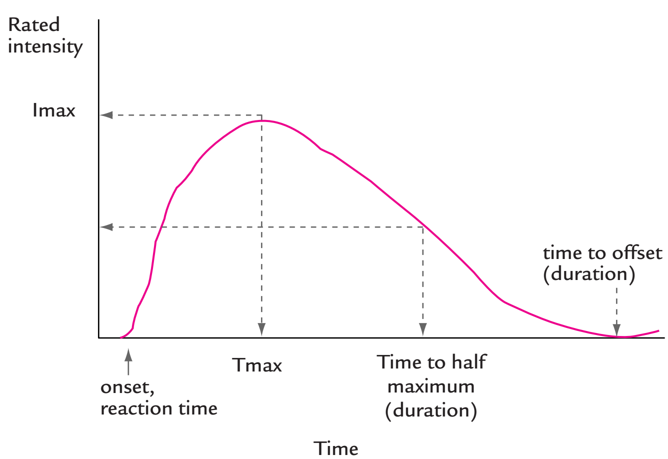


Figure 5.25 Time–intensity scaling (T_{max}, time taken to reach maximum intensity; I_{max}, maximum perceived intensity) (from Lawless and Clark, 1992, reproduced by permission).

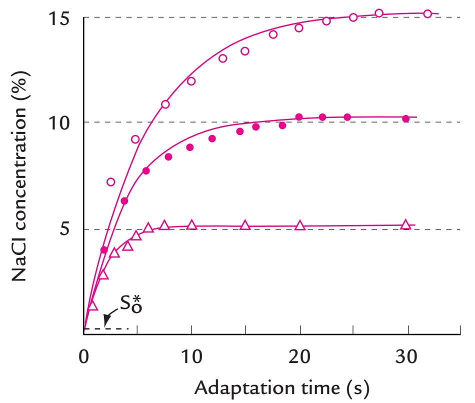


Figure 5.26 Adaptation during 30 s of the threshold of perception under stimulation with 5% (△), 10% (●), and 15% (○) sodium chloride solutions. The unadapted threshold S_o* is 0.24%. The measuring points are from Hahn (1934) (from Overbosch, P. (1986). A theoretical model for perceived intensity in human taste and smell as a function of time. *Chem. Senses* **11**, 315–329. Reproduced by permission of Oxford University Press).

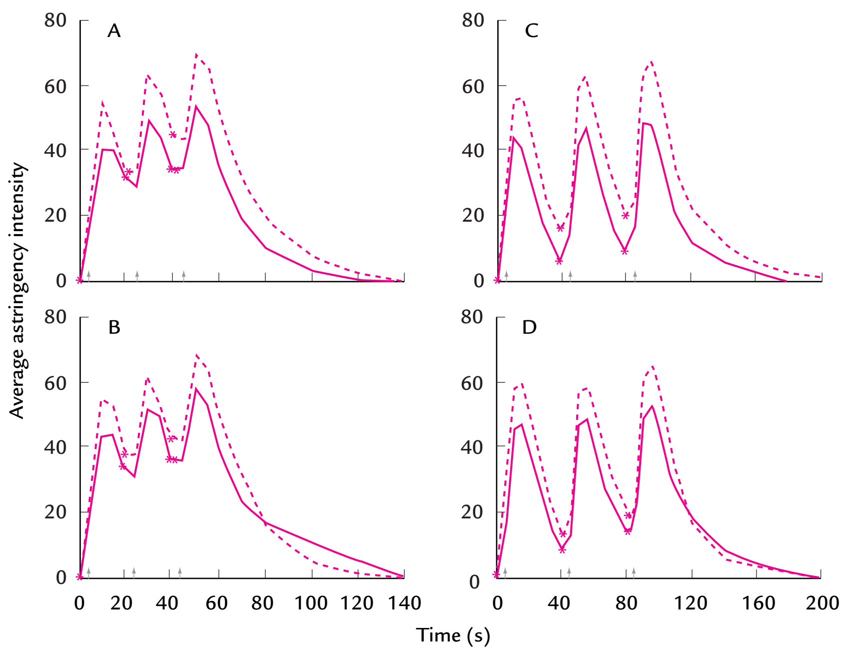


Figure 5.27 Average time-intensity curves for astringency in wine with 0 (——) and 500 (- - -) mg/l of added tannic acid upon three successive ingestions: (A) 8 ml samples, 20 s between ingestions; (B) 15 ml samples, 20 s between ingestions; (C) 8 ml samples, 40 s between ingestions; and (D) 15 ml samples, 40 s between ingestions. Sample uptake and swallowing are indicated by a star and an arrow, respectively (*n* = 24) (from Guinard *et al*., 1986, reproduced by permission).

chromatography effectively separates aromatic compounds, providing their relative concentration, but it supplies no information about their olfactory impact. In charm analysis, the taster sniffs the compounds as they are separated, and indicates when and at what intensity the compound is perceived. These data are then adjusted to account for the variable rates at which compounds are separated. By so doing, the results of many individuals, obtained on different occasions, or with different instruments, can be compared with the compounds isolated. In this manner, only *aromatically significant compounds* (from among the hundreds that may be isolated) are studied to establish chemical identity and sensory significance. Figure 5.28 illustrates the difference between the data obtained by gas chromatography and charm analysis.

Chemical analysis of wine quality

Standard chemical analysis

In the previous section, emphasis has been placed on direct human assessment of wine. Nevertheless, surprisingly good correlation has been obtained between the phenolic content and assessed quality of certain red wines (Fig. 8.11). These data indicate that color density (measured as the sum of absorbence values at 420 and 520 nm) is highly correlated with quality.

Absorbence at 420 and 520 nm was chosen because these values change dramatically during aging. Visually perceptible differences in color depth were not the cause of the color–quality correlation, because tasters inconsistently recognized color in the wines. In addition, only 3 out of the potential maximum of 20 marks were assigned to color (Somers, 1975). Color density is also closely linked to total phenolic extract (as measured by UV absorbence at 280 nm). It remains relatively

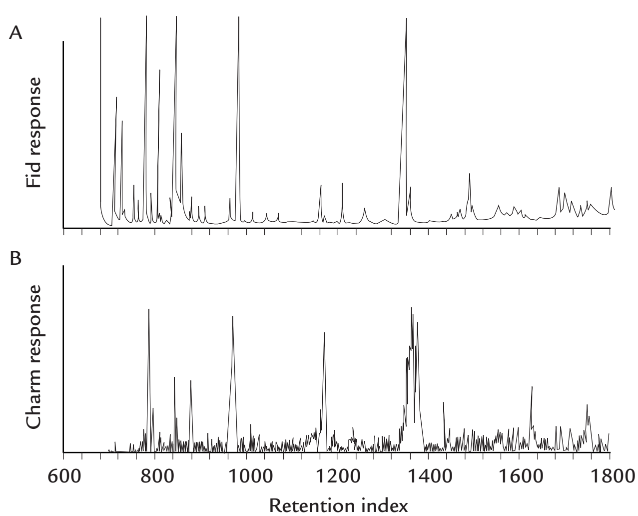


Figure 5.28 A comparison between (A) a gas chromatogram and (B) a charm response produced from extracts of 40 different cultivars of apples (from Acree *et al.*, 1984).

constant during aging. Another parameter that correlates well with assessed wine quality is the proportion of colored anthocyanins (notably ionized flavylium forms). Unfortunately, these studies have been conducted with only two deeply pigmented varieties, *Cabernet Sauvignon* and *Shiraz*. Studies with white wines have not shown a relationship between phenolic content and assessed quality (Somers and Pocock, 1991).

Another potential objective measure of wine and grape quality is its glycosyl-glucose (G-G) content (Iland *et al*., 1996). It has the advantage that most known flavor-impact compounds in wine accumulate in grapes as glycosylated conjugates of glucose (Williams, 1996). Therefore, a single test might measure potential grape flavor intensity. Such a measure would greatly assist researchers, grape growers, and winemakers in assessing those factors that influence wine sensory quality and aging potential. Admittedly less detailed and informative than the measurement of specific flavor-impact compounds, the G-G value has the advantages of comparatively rapid assessment and potential universal relevance.

Electronic noses

Potentially the most significant advance in objective sensory analysis may come from the development of instruments called electronic noses (e-noses; Hurst, 1999). Some are now produced in handheld models. Most possess a collection of discs (sensors) composed of an electrical conductor (such as carbon black) homogeneously embedded in a non-conducting absorptive polymer. Each sensor possesses a distinctive polymer that differentially absorbs a range of aromatic compounds. Each disc also possesses a pair of electrical contacts bridged by a composite film (such as alumina). When volatile compounds pass over the sensors, absorption causes the disc to swell (Fig. 5.29A). The swelling progressively separates the electrically conductive particles. This results in a rise in electrical resistance. The speed and degree of resistance is recorded from each sensor, generating a unique fingerprint of the odor mixture (Fig. 5.29B). As the number of sensors increases, so does the potential discriminating power of the e-nose. Commercial e-nose systems, such as the Cyranose 320™, possess 32 unique sensors. After each sample, the sensors regain their original size and sensitivity, as the aromatics absorbed escape into a flushing gas.

Electrical resistance data from each sensor are adjusted (smoothed) for background electrical noise before being analyzed. The data can generate a histogram, but, because of the complexity of the pattern and overlaps, they are typically subjected to one or more statistical recognition tests. These usually include principal component analysis and mathematical algorithms. The patterns generated resemble the principal component relationships derived from descriptive sensory analysis (Fig. 5.30). Computer software supplied with the machine conducts the mathematical analyses automatically.

By combining the data with computer neural networks (Gopel *et al.*, 1998), recognizable odor patterns can be derived. However, reference samples must be chosen carefully to represent the full range of characteristics found in the wines tested. Similar to sensory descriptive analysis, but unlike traditional analytic techniques,

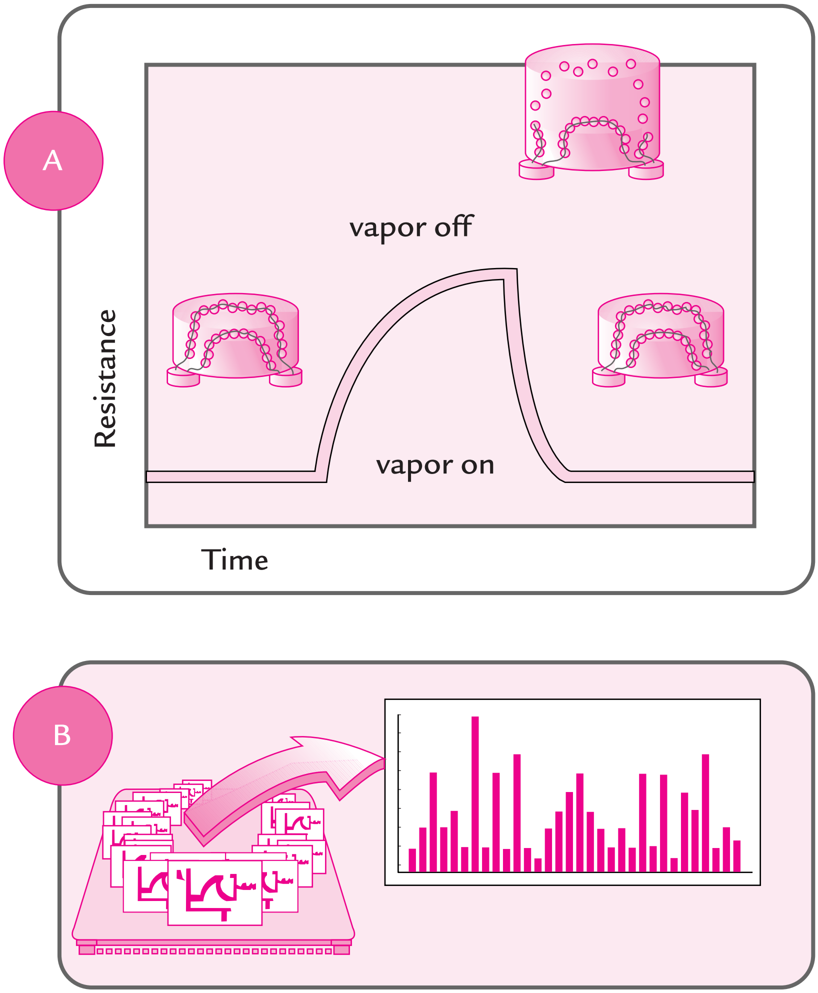


Figure 5.29 Most electronic noses consist of a series of sensors that on absorbing a compound start to swell, increasing the electrical resistance, until current flow stops (A). The different absorption properties of the sensors generates a pattern that is often unique to a particular aromatic object or substance (B) (courtesy of Cyrano Sciences, Inc., Pasadena, CA).

separation, identification, and quantification of individual volatile compounds is not obtained. This potential drawback may be reduced with the potential introduction of genetically engineered olfactory proteins (Wu and Lo, 2000). Their use would dramatically increase sensitivity and reduce "noise" from non-target chemicals.

A different e-nose technology is based on flash chromatography. Unlike traditional gas chromatography, samples can be analyzed in a few seconds, rather than hours. In the zNose™, a sample is initially preconcentrated in a Tenax trap, before heat vaporizing the aromatics into a stream of helium gas. The gas passes through a heated, 1 m long, capillary column to separate the constituent volatiles. When the chemicals emerge from the column, they are directed onto a

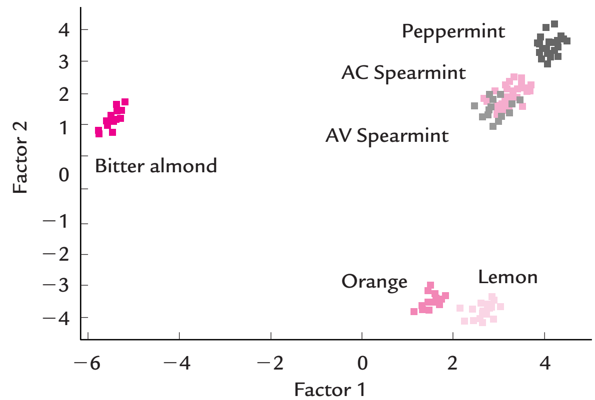


Figure 5.30 Principal factor analysis of different essential oils using the Cyranose 320 electronic nose (courtesy of Cyrano Sciences, Inc., Pasadena, CA).

quartz surface acoustic wave (SAW) detector. As the aromatics absorb and desorb from the SAW detector, the frequency of sound emitted from the acoustic detector changes. The frequency change is recorded every 20 ms, with the degree of change indicating the concentration. Because the acoustic impulse can be correlated with retention time on the capillary column, specific identification of the compounds is possible. This involves reference standards, as is typical with traditional gas chromatography. What is especially appealing is that the data can be quickly presented in a manner reminiscent of polar plots. As such, they visually represent the aromatic nature of a wine. Because the presence or concentration of most wine aromatics is not unique to particular wines or cultivars, the instrument can be instructed to record only the emissions from selected compounds. This presents a clearer visual representation of the distinctive aromatic character of the wine. Adjustment of features such as preconcentration, coil temperature, and acoustic sensor temperature can influence both sensitivity and chemical resolution.

Present z-Nose models primarily resolve and quantify hydrocarbons. Because wines contain many hydrocarbons, their dominant presence could mask the presence of significant impact compounds. For example caprylate and caproate might mask the presence of the off-odor caused by 2,4,6-trichloroanisole (Staples, 2000). In addition, certain impact compounds, specific to particular cultivars, cannot be currently resolved. This drawback may disappear as improvements in the carrier system are developed. Nevertheless, current models can readily distinguish between several varietal wines (Fig. 5.31).

Electronic-nose technology is already routine in assaying off-odors in several foods and beverages. Their speed, accuracy, economy, portability, as well as applicability to almost any task involving odor assessment (including disease detection, crime investigation and military uses) have greatly spurred their rapid development.

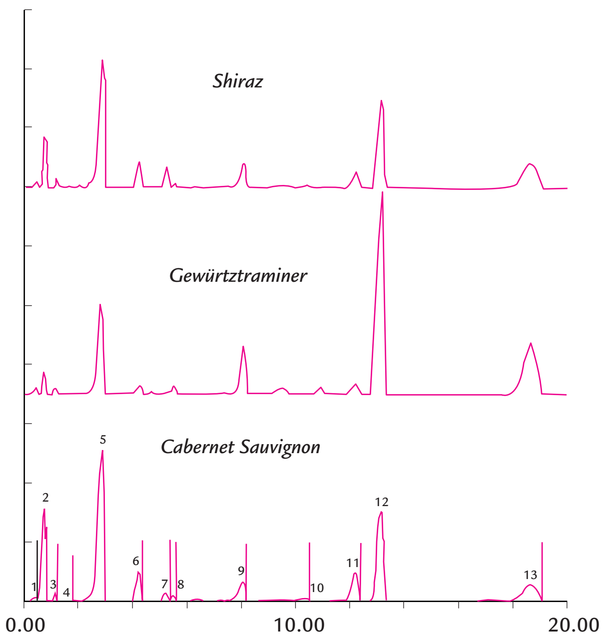


Figure 5.31 Example of the differentiation possible between varietal wines using z-nose™, a chromatographic form of electronic nose technology (courtesy of Electronic Sensor Technology, Newbury Park, CA).

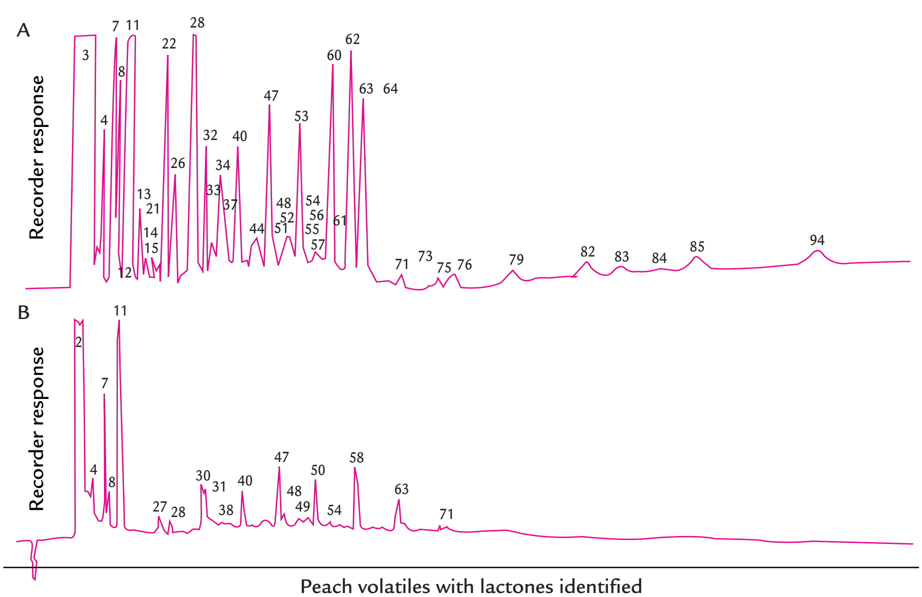


Figure 5.32 Chromatograms illustrating the significantly increased aromatic complexity of fully tree-ripened fruit (A) compared with artificially-ripened fruit (B) (from Do *et al.*, 1969, reproduced by permission).

The potential of electronic noses to quickly measure important varietal fragrances, as an indicator of maturity (Young *et al.*, 1999), would facilitate harvest timing to achieve desired flavor characteristics. Figure 5.32 illustrates the vastly enhanced aromatic complexity of fully ripened fruit. Electronic-nose technology may also supply needed quantitative quality control. For example, it is being investigated as a tool in discriminating among oak barrel toasting levels (Chatonnet and Dubourdieu, 1999), and detecting cork and wine contamination with 2,4,6-trichloroanisole.

Humans will always be needed to assess features such as taste, mouth-feel, flavor and finish, as well as subjective aspects such as complexity, balance, and body. However, electronic noses are likely to join, if not replace, panels in many situations where people are used in lieu of objective olfactory instruments. In addition, panels of trained tasters will coexist with instrumental analysis as the chemical nature of sensory perception is clarified. Once achieved, the ease, efficiency, reliability, and accuracy of electronic-nose technology (and the forthcoming electronic tongue) may replace the expense and imprecision of human panels for objective olfactory assessment in many routine areas of sensory evaluation.

Appendices

Appendix 5.1 Response sheet for taste-mouthfeel test

Name: ______________________ Session: 1 ☐ 2 ☐ 3 ☐

Sample# INTENSITY OF SENSATION

Weak Medium Intense

1 ____

Sensations:
Location:

2 ____

Sensations:
Location:

3 ____

Sensations:
Location:

4 ____

Sensations:
Location:

5 ____

Sensations:
Location:

6 ____

Sensations:
Location:

Appendix 5.2 Aroma and bouquet samples[c]

Sample	Amount per 300 ml of base wine[a]
Temperate tree fruit	
Apple	15 mg Hexyl acetate
Cherry	3 ml Cherry brandy essence (Noirot)
Peach	100 ml Juice from canned peaches
Apricot	2 Drops of undecanoic acid γ-lactone plus 100 ml juice from canned apricots
Tropical tree fruit	
Litchi	100 ml Litchi fruit drink (Leo's)
Banana	10 mg Isoamyl acetate
Guava	100 ml Guava fruit drink (Leo's)
Lemon	0.2 ml Lemon extract (Empress)
Vine fruit	
Blackberry	5 ml Blackberry essence (Noirot)
Raspberry	60 ml Raspberry liqueur
Blackcurrant	80 ml Blackcurrant nectar (Ribena)
Passion fruit	10 ml Ethanolic extract of one passion fruit
Melon	100 ml Melon liqueur
Floral	
Rose	6 mg Citronellol
Violet	1.5 mg β-Ionone
Orange blossom	20 mg Methyl anthranilate
Iris	0.2 mg Irone
Lily	7 mg Hydroxycitronellal
Vegetal	
Beet	25 ml Canned beet juice
Bell pepper	5 ml 10% Ethanolic extract from dried bell pepper (2 g)
Green bean	100 ml Canned green bean juice
Herbaceous	3 mg 1-Hexen-3-ol
Spice	
Anise/licorice	1.5 mg Anise oil
Peppermint	1 ml Peppermint extract (Empress)
Black pepper	2 g Whole black peppercorns
Cinnamon	15 mg *trans*-Cinnamaldehyde
Nuts[b]	
Almond	5 Drops bitter almond oil
Hazelnut	3 ml Hazelnut essence (Noirot)
Coconut	1.0 ml Coconut essence (Club House)
Woody	
Oak	3 g Oak chips (aged ≥ 1 month)
Vanilla	24 mg Vanillin
Pine	7.5 mg Pine needle oil (1 drop)
Eucalyptus	9 mg Eucalyptus oil
Pyrogenous	
Incense	half a Stick of Chinese incense
Smoke	0.5 ml Hickory liquid smoke (Colgin)

Mushroom	
Agaricus	Juice from 200 g microwaved mushrooms
Truffle	30 ml Soy sauce
Miscellaneous	
Chocolate	3 ml Chocolate liqueur
Butterscotch	1 ml Butterscotch flavor (Wagner)

[a] With whole fruit, the fruit is ground in a blender with 95% alcohol. The solution is left for about a day in the absence of air, filtered through several layers of cheesecloth, and added to the base wine. Several days later, the sample may need to be decanted to remove excess precipitates.
[b] To limit oxidation, about 20 mg potassium metabisulfite may be added per sample.
[c] **Important**: all participants should be informed of the constituents of the samples. For example, people allergic to nuts may have adverse reactions even to their smell.

The recipes are given only as a guide as adjustments will be required based on both individual needs and material availability. They are adequate for most purposes, but where used in research where purity and consistency of preparation is paramount details give in Meilgaard *et al.* (1982) are essential reading. (Additional recipes may be found at http://www.nysaes.cornell.edu/fst/faculty/acree/fs430/aromalist/sensorystd.html, or in Meilgaard, 1988; Noble *et al.*, 1987; Peynaud, 1980; and Williams, 1975.) Pure chemicals have the advantage of providing highly reproducible samples, whereas "natural" sources are more complex, but more difficult to standardize. Readers requiring basic information for preparing samples may find Stahl and Einstein (1973), Furia and Bellanca (1975), Heath (1981) especially useful. Most specific chemicals can be obtained from major chemical suppliers, while sources of fruit, flower, and other essences include wine supply, perfumery, and flavor supply companies.

Because only 30 ml samples are required at any one time, it may be convenient to disperse the original sample into 30-ml screw-cap test tubes for storage. Parafilm can be stretched over the cap to prevent oxygen penetration. Samples stored in a refrigerator usually remain good for several months. Alternatively, samples may be stored in hermetically sealed vials in a freezer and opened only as required.

Appendix 5.3 Basic off-odor samples[abcd]

Sample	Amount (per 300 ml neutral-flavored base wine)
Corked	
2,4,6-TCA	3 μg 2,4,6-trichloroanisole
Guaiacol	3 mg Guaiacol
Actinomycete	2 mg geosmin (an ethanolic extract from a *Streptomyces griseus* culture[e])
Penicillium	2 mg 3-octanol (or an ethanolic extract from a *Hemigera* (*Penicillium*) culture[f])
Chemical	
Fusel	120 mg Isoamyl and 300 mg isobutyl alcohol
Geranium-like	40 mg 2,4-Hexadienol
Buttery	12 mg Diacetyl[g]
Plastic	1.5 mg Styrene
Sulfur	
Sulfur dioxide	200 mg Potassium metabisulfite
Goût de lumière	4 mg Dimethyl sulfide[g] and 0.4 mg ethanethiol
Mercaptan	4 mg Ethanethiol
Hydrogen sulfide	2 ml Solution with 1.5 mg $Na_2S.9H_2O$
Miscellaneous	
Oxidized	120 mg Acetaldehyde
Baked	1.2 g Fructose added and baked 4 weeks at 55°C
Vinegary	3.5 g Acetic acid
Ethyl acetate	100 mg Ethyl acetate
Mousy	alcoholic extract culture of *Brettanomyces* (or 2 mg 2-acetyltetrahydropyridines)

[a] To limit oxidation, about 20 mg potassium metabisulfite may be added per 300 ml base wine.
[b] Because only 30 ml samples are required at any one time, it may be convenient to disperse the original sample into 30 ml screw-cap test tubes for storage. Parafilm can be stretched over the cap to further prevent oxygen penetration. Samples stored in a refrigerator usually remain good for several months.
[c] Other off-odor sample preparations are noted in Meilgaard *et al*. (1982).
[d] **Important:** participants should be informed of the chemical to be smelt in the test. For example, some asthmatics are highly sensitive to sulfur dioxide. If so, such individuals should not serve as wine tasters.
[e] *Streptomyces griseus* is grown on nutrient agar in 100 cm diameter petri dishes for 1 week or more. The colonies are scraped off and added to the base wine. Filtering after a few days should provide a clear sample.
[f] *Penicillium* sp. isolated from wine corks is inoculated on small chunks (1–5 mm) of cork soaked in wine. The inoculated cork is placed in a petri dish and sealed with Parafilm to prevent the cork from drying out. After 1 month, obvious growth of the fungus should be noticeable. Chunks of the overgrown cork are added to the base wine. Within a few days, the sample can be filtered to remove the cork. The final sample should be clear.
[g] Because of the likelihood of serious modification of the odor quality of these chemicals by contaminants, Meilgaard *et al*. (1982) recommend that they be purified prior to use: for diacetyl, use fractional distillation and absorption (in silica gel, aluminum oxide, and activated carbon); for dimethyl sulfide, use absorption.

Appendix 5.4 Off-odors in four types of wine at two concentrations

Wine	Off-odor	Chemical added	Amount (per 300 ml)
Gewürztraminer			
	Oxidized	Acetaldehyde	20, 60 mg
	Sulfur dioxide	Potassium metabisulfite	67, 200 mg
	2,4,6-TCA	2,4,6-Trichloroanisole	2, 10 μg
	Plastic	Styrene	1.5, 4.5 mg
Sauvignon blanc			
	Vinegary	Acetic acid	0.5, 2 g
	Buttery	Diacetyl	2, 6 mg
	Ethyl acetate	Ethyl acetate	40, 100 mg
	Geranium-like	2,4-Hexadienol	10, 40 mg
Beaujolais			
	Geranium-like	2,4-Hexadienol	10, 40 mg
	Buttery	Diacetyl	5, 24 mg
	Ethyl acetate	Ethyl acetate	40, 100 mg
	Oxidized	Acetaldehyde	20, 60 mg
Pinot Noir			
	Guaiacol	Guaiacol	0.2, 0.6 mg
	Mercaptan	Ethanethiol	5, 24 μg
	2,4,6-TCA	2,4,6-Trichloroanisole	2, 10 μg
	Plastic	Styrene	1.5, 4.5 mg

Appendix 5.5 Minimum number of correct judgements to establish significance at various probability levels for the triangle test (one-tailed, $p = 1/3$)*

No. of trials (n)	Probability levels						
	0.05	0.04	0.03	0.02	0.01	0.005	0.001
5	4	5	5	5	5	5	
6	5	5	5	5	6	6	
7	5	6	6	6	6	7	7
8	6	6	6	6	7	7	8
9	6	7	7	7	7	8	8
10	7	7	7	7	8	8	9
11	7	7	8	8	8	9	10
12	8	8	8	8	9	9	10
13	8	8	9	9	9	10	11
14	9	9	9	9	10	10	11
15	9	9	10	10	10	11	12
16	9	10	10	10	11	11	12
17	10	10	10	11	11	12	13
18	10	11	11	11	12	12	13
19	11	11	11	12	12	13	14
20	11	11	12	12	13	13	14
21	12	12	12	13	13	14	15
22	12	12	13	13	14	14	15
23	12	13	13	13	14	15	16
24	13	13	13	14	15	15	16
25	13	14	14	14	15	16	17
26	14	14	14	15	15	16	17

27	14	14	15	15	16	17	18
28	15	15	15	16	16	17	18
29	15	15	16	16	17	17	19
30	15	16	16	16	17	18	19
31	16	16	16	17	18	18	20
32	16	16	17	17	18	19	20
33	17	17	17	18	18	19	21
34	17	17	18	18	19	20	21
35	17	18	18	19	19	20	22
36	18	18	18	19	20	20	22
37	18	18	19	19	20	21	22
38	19	19	19	20	21	21	23
39	19	19	20	20	21	22	23
40	19	20	20	21	21	22	24
41	20	20	20	21	22	23	24
42	20	20	21	21	22	23	25
43	20	21	21	22	23	24	25
44	21	21	22	22	23	24	26
45	21	22	22	23	24	24	26
46	22	22	22	23	24	25	27
47	22	22	23	23	24	25	27
48	22	23	23	24	25	26	27
49	23	23	24	24	25	26	28
50	23	24	24	25	26	26	28
60	27	27	28	29	30	31	33
70	31	31	32	33	34	35	37
80	35	35	36	36	38	39	41
90	38	39	40	40	42	43	45
100	42	43	43	44	45	47	49

* Values (X) not appearing in table may be derived from $X = (2n + 2.83\, z \sqrt{n} + 3)/6$.
Source: After tables compiled by Roessler *et al*. (1978), from Amerine and Roessler, (1983).

Appendix 5.6 Rank totals excluded for significance differences, 5% level. Any rank total outside the given range is significant

Number of judges	Number of wines										
	2	3	4	5	6	7	8	9	10	11	12
3				4–14	4–17	4–20	4–23	5–25	5–28	5–31	5–34
4		5–11	5–15	6–18	6–22	7–25	7–19	8–32	8–36	8–39	9–43
5		6–14	7–18	8–22	9–26	9–31	10–35	11–39	12–43	12–48	13–52
6	7–11	8–16	9–21	10–26	11–31	12–36	13–41	14–46	15–51	17–55	18–60
7	8–13	10–18	11–24	12–30	14–35	15–41	17–46	18–52	19–58	21–63	22–69
8	9–15	11–21	13–27	15–33	17–39	18–46	20–52	22–58	24–64	25–71	27–77
9	11–16	13–23	15–30	17–37	19–44	22–50	24–57	26–64	28–71	30–78	32–85
10	12–18	14–26	17–33	20–40	22–48	25–55	27–63	30–70	32–78	25–85	37–93
11	13–20	16–28	19–36	22–44	25–52	28–60	31–68	34–76	36–85	39–93	42–101
12	15–21	18–30	21–39	25–47	28–56	31–65	34–74	38–82	41–91	44–100	47–109
13	16–23	20–32	24–41	27–51	31–60	35–69	38–79	42–88	45–98	49–107	52–117
14	17–25	22–34	26–44	30–54	34–64	38–74	42–84	46–94	50–104	54–114	57–125
15	19–26	23–37	28.47	32–58	37–68	41–79	46–89	50–100	54–111	58–122	63–132
16	20–28	25–39	30–50	35–61	40–72	45–83	49–95	54–106	59–117	63–129	68–140
17	22–29	27–41	32–53	38–64	43–76	48–88	53–100	58–112	63–124	68–136	73–148
18	23–31	29–43	34–56	40–68	46–80	52–92	57–105	61–118	68–130	73–143	79–155
19	24–33	30–46	37–58	43–71	49–84	55–97	61–110	67–123	73–136	78–150	84–163
20	26–34	32–48	39–61	45–75	52–88	58–102	65–115	71–129	77–143	83–157	90–170

Source: Adapted by Amerine and Roessler (1983) from tables compiled by Kahan *et al*. (1973).

Appendix 5.7 Rank totals excluded for significance differences, 1% level. Any rank total outside the given range is significant

Number of judges	Number of wines										
	2	3	4	5	6	7	8	9	10	11	12
3									4–29	4–32	4–35
4				5–19	5–23	5–27	6–30	6–34	6–38	6–42	7–45
5			6–19	7–23	7–28	8–32	8–37	9–41	9–46	10–50	10–55
6		7–17	8–22	9–27	9–33	10–38	11–43	12–48	13–53	13–59	14–64
7		8–20	10–25	11–31	12–37	13–43	14–49	15–55	16–61	17–67	18–73
8	9–15	10–22	11–29	13–35	14–42	16–48	17–55	19–61	20–68	21–75	23–81
9	10–17	12–24	13–32	15–39	17–46	19–53	21–60	22–68	24–75	26–82	27–90
10	11–19	13–27	15–35	18–42	20–50	22–58	24–66	26–74	28–82	30–90	32–98
11	12–21	15–29	17–38	20–46	22–55	25–63	27–72	30–80	32–89	34–98	37–106
12	14–22	17–31	19–41	22–50	25–59	28–68	31–77	33–87	36–96	39–105	42–114
13	15–24	18–34	21–44	25–53	28–63	31–73	34–83	37–93	40–103	43–113	46–123
14	16–26	20–36	24–46	27–57	31–67	34–78	38–88	41–98	45–109	48–120	51–131
15	18–27	22–38	26–49	30–60	34–71	37–83	41–94	45–105	49–116	53–127	56–139
16	19–29	23–41	28–52	32–64	36–76	41–87	451–99	49–111	53–123	57–135	62–146
17	20–31	25–43	30–55	35–67	39–80	44–92	49–104	53–117	58–129	62–142	67–154
18	22–32	27–45	32–58	37–71	42–84	47–97	52–110	57–123	62–136	67–149	72–162
19	23–34	29–47	34–61	40–74	45–88	50–102	56–115	61–129	67–142	72–156	77–170
20	24–36	30–50	36–64	42–78	48–92	54–106	60–120	65–135	71–149	77–163	82–178

Source: Adapted by Amerine and Roessler (1983) from tables compiled by Kahan *et al*. (1973).

Appendix 5.8 Multipliers for estimating significance of differnece by range. Two-way classification. A, 5% level; B 1% level

A

Number of judges	Number of wines 2	3	4	5	6	7	8	9	10	11	12
2	6.35	2.19	1.52	1.16	0.94	0.79	0.69	0.60	0.54	0.49	0.45
	6.35	1.96	1.39	1.12	0.95	0.84	0.76	0.70	0.65	0.61	0.58
3	1.96	1.14	0.88	0.72	0.61	0.53	0.47	0.42	0.38	0.35	0.32
	2.19	1.14	0.90	0.76	0.67	0.61	0.56	0.52	0.49	0.46	0.44
4	1.43	0.96	0.76	0.63	0.54	0.47	0.42	0.38	0.34	0.31	0.29
	1.54	0.93	0.76	0.65	0.58	0.53	0.49	0.45	0.43	0.40	0.38
5	1.27	0.89	0.71	0.60	0.51	0.45	0.40	0.36	0.33	0.30	0.28
	1.28	0.84	0.69	0.60	0.53	0.49	0.45	0.42	0.40	0.38	0.36
6	1.19	0.87	0.70	0.58	0.50	0.44	0.39	0.36	0.33	0.30	0.28
	1.14	0.78	0.64	0.56	0.50	0.46	0.43	0.40	0.38	0.36	0.34
7	1.16	0.86	0.69	0.58	0.50	0.44	0.40	0.36	0.33	0.30	0.28
	1.06	0.74	0.62	0.54	0.48	0.44	0.41	0.38	0.36	0.34	0.33
8	1.15	0.86	0.69	0.58	0.50	0.44	0.40	0.36	0.33	0.30	0.28
	1.01	0.71	0.59	0.52	0.47	0.43	0.40	0.37	0.35	0.33	0.32
9	1.15	0.86	0.70	0.59	0.51	0.45	0.40	0.36	0.33	0.31	0.29
	0.97	0.69	0.58	0.51	0.46	0.42	0.39	0.36	0.34	0.33	0.31
10	1.15	0.87	0.71	0.60	0.51	0.45	0.41	0.37	0.34	0.31	0.29
	0.93	0.67	0.56	0.50	0.45	0.41	0.38	0.36	0.34	0.32	0.31
11	1.16	0.88	0.71	0.60	0.52	0.46	0.41	0.37	0.34	0.32	0.29
	0.91	0.66	0.55	0.49	0.44	0.40	0.38	0.35	0.33	0.32	0.30
12	1.16	0.89	0.72	0.61	0.53	0.47	0.42	0.38	0.35	0.32	0.30
	0.89	0.65	0.55	0.48	0.43	0.40	0.37	0.35	0.33	0.31	0.30

The entries in this table are to be multiplied by the sum of the ranges of differences between adjacent wine scores to obtain the difference required for significance for wine totals (use upper entry) and/or judge totals (use lower entry).

B

Number of judges	Number of wines 2	3	4	5	6	7	8	9	10	11	12
2	31.83	5.00	2.91	2.00	1.51	1.20	1.00	0.86	0.75	0.66	0.60
	31.83	4.51	2.72	1.99	1.59	1.35	1.19	1.07	0.97	0.90	0.84
3	4.51	1.84	1.31	1.01	0.82	0.70	0.60	0.53	0.48	0.43	0.39
	5.00	1.84	1.35	1.10	0.94	0.83	0.76	0.69	0.65	0.61	0.57
4	2.63	1.40	1.04	0.83	0.69	0.59	0.52	0.46	0.42	0.38	0.35
	2.75	1.35	1.04	0.87	0.76	0.68	0.63	0.58	0.54	0.51	0.48
5	2.11	1.25	0.95	0.77	0.64	0.56	0.49	0.44	0.40	0.36	0.33
	2.05	1.14	0.90	0.77	0.68	0.61	0.56	0.52	0.49	0.46	0.44
6	1.88	1.18	0.91	0.74	0.63	0.54	0.48	0.43	0.39	0.36	0.33
	1.71	1.02	0.82	0.71	0.63	0.57	0.52	0.49	0.46	0.43	0.41
7	1.78	1.15	0.89	0.73	0.62	0.54	0.48	0.43	0.39	0.36	0.33
	1.52	0.95	0.77	0.66	0.59	0.54	0.50	0.46	0.44	0.41	0.39
8	1.72	1.14	0.89	0.73	0.62	0.54	0.48	0.43	0.39	0.36	0.33
	1.40	0.90	0.73	0.63	0.57	0.52	0.48	0.45	0.42	0.40	0.38
9	1.69	1.14	0.89	0.73	0.62	0.54	0.48	0.43	0.39	0.36	0.33
	1.31	0.86	0.71	0.61	0.55	0.50	0.46	0.43	0.41	0.39	0.37
10	1.67	1.14	0.89	0.74	0.63	0.55	0.48	0.44	0.40	0.36	0.34
	1.24	0.83	0.68	0.59	0.53	0.49	0.45	0.42	0.40	0.38	0.36
11	1.67	1.15	0.90	0.74	0.63	0.55	0.49	0.44	0.40	0.37	0.34
	1.19	0.80	0.67	0.58	0.52	0.48	0.44	0.41	0.39	0.37	0.35
12	1.67	1.15	0.91	0.75	0.64	0.56	0.50	0.45	0.41	0.37	0.35
	1.15	0.78	0.65	0.57	0.51	0.47	0.43	0.41	0.38	0.36	0.35

The entries in this table are to be multiplied by the sum of the ranges of differences between adjacent wine scores to obtain the difference required for significance for wine totals (use upper entry) and/or judge totals (use lower entry).

Source: After Kurtz *et al*. (1965). Reprinted with permission of *Technometrics* through the courtesy of the American Statistical Association, modified in Amerine and Roessler (1983).

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Qualitative (general) wine tasting

6

In Chapter 5, tasting was discussed as a means of differentiating and characterizing wine based on a critical look at its sensory properties. In this chapter, the primary concern is the expression of the wine's varietal, stylistic, regional, or artistic characteristics. This usually involves qualitative ranking based on these traits. Despite the impression often given by wine critics, detection of these features is not easy; it is often more difficult than the tasks asked of the technical taster in Chapter 5. Most wines do not express a readily detectable varietal or regional character. Therefore, the search for these traits is often fruitless. Only the best examples clearly show the ideal features attributed to a variety or region. Experience provides the knowledge to recognize these features, when they exist, and the ability to rank their expression. Somewhat easier to detect are stylistic differences. The method of fermentation or processing usually stamps the wine with a distinct set of sensory characteristics. General esthetic attributes are also comparatively readily recognized, with experience. More difficult is describing these features in meaningful words, and agreeing on how they should be rated. Because reference standards for complexity, development, balance, body, finish, etc. do not exist, and integrative sensory terms are so subjective, clear and precise definition is impossible. Despite these difficulties, and possibly because of them, wine provides much pleasure and intrigue, and an endless source of discussion.

Tasting room

Where possible, the tasting room should be bright, of neutral color, quiet, and odor-free. Wine cellars may be "romantic" sites for a tasting, but their permeation with vinous and moldy odors typically makes reliable assessment impossible.

Opaque plastic buckets should be available for disposal of excess wine (or rinse water if glasses are used repeatedly). In the latter situation, jugs of water are required.

Because tasting should permit the taster to obtain an unbiased opinion of the wine, direct and indirect physiological and psychological hindrances to impartial assessment must be avoided. These are discussed in Chapter 5. In contrast, if the intent is to enhance appreciation, discussion is encouraged. Participants usually appreciate suggestions and support. In addition, where expensive or rare wines are being sampled, cold critical analysis is probably counter productive. On the negative side, psychological factors may be used to veil attempts to influence opinion.

Information provided

Details provided about the wines depends on the objective of the tasting. For example, if varietal or regional differences are being evaluated or illustrated then this aim should be conveyed to the tasters. Otherwise, there is considerable likelihood that the essential feature of the tasting may be missed by the tasters. Precise identity must be withheld, either to avoid unduly influencing taster evaluation, or to encourage participants to search for the demonstrated features. However, if marketing is the primary purpose (e.g., in-store tastings), identity is supplied as the wines are sampled.

Wrapping bottles in paper bags is the typical means of concealing wine identity at most informal tastings. Prepouring or decanting are often unwarranted and impractical. However, bagging covers neither bottle color or shape, neck design, nor residual corroded material on the neck. These features can give hints as to potential identity and age.

An alternative technique is simply to remove the label. In wine appreciation courses, this has the additional advantage of permitting labels to be reproduced, for distribution before or after the tasting. Because bottles are usually opened during the session, the instructor may personally wish to remove the corks. Otherwise, notations on the cork may identify the wines. Prior identification of the wine is appropriate only in the most elementary of tastings.

Sample preparation

Decanting and "breathing"

Separating wine from sediment that may have precipitated since bottling is the primary function of decanting. This applies particularly to old red wines, but it can also apply to some aged white wine. Although the associated air exposure does not produce noticeable wine oxidation,[1] the interval between decanting and tasting should be kept short, especially for old wines as their fragrance rapidly dissipates upon opening.

Despite its principal function, much misinformation surrounds the benefits of decanting. This has been considered to relate to the wine's incidental exposure to air. However, several hours exposure is necessary to produce detectable losses in perceived quality (Ribéreau-Gayon and Peynaud, 1961). In contrast, short-term

[1] The only known, potentially beneficial, rapid oxidation that might occur is the oxidation of hydrogen sulfide.

exposure to air, such as during swirling in the glass, can be beneficial. The aromatic character of the wine may both increase in intensity and change in character (develop). Both features are part of what is often called the "opening" of the wine.

During the 1800s, aeration associated with decanting helped dissipate off-odors—the "bottle stink" with which wines of the time were often afflicted. Modern wines are neither so plagued, nor develop copious amounts of sediment. Therefore, few wines need decanting. Despite this, opening bottles in advance to permit the wine to "breath" is still frequently recommended—even if this involves only pulling the cork a few minutes before pouring. Surface to volume exposure of bottled wine approximates 0.4 cm^2/100 ml via the neck. This increases to about 60 cm^2/100 ml when wine is poured into a glass, or to around 150 cm^2/100 ml when swirled in the glass. Thus, if benefits accrue from aeration, they may occur over 100 times faster in the glass than in the bottle.

Although the origin of "opening" is still speculation, it may relate to rapid equilibrium changes between volatile and fixed aromatic complexes in wine. Mannoproteins (Lubbers *et al*., 1994), amino acids (Maier and Hartmann, 1977), sugars (Sorrentino *et al*., 1986), and reductones (Guillou *et al*., 1997) are examples of compounds that could weakly fix aromatics in wine. Upon opening, aromatics in the headspace escape into the surrounding air, permitting molecules fixed in the wine to be liberated. This may increase the concentration sufficiently to surpass the sensory threshold. This feature would undoubtedly be enhanced by swirling. Following swirling, ethanol evaporation from wine coating the sides of the glass could further affect the vapor pressure of wine aromatics (Williams and Rosser, 1981). Progression of these or related phenomena during tasting could generate what is called development. Thus, breathing, opening and development may all be elements of the same phenomena. Because this is one of the more fascinating features of quality wines, it should not transpire undetected in the bottle or a decanter.

Depending on the wine, the unique aromatic character may dissipate within a few minutes to several hours. Few white wines develop significantly in the glass, except for those produced from cultivars such as *Riesling*, or *Chardonnay*. Very old wines, regardless of color, do not improve aromatically upon opening, usually losing quickly whatever fragrance they had. In contrast, young red wines that age well often develop aromatically in the glass.

For old wines, decanting often involves an elaborate ritual. This may include the use of decanting machines to minimize agitation during decanting. Decanting must occur slowly, so that the incoming air, replacing the wine, moves past the shoulder without producing significant turbulence. In addition, the fulcrum (pivot point of the decanting machine) should be near the neck of the bottle. Otherwise, the mouth of the bottle can pass through more than a 60°angle during decanting. This requires continual readjustment of the carafe to catch the wine as it pours out. Pouring ceases when sediment reaches the neck. While machines are effective, anyone with a steady hand can manually decant a bottle of wine, if it is performed slowly. Checking for sediment flow toward the neck need begin only when about 80% of the wine has been poured.

Decanting is effective only if the wine has been handled carefully before pouring. Wines requiring decanting should be moved delicately to the tasting site several hours, or days, in advance. Sitting the bottle upright results in loose sediment settling to the base of the bottle.

Temperature

White wines are generally recommended to be served at between 8 and 12°C—sweet versions at the lower end of the range and dry versions near the higher end. Dry white wines may even show well up to 20°C. Red wines are generally tasted at between 18 and 22°C. Only light, fruity red wines, such as Beaujolais, show well at 15°C. Rosé wines also express their attributes optimally around 15°C.

Sparkling wines are generally served at between 4 and 8°C. This enhances their toasty fragrance and favors the slow, gentle, steady release of bubbles. Cool temperatures also maximize the prickling sensation of carbon dioxide and generate a refreshing mouth-feel.

Sherries are generally presented between 6 and 8°C. This mellows their intense bouquet and diminishes the potential cloying sweetness of some sherries. In contrast, ports are served at about 18°C. This diminishes the burning sensation of alcohol and extends the release of their complex aromatics.

Some of these preferences probably arose from habituation to the house temperatures typical of Europe prior to central heating. More significant, though, may be the effects of heat on chemical volatility and gustatory sensitivity. The increase in volatility, associated with a rise in temperature, varies considerably with the compound. This can diminish or enhance the perception of particular compounds, due to masking or synergistic effects, respectively. This may partially explain why white wines generally appear more pleasant at cooler rather than warmer temperatures.

Temperature also has pronounced effects on gustatory sensations. Cool temperatures reduce sensitivity to sugars, but they enhance the perception of acidity. Consequently, dessert wines appear more balanced at cooler temperatures. Coolness can also generate an agreeable freshness in the mouth. In contrast, warmer temperatures reduce perceived bitterness and astringency. This helps explain why red wines are generally preferred above 18°C.

Where possible, wines should be brought to the desired temperature several hours before tasting. Alternatively, wines may quickly be brought to a selected temperature by immersion in cold or warm water, as required (Fig. 5.8B).

Because wine begins to warm after pouring, presenting the wine at a temperature lower than that desired has benefit. It results in wine remaining within a desirable range for a longer period.

Wine temperature seldom is measured directly. Normally, it is assumed to be correct if the bottle has been stored for several hours at the chosen temperature. Alternatively, it can be assessed indirectly with a device that records the surface temperature of the bottle. It uses a colored plastic strip that becomes translucent across a range of temperatures. If the wine has had sufficient time to equilibrate, the strip accurately measures the wine's temperature.

Glasses

Wine glasses should be clear, uncolored, and have sufficient capacity and shape to permit vigorous swirling. The International Standard Organization (ISO) Wine Tasting glass (Fig. 1.2) fully satisfies these requirements. Its narrow mouth concentrates aromatics, while the broad base and sloped sides expedite viewing and vigorous swirling.

The problem with most ISO glasses is their fragility (made of slim crystal). Therefore, thicker glass versions, such as the Durand Viticole Tasting Glass may be preferable. Another example of an adequate substitute is the Libby Citation #8470.

For sparkling wines, tall slender flutes aid assessment of the wine's effervescence. This involves careful observation of the chains of bubbles (size, tightness, number, and persistence), the mound of bubbles (*mousse*) in the center of the glass, and the ring of bubbles (*chordon de mousse*) around the edge of the glass.

Except for flute-shaped glasses, only tulip-shaped glasses are used for critical wine tasting. This does not mean that other glasses do not have their place. They can have value in a social setting. Different glass shapes for different wines have the same esthetic appeal as changing the size or design of the chinaware during the meal. Whether these changes are considered beneficial depends on personal preference, not objective considerations. However, because glass shape can influence perceived quality (Fischer, 2000; Cliff, 2001), it is important that all participants use identical glasses in a tasting.

Because glasses pick up odors from the environment, glassware must be adequately cleaned, rinsed, and stored. Detergents are usually required to remove oils, tannins, and pigments that may adhere to the glass. Consequently, nonperfumed detergents, water-softeners, or antistatic agents must be used. Equally important is adequate rinsing to remove detergent residues. Hot tap water is usually adequate. If the glasses are hand dried, then lint-free, odorless tea towels should be used.

Although it may appear to be a fetish, smelling glasses before filling can avoid instances of odor contamination seriously adulterating the wine's fragrance. It is discouraging to realize how commonly glassware odors ruin a wine's quality.

The removal of detergent residues is particularly important for assessing sparkling wines. The formation of a continuous chain of bubbles is largely dependent on the presence of nucleation sites along the bottom and sides of the glass. These nucleation sites consist of minute edges, bumps, or other rough surfaces. They reduce the activation energy required for bubble initiation. Detergent residues leave a molecule-thin film that smooths these surfaces, limiting or preventing nucleation and bubble formation. To promote bubble formation, some people etch a star or cross on the bottom of the glass.

Once glasses have been cleaned and dried, they should be stored upright in a dust- and odor-free environment. The upright position limits odor contamination on the insides of the glass. Hanging glasses upside down may be adequate for short-term storage,[2] but generally is unacceptable in cabinetry.

[2] This facilitates glass pickup by the base, thereby preventing finger marks on the bowl.

Sample number and volume

The number of samples appropriate for a tasting depends on the occasion. For wine courses or tasting societies, six wines are usually adequate—not too few for the effort, but not too excessive in terms of expense or potential for over consumption. In contrast, where sampling and note taking are brief (large trade tastings), upwards of 30, to over 100, wines may be available.

Between 35 to 70 ml is an adequate volume for most tastings. If only a simple assessment is required, sample volumes less than 35 ml can be sufficient. For detailed or prolonged assessment, 50 to 70 ml is preferable. Etching a line around the outer circumference of the glass demonstrates when the desired fill volume has been reached. It also aids the presentation of similar volumes to all tasters.

With portions in the range of 35 ml, a 750 ml bottle can supply up to 20 tasters. This limits wastage because additional wine is usually discarded. At trade tastings, for example, people usually take only one or two sips, pouring out the remainder. Limiting sample volume also leaves an unspoken message that tastings are not consumption.

Cork removal

Corkscrews come in an incredible range of shapes, sizes, and modes of action. Those with a helical coil are the easiest and most efficient to use. The waiter's corkscrew is a classic example. Its major liability is the force needed to extract the cork. By adjusting the design, the same action that forces the screw into the cork can also lift it out of the neck. One of most popular of this type is the Screwpull®. Its Teflon-coated screw makes cork removal particularly easy. A lever model is available for commercial use. Regardless of design, removing old corks is always a problem. Over time the cork loses its resiliency and it tends to split or crumble on extraction. The two-prong, U-shaped Ah-so (Fig. 6.1A) can be invaluable in these situations. If the cork's adherence to the neck is not too loose, gentle, side-by-side pushing slowly slides the prongs down between the cork and the bottle. Combined twisting and pulling can remove weak corks without difficulty. Alternatively, one of the devices using a pump connected to a long hollow needle can prove effective. After the needle is slowly pushed through the cork, pumping injects air into the headspace. The buildup of pressure forces the cork out. If the cork does not budge after 5 to 10 strokes of the pump, pumping should stop, the needle be removed, and some other means used to remove the cork. In situations where the cork crumbles, and fragments enter the wine, they may be removed by filtering. Coffee filters are fully adequate, but inelegant means of removing cork debris. Rinsing the bottle permits its refilling with the filtered wine.

A final device in the arsenal of the wine taster is one of several gadgets that can remove a cork that inadvertently gets pushed into the bottle. One particularly useful model possesses several flexible, plastic, appendages attached around a hollow core (Fig. 6.1B). The appendages are held together as they are inserted in the neck of the bottle. Past the neck they flare out and surround the cork. As the device is pulled back, the barbs on the appendages bite into the cork. Slow steady pulling removes the cork.

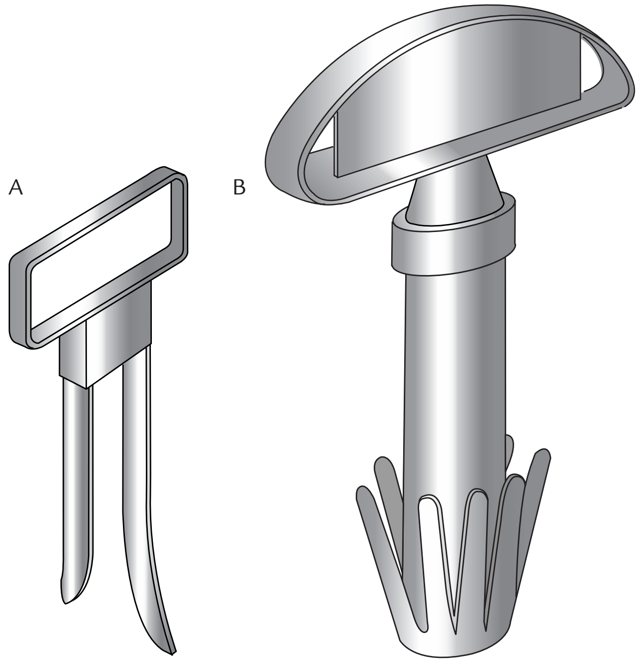


Figure 6.1 Illustration of the U-shaped Ah-so (A) and Wine Waiter™ (B) corkscrews (Courtesy of H. Casteleyn).

Use of lead–tin capsules tends to promote the accumulation of a crust around the rim of the glass, especially when the wine has been stored in damp cellars. This is typically associated with the growth of fungi on wine residues or cork dust. It can produce a dark deposit on the cork and lip of the neck, as well as promote capsule corrosion. If present, the neck should be wiped (scrubbed) clean with a damp cloth. Aluminum or plastic capsules have a looser fit or perforations that limit fungal growth. Use of a wax plug, in lieu of a capsule, is even less likely to permit development of a dark growth of fungi on the cork.

Palate cleansing

Where wines are sampled in rapid succession, as at trade tastings, small cubes of white bread or water are present as palate cleansers. They refresh the mouth for the next sample. Presenting cheese, fruit, and cold cuts, however, gives the tasting a social aspect. Their presence tends to convert the science of wine tasting into the esthetics of wine consumption. Where marketing and public relations are the prime (but unmentioned) focus of the presentation (most public tasting), the presence of food has value. Although most cheeses, and other foods, interfere with detection of subtle differences among wines, they can also mask the bitter/astringent sensations of red wines.

Language

The deficiencies in human language relative to sensory experience have already been noted in Chapter 5. For descriptive sensory analysis, the solution has been to develop terminologies specific to the wines studied. This, of course, is of little help to the general problem most people face in describing their reactions to wine.

Wine language use has been covered in impressive detail by Lehrer (1983). Amerine and Roessler (1983) and Peynaud (1987) also have reviewed the topic, from markedly different viewpoints. Nonetheless, the primary goal of any language is to facilitate clear and precise communication. To this end, the Glossary lists terms with distinct and commonly accepted meanings. Intensity and duration attributes are most simply expressed as adjectives, such as mild, moderate, marked, and short *vs* long, respectively. Figures 1.3 and 1.4 list standard fragrance and off-odor descriptors.

Only rarely do varietal aromas clearly resemble a particular descriptive term. Exceptions are the blackcurrant and litchi aspects of *Cabernet Sauvignon* and *Gewürztraminer*, respectively. More commonly, particular descriptors provide only hints of the context or object's odor. Fruits and flowers, like wines, rarely have a single characteristic odor. While apples and roses may have common elements to their respective odors, most cultivars of these plants are aromatically distinct. Even combinations of descriptive terms seldom give a clear image of a wine's aroma. It is the fascinating diversity that gives wine one of its most endearing and captivating properties.

The spider plots generated by descriptive sensory analysis (Figs 5.21 and 5.22) selectively use terms that permit discrimination among samples. Thus, they may exclude attributes that uniformly characterize the wines as a group. Also, the features alluded to by specific descriptors appear against a general aromatic background. For white wines, this typically involves a nebulous collection of fruity–floral scents, with occasional herbaceous aspects. In red wines, the aromatic spectrum possesses an aspect of ripe berries or fruit jam, with spicy or peppery overtones. These features may be complexed or partially obscured by oak flavors (if matured in oak), or infused with mushroom–truffle and leathery odors as the wine ages.

Although the terms noted in the Glossary describe the wine's sensory characteristics, they seem to consumers to be somewhat sterile. They do not convey the taster's emotional response. Because this aspect is one of a wine's most important attributes to consumers, it must be expressed. Therefore, the metaphoric, emotive illusions typically used to describe wines have their legitimate place, despite their inherent imprecision. As long as this poetic language is used to express inner feelings, it fulfills an obvious need. Caution must be used, though, or as Samuel Johnson noted:

> "This is one of the disadvantages of wine, it makes man mistake words for thoughts."

What should be avoided are anthropomorphic terms, such as feminine, fat, or aggressive. In addition, terms such as *terroir* (to describe flavors supposedly derived from particular vineyard sites) are figments of the imagination—thankfully so, as anyone who has put their nose to the soil or a compost pile can attest.

Descriptions should normally be kept terse, specifically recording only those attributes that are noteworthy. Where time permits, and there is reason, complete notes on all sensory features may be taken. Typically, though, this is unnecessary. Use of one of the many score sheets available encourages economic use of both time and words.

Wine score sheets

Detailed score sheets (Figs. 5.12 to 5.15) are appropriate if analysis is intended. However, for most informal tastings, data analysis is neither necessary nor warranted. Under these conditions, a form such as illustrated in Fig. 1.5 may be adequate. Figure 6.2 illustrates a variation of this sheet, developed for a wine-appreciation course. It is normally enlarged and reproduced on 11 × 17 inch sheets. Labels, reduced in size, are added to act as visual aids in remembering the wines tasted. Because the sheet is designed for an introductory course, verbal descriptions of the wines' characteristics and varietal origin are noted to assist student identification.[3] Little space is provided for student comments because they have difficulty verbally expressing their reactions, and write little. In subsequent tastings, more space is allotted for comments (Fig. 1.5). Varietal and regional characteristics of each wine are noted on overheads (instead of the tasting sheet) before, during, or after the tasting—depending on its purpose. Quality concepts and fragrance descriptors are noted to the left of the sheet to encourage concentration on the wine's attributes.

For a more extensive discussion of tasting forms, refer to the equivalent section in Chapter 5.

Sensory training exercises

Sensory training and testing for professional tasters has been covered in Chapter 5. In this chapter, exercises are provided to help those with little professional training to recognize the diversity and complexities of the tastes found in wine. Occasionally, these exercises are used in training tasters.

Several exercises have been proposed by authors such as Marcus (1974) and Baldy (1995). They typically commence with a demonstration of basic taste sensations, such as that noted in Table 5.4. It is usually followed by exercises designed to illustrate how the major vinous constituents affect taste and touch sensations. Exercises for the primary sweet, sour, bitter and astringent compounds found in wine are given in Appendices 6.1 through 6.4. Subsequently, exercises illustrate how these compounds may interact to augment, diminish, or modify perceptions. Appendix 6.5 provides exercises demonstrating the interaction of sugar and bitter compounds, and sugar–acid balance.

[3] Initially the order of wine presentation may correspond to the sequence of the descriptions; subsequently, though, the order of the descriptions is randomized to induce the students to correlate the wines to their description.

APPEARANCE

Color – hue
– depth
– clarity

Spritz

Score (Maximum +/−1)

FRAGRANCE

General Features
Duration
Intensity
Development
Varietal Character

Fragrance
Berry Fruit – Blackberry, Blackcurrant, Grape, Melon, Raspberry, Strawberry
Tree Fruit – Apple, Apricot, Banana, Cherry, Guava, Grapefruit, Lemon. Litchi, Peach, Passion Fruit, Quince
Dry Fruit – Fig, Raisin
Floral – Camellia, Citronella, Iris, Orange blossom, Rose, Tulip, Violet
Nuts – Almond, Hazelnut, Walnut
Vegetable – Asparagus, Beet, Bell pepper, Canned Green beans, Hay, Olives, Tea, Tobacco
Spice – Cinnamon, Cloves, Incense, Licorice, Mint, Pepper
Roasted – Caramel, Coffee, Smoke, Toast
Other – Buttery, Cheese, Cigar box, Honey, Leather, Mushroom, Oak, Pine, Phenolic, Truffle, Vanilla

Score (Maximum 5)

TASTE

General Features
Duration
Development
Intensity
Balance

Specific Aspects
Sweetness, acidity, astringency, bitterness, body, heat (alcohol level), mellowness, spritz (prickling)

Score (Maximum 3)

OVERALL ASSESSMENT

General quality
Potential
Memorableness

Score (Maximum +/−)

TOTAL SCORE (Maximum 10)

1 2 3 4 5 6

WINES

WINE APPRECIATION

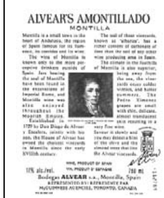
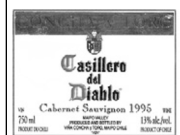
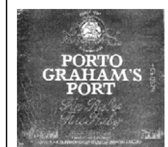
	#1	#2	#3	#4	#5	#6
						
	Palomino Amontillado Sherry pale brown color intensely flavored complex oxidized fragrance hint of walnuts caramel/butterscotch aspect mid sweetness very long finish	**Chardonnay** mid straw color mild fruity fragrance hints of apple and peach mild vanilla for oak aging ample acidity, dry short finish	**Muller-Thurgau,** etc. light straw color fresh floral fragrance apple-core perfumed mild sweetness balanced with acidity light body short finish	**Cabernet Sauvignon** dark brick-red color fragrance with aspects of black currant and bell pepper complex berry flavors full bodied long finish	**Xarel-lo, Macabeo, & Parellada** mid straw color fine chains of small bubbles delicate non-fruity fragrance light toasty flavor mildly acidic & dry clean but short finish	**Touriga National** etc. rich deep ruby color intense berry fruitiness traditional hints of fusel oil marked sweetness balanced with tannins full bodied long finish
Appearance (1)						
Fragrance (5)						
Taste (3)						
Overall (1)						
Total (10)						

Figure 6.2 (opposite) Tasting sheet as used for the first session in a wine appreciation course. Photocopies of the labels serve as reminders of wines tasted. Description of the essential attributes of the wines act as guides. In subsequent tasting, the verbal descriptions are placed at random to force the students to match the descriptions to the wines. Fig. 1.5 is a related form without added wine descriptions but with ample space for student comments on the wines' sensory attributes (from Jackson, 2000, reproduced by permission).

From the author's experience, a few exercises of this type usually suffice. Once students recognize the subtleties in taste sensation, there seems little value in repeating this observation with other compounds. In addition, taste sensations are less important to quality perception than are the perceptions of fragrance and flavor.

Exercises designed to demonstrate the different perceptions of major flavorants in wine, such as esters, lactones, or pyrazines could be prepared, but they are more expensive to prepare. They also are no more illustrative than tastants. However, for those desiring to prepare such exercises, the Aldrich Chemical Co. has prepared kits containing small samples of a variety of aromatic compounds, some of which occur in wine. They also produce a catalogue specifically dealing with flavors and fragrances.

Tasting situations

Wine competitions

Wine competitions are primarily public relations events, designed to attract attention to wine. Government-run competitions tend to be more regional in scope, acting as a vehicle to promote local wines. They also tend to be conducted professionally, with due concern for selecting qualified judges and the use of proper tasting procedures. The process for qualifying judges at the California State Fair is a model others could follow. The tests are administered several weeks in advance of the competition. Privately run competitions may or may not be conducted in accordance with accepted procedures. Medals may also be awarded simply on the basis of achieving a preset minimum mark.

One of the problems associated with qualifying tests, especially for those without formal training in sensory evaluation, is the specter of failure. This could deal a serious blow to a critic's public persona, since peers in attendance would realize who had failed. A potential solution is to base the tests partially on suggestions supplied by the candidates. By requiring each candidate to submit a potential qualifying sensory test, they would feel actively involved in the selection process. This should reduce apprehension about the relevance of the tests.

Although not perfect, wine competitions are one of the best means by which an unknown winery or little-known region can achieve public attention. The recognition obtained can significantly affect a winery's reputation (and sales) and, by reflection, the region from which the wine comes. An example is the greatly enhanced prestige of Ontario wines following the slate of awards given its icewines at international competitions. Media reports of these awards have influence far beyond those garnered by evaluations conducted in research laboratories. In addition, wine competitions act as one of the few vehicles by which winemakers and producers can receive public acclaim for their efforts in providing consumers with fine quality wines.

Although wine competitions can provide exposure and marketing advantage, they do not necessarily accurately reflect true merit. Comparisons of winners from different competitions rarely correlate with one another. In addition, the best wines may not be entered. Consequently, competition results must also be taken "with a grain of salt." Because no clearly enunciated objective standards of wine quality exist, competition results are relative. This situation applies equally to all tastings.

Wines are typically grouped by category to avoid the significant halo effects that can occur when wines of markedly different character are tasted together. When categories contain many representatives, they are further subdivided into groups of no more than ten wines. These are rapidly sampled to eliminate wines of poor or mediocre quality. Once the number has been reduced to a manageable level, the remaining wines are retested at a more unhurried and critical pace.

For each set of wines, there should ideally be six to seven tasters. Presentation of the wines to each taster should be in a different order. This helps to minimize (by randomization) the influence of sequence errors. In other aspects, the conditions of tasting should conform to those described in Chapter 5.

How awards are presented varies considerably. However, it is recommended that a preset qualifying mark be set for each medal category. Thus, if no wines reach these levels, no awards are presented. For clarity, it is also suggested that a maximum of one gold, one silver, and one bronze medal be permitted in each category. Although the winners may be statistically inseparable, organizers, participants and the public are accustomed to winners.

Trade tastings

Trade tastings are normally organized to expose those with an interest in wine marketing or sales to a selection of wines. Such tastings are often hosted by national or regional delegations. Because of the effort and expense of the event, the trade component is usually held in the afternoon so that the evening is available for the paying public.

Because of the large number of wines and attendees, much more than normal preparation is required. Serving staff should be attentive, cordial, and fully cognizant with the wines. Responses to questions should be quick and accurate. Glasses should be of a type specifically designed for wine tasting. Single glasses are typically provided to each participant on entering the tasting room. Pitchers of water and buckets for rinsing glasses between samples should be available at the ends of every table, and frequently refilled and emptied respectively.

Most trade tastings are stand-up affairs, where attendees move from table to table inspecting and sampling wines of interest. To facilitate note taking, an accurate and complete wine list should be supplied, organized by table. Space should be available to record impressions. These data should be available in booklet form and on relatively hard paper. Ideally, wines should be arranged on a varietal or stylistic basis, but typically they are organized relative to the merchant/producer supplying the wine.

Occasionally, trade tastings are sit-down affairs. In this situation, the wines are presented in a particular sequence, with a separate glass for each wine. One or more speakers guide the participants through the wines, to draw attention to the feature or features they wish emphasized. Typically, only six to ten wines are presented.

In-store tastings

Most in-store tastings are the equivalent of food sampling in grocery stores. Although the volumes supplied are generally correct, the plastic cups normally used are more appropriate for juice than wine sampling. Regrettably, the personnel are typically employed to dispense, not inform. Whether such tastings have real value is dubious.

In contrast, a well administered in-store tasting can positively affect sales. In addition, it can increase consumer wine awareness and enhance store image. Tastings should be conducted by knowledgeable staff, willing and able to lucidly describe the wine's characteristics without being officious or dogmatic. The glasses should be adequate to illustrate the qualities of the wine and be impeccably clean. The timing and duration of the tasting should correspond to the period when the more serious clientele frequent the store. Ideally, tastings should be held at similar times, so that regular customers come to know when to expect tastings. Because of the intimate nature of the tasting, only one or two wines should be featured at any one time, usually newly arrived wines. If the wines are expensive, it is reasonable to charge a nominal fee to eliminate those interested only in a free sample. Finally, the tasting should be held in the most appealing portion of the store, to heighten the esthetic and educational aspect of the sampling.

Occasionally, stores hold wine appreciation courses during off-hours. Tastings of this nature are discussed below.

Wine appreciation courses

Although training is not a prerequisite for appreciation, it can alert people to subtleties of which they were formerly unaware. Recognizing a wine's style, varietal origin, or relative age can enhance intellectual appreciation. Nevertheless, these features are only accessory to actual sensory enjoyment—just as identifying a piece of music or its composer are incidental to music appreciation. Enjoyment requires only the basic rudiments of sensory acuity. Superior skills improve differentiation, but whether this increases appreciation is a moot point. Is the critical assessor the most appreciative? Exceptional acuity is like a two-edged sword: it enhances detection of both the wine's finest attributes and its marginal faults. It can result in losing satisfaction with the norm.

Except in those instances where the wines are donated, or students are willing to pay high course fees, wines must be selected for their optimal price/quality ratio. They also should clearly demonstrate the features desired. Repeatedly finding excellent representatives, within a limited budget, is one of the most daunting tasks for the instructor. In choosing the samples, the instructor should also attempt to avoid instilling personal biases into the course. It is far too easy to create undue trust, or distrust, in the value of appellation control laws, vintage charts, regional superiority, and other "sacred cows." It behooves the instructor to guide students to their own, hopefully rational, conclusions about the origins and nature of wine quality, as well as to discover their own preferences.

Wine appreciation courses run the gamut from one-session illustrations on how to taste wine, to elaborate multiple-week university courses. Most courses involve from six to ten sessions, dealing with topics such as sensory perception, wine evaluation, wine production, major grape varieties, wine regions, label interpretation, appellation control law, wine aging, wine storage, wine and health, and wine and food combination. Combined with the instruction are tastings that, to varying degrees, complement the lecture material. Because many people take these courses for enjoyment as much as for education, the instructor must conscientiously avoid verbosity and unnecessary detail.

Typically the first tasting involves a sampling of the major wine styles (sherry, white, red, sparkling, port). Subsequent tastings explore each of these wine types, regional and/or stylistic versions of several major cultivars, and quality differences. They may also include training exercises to illustrate the basic taste sensations, and how they interact with one another. Presenting legitimate examples of wine faults can be particularly useful. Too often, consumers are ill-informed as to the difference between wine faults and personal dislikes. Here is an opportunity to do consumers, and the wine industry, a great service. Table 6.1 lists examples of tastings designed for wine appreciation courses. Additional or alternative tastings may be based on suggestions mentioned in Table 6.2.

Table 6.1 Examples of various tasting for a wine appreciation course

Tasting	Example
Introduction	Amontillado Sherry, *Riesling* Kabinett, *Chardonnay*, *Cabernet*, Sparkling, Porto
Taste detection	Sweet, Acid, Bitter, Astringent, Astringent–Bitter, Heat, Spritz
Odor detection	Off-doors (e.g., oxidized, sulfur, volatile acidity, fusel, baked, corked, buttery) Fragrance (e.g., fruits, flowers, vegetal, spices, smoky, nuts, woody)
Quality detection	Pairs of average and superior quality sweeter (e.g., *Riesling*) and drier (e.g., *Chardonnay*) white wines and a red wine (e.g., *Cabernet Sauvignon*)
White varietals	*Pinot Grigio*, *Riesling*, *Sauvignon Blanc*, *Chardonnay*, *Gewürztraminer*, *Viura*
Red varietals	*Zinfandel*, *Sangiovese*, *Tempranillo*, *Pinot Noir*, *Merlot*, *Shiraz*
Varietal variation I	Three examples of different expressions of two white varietals
Varietal variation II	Three examples of different expressions of two red varietals
Sparkling wines	Regional expressions (e.g., Champagne, Cava, Sekt, Spumante, Californian, Australian) or production technique (method champenoise, transfer, charmat)
Fortified wines	Fino, amontillado and oloroso sherries plus ruby, tawny and vintage ports
Winemaking technique I	Several examples each of the use of procedures such as carbonic maceration (Beaujolais), the recioto process (Amarone), or the governo process (some Chianti)
Winemaking technique II	Several examples each of the effect of procedures such as oak exposure, sur lies maturation, prolonged in-bottle aging.

Data, such as given in Tables 7.2 and 7.3, can help students begin to recognize various varietal aromas. Students should not view the descriptors noted as representing the *actual* aroma of the varieties mentioned, nor should they come to believe that description of wine fragrance is an end in itself. The terms only allude to aspects of the fragrance that may remind one of specific aromatic objects or situations. Students should be encouraged to develop odor memories for the major grape cultivars and wine styles. Nevertheless, it should be stressed that attaining such skill is not necessarily a prerequisite for enjoying or assessing wine quality. Even the most seasoned wine judges have difficulty identifying the varietal, let alone regional origin of most wines. In Europe, most regional (appellation) styles are just local expressions of the particular cultivar(s) or techniques used in their production.

If a wine closely resembles its descriptors, the wine probably lacks subtlety and complexity. For example, most *Cabernet Sauvignon* wines show a bell pepper aspect. If this is marked, it is a negative attribute. It probably indicates that the fruit was insufficiently or poorly ripened. Fully ripened fruit of *Cabernet Sauvignon* should yield wines expressing a rich, blackcurrant fragrance. There should be no more than just a hint of bell pepper, usually in the after taste.

Societal tastings

Wine societies come in as many variants as there are examples. Too often, they seem more interested in social and gastronomic interests than assessing wine quality. This undoubtedly reflects the reality that a majority of wine lovers are uninterested in objective wine assessment. Nevertheless, that these societies benefit wine sales is without question. They also spread consumer interest in wine.

Other associations are more oriented toward improving wine knowledge and experience. These are strictly tasting societies, with only minimal use of cheese or bread as palate cleansers. These are clearly the preference of the author. Tastings are always conducted blind, with only the names of the wines noted in advance. To add an element of challenge, participants are encouraged to match the numbered samples with the wines. Once everyone has had sufficient time to sample the wines (about 30 min), the wines are ranked in accordance to preference. Participants usually are interested in how their ranking correlates with that of the group. Finally, the identity and price of the wines are announced. Price is often the most eagerly awaited piece of information. Frequently, people's first and second choices are not the most expensive. This awareness encourages members to broaden their wine purchases, especially within the price range they can afford. It also has the salutary message that quality is expressed in the wine, not in its public prestige, elevated price, or rarity.

To increase the educational value of the tastings, each is related to a particular theme. There is an endless supply of themes, but most fall into one of several standard categories. A frequent subject focuses on differentiating between the varietal characteristics of several cultivars. Such tastings act not only as a refresher for seasoned tasters, but also function as valuable training for new members. Other frequent topics are to compare samples of a particular cultivar or style; probe the significance of quality; or explore the expression of a producer, region, or country.

Other tastings may examine the effects of winemaking technique or vintage differences. Table 6.2 provides several examples.

Home tastings

Tastings at home typically fall into one of a few categories: games of identification, comparing wines before a meal, or comparative tastings in combination with a meal. Identification games are popular, but they have more to do with guessing than wine assessment. Sampling two or more wines with a meal may

Table 6.2 Examples of various types of wine society tastings

Type	Subtype	Example
Intervarietal comparison	White *vinifera* cultivars	Six samples showing the distinctive varietal aroma of the representative cultivars (e.g., *Chardonnay*, *Riesling*, *Sauvignon Blanc*, *Parellada*, *Gewürztraminer*, *Rhoditis*)
	Geographic expression	German *Riesling*, *Silvaner*, *Müller-Thurgau*, *Ehrenfelser Gewürztraminer*, *Ortega*
	Red *vinifera* cultivars	Six samples showing the distinctive varietal aroma of the representative cultivars (e.g., *Cabernet Sauvignon*, *Tempranillo*, *Sangiovese*, *Nebbiolo*, *Pinot Noir*, *Malvasia Nero*)
	Red non-*vinifera* cultivars	*Chambourcin*, *Marechal Foch*, *Baco noir*, *de Chaunac*, *Concord*, *Norton*
Intravarietal comparison	International	Six similarly priced representatives (e.g., Australian, Californian, French, Italian, Canadian, Bulgarian)
	Regional	Six similarly priced representatives (e.g., Napa, Sonoma, Mendocino, Santa Barbara, Santa Clara, Central Valley)
	Producers	Six regional wines from the same variety but different producers (e.g., Rioja, Chianti, or Bordeaux)
	Vintages	Six different vintage wines from the same producer (e.g., Don Miguel *Cabernet Sauvignon*, or Wolf Blass *Chardonnay*)
	Quality	Representatives of the quality scale of German wines (e.g., QbA, Kabinett, Spätlese, Auslese, Beerenauslese, Trockenbeerenauslese) or different grades of wines from the same procedures (e.g., Robert Mondavi *Cabernet* wines: Reserve, Oakville and Stages Leap District, Coastal, Woodbridge and Opus One)
Winemaking style	White	Several different representatives of one or several of the following different styles—Oaked and unoaked *Chardonnay*; trocken, halbtrocken and traditional auslese *Riesling*; modern and traditional white Rioja wines; effects of the use of different yeast or malolactic bacterial strains[a]
	Red	Several different representatives of one or several of the following different styles—Recioto (Amarone vs Valpolicella); Governo (older vs modern Chianti); Carbonic Maceration (Beaujolias vs non–beaujolais *Gamay Noir*); Fermenter (Rotary vs Stationary tank)

[a]Examples such as these are obtainable only from winemakers or researchers who are conducting experiments with these. Although difficult for most groups to obtain, the often marked effect of the use of different microbial strains makes the effort in obtaining the samples well worth the while.

be pleasurable, but it has little to do with wine evaluation. Food flavors may enhance appreciation, but they conflict with objective assessment. Social interaction and alcohol consumption make impartial assessment next to impossible. Consequently, the only home tastings that even approach critical assessment are those where the wines are sampled before the meal. Ideally, these should be blind tastings. Without this precaution, the probability that prior knowledge will prejudice opinion is considerable. Because serious tasting tends to distract from the primary purpose of the tasting (pleasure), home tastings are best considered as enjoyable social occasions, with an educational twist.

Appendices

Appendix 6.1 Sweetness in Wine

All wines possess some sugar. In dry wines, these consist of grape sugars that were not, or could not be, fermented by the yeasts during fermentation. Because they occur at concentrations below their detection thresholds, they do not induce sweetness. Wine acidity and bitterness also suppress the perception of sweetness. Conversely, some aromatic compounds may generate the sensation of sweetness, even in the absence of detectable concentrations of sweet-tasting compounds.

The compounds most frequently inducing actual sweetness in wine are glucose, fructose, ethyl alcohol and glycerol. Glucose and fructose come from grapes, ethanol is produced during fermentation, and glycerol may be derived from grapes or be synthesized during fermentation. Other potentially sweet compounds are the grape sugars arabinose and xylose, and by-products of fermentation such as butylene glycol, inositol, and sorbitol. Mannitol and mannose occur in wine in detectable concentrations only as a result of bacterial spoilage. Table 6.3 illustrates the normal concentration range of the major sweet-tasting compounds found in wines.

Table 6.3 Typical concentration range of sweet-tasting substances commonly found in wine

Group	Compound	Wine type	Concentration (g/l)
Sugars	Glucose	Dry	up to 0.8
		Sweet	up to > 30
	Fructose	Dry	up to 1
		Sweet	up to > 60
	Xylose		up to 0.5
	Arabinose		0.3 to 1
Alcohols	Ethanol		70 to 150
	Glycerol		3 to 15[a]
	Butylene glycol		up to 0.3
	Inositol		0.2 to 0.7
	Sorbitol		0.1

[a]in botrytized grapes.

To demonstrate the relative sweetness of the major sweet-tasting compounds found in wine, prepare aqueous solutions of glucose (20 g/l), fructose (20 g/l), ethanol (32 g/l), and glycerol (20 g/l). Participants arrange the samples (presented at random) in order of ascending relative sweetness. The form given below can be used to record relative sweetness (Table 6.4).

Table 6.4 Assessment sheet for sweetness

Sample	(Driest)			(Sweetest)	Additional taste or odor sensations
	1	2	3	4	
A					
B					
C					
D					

Appendix 6.2 Sourness

Acids are characteristic of all wines, being important to their taste, stability, and aging potential. Sourness is a complex function of the acid, its dissociation constant, and wine pH. Acids that occur as salts do not effect sourness.

Of the many acids in wine, the most significant are organic acids. The principal examples are natural grape constituents (tartaric, malic and citric acids), or yeast and bacterial by-products (acetic, lactic and succinic acids). Only acetic acid is sufficiently volatile to affect wine fragrance, usually negatively. The taste perceptions of grape acids are similar, possessing only subtle differences—tartaric acid being viewed as "hard," malic acid considered "green," and citric acid deemed to possess a "fresh" taste. Those acids of microbial origin generate more complex responses. Lactic acid is reckoned to possess a light, fresh, sour taste; acetic acid shows a sharp sour taste and a distinctive odor; whereas succinic acid (seldom present at above threshold levels) exhibits salty, bitter side tastes. Gluconic acid typically occurs only in wines made from moldy grapes. By itself, it affects neither taste nor odor. These compounds frequently occur in table wines within the ranges indicated in Table 6.5.

A. To demonstrate their differences, prepare the following aqueous solutions: tartaric acid (1 g/l), malic acid (1 g/l), citric acid (1 g/l), lactic acid (1 g/l), acetic acid (1 g/l), succinic acid (1 g/l). Present them in random order for arranging in order of increasing sourness. Their relative sourness and any distinctive attributes should be recorded on a form similar to that provided below Table 6.6.

B. To roughly assess ability to detect differences in acidity, prepare aqueous solutions containing 0, 0.5, 1.0, 2.0, 4.0 g tartaric acid per liter. Alternatively, the acids may be dissolved in a 10% ethanol, 0.5% glucose solution to provide a more wine-like medium. Participants arrange the samples in ascending order of acidity. For accuracy, the test should be conducted on several occasions and the results averaged.

Table 6.5 Typical ranges of several acids found in wine

Acid	Concentration (g/l)
Tartaric	2 to 5
Malic	0 to 5
Citric	0 to 0.5
Gluconic	0 to 2
Acetic	0.5 to 1
Lactic	1 to 3
Succinic	0.5 to 1.5

Table 6.6 Assessment sheet for wine acidity

Sample	(Least sour)					(Most sour)	Additional taste or odor sensations
	1	2	3	4	5	6	
A							
B							
C							
D							
E							
F							

Appendix 6.3 Phenolic compounds

Bitterness and astringency

Phenols and their phenyl derivatives are the principal source of bitter–astringent sensations in wine. As discussed in Chapter 4, these fall into two major categories—flavonoid and nonflavonoids. Polymers of these compounds generate a complex group of compounds called tannins. The flavonoid tannins are generally more stable (do not breakdown to their monomers in wine) and they generally increase in size during aging. If present in sufficient amounts, they can contribute to the formation of sediment in red wine. Nonflavonoid-based tannins are less stable in wine and they may breakdown to their individual monomers. As such, they can contribute to the continuing bitterness of some red wines. Tannins comprising both flavonoid and nonflavonoid constituents are generally stable and these do not breakdown to their component monomers.

Because of their diverse origins, composition, changing concentration, and chemical makeup, it is not surprising that tannins (and their subunits) differ in sensory quality. Some generalities tend to apply, though, such as complex tannins tend to be the most astringent; tannin monomers tend to be primarily bitter, showing little astringency; and moderately sized polymers tend to be both bitter and astringent. Anthocyanins are generally neither bitter nor astringent.

The perception of tannins depends both on their absolute and relative concentrations. For example, some tannins appear to be more astringent at higher concentrations, but more bitter at lower concentrations. Aging affects their sensory characteristics by modifying their chemical composition and concentration. The smaller monomeric phenolics are less affected by aging.

To obtain practical experience with some of their sensations, prepare aqueous or 10% ethanolic solutions of grape tannins (a flavonoid tannin complex) and tannic acid (a hydrolyzable tannin complex) at 0.01, 0.1, and 0.5 g/l. These samples demonstrate not only their taste and touch sensations, but also illustrate their olfactory attributes. To represent monomeric flavonoid and nonflavonoid phenolics prepare aqueous or 10% ethanolic solutions of quercetin (30 and 100 mg/l) and gallic acid (100 and 500 mg/l), respectively.

Oak

Another informative exercise involves preparing oaked wine samples. Add 10 g/l oak chips[4] to either unoaked[5] white or red wine. After one week, decant the wine, add 30 mg/l potassium metabisulfite (as an antioxidant), and store in sealed glass bottles for at least three months. During storage, acetaldehyde produced following inadvertent exposure to air reacts with sulfur dioxide or combines with other wine constituents to neutralize its mild oxidized (acetaldehyde) character.

This exercise can be expanded to include observing the various effects of different oak species (American vs European), or the effects of the degree of toasting (produced during barrel construction). In general, American oak donates more of a coconut character than do European oaks. Toasting progressively reduces the natural woody fragrance supplied by the oak, successively generating vanilla-like flavors, and then smoky, spicy odors. Toasting also reduces the extraction of tannins from the wood during maturation. Small samples often can be obtained from commercial barrel suppliers.

Appendix 6.4 Alcoholic wine constituents

Ethanol

Many alcohols occur in wine, but only a few are present at sufficient concentrations to affect its characteristics.[6] This is even more so when taste alone is considered. Of these, ethyl alcohol is the most important. As noted previously, ethanol generates a complex of sensory perceptions. It possesses a distinctive odor, activates the perception of sweetness, and stimulates the sensations of heat and weight in the mouth. It can also mask or modify other wine perceptions.

To illustrate these complex effects, and how concentration influences their perception, prepare solutions of 4, 8, 10, 12, 14, and 18% ethanol. These also can be used to detect individual sensitivity to ethanol by asking participants to arrange the samples in ascending order of concentration (Table 6.7).

[4] Soak the chips in ethanol for a few minutes before adding to the wine to expel air from the wood.

[5] Most inexpensive wines are unoaked.

[6] The negative influence of fusel alcohols is illustrated in the exercise associated with off-odors (Appendix 5.3).

Table 6.7 Assessment sheet for ethanol sensations (rank in ascending order the alcohol content of the samples)

Sample	(Least alcoholic) 1	2	3	4	5	(Most alcoholic) 6	Additional taste or odor sensations
A							
B							
C							
D							
E							
F							

Glycerol

Glycerol (a polyol containing three alcohol groups) is the next most common alcohol in wine. Because of its low volatility, glycerol has no detectable odor. Glycerol possesses a sweet taste, but it is so mild that it is likely to affect sweetness only in dry wines, if the concentration surpasses 5 g/l. Because glycerol is viscous, it has commonly been thought to noticeably affect wine viscosity. However, glycerol rarely reaches a concentration that perceptibly affects viscosity (≥26 g/l) (Noble and Bursick, 1984). At lower concentration, it may reduce the perception of astringency (Smith *et al*., 1996) and contribute to the perception of body.

To assess the effect of glycerol on the sensory characteristics of wine, prepare solutions containing 0, 2, 4, 8, 12, and 24 g of glycerol per liter in a simulated wine solution (3 g glucose, 4 g tartaric acid and 100 g ethanol). Participants arrange the samples in ascending order of glycerol content, and remark on those features that permit them to make this arrangement (Table 6.8).

Glycerol was once believed to be involved in the production of "tears." Swirling the ethanol and glycerol samples in this exercise quickly demonstrates that it is ethanol, not glycerol that generates tears.

Table 6.8 Assessment sheet for glycerol sensations

Sample	None 1	2	3	4	Maximal 5	Taste or odor effect
A						
B						
C						
D						
E						
F						

Appendix 6.5 Taste interaction

The most frequent taste interactions result in mutual suppression. The reduction in perceived bitterness by the presence of sugar (and vice versa) is well-known. Less well-known is the influence of personal taste acuity on one's subjective response (appreciation vs disappreciation) to particular sensations. This can easily affect a taster's rating of wines.

The following exercises allow participants to recognize their particular reactions to several taste interactions. In addition, it helps potential tasters understand their personal sensory biases. This knowledge may encourage tasters to excuse themselves from certain tastings. Sensory idiosyncracies can make it difficult for tasters to be impartial judges of certain wines.

Sweet–bitter interactions

Provide participants with a series of aqueous bitter/astringent solutions containing 1 g/l grape tannins. The samples also contain 0, 20, 40, 80 g/l sucrose. Tasting the samples in random order,[7] have the participants rank the samples both on the speed of bitterness detection and maximum perceived intensity (0 to 10) on a form as provided below (Table 6.9). A crude time–intensity graph may be prepared for each sample to better illustrate the dynamics of sugar's influence on perceived bitterness (see Fig. 4.13). The time–response curve of the loss of bitterness can also be determined after expectoration. Quinine (0.1 g/l) can be substituted for grape tannins if only a bitter sensation is desired (grape tannins induce both bitter and astringent sensations). Combining the data generated from all participants can be used to illustrate the degree of variation that exists within the group.

This exercise can be reversed to observe the effect of tannic bitterness on the perception of sweetness. For this, the amount of sugar is held constant while adjusting tannin content. An example of such a test could use 40 g sucrose combined with either 0, 0.5, 1, 2, or 4 g grape tannins.

Because ethanol has a sweet attribute, an alternative exercise could involve substitution of alcohol for sugar. For example, dissolve 4 g grape tannins in a series of solutions containing 0, 4, 8, 10, 12, and 14% ethanol. These will clearly demonstrate

Table 6.9 Assessment sheet for sweet–bitter interactions

Sample	Bitterness[a]	When first detected (seconds after tasting)										
		0	1	2	3	4	5	6	7	8	9	10
A												
B												
C												
D												

[a]scale from 0 to 10.

[7] At least 2 min should separate each tasting to allow the mouth to establish its baseline sensitivity.

Table 6.10 Assessment sheet for sweet–sour balance

Sample	Intensity* of sweetness	Duration of sweet sensation(s)					Intensity* of sourness	Duration of sour sensation(s)				
		2	4	6	8	10		2	4	6	8	10
A												
B												
C												
D												
E												
F												

*scale of 0 to 10.

the effect of alcohol content on both the bitter and astringent characteristics of tannins.

Sweet–sour balance

Balance between the various sapid compounds is an important quality attribute in wines. This interaction can be demonstrated in the same manner as sweet–bitter interactions noted above. However, it may be more interesting if the procedure is changed.

In this exercise, provide participants with at least six aqueous solutions. One pair contains sucrose (20 and 40 g/l), a second pair contains tartaric acid (0.7 and 1.4 g/l), and the third pair combines different sugar and acid combinations, but at the same ratio (20 g/l sucrose + 0.7 g/l tartaric acid, and 40 g/l sucrose + 1.4 g/l tartaric acid).

Participants taste the samples at random, noting the relative intensity (0 to 10) of the sweet and/or sour sensations on a form provided (Table 6.10). The duration(s) of each sensation may also be recorded for comparison. When the exercise is complete, suggest combining the lower sugar concentration with the higher acid solution and vice versa. This will give a further indication of the complexities of sweet–sour balance.

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7 Types of wine

Only in the broadest sense is there an accepted classification of wines. For tax purposes, wines often are divided into three categories: **still** (absence of effervescence), **sparkling** (marked effervescence), and **fortified** (supplemented with alcohol). The last two are typically taxed at a higher rate. Subsequently, wine may be grouped by color and geographic origin. This classification has the sanction of familiarity and acknowledges significant differences in production method and consumer use.

In many European countries, geographic classification signifies a particular traditional style. Production is usually associated with specific grape cultivars, grape growing procedures, and winemaking techniques. Thus, geographic designation can be an indicator of flavor characteristics. In the New World, geographic designation is less associated with a particular style or flavor. Most regions (and even wineries) may produce a wide diversity of wines from a variable number of grape varieties. Nevertheless, within particular categories (e.g., *Chardonnay*), there may be discernable regional trends. In general, though, varietal origin is a better indicator of flavor characteristics than regional origin. The old tendency of naming New World wines after European regions is finally falling into disuse. This pleases not only producers in the named regions, but it also removes a potential source of confusion. In addition, it stops promoting the recognition of appellations other than those from which the vine comes. For example, the generic use of champagne for sparkling wines only encourages consumers to think that champagne is the standard against which all sparkling wines should be compared.

Because of the increasing importance of wine from regions other than Europe, geographically based wine classifications are becoming less useful as indicators of sensory characteristics. Even in Europe, except for a few classified regions, regional wines may not have a distinctive or consistent character. Therefore, the arrangement presented here is based primarily on stylistic differences.

As mentioned, wines are often grouped relative to alcohol content. This commonly is indicated by the terms **table**—alcohol contents ranging between 9 and 14% (by volume), and **fortified**—alcohol contents ranging between 17 and 22%. Table wines are subdivided into still and sparkling categories, depending on the wine's relative carbon dioxide content.

Still table wines

As most wines fall into the category of still table wines, it requires the most complex classification (Table 7.1). The oldest division, based on color, separates wines into white, red, and rosé categories. Not only does this have the benefit of long acceptance, it reflects distinct differences in flavor, use, and production method.

Wines possessing a distinctive varietal aroma generally increase in flavor complexity during the first few years of in-bottle aging. Correspondingly, they are more highly regarded and command a higher price, even when young. Depending on their geographical origin, the label may or may not indicate varietal origin. Many long-established regions in Europe do not mention cultivar origin. While now seeming an oversight, local consumers were unconcerned about varietal origin, since regional wines were often the only ones available. Because most were made from one or a few cultivars (usually blended together), the wines possessed a fairly consistent character. In contrast, regions producing several distinct varietal wines developed a tradition of recording varietal names on the label. It is the latter feature that tends to

Table 7.1 Categorization of still wines based on stylistic differences

A White*

Better when consumed young (seldom matured in oak cooperage)		**Potential for aging well** (often matured in oak cooperage)	
Varietal aroma atypical	*Varietal aroma typical*	*Varietal aroma atypical*	*Varietal aroma typical*
Trebbiano	*Müller-Thurgau*	Sauternes	*Riesling*
Muscadet	*Kerner*	Vernaccia di San Gimignano	*Chardonnay*
Folle blanche	*Pinot grigio*	Vin Santo	*Sauvignon blanc*
Chasselas	*Chenin blanc*		*Parellada*
Aligoté	*Seyval blanc*		*Sémillon*

B Red*

Better when consumed young		**Potential for aging well**	
Varietal aroma atypical	*Varietal aroma typical*	*Maturation in-tank traditional*	*Maturation in-barrel*
Gamay	*Dolcetto*	*Tempranillo*	*Cabernet Sauvignon*
Grenache	*Grignolino*	*Sangiovese*	*Pinot noir*
Carignan	*Baco noir*	*Nebbiolo*	*Syrah*
Barbera	*Lambrusco*	Garrafeira	*Zinfandel*

C Rosé*

Dry	**Sweet**
Tavel	Mateus
Cabernet rosé	Pink Chablis
White *Zinfandel*	Rosato
some Blush wines	some Blush wines

*Representative examples in italics refer to the names of grape cultivars used in the wine's production.

characterize most New World wines, and the majority of wines produced in German-speaking countries. A recent trend for some of the more expensive premium wines is to no longer specify their varietal origin. Instead, they are named as proprietary blends, christened with artful and (hopefully) inviting names (e.g., Opus One, Tignanello, Dominus).

Although many wines are varietally designated, this does not guarantee that the wine will clearly express its varietal aroma. This applies equally to appellation control wines. Expression of features considered standard for a wine depends on many factors. Primary among these are the degree of health and ripeness of the fruit and the skill of the winemaker in balancing aromatic expression with subtlety of flavor.

The geographic origin (appellation) of a wine is often advertised as a guarantee of style and quality. In reality, it is often neither. As the name (appellation) clearly signifies, it is a certification of geographic origin. It may or may not incorporate restrictions on varietal use, grape cultivation, and wine production techniques. Even as a geographic indicator, appellation designation acts as a major hurdle for most consumers. Geographic names bear no logical relationship one to another. For example, Pommard and Pauillac do not obviously suggest that the first is from Burgundy and the second from Bordeaux. Correspondingly, wine shops organize wines by major geographical regions, otherwise few customers would know from where the wines come. Even with this help, most people choose wine either by chance, price, or "expert" opinion. Although regrettable, this situation is unlikely to change. Learning appellation names is often considered one of the initiation rites to wine connoisseurship.

White wines

White wines come in a wide diversity of styles. The major production options leading to these styles are outlined in Figure 7.1.

Particularly popular are dry wines possessing a clean refreshing mouth-feel and fruity bouquet, balanced with lively acidity. This is often characterized as the international style. Cool fermentation favors its development by enhancing both the production and retention of "fruit" esters (ethyl esters of low-molecular-weight fatty acids). These fermentation by-products occur in excess of their equilibrium constants in young wine. As they hydrolyze back to their alcohol and acid constituents fairly rapidly, the wine loses its fruitiness. Storage under cool conditions slows this hydrolysis, helping to retain the fragrance donated by these esters. Because fruit esters are produced by yeasts, grape variety has little effect on their production. Consequently, choice of yeast strain is particularly important when producing white wine from cultivars lacking a marked or distinctive varietal aroma.

Only a comparatively few white grape varieties are noted for their aging potential, for example *Riesling*, *Chardonnay*, and *Sauvignon blanc*. As the aroma fades, it is replaced by a pleasing aged bouquet. The chemical nature of this change is unknown.

Most white wines are dry, as befits their primary use as a food beverage. The fresh, crisp acidity achieves balance in combination with food, enhancing food flavor and

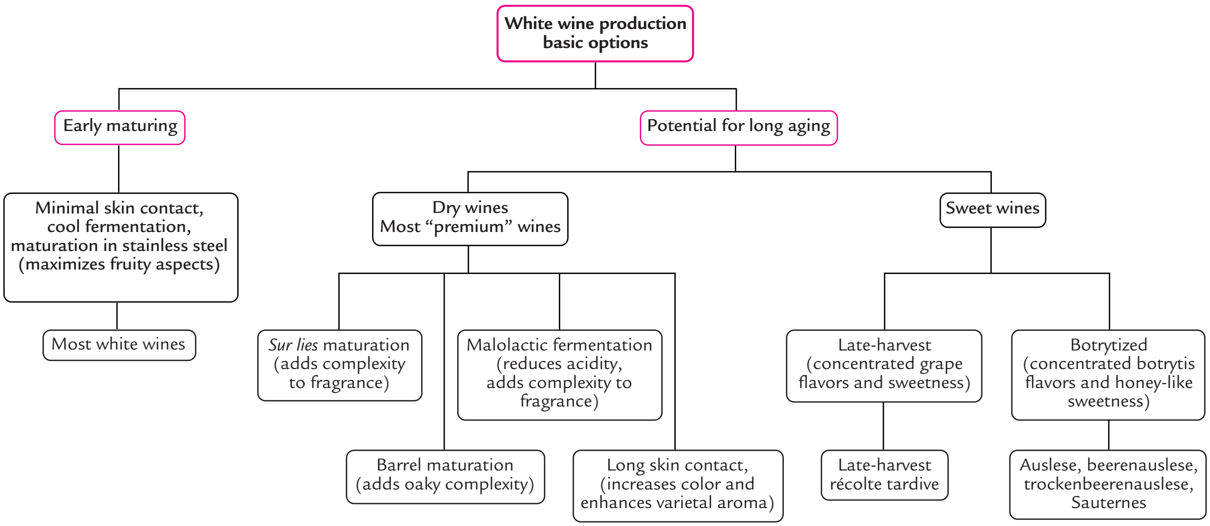

Figure 7.1 Classification of white wines based on basic production options.

reducing the fishy character of some sea-foods. The lower flavor intensity of most white wines also suits their combination with relatively mild-flavored foods. Premium quality white sweet wines also have a bracing acidity. It provides the balance they otherwise would lack. The lighter of semi-sweet wines are often taken cold, by themselves as a "sipping" wine. In contrast, sweeter versions typically replace dessert. Consequently, the term dessert wine refers more to their substitution for, rather than compatibility with, dessert.

Although the presence of a varietal aroma is important to most premium white wines, a few are characterized by the loss of their varietal aroma. A classic example involves "noble" rotted grapes. Under a unique set of autumn conditions, infection by *Botrytis cinerea* leads to juice concentration and degradation of most varietal impact compounds. This loss is replaced with a distinctive botrytized fragrance. Wine derived from these grapes has a rich, luscious, apricoty, honey-like aroma. Examples of botrytized wines are the "beerenausleses" and "trochenbeerenausleses" of Germany and Austria, the Tokaji aszus of Hungary, and the Sauternes of France. In the New World, they may be variously called botrytized or selected-later-harvest wines. Additional styles that age well, without the benefit of a marked varietal character are icewines ("eisweins") and "vino santo" (partially oxidized, sweet wine). Figure 7.2 outlines the various procedures leading to the major styles of sweet white wines.

Recognizing the varietal characteristic of a wine is often difficult. Factors such as vintage, fermentation, and maturation conditions can minimize or modify the wine's varietal character. Nevertheless, to aid varietal character recognition, Table 7.2 provides a list of descriptors often thought to distinguish several white grape cultivars.

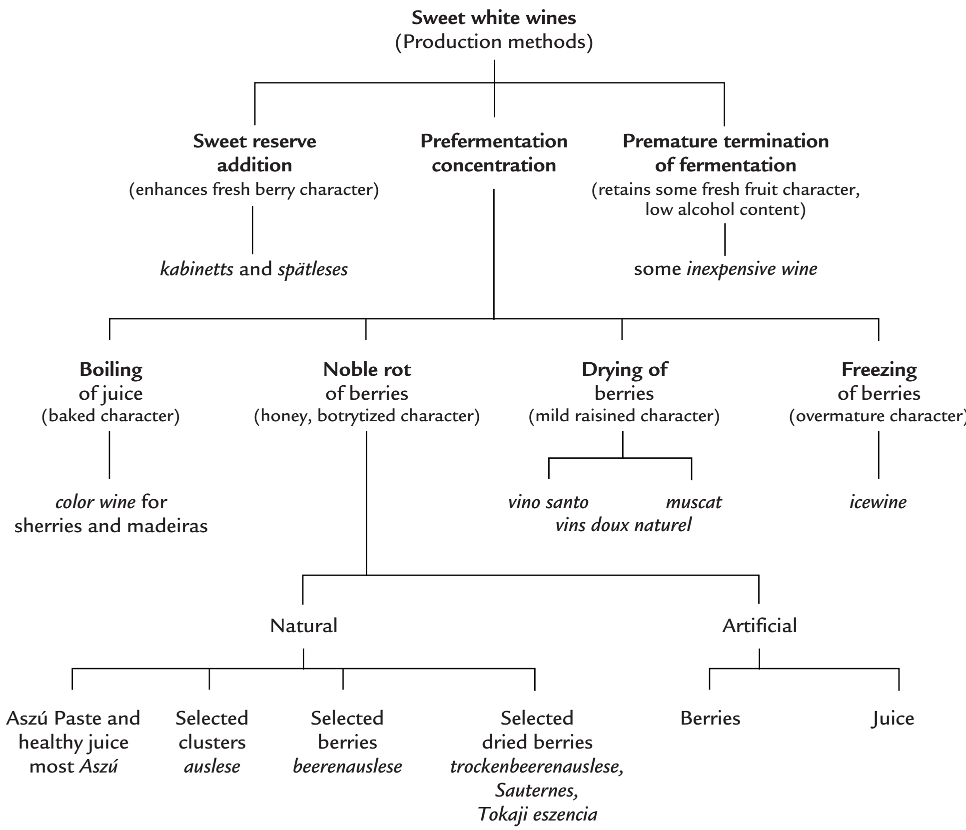

Figure 7.2 Classification of sweet white wines based on production method.

Table 7.2 Aroma descriptive terms for several varietal white wines

Grape variety	Country of origin	Aroma descriptors
Chardonnay	France	apple, melon, peach, almond
Chenin blanc	France	camellia, guava, waxy
Garganega	Spain	fruity, almond
Gewürztraminer	Italy	litchi, citronella, spicy
Muscat	Greece	muscaty
Parellada	Spain	citrus, green apple, licorice
Pinot Gris	France	fruity, romano cheese
Riesling	Germany	rose, pine, fruity
Rousanne	France	peach
Sauvignon blanc	France	bell pepper, floral, herbaceous
Sémillon	France	fig, melon
Torbato	Italy	green apple
Viognier	France	peach, apricot
Viura	Spain	vanilla, butterscotch, banana

Red wines

Modern red wines are almost exclusively dry. The absence of detectable sweetness is consistent with their use as a food beverage. The bitter and astringent compounds characteristic of most red wines bind with food proteins, producing a balance that otherwise would not develop for years. In contrast, well-aged red wines are more appreciated alone. Their diminished tannin content does not require food to develop smoothness. Also, the subtly complex bouquet of well-aged wines is more apparent in the absence of food flavors.

Most red wines that age well are matured in oak cooperage. Storage in small oak cooperage (~225 l barrels) usually speeds wine maturation and adds complementary oaky, vanilla, or spicy/smoky flavors. Following maturation, the wines generally receive additional aging in-bottle, either at the winery or by the consumer. Where less oak character is desired, used barrels or large (> 1000 l) oak cooperage may be employed. Alternatively, the wine may be matured in inert tanks to avoid oxidation or the uptake of accessory flavors.

Production procedures used in red winemaking often depend on the consumer group for whom the wine is designed. Wines expected to be consumed early tend to have light flavors, whereas those requiring extended aging (to develop their full flavor potential) are initially tannic and bitter. Beaujolais nouveau is a prime example of a wine destined for early consumption. Its production by carbonic maceration, and the inclusion of little press-wine, gives it a distinctive fresh, fruity flavor. The early drinkability of the wine (within a few weeks of fermentation) comes at the cost of short shelf-life. Nouveau wines seldom retain their typical attributes for more than twelve months. Loss of appeal often begins within six months. In contrast, premium *Cabernet Sauvignon* and *Nebbiolo* wines illustrate the other extreme. They may require one to several decades before they develop a smooth mouth-feel and refined bouquet. Some of the basic options in red wine production are illustrated in Figure 7.3.

The reasons for these differences in aging potential are poorly understood. Features that favor fruit maturation, such as adequate temperature and sun exposure, moisture and nutrient conditions, and fruit/leaf ratio, are clearly important. Vinification at moderate temperatures in the presence of the seeds and skins, followed by skillful maturation is also essential. Nevertheless, these techniques alone cannot explain why most red cultivars do not produce wines that age well, even following optimal processing. Part of the answer possibly relates to the types and ratios of anthocyanins and tannins. Red cultivars vary markedly in their anthocyanin and tannic composition. Retention of sufficient acidity and the judicious uptake of oxygen during maturation favor color retention. Distinctive aromatic constituents, such as the methoxypyrazines, eventually oxidize, isomerize, hydrolyze, or polymerize to less aromatic compounds. They may be the origin of the cigar box, leather, and mushroomy scents that characterize the aged bouquets of the best premium red wines.

Emphasis on aging potential generates questions on when wines should be consumed. This, however, reflects a misconception that wines are best at some

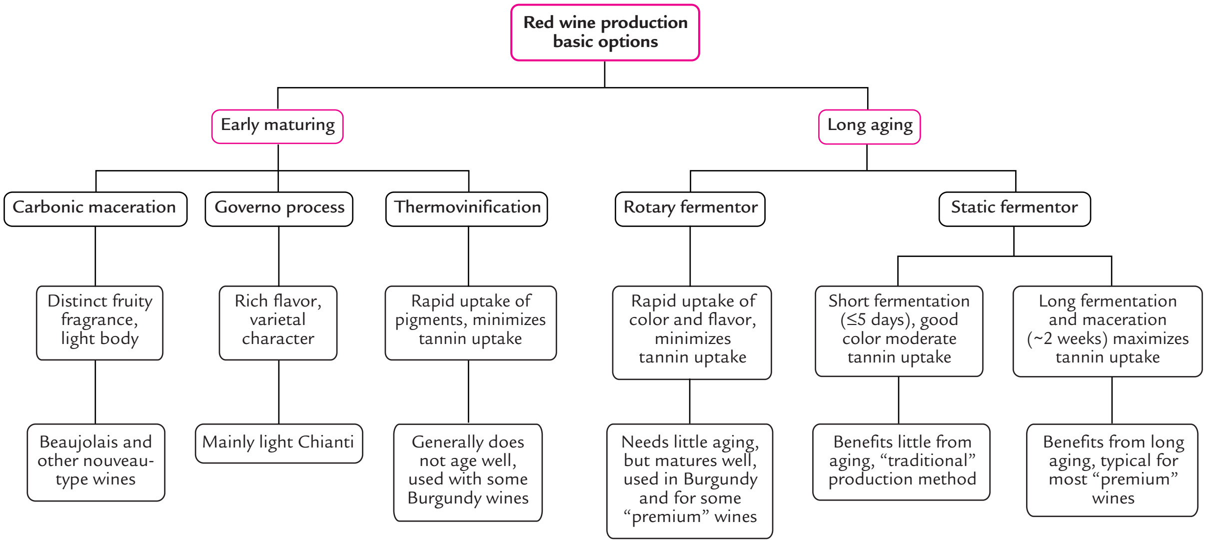

Figure 7.3 Classification of red wines based on basic production options.

particular time. In reality, wine progresses through a spectrum of aromatic changes, many of which are equally pleasurable. The aging question relates to how the wine is consumed (with a meal or by itself), and whether the consumer prefers the fresh fruity aroma of a young wine, the more complex, jamy attributes of mature wines, or the subtle bouquet of a fully-aged premium red wine. It is more appropriate to refer to a wine's plateau, rather than its peak (Fig. 7.4). One of the major features that distinguish superior wines is the duration of the plateau. Wines with little aging potential have comparatively short plateaux, whereas premium wines ideally have plateaux that span many decades.

Because most grape varieties are still cultivated locally, close to their probable geographic origin, limited information is available on their winemaking potential elsewhere. New World experience has been largely restricted to a few cultivars from France and Germany—reflecting the biases of those who started vineyards in colonial regions. Consequently, the qualities of the extensive number of cultivars that characterize Italy, Spain and Portugal, let alone those from Eastern Europe, are essentially unexplored. How many varietal gems await discovery only time will tell. This does not negate the qualities of the cultivars that provide the majority of the world's varietally designated wines. It does indicate, though, the limited aroma base available for producing most New World wines. Sadly, the self-perpetuating cycle of consumer, critic, and producer conservatism limits the more extensive investigation of other cultivars.

As noted relative to white wines, aroma expression is often indistinct. Clear demonstration of a wine's varietal fragrance depends on optimal grape growing, winemaking, and storage conditions. Under these conditions, the aroma characteristics of several red cultivars are approximately as noted in Table 7.3.

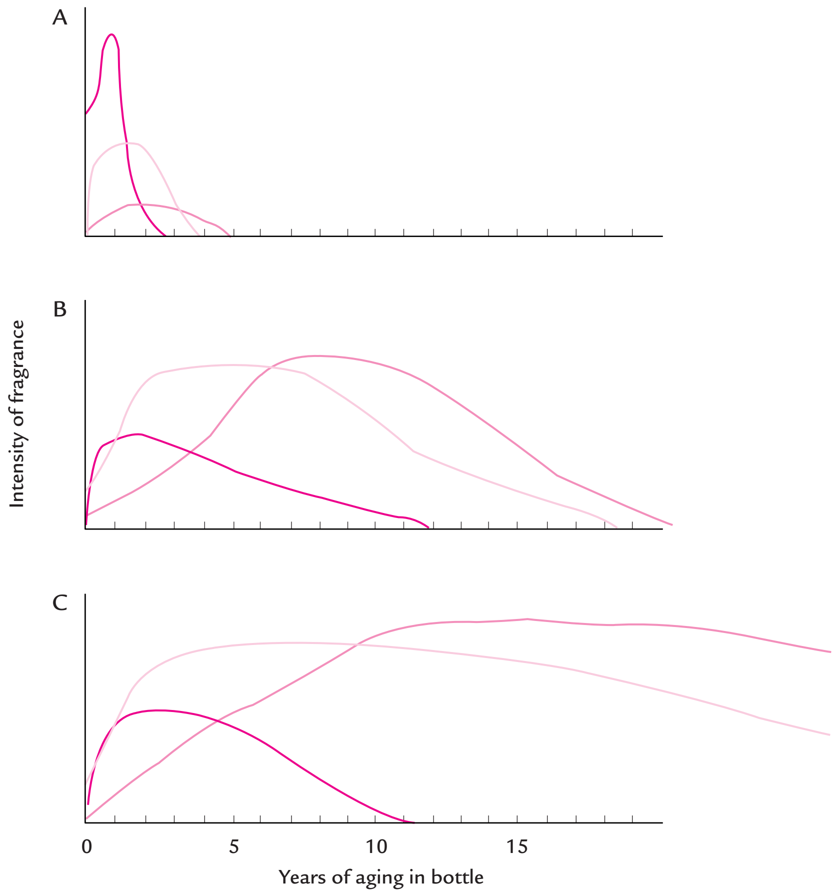

Figure 7.4 Diagrammatic representation of the changes in aromatic character associated with aging in (A) Nouveu-type wine (Beaujolais nouveau), (B) standard quality red wine (generic red Bordeaux), and (C) premium quality red wine (cru red Bordeaux) (——, fermentation bouquet; — — —, aroma; ········, aging bouquet).

Rosé Wines

Rosés have the stigma of lacking aging potential. Correspondingly, they have never been taken seriously by connoisseurs. Part of this probably relates to their possessing the bitterness but not the flavor of red wines, while not exhibiting the fresh crispness or fruitiness of white wines. To achieve the desired color, the duration of skin contact is sufficient to extract bitter phenolics. Correspondingly, most rosés are processed to be semi-sweet to mask their bitterness. Carbonation is often used to increase their appeal as a cool refreshing drink. Both features augment their negative connotation among wine fanciers. To counter the denigration associated with the name rosé, some ostensively rosé wines are now termed "blush" wines.

Most red grape varieties can be used in producing rosé wines. Nevertheless, *Grenache* is one of the favorite cultivars so used. In California, *Zinfandel* is also

Table 7.3 Aroma descriptive terms for several varietal red wines

Grape variety	Country of origin	Aroma descriptors
Aleatico	Italy	cherries, violets, spice
Barbera	Italy	berry jam
Cabernet Franc	France	bell pepper
Cabernet Sauvignon	France	blackcurrant, bell pepper
Corvina	Italy	berry (tulip/daffodil in Amarone)
Dolcetto	Italy	quince, almond
Gamay noir	France	kirsch, raspberry (after carbonic maceration)
Grignolino	Italy	clove
Merlot	France	blackcurrant
Nebbiolo	Italy	violet, rose, truffle, tar
Nerello Mascalea	Italy	violet
Pinot noir	France	cherry, raspberry, beet, mint
Sangiovese	Italy	cherry, violet, licorice
Syrah/Shiraz	France	currant, violet, berry jam, pepper
Tempranillo	Spain	citrus, incense, berry jam, truffle
Touriga Nacional	Portugal	cherry, mint
Zinfandel	Italy	raspberry, berry jam, pepper

popular for rosé (blush) production. Some *Pinot noir* wines are so pale as to be *de facto* rosés, notably the *Spatburgunder* (*Pinot noir*) wines of Germany.

Sparkling wines

Sparkling wines are typically classified relative to production method (Table. 7.4). These include the standard (champagne), transfer, and bulk (Charmat) methods. Each derives its effervescence from trapping carbon dioxide produced by a second yeast fermentation. Although definitive, production method does not necessarily generate clear sensory differences. For example, both standard and transfer methods are used to produce wines that are dry to semidry, emphasize subtlety of flavor, limit varietal expression, and possess a "toasty" bouquet. Differences often reflect more

Table 7.4 Sparkling-type wines

With added flavors	Without added flavors		
Fruit flavored	Highly Aromatic	Subtle Flavor	
Carbonated	Muscat based, sweet	Crackling/Carbonated	Traditional style, dry/sweet
Coolers	Asti	Perlwein Lambrusco Vinho Verde	Champagne Cava Spumante Sekt

Table 7.5 Desired characteristics for most sparkling wines

Appearance

1. Brilliantly clear.
2. Pale straw-yellow to bright gold.
3. Slow prolonged release of carbon dioxide that produces many, long, continuous chains of minute bubbles.
4. Bubbles mound on the surface in the center of the glass (*mousse*) and collect around the edges of the glass (*chordon de mousse*).

Fragrance

1. Presence of a complex subtle bouquet that shows a hint of toastiness.
2. Subdued varietal character (to avoid masking the subtle bouquet).
3. Possess a long finish.
4. Absence of atypical or grape-like aspects.

Taste

1. Bubbles that explode in the mouth, producing a tingling, prickling sensation on the tongue.
2. Possess a zestful acidity without tartness.
3. Presence of a clean, lingering, after-taste.
4. Well-balanced.
5. Absence of a noticeable astringency or bitterness

the cultivars used and the duration of yeast autolysis (following the CO_2-producing fermentation) than production method. Although most bulk-method wines are sweet and aromatic (e.g., Asti Spumante) they can produce dry versions with subtle fragrances. Properties considered appropriate for the majority of dry sparkling wines are outlined in Table 7.5.

Sparkling wines are predominantly white because of difficulties posed by the presence of phenolics in red wine. Phenolics not only suppress yeast action (and, therefore, CO_2 production), but they also favor gushing when the bottle is opened. Consequently, few sparkling rosé or red wines are produced, even though most champagnes are made from red grapes (*Pinot noir* and *Pinot Meunier*). Blending a small amount of light red wine with the white is permitted in the production of rosé champagnes. Sparkling red wines are usually carbonated and possess a lower carbon dioxide content (to minimize gushing).

Extensive blending is used in the production of sparkling wines. This usually involves combining wines from many vineyards, as well as several vintages and cultivars. Only in superior years are all the blended wines derived from a single vintage. Blending not only minimizes deficiencies in the component wines, but also accentuates their separate qualities. Examples of cultivars used are *Parellada*, *Xarel-lo*, and *Viura* in Catalonia, and *Chardonnay*, *Pinot noir*, and *Pinot Meunier* in Champagne. In other regions, single varieties are used, for example *Riesling* in Germany, and *Chenin blanc* in the Loire.

Carbonated[1] sparkling wines show a wide diversity of styles. These include dry white wines, such as "vinho verde" (historically obtaining its sparkle from malolactic

[1] Carbon dioxide incorporated under pressure.

fermentation); sweet sparkling red wines, such as Lambrusco; most crackling rosés; and fruit-flavored coolers.

Fortified wines (dessert and appetizer wines)

All terms applied to this category are somewhat misleading. For example, the sherry-like wines from Montilla, Spain achieve their elevated alcohol contents naturally (without fortification). The alternative designation of aperitif and dessert wines is also somewhat erroneous because sparkling wines are often viewed as the ultimate aperitif, and botrytized wines considered the preeminent dessert wine. Table 7.6 provides a categorization of the more common types of fortified wines.

Regardless of designation, these wines are generally consumed in small amounts. Therefore, individual bottles are rarely consumed completely on opening. Their high alcohol content limits microbial spoilage, and their marked flavor and oxidation resistance permits them to remain stable for weeks after opening. Exceptions are fino sherries and vintage ports. Fino sherries lose their distinctive properties several months after bottling, whereas the unique character of vintage ports erodes as quickly as do table wines after opening.

Fortified wines come in a diversity of styles. Dry and/or bitter versions function as aperitifs before meals. By activating the release of digestive juices, they promote digestion. Examples are fino sherries and dry vermouths. The latter are flavored with a variety of herbs and spices. Typically, though, fortified wines are sweet. Major examples are oloroso sherries, ports, madeiras, and marsalas. These wines are traditionally consumed after meals in lieu of dessert.

Table 7.6 Fortified wines

With added flavors	Without added flavors	
Vermouth	Sherry-like	
Byrrh		Jerez-Xerès-sherry
Marsala (some)		Malaga (some)
Dubonnet		Montilla
		Marsala
		Château-Chalon
		New World solera & submerged sherries
	Port-like	
		Porto
		New World ports
	Madeira-like	
		Madeira
		baked New World sherries & ports
	Muscatel	
	Muscat-based wines	
		Setúbal
		Samos (some of)
		Muscat de Beaunes de Venise
	Communion wine	

Unlike table wines, that have been produced for millennia, fortified wines are of comparatively recent origin. The oldest may be fino-type sherries. Sherry-like wine may have been made as far back as Roman times. Under hot dry conditions, production is possible without the addition of alcohol. The extremely low humidity in bodegas (above-ground wine cellars), selectively favors water evaporation from the surfaces of storage barrels. This results in a progressive rise in the wine's alcohol content. The alcohol both suppresses bacterial spoilage and favors the development of a yeast pellicle on the wine's surface. Addition of distilled spirits produces the same effects, but more rapidly and consistently. The other major types of fortified wines—port, madeira, marsala, and vermouth—had to await the development of alcohol distillation.

Concentration via distillation is an ancient technique. It was practiced by the Egyptians at least 2500 years ago. However, its use to concentrate alcohol developed much later. About the tenth century A.D., the Arabs were the first to develop efficient stills for alcohol purification. Alcohol distillation developed in Europe following the importation of still-making technology by alchemists in the 1500s. The fortification of wine with distilled spirits was first used in preparing a herb-flavored medicinal wine called "treacle." This evolved into modern vermouth.

The use of brandy in sherry production was occasionally practiced by the middle 1600s. Its use in port stabilization began about 1720. By 1750, the fermenting must was being fortified, rather than the finished wine. The resultant disruption of fermentation retained up to 50% of the original sugar content of the grapes. Extensive treading[2], throughout the short fermentation period, achieved sufficient pigment extraction to produce a dark red wine. The tannins, sugar, and alcohol content helped supply the wine with long-aging potential. Combined with the use of cork as a bottle closure, evolution of bottle-shape led to the rediscovery of the benefits of wine aging. These advantages were clearly recognized by 1800.

Sherry

Sherry is produced in two basic styles—fino and oloroso. Each comes in a number of subcategories. In fino production, the alcohol content is raised to between 15 and 15.5% before maturation begins, whereas with oloroso, the alcohol content is increased to 18%. At about 15% ethanol, changes in yeast cell wall composition lead to their forming a pellicle (*flor*) that covers the wine. At 18% , all microbial activity in the wine ceases.

The flor covering protects the wine, stored in partially filled barrels, from excessive oxidation. While oxidation does occur, it is slow and involves the synthesis of a wide range of aldehydes and acetals. There is also production of important flavorants, notably soloton.

Aging involves sequential blending. After about five years, the wine has reached an average alcohol content of 16 to 17% alcohol. Unlike most other categories, fino sherries are typically left unsweetened, even for export. They are pale to light gold in

[2] Foot tramping and stirring of the grapes and fermenting must in shallow stone fermentors called *legars*.

color and characterized by a mild walnut-like bouquet. Manzanilla are the palest and lightest of all fino sherries. Amontillado sherries begin their development as a fino, but they complete their maturation as an oloroso. This style is darker in color and often 1 to 3% stronger in alcohol content than typical of finos. Amontillados are also more full-flavored, with a clean, nutty bouquet. For export, it is usually slightly sweetened.

Oloroso sherries are the most oxidized of sherry styles. They receive no flor protection and undergo little fractional blending. Consequently, they possess a more pungent, aldehydic, nutty bouquet, which can give a false impression of sweetness. Amoroso sherries are heavily sweetened versions, usually with a golden-amber to brown color. The dark color comes from the melanoid pigments produced during the heat concentration of the sweetening juice. Cream sherries are *de facto* amaroso sherries initially developed for the English market.

Sherry-like wines are produced elsewhere, but they seldom approach the diversity that epitomizes Spanish sherries. Some European semi-equivalents are noted in Table 7.6. There are few equivalents made outside Europe, despite the name. Those that display the name solera may be similar. Most non-European sherries are baked, producing a caramelized character more typical to inexpensive madeiras. They are essentially always sweet.

Port

Port is made from red, and occasionally white, grapes in the Duoro region of Portugal. Fermentation is stopped prematurely by the addition of brandy, retaining about half of the original grape sugars. This produces a sweet wine with an alcohol content of about 18%. Subsequent maturation defines the various port styles. The blending of wines from various cultivars and locations produces the consistency required for the production of "house" brands. Proprietary styles typify ports as much as they do sherries and sparkling wines.

Vintage-style ports are blended from wines produced during a single vintage, and aged in inert cooperage. Vintage Port is the most prestigious example. It is produced only in exceptional years when the grape quality is especially high. Only rarely are the grapes derived from a single vineyard ("quinta"). After maturing for about two years, the wine is bottled unfined. Consequently, the wine "throws" considerable sediment. It is normally considered that the wine requires from 10 to 20 years before its famously complex aroma and bouquet develop fully. Late-bottled Vintage Port (L.B.V.P.) is treated similarly, but it receives about 5 years maturation before bottling. By this time, most of the sediment has settled, eliminating the need for decanting. The style possesses some of the character of Vintage Port, but benefits little from bottle aging.

Wood ports are derived from the blending of wines from several vintages. Aging occurs predominantly in small oak casks (pipes). Maturation is not intended to give the wine an oak flavor, but to permit slow oxidation (casks are not filled completely). The cooperage is used repeatedly to minimize uptake of an oak character. The most common wood port is Ruby port. The wine receives 2 to 3 years maturation before bottling. Tawny port is a blend of long-aged ruby ports that have lost most of their bright red color. The finest tawnys are sold with an indication of their average age, typically more than 10 years. Inexpensive tawny ports are frequently a blend of ruby and white ports. White ports, derived from white grapes, are matured similarly to ruby ports. They may come in dry, semisweet, and sweet styles, and they often superficially resemble amaroso sherries.

Port-like wines are produced in several countries, notably Australia and South Africa. Only seldom are similar cultivars and aging procedures used. Fortification is usually with highly rectified (flavorless) alcoholic spirits. Thus, they lack the distinctive flavor of Portuguese ports that comes partially from fortification with unrectified (naturally flavored) brandy spirits. Most ports produced in North America are baked. Thus, they typically possess a madeira-like (caramelized) odor.

Madeira

Fortification of madeira wine developed as a means of stabilizing the wine for long sea voyages. However, during voyages to North America, the wine often experienced prolonged heating in the hulls. When it became clear that the colonists preferred the "baked" version, producers began to intentionally heat the wine before shipping (over 40°C for up to three months). Maturation occurs in wooden cooperage for several years. To avoid giving the wine an oaked character, the barrels are used repeatedly.

Madeira is produced in diverse styles, ranging from dry to very sweet. They may involve the use of a single cultivar and be vintage-dated, or they may be extensively blended and carry only a brand name. Despite these variations, the predominant factor that distinguishes madeira is the pronounced baked (caramelized) flavor. With prolonged aging, a complex, highly distinctive bouquet develops that many connoisseurs adore. In contrast, inexpensive versions are used primarily in cooking.

Vermouth

Since ancient times, various herbs and spices have been added to wine. Present-day vermouth evolved from a herb-flavored medicinal wine. Fortification aided both its preservation and facilitated the extraction of flavorants.

Modern vermouths are subdivided into Italian and French styles. Italian vermouths are fortified to between 16 and 18% alcohol and contain from 4 to 16% sugar (for dry and sweet versions, respectively). French vermouths contain about 18% alcohol and 4% sugar. Sugar partially helps to mask the wine's bitterness.

The base wine is often a neutral-flavored white wine, though, the best Italian vermouths are produced from the aromatic *Muscato bianco* variety. Upward of 50 herbs and spices may be used in flavoring; the types and quantities employed are trade secrets. After extraction of the flavorants, the wine is aged for 4 to 6 months. During this period, the components "blend in." Before bottling, the wine may be sterile filtered or pasteurized.

Suggested reading

Amerine, M. A., and Singleton, V. L. (1977). "Wine – An Introduction." University of California Press, Berkeley, CA.

Jackson, R. S. (2000). "Wine Science: Principles, Practice, Perception" 2nd ed. Academic Press, San Diego, CA.

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Origins of wine quality

8

Inherent in all serious wine tastings is the explicit or tacit exploration of quality. The major problem is that no clear consensus exists as to what constitutes wine quality. Quality (like beauty) is in the eye of the beholder.

It has frequently been noted that it is easier to perceive quality than to describe it. All broadly based concepts of quality are predicated on attributes such as sensory complexity, subtlety, balance, elegance, development, duration, and uniqueness. Such measures are all subject to marked variation in perception, not only because of differences in human sensory skill, but also because of experience. Although this makes precise description and comparison of wine quality difficult, there is often surprising agreement among judges. This has permitted grape growers and winemakers to roughly understand those practices and features that can lead to wine greatness.

Although seldom acknowledged, the most critical factor in wine quality is the winemaker (Fig. 8.1). Without the winemaker there would be no wine. This lack of credit reflects our limited sensory acuity, not human humility. Our olfactory skills are not up to the task of recognizing the styles of individual winemakers. If the enological equivalents of a Michelangelo or Mozart exist, their finesse largely goes unnoticed. In addition, aging both modifies and eventually erases most influences affected by the winemaker. Even with considerable training, few individuals recognize the much more marked effects of varietal origin. The subtle effects of regional influences can only rarely be clearly identified.

Grape cultivar use and production style are next in importance to wine quality. The vast majority of grape cultivars are not known to produce wine with a distinctive aroma. Even some famous cultivars are notorious for their elusive varietal aroma, notably *Pinot noir*. Production style more distinctly stamps its particular flavor profile on a wine. For example, red grapes can generate either a red, rosé, or white wine, that may be dry, sweet, sparkling, or fortified, each potentially appearing in an incredible diversity of substyles.

Aside from varietal attributes, grape quality sets limits on potential wine quality. It is at this level that macro- and microclimate have their major impact on wine excellence. Finally, storage conditions and aging progressively modify wine character.

What follows is a discussion of those features that influence wine quality. Although trends can be noted, quality involves the complex interaction of innumerable factors,

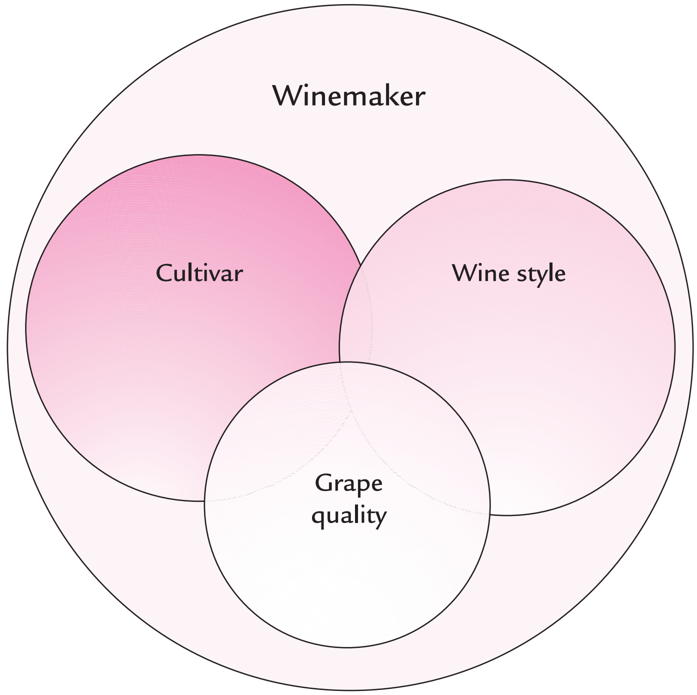

Figure 8.1 Diagrammatic representation of the major sources of wine quality.

where alteration of one is likely to affect the influence of others. For example, wines produced from older vines of *Cabernet Sauvignon* are often considered to be more berry-like, and possess less of a vegetal character (Heymann and Noble, 1987). However, this may simply be a consequence of the vine's lower vigor and associated improved light exposure of the fruit. Caution must be taken not to overextend the significance of research. Most studies are based on comparatively small samples, without the control of additional factors typically considered essential in rigorous experimentation. For example, the effect of vine age noted above was based on an analysis of twenty-one wines. Their results are consistent, though, with commonly held beliefs in the wine community.

Vineyard

Before the microbial nature of fermentation was appreciated, wine quality was attributed to the soil and grape production procedures. Subsequently, the significance of winery technology dominated explanations of wine quality, at least in the New World. More recently, winemakers ascribe quality to what occurs in the vineyard, possibly as a response to growing public distrust of technology. In reality, both viticultural and enological practice are of importance. The adage "one cannot make a silk purse out of a sow's ear" applies to wine, in that a great wine cannot be produced from poor grapes. However, without skilled guidance, the finest grapes will never produce a superior wine.

Macroclimate

Macroclimate refers to the climatic influences produced by major regional features such as latitude, proximity to ocean currents or mountain ranges, and size of the landmass. Clearly these features can have dramatic effects not only on the styles of wine most easily produced, but also on whether viticulture is possible. For example, early cold winters are as essential to the efficient production of ice wines, as is a dry hot climate conducive to sherry production. Equally, cool fall conditions favor acid retention during ripening and slow fermentation—both beneficial to producing dry, stable, table wines. However, modern viticultural and enological procedures can offset many of the climatic conditions that once regulated regional wine production. Therefore, no region or country can legitimately claim that it is preeminent in wine production. One certainly may have favorites, based usually on habituation. However, wine quality is more likely to depend on the judicious and skillful application of technological know-how than geographic origin.

Microclimate

Microclimate involves local conditions induced by features such as the soil, vine training, and topography. In the older wine vocabulary this was termed "terroir." Unfortunately, the term has been misappropriated and frequently imbued with elitist connotations that verge on the mystic. Microclimate is a more precise and emotionally neutral term. If greater precision were needed, the acronym SAM (soil–atmosphere microclimate) could be employed.

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

Only rarely is the geologic origin of the soil of significance. Typically, centuries of weathering have fundamentally transformed the chemistry and structural character of the parental rock material. Therefore, famous wine regions are as likely to be situated on geologically uniform (e.g., Champagne, Jerez, Mosel) as on geologically heterogeneous soils (e.g., Bordeaux, Rheingau). Homogeneity within a vineyard, however, is of importance. Nonuniformity is one of the prime sources of uneven berry ripening that can severely lower wine quality.

Viticultural practice, such as vine density and training system, affect light penetration and wind flow within and among vines. These influences can markedly affect fruit ripening, disease susceptibility, and flavor development. Each significantly affects the potential of the fruit to generate high-quality wine.

Topographic influences, such as vineyard slope and orientation, affect the growing season, and thereby, the potential of the vine to fully ripen its fruit. Sloped sites become increasingly significant the higher the latitude (steeper solar angles). Figure 8.2 illustrates that the slope's major benefit occurs during the autumn, when extra radiation is most needed. Slope also increases the exposure to sunlight reflected off water bodies. At low sun angles (< 10°), reflected radiation can amount to almost half the light falling on vine leaves on steep slopes (Büttner and Sutter, 1935). Slopes also facilitate water drainage and they can direct cold (frost-inducing) air away from vines.

Nearby bodies of water often generate significant microclimatic influences. These may be beneficial, by reducing summer and winter temperature fluctuations in continental climates, or negative, by shortening the growing season in cool maritime climates. Fog development can also nullify the benefits of a slope noted above, as well as increase disease incidence.

In a few instances, adequate studies have demonstrated detectable regional differences (Fig. 8.3). While interesting, whether these effects are consistent from year to

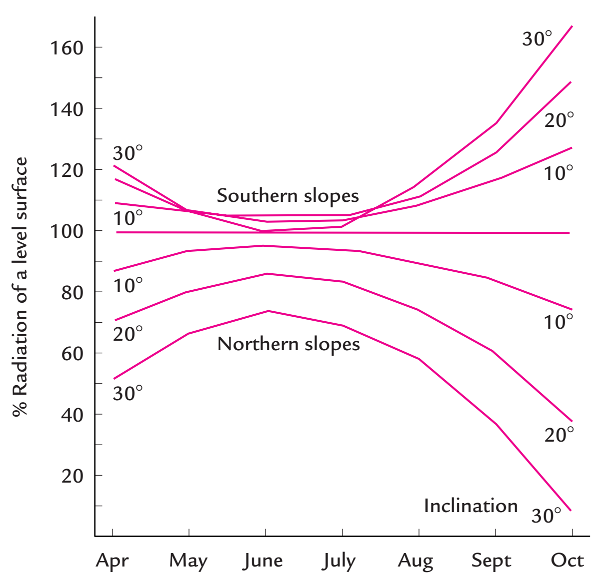

Figure 8.2 Reception of direct sunlight in relation to position and inclination of slope in the northern hemisphere. This example is in the upper Rhine Valley, Germany: 48°15´N (from Becker, 1985, reproduced by permission).

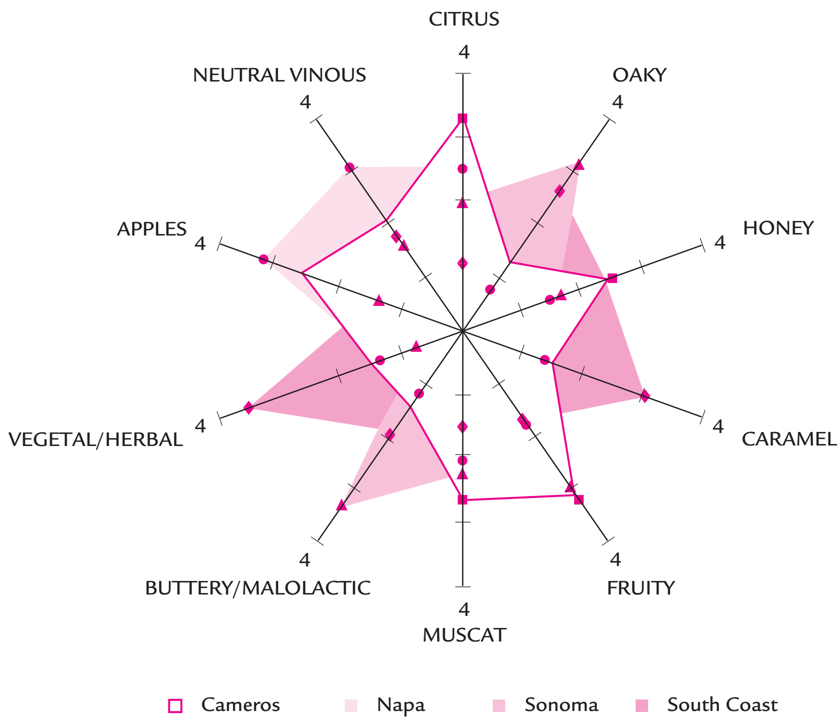

Figure 8.3 Polar plot derived from 10 aroma attributes of 1991 *Chardonnay* wines, showing regional variation within four viticultural areas of California (reprinted with permission from Arrhenius, S. P., McCloskey, L. P., and Sylvan, M. (1996). Chemical markers for aroma of *Vitis vinifera* var. Chardonnay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

year is unclear. Vintage (or age) effects may be more marked than regional influences (Noble and Ohkubo, 1989). In addition, trends do not mean that all wine from a region will be similarly affected. Nor can it be assumed that even skilled tasters can recognize these difference when the wines are sampled individually. Nevertheless, there is considerable financial importance to the implication that sensory differences are detectable. It justifies the creation and promotion of appellations as indicators of uniqueness, if not quality.

Species, variety, and clone

Conventional wisdom implies that only cultivars of the European grape (*Vitis vinifera*) produce wines of quality. Other species and interspecies crosses, even possessing *vinifera* heritage, are viewed as unworthy of consideration. This prejudice provoked laws restricting the cultivation of interspecific hybrids in most of western Europe. This misguided decision partially arose from unfamiliarity with the “foreign” flavors occasionally associated with some interspecies hybrids, and partially because of their higher yield. They were contributing to the growing problem of excess wine production in Europe. The ill-considered nature of their insularity is clearly evident in the quality of the *Chambourcin* wines from Australia. They are an example of the heights attainable by hybrid cultivars. *Maréchal Foch* and *Cayuga White* wines are other examples of the potential achievable by hybrid cultivars.

Even more unjustly maligned have been non-*vinifera* wines. Part of this rejection is derived from their historic association with syrupy sweet wines. Many people came to believe that these were the only wines possible from these cultivars. Their non-*vinifera* aromas also conflicted with the sensibilities of those habituated to *vinifera* wines. Thus, habituation has been a major hindrance. The flavor intensity of cultivars such as *Concord*, *Catawba*, and *Niagara* has also been claimed to be a negative attribute. However, if this were so, then *vinifera* cultivars such as *Gewürztraminer* and *Muscat* should equally be shunned. They are not. In the southern United States, considerable interest is shown in producing *V. rotundifolia* and *V. aestivalis* wines. Only prolonged experimentation and work by dedicated winemakers will reveal the full potential of native *Vitis* species.

The preponderance of western European cultivars in world viticulture originates from favorable climatic and socio-economic factors. The moderate climate of western Europe provided conditions that permitted the production of wine that could age well. The same conditions allowed the better cultivars to be recognized as such. Coincidentally, the Industrial Revolution developed in proximity to these wine-producing regions. The free capital generated supported the evolution of a social class willing and able to sustain the added expense of producing fine wines. With the expansion of the British Empire, propagation of the views of wine-conscious Europeans spread worldwide. Their biases significantly influenced the varieties chosen for planting in New World vineyards. Regrettably, southern Europe (and its grape cultivars) did not fair equally well, either climatically or socio-economically. Consequently, their equivalents of *Cabernet Sauvignon*, *Riesling*, and *Chardonnay* are largely unknown, except locally.

Most cultivars exist as a collection of clones—forms genetically identical in all but a few mutations. Occasionally these mutations significantly influence winemaking potential by directly or indirectly affecting fruit flavor. For example, certain clones of *Chardonnay* possess a distinct muscat character whereas particular clones of *Pinot noir* are better for champagne than for red wine production. Clones can also differ significantly in yield. Until recently, growers typically planted a single clone. This is beginning to change as winemakers search for new ways to increase aromatic complexity. This feature can add significantly to the distinctiveness of a producer's wine.

As part of the ongoing process of eliminating systemic pathogens from grape varieties, there is also selection of clones with both enhanced yield and improved grape quality. Figure 8.4 shows that although yield increased dramatically (almost by a factor of 4) since the mid 1920s, the average quality of the fruit (as measured by sugar content) remained relatively constant (excepting a slight decline between the 1950s and 1980s).

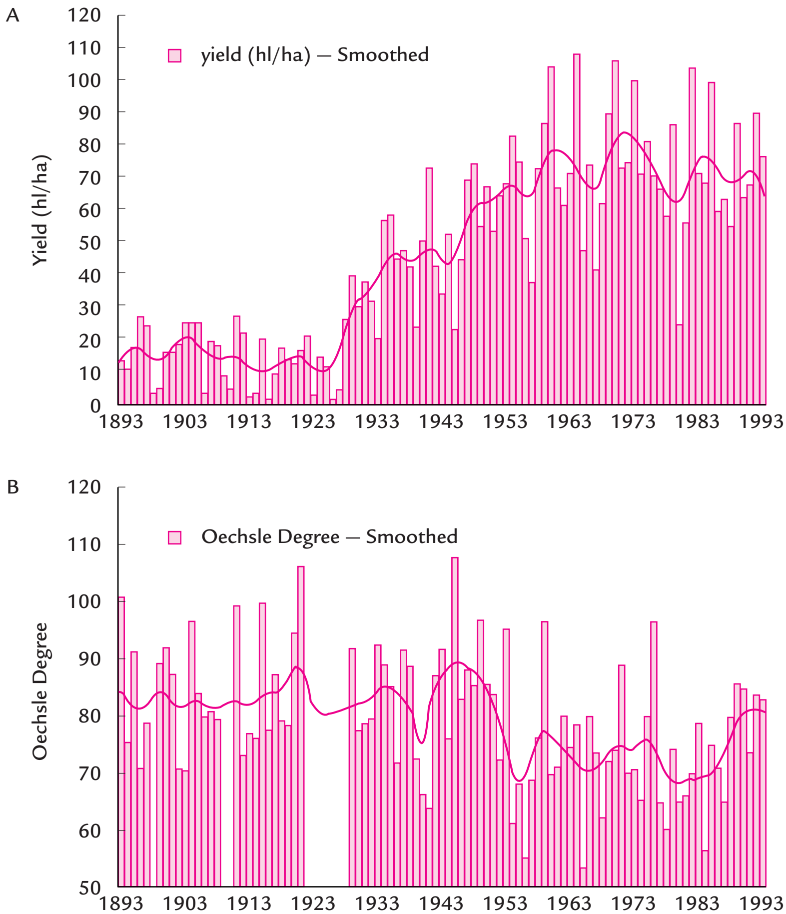

Figure 8.4 Time series of (A) grape yield and (B) must quality *White Riesling* at Johannisberg (Rheingau, Germany) from 1893 to 1993 (from Hoppmann and Hüster, 1993, reproduced by permission).

Rootstock

Rootstocks produce the root system of grafted vines. Although vital to the growth of the fruit-bearing portion (scion), rootstocks seldom receive public acknowledgment of their importance to wine quality. Nonetheless, they affect vine vigor (and thereby, the vine's potential to ripen its fruit), as well as influencing vine nutritional and hormonal balance. Rootstock selection can also affect potential wine quality by improving vine health (donating resistance or tolerance to various pests, diseases and unfavorable environmental conditions). Grafting to rootstocks began in the late 1800s, as the only means of effectively combating the damage caused by the phylloxera invasion. At the time, the root louse was decimating European vineyards. Early rootstock selections, however, were not well suited to the alkaline soils of many European vineyards. This may be the origin of the impression that wine quality suffered as a consequence of grafting. This is no longer the case. The only advantage to own-rooted vines is the economy of escaping the cost of grafting.

Yield

The relation between vine yield and grape (wine) quality is complex. Increased yield tends to retard sugar accumulation during ripening, which is a rough indicator of fruit flavor development. Figure 8.5 illustrates the considerable variability in expression of the general tendency for grape sugar content (noted as potential alcohol content in the wine) to decline as yield increases. Although enhanced flavor is inherently beneficial to wine quality, the benefits of increased aroma potential associated with reduced grape yield may eventually be offset by excessively aggressive taste (Fig. 8.6).

What is commonly missing in most discussions of yield–quality correlations is acknowledgment of the importance of capacity. Capacity is the measure of a vine's ability to fully ripen its fruit load. Vigorous vines continue to produce new shoots late in the season, drawing nutrients away from ripening fruit (reducing capacity). Equally, undue pruning of vines (in an attempt to direct nutrients to the fruit) can inadvertently affect hormonal balance, and both activate and prolong shoot growth. With vines growing on relatively dry or nutrient-poor hillside sites (common in several European viticultural regions), severe pruning tends to induce early-season cessation of growth, resulting in full ripening of the limited fruit crop. The same procedure, applied to healthy vines, adequately supplied with nutrients and water (as in most New World vineyards), has the effect of prolonging shoot growth to the detriment of fruit quality. This led to the belief that small yields were inherently correlated with quality. The error of this interpretation became clear when new training systems were developed to improve light exposure to large vines. This helped to deflect the increased capacity of vines into improved fruit maturity, not enhanced shoot growth.

Central to most new training systems has been the division of large vine canopies into several separate canopies (canopy management). The resultant increase in water demand limits mid-season shoot growth. Judicious use of shoot topping and devigorating rootstocks further help to limit mid- to late-season vegetative growth. The division of the canopy into several smaller, thinner canopies opens the fruit to

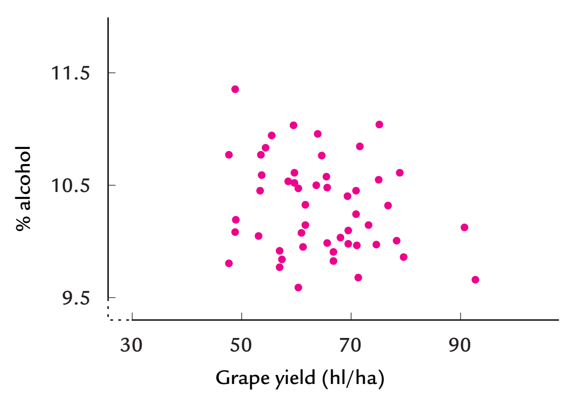

Figure 8.5 Relation between grape yield and alcohol content of the wines produced from 51 vineyards in the south of France. Data from each vineyard are averaged over 22 years (from Plan *et al.*, 1976, reproduced by permission).

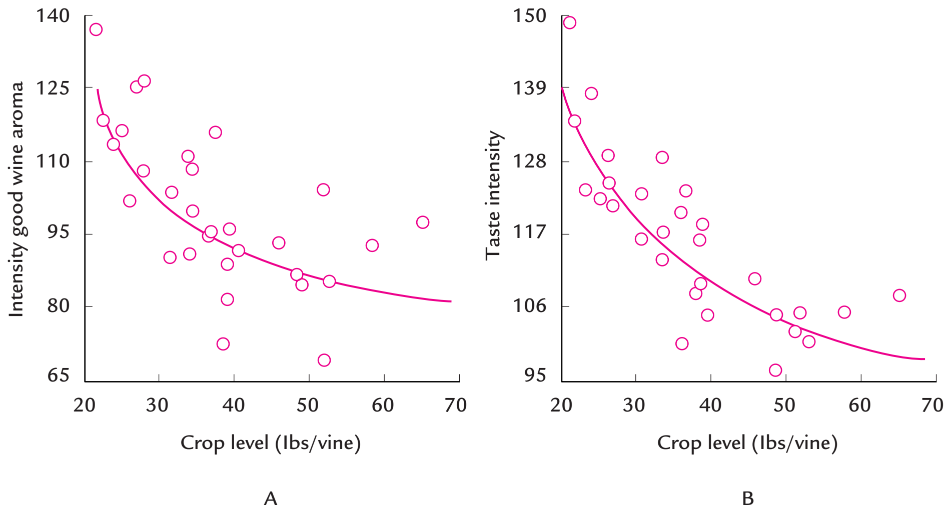

Figure 8.6 Relation between crop level of *Zinfandel* vines and (A) good wine aroma and (B) taste intensity (from Sinton *et al.*, 1978, reproduced by permission).

increased sun and wind exposure, both tending to favor early and complete fruit ripening. Figure 8.7 illustrates the effect improved sun exposure can have on reducing excess fruit acidity. This means that increased fruit yield can be associated with enhanced fruit quality. High density planting (common in Europe) is an old alternative of achieving the same ends. Table 8.1 illustrates the value of high-density planting on color density. However, these benefits come at considerable development and maintenance costs. Canopy management is a far more economic means to producing high-quality grapes.

Other means of directing vine vigor into increased capacity involve procedures such as minimal pruning and partial rootzone drying. Minimal pruning allows the vine to grow and self-adjust its size. After several years, most cultivars establish a canopy structure that permits excellent fruit exposure (for optimal maturation), combined with high yield and limited need for pruning. Partial rootzone drying is a

Table 8.1 Effect of plant spacing on the yield of 3-year-old *Pinot noir* vines[a] (from Jackson, 2000, reproduced by permission)

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

[a]Data from Archer, 1987; Archer and Strauss, 1985; Archer *et al.*, 1988.

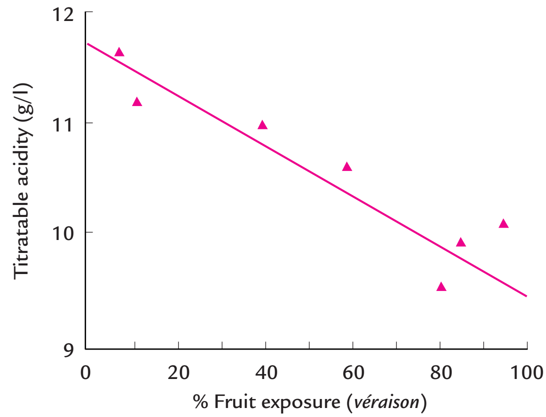

Figure 8.7 Relation between fruit exposure at *véraison* and titratable acidity at harvest of *Sauvignon blanc* (from Smith *et al*., 1988, reproduced by permission).

technique applicable under arid to semi-arid conditions, where irrigation is obligatory. By alternately supplying water to only one side of the vine, the root sends hormonal signals that suppress mid- to late-season shoot growth, despite a fully adequate water supply. The consequence is the production of an abundant fruit crop that ripens fully.

A new and apparently better relation between fruit yield and quality is obtained by relating the active leaf area to the weight of fruit produced (LA/F ratio). It focuses attention on the fundamental relationship between energy supply and demand. An appropriate value for many cultivars tends to be about 10 cm^2 active leaf area per gram fruit. However, this value can be modified by several factors, such as the cultivar (Fig. 8.8), training system, soil nutrients, water supply, and climatic conditions. The objective is to establish the optimal canopy size and fruit placement to promote exceptional fruit ripening.

Training

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

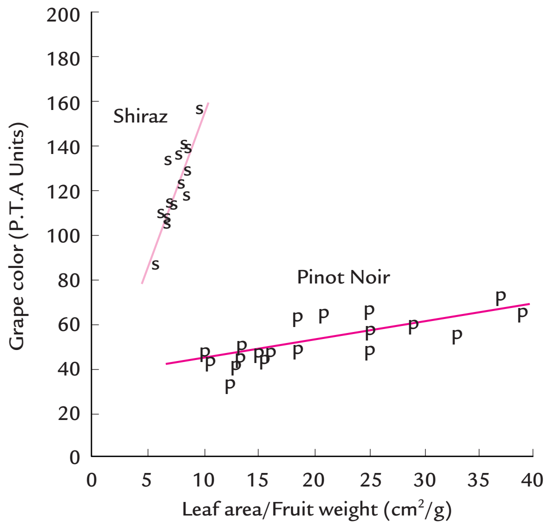

Figure 8.8 Relation between grape color and leaf area/fruit ratio for *Shiraz* and *Pinot noir* vines, P.T.A, potential total anthocyanin (from Iland *et al*., 1993, reproduced by permission).

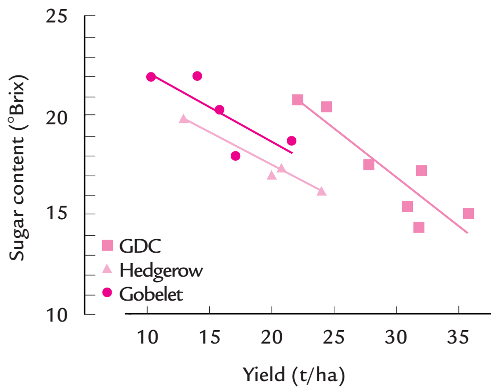

Figure 8.9 Relation between yield and soluble solids (5-year average) using three distinct training systems (from Intrieri and Poni, 1995, reproduced by permission).

As previously noted, the vine's inherent vigor must be restrained on relatively nutrient-poor, dry soils. This has traditionally been achieved by dense vine planting (about 4000 vines/ha) and severe pruning (removal of > 90% of the yearly shoot growth). However, on rich, moist, loamy soil, limited pruning is preferable with wide vine spacing (about 1500 vines/ha). Under these conditions, it is prudent to redirect the increased growth potential of the vine into greater fruit production, not prune it away. When an appropriate LA/F ratio is established, increased yield and quality can exist concurrently. It is on rich soils that the newer training systems succeed so well. These systems not only achieve a desirable LA/F ratio, but they also provide improved exposure of the grapes to light and air. These features promote ideal berry coloration, flavor development, fruit health, and flower-cluster initiation.

Nutrition and irrigation

In the popular literature, stressing the vines is often viewed as essential to fine wine production. This view probably arose from the reduced-vigor, improved-grape-quality association found in some renowned European vineyards. However, as noted above, balancing vegetative and fruit-bearing functions is the real goal. Exposing the vine to extended periods of water or nutrient stress are always detrimental. Equally, supplying nutrients and water in excess is detrimental, as well as wasteful.

In practice, regulating nutrient supply to improve grape quality is difficult. Because the nutrient demands of grapevines are surprisingly small (partially because of the nutrient reserves of the vine's woody parts), deficiency symptoms may not express for several years. In addition, establishing nutrient availability (vs simple presence) is still an inexact science.

Irrigation, as noted above (partial rootzone drying), can be used to regulate vine growth and promote optimal fruit ripening. Irrigation water can also supply nutrients and disease-control chemicals directly to the roots in precisely regulated amounts and at specific times. These possibilities are most applicable in arid and semi-arid conditions, where most of the water supply comes from irrigation.

Disease

Only in a single instance can a grape disease be considered a quality feature. This occurs under the special atmospheric conditions that permit the development of noble rot, caused by *Botrytis cinerea*. Under these conditions, the normally destructive pathogen concentrates grape constituents, as well as synthesizing its own special aromatics. Otherwise, grape disease always reduces quality. Procedures used to control pests and disease agents may themselves be harmful to grape and wine quality. If used in excess and late in the season, disease-control agents can disrupt fermentation. Even the chemicals permitted in organic viticulture may not be devoid of their detrimental effects on grape and wine quality.

Maturity

Most vineyard activity is designed to promote optimal fruit maturity. Once achieved, the grapes are normally harvested and processed into wines. Measuring optimum maturity is, however, far from simple. Maturity can be estimated by grape sugar or acid contents, their ratio, color intensity, or flavor intensity. Depending on legal constraints, the sugar and acid content of the juice may be adjusted to account for slight deficiencies or imbalances. However, color and flavor intensity cannot be directly augmented. The only accepted methods of their adjustment relate to procedural or enzymatic techniques that enhance pigment coloration or the volatility of existing flavorants. Therefore, there would be considerable interest if color or flavor intensity could be used as measures of grape maturity. However, fermentation and maturation conditions so affect color development and stability that fruit color cannot predict eventual wine color. For Muscat and related grape varieties, the presence of monoterpenes in the juice is an indicator of wine flavor. For other varieties, not dependent on terpenes for their flavor, other techniques are required. To date, the best general indicator of potential grape flavor comes from measurement of the glycosyl-glucose content of the juice. Most grape flavorants are loosely bound to glucose. Thus, determining the glycosyl-glucose content is a gauge of potential wine flavor. Under some conditions, the accumulation of glycosyl-glucose correlates well with the general buildup of sugars during ripening. In these situations, measuring sugar content is an indirect measure of flavor content. However, in cool climatic regions, there is a poor correlation between grape sugar content and juice flavor potential. Thus, the more laborious measures of free terpene or glycosyl-glucose contents are required if flavor is to be the critical measure of fruit maturity.

Once the decisions on maturity and harvest date have been taken, the next question involves the method of harvest. In the past, hand picking was the only option. Even today, for some wine styles and with some grape varieties, manual harvesting is the only choice. For example, wine made by carbonic maceration (such as Beaujolais) involves a grape-cell fermentation before crushing. This preferentially requires the collection of whole grape clusters, not just berries, a portion of which break open during harvesting. In most cases, the choice between manual and mechanical harvesting has more to do with economics than wine quality. Premium wines can justify the expense of manual harvesting, but, increasingly, mechanical harvesters are used for all categories of wines. In most instances, sensory differences between manual and mechanical harvest methods are either undetectable or negligible (see Clary *et al*., 1990).

Winery

Winemaker

Wine is the vinous expression of a winemaker's technical and artistic skills. As such, no two winemakers produce identical wines. Each person brings to the process the culmination of their experience and concepts of quality. How well these are transformed into wine defines the difference between the skilled technician and the creative artist.

Increasingly, the winemaker is in frequent contact with the grape grower. The interaction helps supply the raw material the winemaker needs, as far as nature permits. Depending on the characteristics of the grapes reaching the winery, the winemaker must make decisions on how to process the juice into wine. Figure 8.10 illustrates the basic sequence of events that convert grapes into wine. None of these stages is without choices, each of which can affect the wine's sensory attributes. While most decisions affect style, others primarily influence quality. Some of these decisions, and their quality implications, are discussed below.

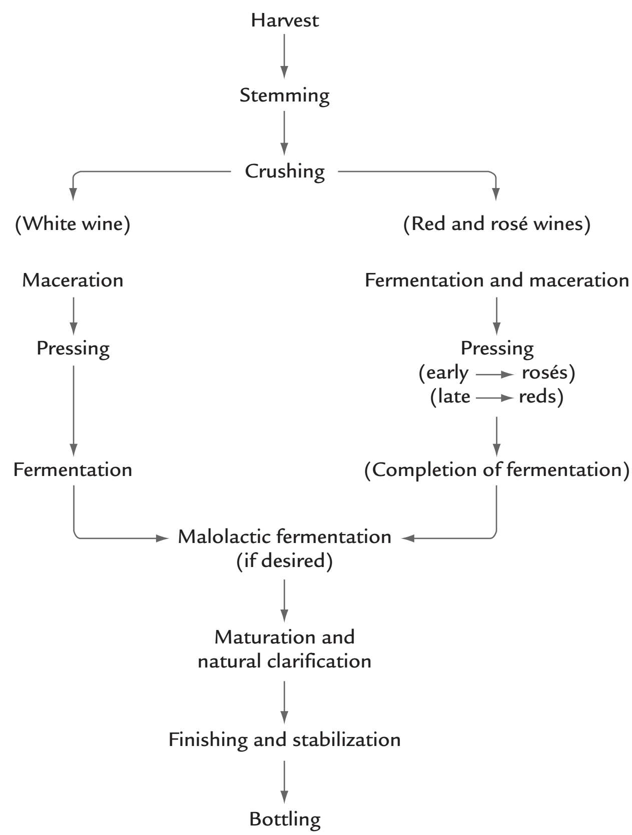

Figure 8.10 Flow diagram of winemaking (from Jackson, 2000, reproduced by permission).

Prefermentation processes

Typically, grapes are crushed immediately upon reaching the winery. This allows the juice to escape and it disrupts the integrity of the grape cells. This is essential for the release of flavorants into the juice. It also liberates oxidative enzymes that begin to react with grape constituents. Until recently, exposure to air during or after crushing was considered detrimental based on the belief that it made the wine susceptible to oxidation. In fact, early juice aeration protects the wine from oxidation, by activating the expeditious oxidation and precipitation of readily oxidized compounds. Consequently, most winemakers allow air access during crushing, or aerate the juice after crushing. This enhances the shelf-life of white wines, as well as encouraging complete fermentation (metabolism of fermentable sugars to alcohol). Except for dessert wines, such as botrytized wines and ice wines, slight sweetness is best supplied as sterile grape juice. This is added to dry wine shortly before bottling.

Depending on the intent of the winemaker, the juice is left in contact with the seeds and skins for several hours (white wines) to several weeks (red wines). The duration of skin contact depends on the intensity of flavor to be extracted. Up to a point, flavor intensity and aging potential increase with prolonged skin contact. This period, called maceration, occurs before fermentation with white wines, but simultaneously with fermentation for red wines. The difference relates to the much longer period required for anthocyanin and tannin extraction, the primary chemicals that distinguish red from white wines. The significance of pigmentation to quality is indicated in Figure 8.11. Skin contact also favors quick onset and completion of fermentation, and it alters the synthesis of yeast-produced aromatics. Thus, the fundamental character of a wine is partially determined by the timing and duration of maceration, as well as the temperature at which maceration occurs (Fig. 8.12).

The next major process affecting wine quality is pressing—separation of the juice (or wine) from the seeds and skins. Ideally, this should occur with a minimum incorporation of particulate matter (cellular debris or complexes of macromolecules such as tannins and proteins). This is achieved by applying pressure to the juice, seeds, and skins over as large a surface area as is practical. Most presses of this type are elongated cylindrical chambers positioned horizontally. Pressure is applied either via air pumped against the juice via a membrane or by plates that move in from both ends. The older, basket-type of presses were positioned vertically and they had pressure applied by a plate from the top only. The gentler pressure applied by the new presses liberates juice that is less bitter and astringent, and richer in varietal flavors. In contrast, the older presses produced rougher tasting wines with less fruit flavors.

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

If the sugar and acid composition of the juice is unavoidably inferior, the winemaker usually attempts to make adjustment. The addition of sugar and/or the addition of acidity (or its neutralization) can improve the basic attributes of the wine. It

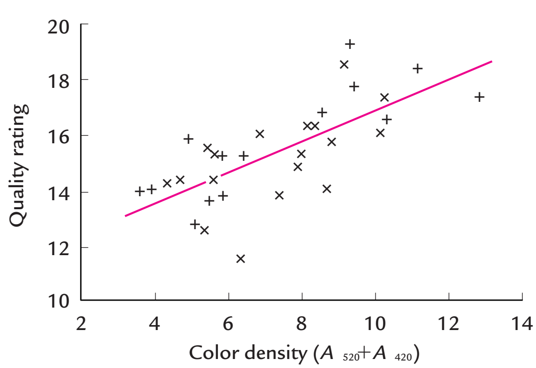

Figure 8.11 Relation between quality rating and wine color density in 1972 Southern Vales wines: (+) *Cabernet Sauvignon*; (x) *Shiraz* (from Somers, T. C., and Evans, M. E. (1974). *J. Sci. Food. Agric.* **25**, 1369–1379. Copyright Society of Chemical Industry. Reproduced with permission. Permission is granted by John Wiley & Sons Ltd on behalf of the SCI).

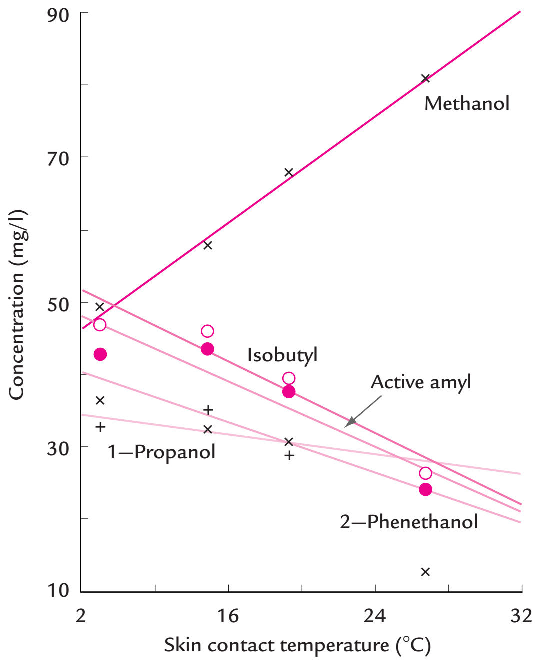

Figure 8.12 Concentration of various alcohols in *Chardonnay* wine as a function of skin contact temperature (from Ramey *et al*., 1986, reproduced by permission).

cannot compensate for a lack of color or flavor, though. As noted earlier, these desirable qualities frequently develop concurrent with desirable acid and sugar levels in the grapes.

Fermentation

Fermentor

The first decision facing the winemaker concerning fermentation is the type of fermentor. Typically this will be a closed tank, and as large as conveniently possible (for the economies of scale). However, small producers may choose fermentation in small (~250 l) oak barrels, especially for lots of high-quality juice. Those who favor this alternative justify the expense by the cleaner (less fruity) expression of the wine's varietal aroma. In addition, in-barrel fermentation can modify the aromatics produced by the fermenting yeasts, as well as those extracted from the oak. These differences may donate the features that distinguish between wines produced from adjacent properties.

For the majority of white wines, fermentation occurs in structurally simple tanks. These are preferentially made from inert materials. This permits transformation of the juice into wine without compromising the natural flavors of the grapes. Red wines are also frequently fermented in inert tanks. However, they vary considerably more in design than white wine fermentors. The difference is imposed by the need to extract color and flavors from the skins during fermentation. As fermentation progresses, the carbon dioxide generated carries the skins and seeds to the surface of the juice. Various means have been developed to periodically or continuously submerge the cap of floating seeds and skins into the fermenting juice. One of the more recent and effective fermentors for cap submersion is the rotary fermentor. These commonly possess several blades attached to a central cylinder that slowly rotates, gently mixing the seeds, skins, and juice. This promotes the rapid extraction of pigments, flavors, and "soft" tannins from the skins, while minimizing the extraction of "hard" seed tannins. The result is a full-flavored wine, of intense color, but smooth enough to be enjoyed without prolonged aging. Most other fermentors giving intensely flavored and colored red wines require many years to "soften."

Yeasts

The next major decision facing the winemaker is whether to permit spontaneous fermentation (by yeasts on the grape and winery equipment), or to add one or more strains of yeast (induced fermentation). There are advocates on both sides claiming superior results. Spontaneous fermentations may yield more complex wines, but at the risk of spoiling the wine. Most of the added complexity comes from compounds such as acetic acid and diacetyl. At threshold levels, these compounds can add an element of "sophistication," but at slightly higher contents generate off-odors. Even where induced fermentation is the choice, the winemaker must decide on which species and/or strain to use. As yet, there are no clear guidelines other than experience. The effect of the strains can be more than just subtle (Figs 8.13 and 8.14).

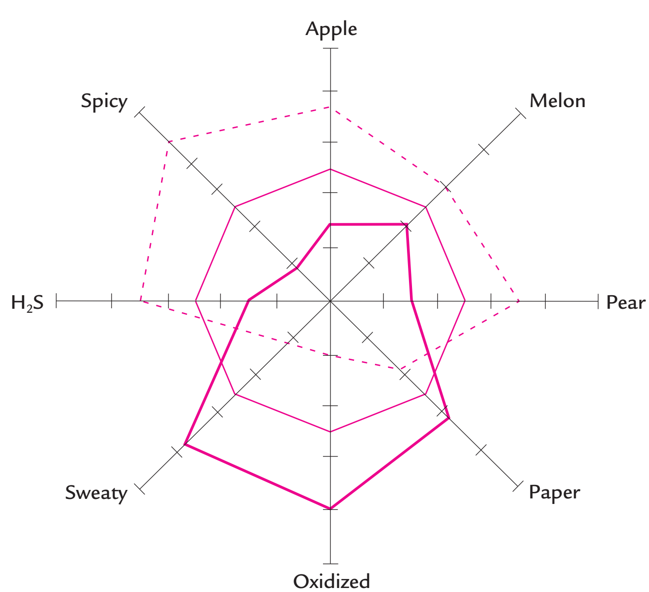

Figure 8.13 The effect of spontaneous (- - -) and induced (–) fermentation on the sensory characteristics of *Riesling* wine; (——) mean score; H_2S, hydrogen sulfide (from Henick-Kling, T., Edinger, W., Daniel, P., and Monk, P. (1998). *J. Appl. Microbiol.* **84**, 865–876; reproduced by permission).

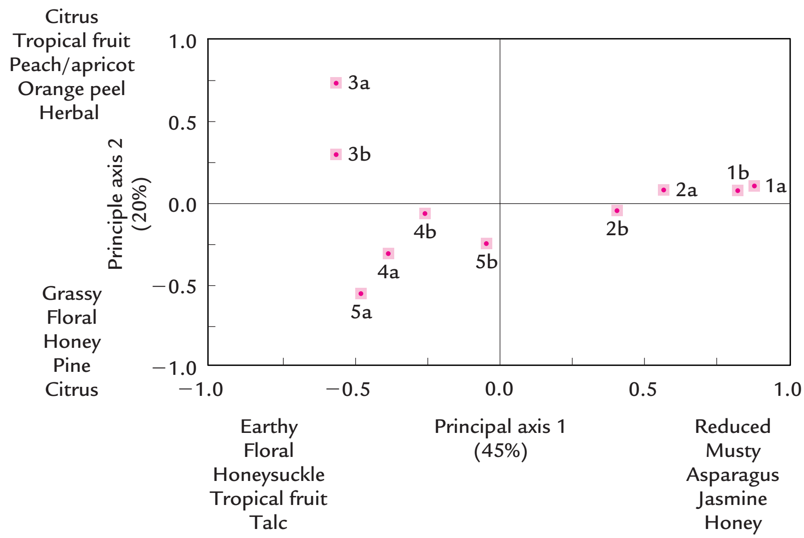

Figure 8.14 Profile of aroma of a *Riesling* wine (after 20 months) fermented with different yeast strains: 1a, 1b, Simi white; 2a, 2b, CS-2; 3a, 3b, VL-1; 4a, 4b, K1; 5a, 5b, CEG (from Dumont and Dulau, 1996, reproduced by permission).

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

Malolactic bacteria

Most wines undergo two fermentations. The first, yeast-induced fermentation generates the alcohol and vinous bouquet that characterizes all wines. The second, a bacteria-induced malolactic fermentation, reduces wine acidity and can both modify and add complexity to a wine's flavor (Fig. 8.15). It is encouraged in most red wines, notably in moderate to cool climatic regions. It makes the wine more drinkable by mollifying the potentially overly sour, rough taste of the wine. In contrast, winemakers attempt to limit malolactic activity in warm to hot climatic regions, where the grapes (and wine) have a tendency to be too low in acidity. The action of malolactic fermentation could give the wine a flat taste. In addition, malolactic fermentation tends to generate off-odors in wines of low acidity.

Because malolactic fermentation is often sporadic, especially in high acid wines, winemakers frequently inoculate their wines with one or more desirable strains of bacteria (typically *Leuconostoc oenos*). As with yeast strains in alcoholic fermentation, bacterial strains differ considerably in the aromatic compounds they produce. Figure 8.16 illustrates the sensory effects potentially induced by different strains of *Leuconostoc oenos*. From the divergence of opinion shown in Figure 8.16, it should be no surprise that there are strong and divergent opinions concerning the benefits and disadvantages of malolactic fermentation.

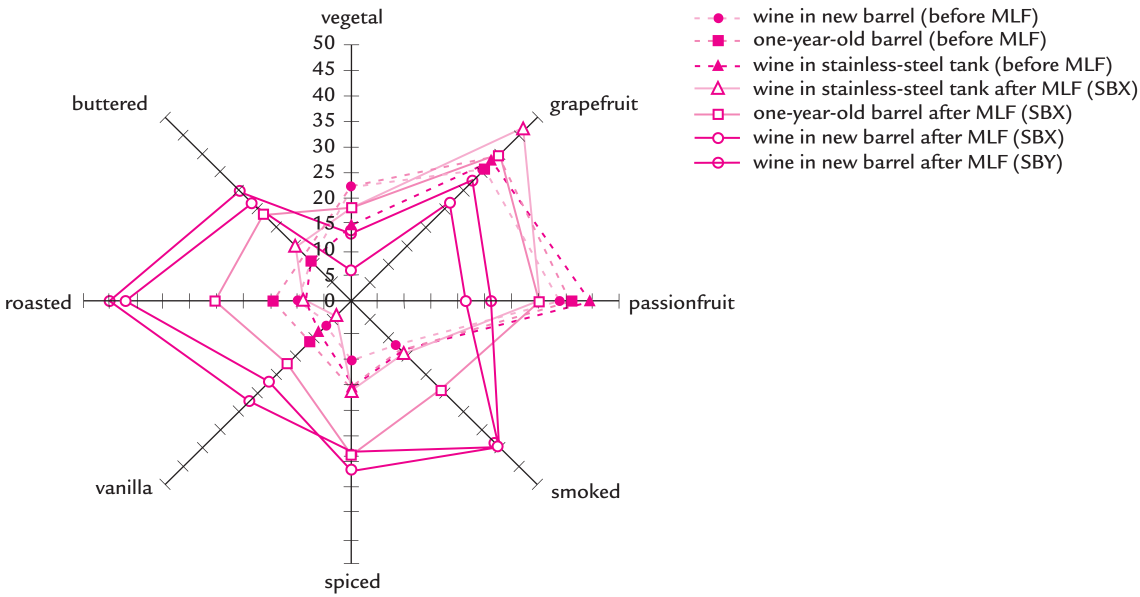

Figure 8.15 Differentiation of wine as affected by malolactic fermentation (MLF) in stainless steel or oak cooperage by two strains of lactic acid bacteria (SBX and SBY) (de Revel, G., Martin, N., Pripis-Nicolau, L., Lonvaud-Funel, A., and Bertrand, A. (1999). *J. Agric. Food Chem.* **47**, 4003–4008. Copyright (1999) American Chemical Society).

Postfermentation influences

Adjustments

Ideally, a wine should require only minimal clarification, such as spontaneous settling and gentle fining before bottling. However, if the wine is bottled early, is imbalanced, or possesses some fault, additional treatment will be necessary. Nevertheless, this should be kept to a strict minimum. Most forms of adjustment have the potential to remove or neutralize the subtle distinctiveness that is inherent in every wine.

Blending

Blending is one of the most misunderstood aspects of wine production. In one or more forms, blending is involved in the production of essentially all wine. It can vary from the simple mixing of wine from different tanks to the complexities of combining wines produced from different cultivars, vineyards, and vintages. For several wines, notably sparkling, sherry, and port, complex blending is central to their quality and brand uniqueness. In other regions, blending wines made from several grape varieties supplies their traditional character (e.g., Chianti and Bordeaux). Blending tends to enhance the best qualities of each wine, while diminishing their individual defects. Figure 8.17 illustrates the general benefit of blending. It shows that blends between wines of roughly similar character and quality were considered as good or better than their components.

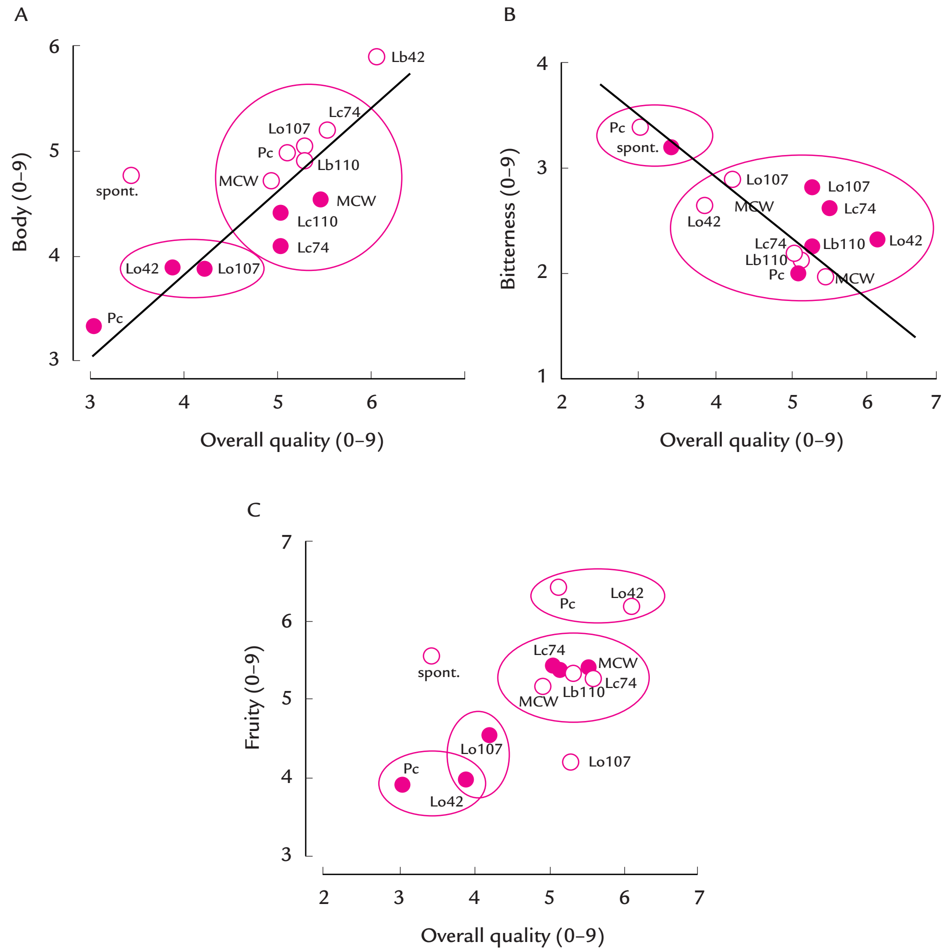

Figure 8.16 Relation of body (A), bitterness (B), and fruitiness (C) to overall quality of *Cabernet Sauvignon* wine fermented with various lactic acid bacteria. The relation was assessed by two different panels, one composed of winemakers (●) and the other a wine research group (○) (from Henick-Kling *et al*., 1993, reproduced by permission).

The negative connotation often attributed to blended wines arises from those with a vested interest in appellation control. Authenticity of geographic or vintage origin is promoted as an indicator of wine quality. Whether this is valid depends more on the skill of the producer and grape maturity, than on geographic origin. Blending wines from different vineyards and regions is no more 'detrimental' to quality than blending between different grape varieties. Geographic identity does, however, give the producer an easily recognized consumer distinction. Consequently, marketing explains most of the appeal of estate-bottled wines.

Processing

An old processing technique receiving renewed attention is *sur lies* maturation. The process leaves white wine in contact with the lees (dead and dying yeast cells) for an

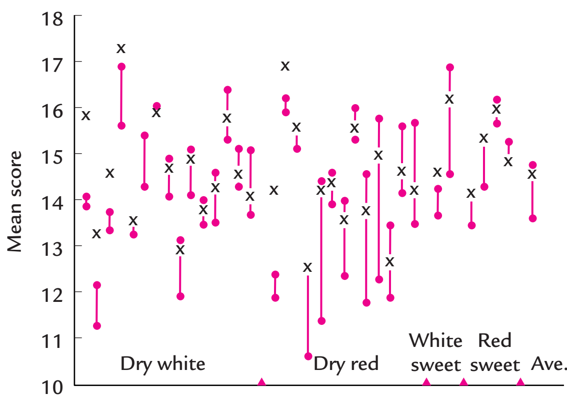

Figure 8.17 Mean quality scores of 34 pairs of wines compared (●) with their 50:50 blend (x), indicating the value of a complex flavor derived from blending (from Singleton, 1990 [based on data from Singleton and Ough, 1962], reproduced by permission).

extended period. Usually, lees contact occurs in the same container (usually a barrel) as did fermentation. *Sur lies* maturation can enhance wine stabilization and increase flavor intensity. This benefit, however, runs the risk of contamination with hydrogen sulfide (released from the lees). To avoid this possibility, the wine is periodically stirred to incorporate small amounts of oxygen. Unfortunately, this can activate dormant acetic acid bacteria that produce acetic acid and ethyl acetate off-odors.

Sparkling wine production also involves extended contact with lees. Autolysis of the yeasts that produced the sparkle supplies the toasty scent that characterizes most sparkling wines. In addition, it is the source of the colloidal mannoproteins that favor the generation of durable, continuous chains of small bubbles (Feuillat *et al.*, 1988; Maujean *et al.*, 1990). The helical structure of these polymers probably entraps carbon dioxide as it does volatile compounds.

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

Oak

Wines with sufficient flavor and distinctiveness may be matured in oak cooperage. This can add a desirable element of complexity, as well as improve varietal expression (Fig. 8.18). Figure 8.19 further illustrates how the presence of one component (oak lactones) correlates with several wine attributes.

Oak can donate a spectrum of flavors depending on a variety of factors. These include the species of oak used (Fig. 8.20), the conditions under which the trees grew (Chatonnet, 1991), the method of seasoning the wood (Chatonnet *et al.*, 1994), the degree of “toasting” (heat applied during barrel construction), and number of times the barrel is reused (Fig. 8.21). Each aspect modifies the oak attributes extracted by the wine. The intensity of these aspects can be partially regulated by the duration of

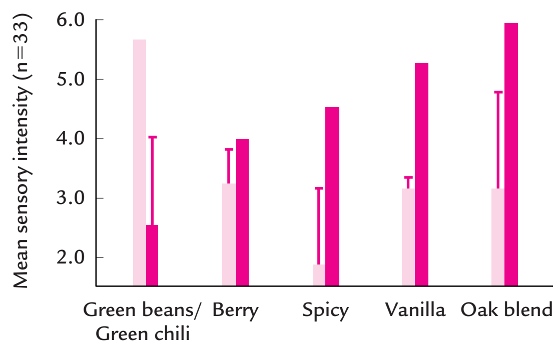

Figure 8.18 Mean intensity rating of aroma terms for *Cabernet Sauvignon* wines aged 338 days in glass (Control) and in French oak barrels (■, control; ■, oak-aged; 11 judges, 3 replications) (from Aiken and Noble, 1984, reproduced by permission).

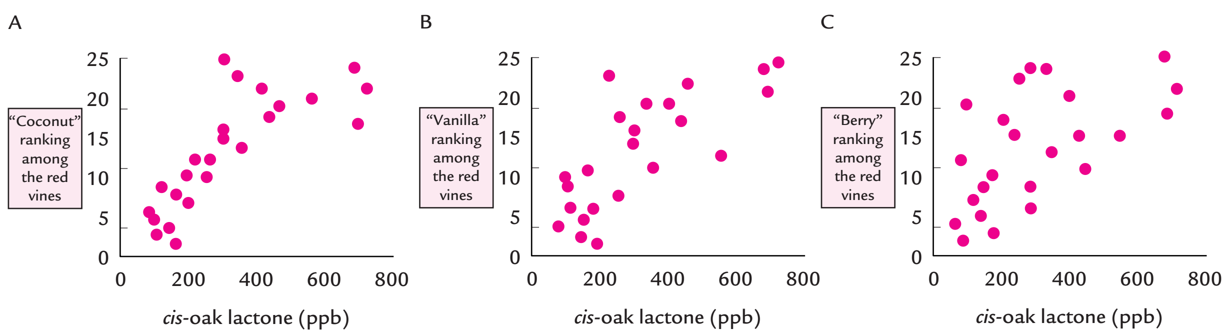

Figure 8.19 Correlation of the perception of several flavor characteristics with the presence of *cis*-oak lactones in red wines matured in oak barrels: (A) coconut; (B) vanilla, and (C) berry. The rank correlation was significant in all three cases ($p < 0.001$) (from Spillman *et al.*, 1996, reproduced by

wine contact (varying from a few weeks to several years). Whether these added flavors enhance or detract from the central character of the wine depends on personal preference. In some appellations, law dictates the type and duration of oak maturation. In such cases, a certain oakiness is considered an obligatory attribute of the wine.

Cork

A choice seldom acknowledged for its potential to affect wine quality is the cork. This refers not just to the absence of contaminants, such as 2,4,6-trichloroanisol, or structural faults, but also to the length and sealing characteristics of the cork. This is of particular concern with premium wines because they are intended to age in-bottle for many years.

Cork progressively loses its elasticity in contact with wine. The deterioration progresses outward, from the end in contact with wine. Therefore, the length of the cork is an indicator of how long it will effectively seal the wine. Another factor little recognized for its importance is the growth rate of the cork tissue. Cork from

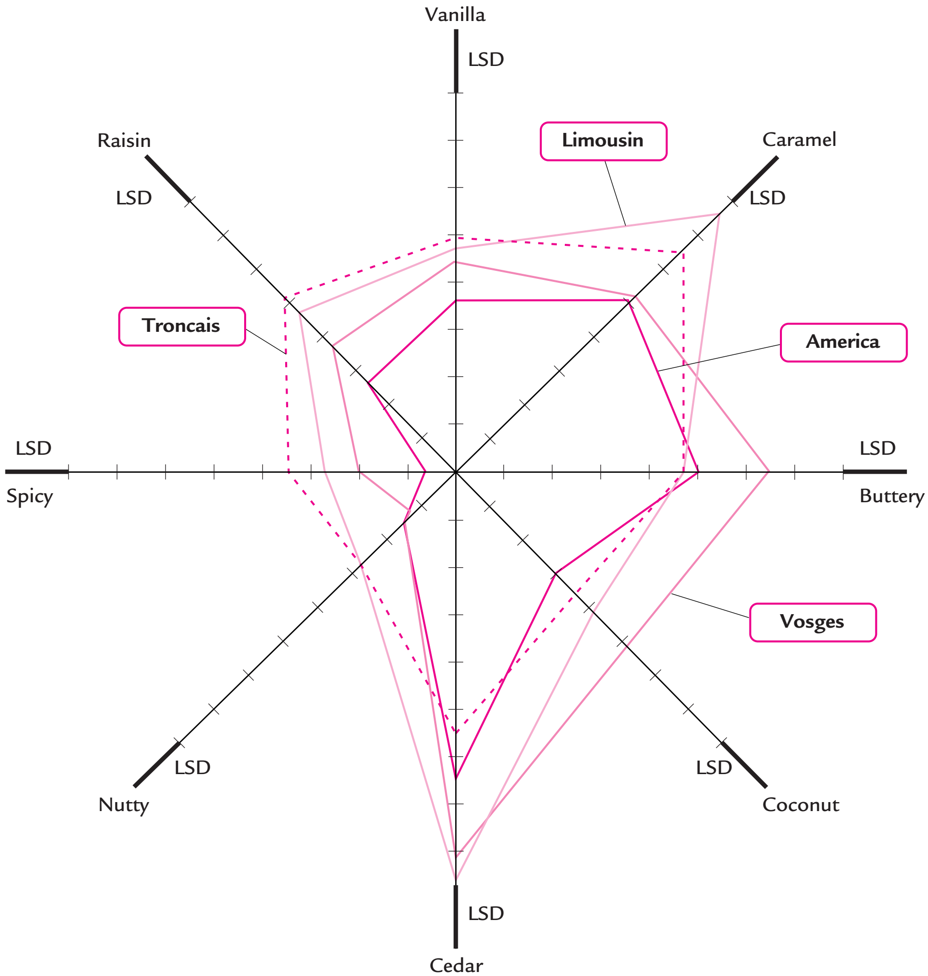

Figure 8.20 Polar coordinate graph of mean intensity ratings and least significant differences (LSD) for descriptors by oak origin (n = 14 judges × 3 reps × 6 samples) (from Francis *et al.*, 1992, reproduced by permission).

trees that grow slowly contains a higher proportion of resilient spring-grown cork (and correspondingly annual rings; Fig. 8.22) than cork from trees that grow more rapidly. Thus, cork harvested from trees grown in drier, mountainous regions has better sealing properties than that derived from trees grown in moister, lowland regions.

Aging

The tendency of wine to improve, or at least change, with aging is one of its most intriguing properties. Unfortunately, most wines improve for only a few months or years, before showing progressive and irreversible deterioration (Fig. 8.23). During the initial stages, loss of yeasty odors, excess dissolved carbon dioxide, and the precipitation of particulate material lead to sensory improvements. Additional

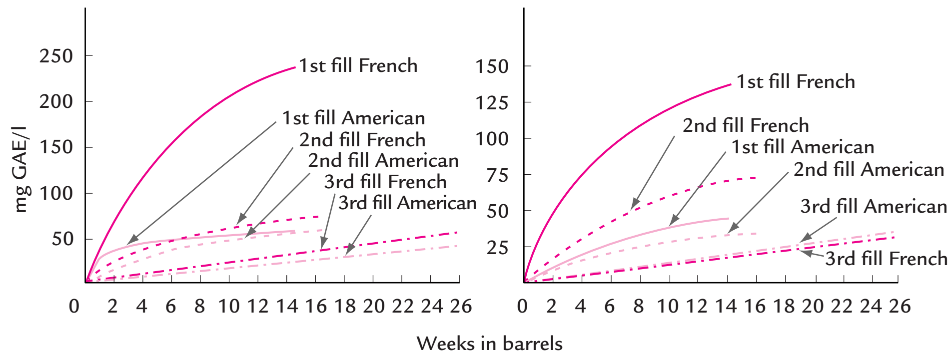

Figure 8.21 Changes in (A) total phenolics and (B) nonflavonoids over time for French and American oak barrels (from Rous and Alderson, 1983, reproduced by permission).

enhancement may result from the acid-induced liberation of terpenes or other aromatics from nonvolatile glycosidic complexes extracted during maceration. Several hundred glycosides have been isolated from varieties such as *Riesling*, *Chardonnay*, *Sauvignon blanc*, and *Shiraz*.

One of the more obvious age-related changes is a color shift toward brown. Red wines may initially deepen in color after fermentation, but they subsequently become lighter and take on a ruby and then brickish hue. Decreased color intensity and browning result from both a disassociation of anthocyanin complexes (typical of young wines) and the progressive formation of anthocyanin–tannin polymers. These changes are detected by a drop in optical density, and a shift in the absorption spectrum, respectively (Fig. 8.24[1]). Without polymerization, anthocyanins fairly rapidly oxidize and the wine would permanently lose color. The precise reasons why some wines retain, whereas others lose, much of their color is still unclear. Nevertheless, small amounts of acetaldehyde produced following the limited aeration that occurs during racking has been suggested to enhance anthocyanin–tannin polymerization. Age-related color changes in red wines can be objectively measured by changes in absorbance at 520 and 420 nm (Somers and Evans, 1977). High 520/420 nm values indicate a bright-red color, whereas low values indicate a shift to brickish tones. In contrast, white wines darken in color and develop yellow, gold, and eventually brown shades during aging. The origin of this color shift is poorly understood. It may involve phenolic oxidation, metal ion-induced structural changes in galacturonic acid, Maillard reactions between sugars and amino acids, or sugar caramelization.

In addition to the hydrolytic breakdown of aromatic and anthocyanin glycosides, flavonol (notably quercetin) and stilbene (primarily resveratrol) glycosides also separate into their components. The sensory significance of these modifications

[1] Compare the slow change observed in Fig. 8.24 (anoxic reducing conditions) to the more rapid changes seen in Fig. 2.1 (mild oxidizing conditions in large oak cooperage).

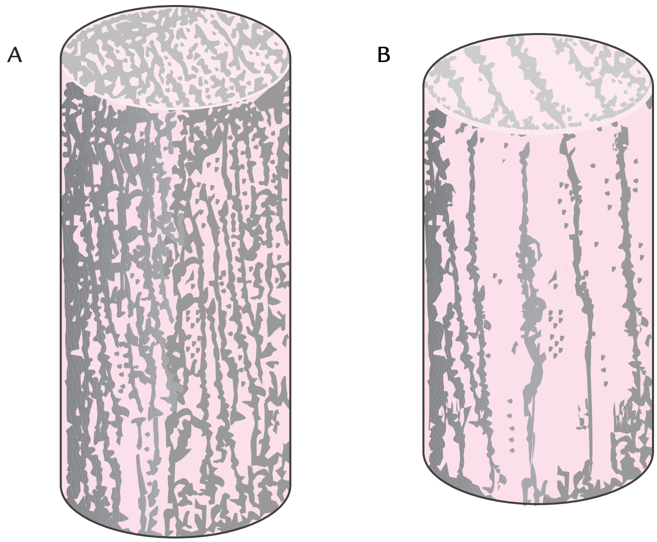

Figure 8.22 Representative diagrams of (A) high quality corks, derived from slow growing cork oaks, and (B) and lower quality cork, derived from rapid-growth cork oaks. Note the large number of growth rings in the cork on the left compared with the one on the right (diagram courtesy of H. Castelyn).

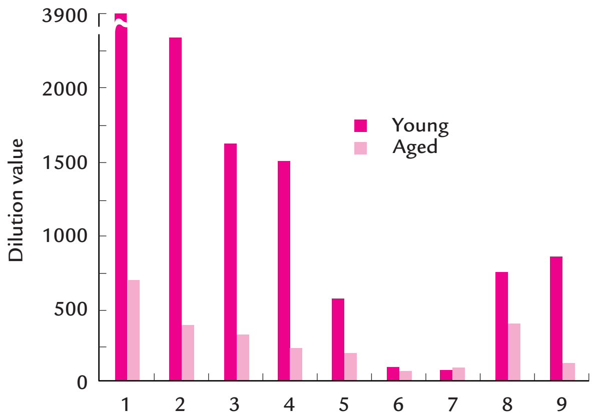

Figure 8.23 Loss of aromatic compounds during the aging of a *Vidal* wine (1,β-damascenone; 2,2-phenylethanol; 3, fruity; 4, floral; 5, spicy; 6, vanilla/woody; 7, vegetative; 8, caramel/oatmeal; 9, negative aromas) (from Chisholm *et al.*, 1995, reproduced by permission).

is unclear. Their reduced solubility may accentuate crystallization and haze generation.

During aging, wines lose their original fresh fruity character. This is especially noticeable when the fragrance depends on fruit esters or certain lactones. They progressively degrade or oxidize to flavorless or less aromatic compounds. Figure 8.25 illustrates the decline in fruit esters (e.g., isoamyl acetate) and the increase in poorly volatile carboxylic acid esters (e.g., diethyl succinate). Wines age well when the varietal character develops, or when it is replaced by a subtle, complex bouquet. In red

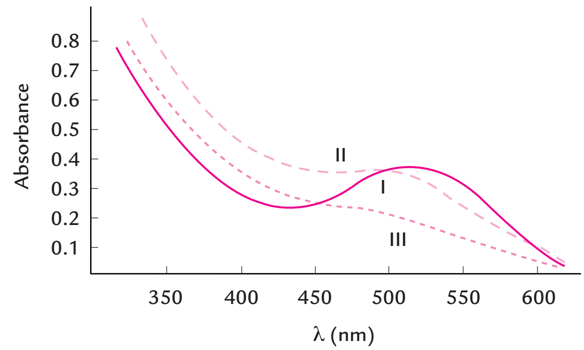

Figure 8.24 Absorption spectra of three red wines of different ages: I, 1-year-old; II, 10-year-old; III, 50-year-old (from Ribéreau-Gayon, 1986, reproduced by permission).

wines, the aged bouquet (if it develops) often has a similar character, regardless of cultivar origin.

The exact origin of the aging bouquet is unknown. However, it likely involves degradation of norisoprenoids and related diterpenes, carbohydrate derivatives, reduced sulfur compounds, and oxidized phenolics.

Of isoprenoid degradation products, 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN), appears to be particularly important in *Riesling* wines. Other isoprenoid degradation products, such as vitispirane, theaspirane, ionene, and damascenone appear little involved in the development of bottle bouquet. Table 8.2 illustrates a few age-related chemical changes that can occur in *Riesling* wines. The table also demonstrates the importance of temperature to the aging process, as also does Figure 8.26.

Carbohydrate degradation products, notably brown Maillard products, develop

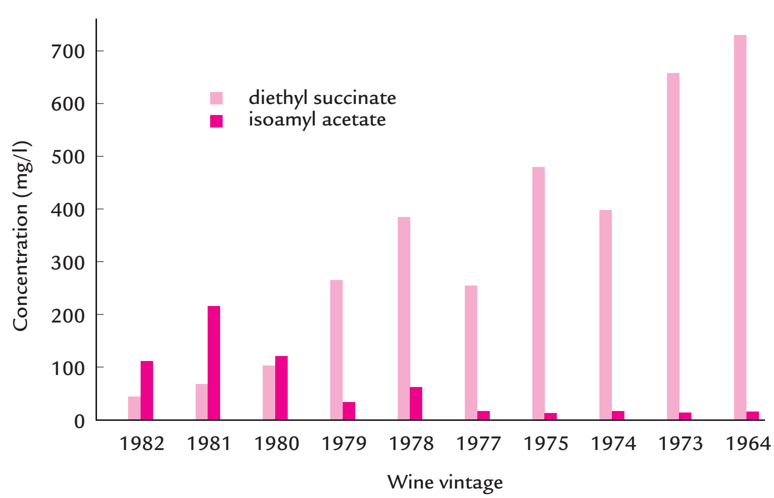

Figure 8.25 Examples of the influence of wine age on the concentration of esters, notably acetate esters (isoamyl acetate) and ethanol esters (diethyl succinate) (from Jackson, 2000, data from Rapp and Güntert, 1986, reproduced by permission).

slowly at ambient temperatures. Also involved is the fruity, slightly pungent ethyl ether, 2-(ethoxymethyl)furan. It develops during the aging of *Sangiovese* wines (Bertuccioli and Viani, 1976). This suggests that etherification of Maillard-generated alcohols may play a role in the development of aged bouquets.

The concentration, and nature, of reduced-sulfur compounds often changes during aging. Of these, only dimethyl sulfide has been correlated with development of a desirable aged aspect (Fig. 8.26D). Its addition to wine (20 mg/l) can enhance its flavor score (Spedding and Raut, 1982). Higher concentrations (≥ 40 mg/l) are considered detrimental. By itself, dimethyl sulfide has a shrimp-like odor. Occasionally, the production of dimethyl sulfide is so marked at warm temperatures that it can mask the varietal character of the wine after several months (Rapp and Marais, 1993).

In red wines, one of the best understood aspects of aging relates to the polymerization of bitter, astringent tannin subunits into large complexes. Initially, polymerization augments astringency. Eventually, these polymers become so large that they lose their ability to effectively bond to proteins. This produces the well known smoothing of the taste of red wines after prolonged aging.

Other than the initial benefits of aging noted above, older wines do not necessarily show greater quality than their younger versions. Younger versions demonstrate more fruitiness and a truer expression of varietal character. As the wine ages, the fragrance tends to become more subtle, less intense, less varietal, and it develops more of an aged aspect. It depends on the preferences of the consumer which, if either, is esteemed more. They are different but often equally enjoyable. The feature that gives old wines their major appeal is not superior quality but exclusivity. Because of age, they are rare and few people have access to them. Very old wines tend to be of greater historic than gastronomic appeal.

In most instances, the best guide to a wine's aging potential is experience. Because most consumers do not have the opportunity to gain this experience, they must depend on advice. Recommendations often show a distinct cultural bias. Early consumption tending to be preferred by French experts, whereas British authorities

Table 8.2 Changes in bouquet composition from carbohydrate decomposition during aging of a *Riesling* wine[a,b] (from Jackson, 2000, reproduced by permission)

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

[a]Data from Rapp and Güntert (1986).

[b]Relative peak height on gas chromatogram (mm).

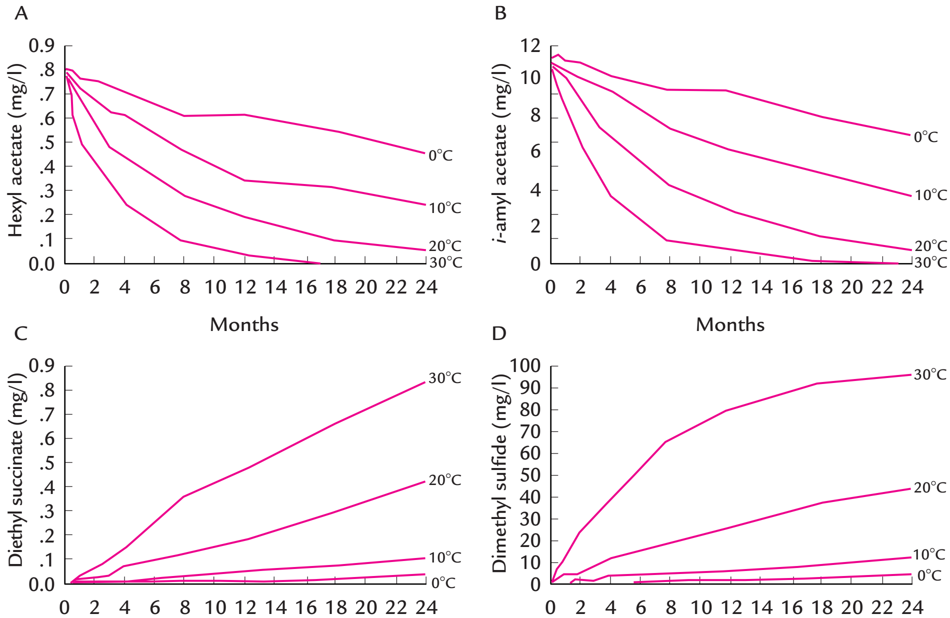

Figure 8.26 Effect of storage temperature and duration on the concentration of (A) hexyl acetate, (B) *i*-amyl acetate, (C) diethyl succinate, and (D) dimethyl sulfide in a *Colombard* wine (from Marais, 1986, reproduced by permission).

encourage longer aging. The personal relevancy of the advice can be established only by experimentation.

Chemistry

Ultimately, the quality of wine is dependent on its chemistry. With more than 800 known organic constituents potentially present in wine, that chemistry is obviously complex. Nevertheless, the vast majority of these compounds occur at concentrations below their individual detection thresholds. Even acknowledging synergistic enhancement of detection, the number of sensorially important compounds may be as low as 50 in any particular wine. Of these, only a few groups—notably sugars, alcohols, carbonic acids and phenolics—affect the sensory attributes of essentially all wines.

It is largely the interaction of sugars, acids, alcohols, and phenolics that generate what is called balance. Because balance can occur equally in dry, sweet, white, red, sparkling, and fortified wines, it is clear that the interaction is chemically perplexing. For example, the high sugar content of botrytized wines is partially balanced by their acidity, alcohol content, or both. Balance is also influenced by fragrance. In full-bodied red wines, balance may develop as the tannins polymerize during aging, losing much of their former bitterness and astringency. The alcohol content and moderate acidity of red wines also contribute to balance. Balance in light red wines is often achieved at a lower alcohol content and higher acidity than full-bodied dark red wines.

Other common constituents that affect the character of all wines are esters, aldehydes, and fusel alcohols. They donate the basic vinous odor of wine.

The remainder of the sensory significant compounds generate the aroma of varietal wines and the bouquet typical of particular wine styles. Most of these occur in trace amounts. Their chemical identity is only now being discovered. Consequently, an understanding of the most intriguing and unique aspects of wine chemistry is still in its infancy. Phenomena, such as duration and development, may arise from the action of polysaccharides and mannoproteins that loosely fix aromatics, slowly releasing them to the air (Lubbers *et al*., 1994). Progressive sensory adaptation may also play a role in the expression of minor aromatic constituents. Nevertheless, what is meant chemically by terms such as complexity, finesse, and power is unknown. It is almost undoubtedly a function of the interaction of multiple aromatic compounds, but at the moment this is just conjecture. It may be decades before the chemical origins of wine quality yield their secrets.

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Wine as a food beverage

9

Although food and wine combination is strictly not the prerogative of the wine taster, the connection between the two is so strong it behooves tasters to be cognizant of the topic. Winemakers need no reminder that their wine should be compatible with, and preferably be ideally suited to, food. Most wines are tasted (albeit not critically) in association with food. Therefore, it is reasonable to include a brief discussion on the history, theory, and practice of food and wine combination.

Human food preferences are primarily culturally based, with only the most fundamental elements being genetically encoded. Examples are the universal appreciation of the smooth texture of creams and the initial aversion to bitter and acidic foods. The appreciation of the mouth-feel of creams and oils probably relates evolutionarily to their high caloric value. In contrast, the typical aversion to bitter compounds undoubtedly involves an evolved protective reflex. Many wild plants contain alkaloids, saponins, and other bitter-tasting toxicants. The inactivation of their production was one of the first benefits of crop domestication. Highly acidic foods also produce a negative response. Presumably this also evolved as a protective measure. However, humans are highly adaptive and can develop a passion for tastes rejected in youth. Cultural norms can also change with surprising speed—for example the rapid adoption of hot spices in North American cuisine over the past twenty years. Consequently, it is not surprising that diverse social, climatic, and geographic conditions have created a wide diversity of food preferences and prejudices. When it comes to food and wine preferences, availability and personal upbringing are the primary defining factors.

Because the diversity of wine is bewildering to the majority of consumers, innumerable books and countless articles have been written to suggest specific food and wine combinations. They can provide a genuine service if the reader agrees with the author's views and percepts. Unfortunately, many consumers never advance beyond this level. Authors have prejudices, as do we all. They also tend to perpetuate conservatism. New styles, varieties, and regions are ignored or given only patronizing attention. While this may be acceptable to most consumers, it can retard innovation and the broadening of the flavor base of wines. Wines made from *Chardonnay*, and *Cabernet Sauvignon* can indeed be wonderful, but there is only a limited range in expression that can be generated by geographic origin or winemaking style. If wine sales are not to stagnate, the flavor diversity needs to be expanded in order to enlarge the consumer base. Market penetration by wine in most countries is static, and in the major wine-producing regions is shrinking (Fig. 9.1).

What follows attempts to rationalize how and why the currently accepted norms of food and wine combination developed, principally in Western cuisine.

Historical origins of food and wine combination

At least since ancient Greek and Roman times, wine has typically been consumed with meals by Mediterranean peoples. With many connoisseurs, this has taken on great complexity—specific wines being sought to match particular dishes. This fixation on finding the perfect amalgam between wine and food is a recent phenomenon.

From the limited written record, there seems to have been little recognition of specific food and wine pairing in the ancient Greek and Roman worlds. In most instances, wines were not of a quality that invited specific food associations. Most of the famous wines of antiquity probably were concentrated sweet wines. To modern taste, such wines would not combine well with food.

During the medieval period, winemaking skill was generally poor. The wines often spoiled within less than a year. To fill the void created by the spoilage, makeshift wine was produced from immature fruit. Because most wine did not travel well, under the primitive transport systems of the time, even the nobility would have had little access to the range of wine considered necessary for refined food and wine harmonization.

Only with improved transport and a general amelioration in living standards did circumstances arise favoring food and wine combination. With increased leisure and disposable income, it became possible to acquire the diversity of wines requisite for connoisseurship.

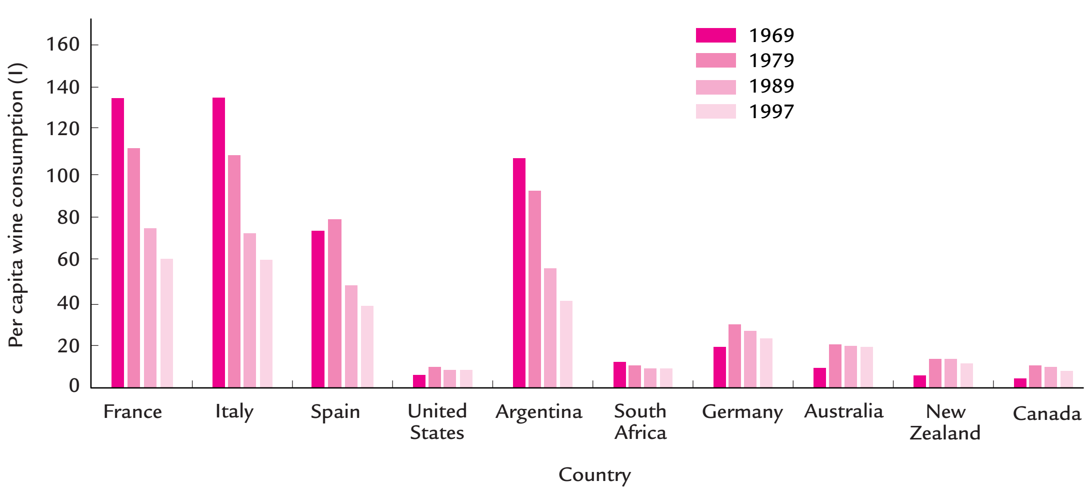

Figure 9.1 Changes in per capita wine consumption in several countries between 1969 and 1997 (from Jackson, 2000, reproduced by permission; data from Anonymous, 1990; Dutruc-Rosset, 1999).

Coincident with the improving economy of western Europe was a change in eating habits. In the mid-1600s, the old pattern of a conglomerate of disparate dishes, all served simultaneously, began to be replaced by an orderly sequence of dishes we would recognize. This offered the chance for specific wines to be selected to complement particular components of a meal. In addition, culinary practice based on the theories of Hippocrates and Aristotle began to be supplanted by those derived from the commentary of Paracelsus, an early sixteenth century German physician (Laudan, 2000). Under the older nutritional concept, diet could affect health by balancing the four basic elements of life (heat, cold, wet and dry). This theory was replaced by the concept that proper nutrition involved three essential components. One, called the "salt" principle, gave food its taste (e.g., salt and flour). The second principle ("mercury") gave food its smell (e.g., wine, and meat sauces). The third principle ("sulfur") bound the two former elements together (e.g., oil and butter).

Dietary recommendation was one of the few pleasant 'remedies' open to the physician in ancient times. Physicians were often employed by the wealthy for their restorative culinary advice. With the change in nutritional theory, heavily spiced dishes disappeared, sugar was relegated to dessert (rather than added to almost every dish), and wines in their natural state replaced the almost universal use of hot, spiced, red wines (*hypocras*). That the goodness of a meal might be concentrated in gases (nourishing the brain) may have favored the acceptance of sparkling wine. The first mention of sparkling wine coincides with the change in culinary habits (late seventeenth century). Equally, the reputed salubrious benefits of distilled spirits (e.g., *eau de vie*) provided a health rationale for adding distilled spirits to wine. In addition, adding distilled spirits to the low acid wines from southern Europe prevented spoilage during their sea voyage to northern centers of commerce. The augmented alcohol content also supplied extra "warmth," a valued property on cold drafty nights. Developments in science also began to improve the stability and general quality of wines. Under such conditions, the stage was set for major refinements in cuisine and the development of sophisticated associations with wine.

Guiding principles of food and wine combination

The central theme of most food and wine pairing is harmony between comparable flavor intensities. This concept has been crystallized in the adage "red wines with red meats, and white wine with poultry and fish." White wines are typically lighter in flavor and more acidic than red wines. What red wines lack in acidity is recompensed by its polyphenolic content. Another element of food and wine harmony relates to color. White wines look better when matched with pale colored foods and sauces, just as red wines are visually more appealing with dark meats and sauces.

At this basic level, the concept of flavor compatibility is easy to comprehend. However, precise pairing of food and wine, based on flavor intensity, is far from simple. There is no easy way of determining accurately flavor intensity. Rietz (1961) attempted to quantify the relative flavor intensities of different foods. By selecting items from various columns of food items, menus could be developed to combine foods of compatible flavor, or to show a predetermined change in flavor intensity throughout a meal. Although interesting, factors such as preparation technique (e.g., poaching, baking, grilling), flavor complexity, and serving temperature can significantly modify flavor intensity—and, thereby, the choice of wine. Establishing an estimate of wine flavor intensity is equally, or even more, complex. Figure 9.2 illustrates the relative flavor intensities of several wines. However, for many types, considerable variation in flavor intensity may be found. For example, *Gewürztraminer* varies from light and slightly sweet, to bone dry and intensely flavored. The former would go well with lightly braised chicken, but the latter with roast turkey and spicy stuffing. The only way of assessing actual flavor intensity is by sampling. Tasting in advance in most instances is either impossible, impractical, or economically unfeasible. Experience and personal preference are again the only certain guides. Although perfect matches are rare, so are disasters.

Although subtle harmony is often considered essential to refined dining, contrasting flavors often give a meal dynamic tension. This is most often provided by the addition of spice. Alternatively, condiments such as a roux or salsa can generate the concentrated flavors desired. Occasionally, though, wine adds the flavor intensity wanted. For example, a red wine may be served with poultry. Conversely, a light wine may soften the intense flavors of the meat.

Occasionally, famous associations occur when seemingly opposed tastes or flavors combine in a dynamic, seemingly unstable, equilibrium. Examples of some of the more well-known opposed combinations are the associations of port with Stilton cheese, the union of Sauternes with Roquefort cheese, venison with *Riesling* auslese, Sancerre with goat cheese, and crab with Chablis. The rationale for the combination of sweet, richly flavored wines (ports and Sauternes) with salty, creamy, blue cheeses (Stilton and Roquefort) seemingly relates to their similar richness and the blend of salt and sweetness. The complexities of their flavors integrate, enhancing mutual enjoyment. In Germany, the gamey character of well-aged venison is considered to be counterbalanced by the sweet, rich flavors of a fully mature *Riesling* auslese. In the Loire, the aggressive dry acidity of Sancerre is viewed as counterpoised when taken with racy goat cheeses. Finally, the sourness of Chablis is deemed to be offset by the sweet flavors of crab. Ingenuity is often the source of new and unexpected gastronomic delights.

The latter may explain the combination of foods and wines that rarely have common flavor qualities. For example, the predominant flavor attributes of wines are fruitiness, floral notes, vegetal, and oaky aromas. These are rarely found in the main constituents of a meal. Conversely, common food flavors are seldom found in wines. Only occasionally will the nutty aspect of cream sherries complement a walnut dessert, or the oaky character of wines blend with the smoke flavors of meat roasted over charcoal. Therefore, wine is most frequently a liquid condiment, appreciated as an alternative flavor component of a meal.

Cheeses are typically served at wine tastings. However, strong-flavored cheeses can easily dominate, masking the subtleties of a fine wine. Conversely, mild

WHITE WINES	Light	Medium Light	Medium	Medium Full	Full
Chardonnay		Chablis	Burgundy	California Australia	
Chenin Blanc		Loire			
Gewürztraminer			New World	Alsace	
Müller-Thurgau			Rheinpfalz Rheinhessen		
Pinot Gris		Veneto	Alsace		
Parellada		Catalonia			
Riesling		Mosel	New World	Rheingau	
Sauvignon Blanc		Loire	Bordeaux	New World	
Sémillon			Bordeaux New World		
Sylvaner		Franconia			
Trebbiano	Soave	Orvieto			
Viura		Rioja (new style)		Rioja (old style)	

RED WINES	Light	Medium Light	Medium	Medium Full	Full
Barbera			Piedmont		
Cabernet Sauvignon			Bordeaux	New World	
Cannonau			Sicily		
Corvina			Valpolicella	Amarone	
Gamay Noir		Beaujolais			
Maréchal Foch			Eastern N. A.		
Merlot			Bordeaux/New World		
Nebbiolo			Barbaresco	Barolo	
Pinot Noir		Burgundy	Oregon		
Sangiovese			Chianti Brunello		
Shiraz (Syrah)			Rhône	Châteauneuf-du-Pape	Australia
Tempranillo			Rioja		
Zinfandel		'White' Zinfandel		Red Zinfandel	

	Light	Medium Light	Medium	Medium Full	Full
SPARKLING		Vinho Verde Cava	Champagne	Vintage Champagne	Asti Spumante
SHERRIES		Manzanilla Fino	Pale Cream	Amontillado Dark Cream	
PORTS		White	Tauny	Ruby	Vintage

Figure 9.2 Relative flavor intensity of wines based on cultivar, geography and style (from Jackson, 2000, reproduced by permission).

cheeses contribute little to enhancing wine appreciation. Salty cheeses can be of benefit, however. The sodium from the salt can miraculously reduce the bitterness (Breslin and Beauchamp, 1995) and astringency of tannic red wines. In addition, fine-flavored cheeses can enhance the apparent quality of mediocre wines. There is much rationale in the old maxim of: “sell wine over cheese, but buy it over water.”

One of the more intriguing developments in Western cuisine is the recent and extensive use of hot spices in our food. The burning sensation of chilies and most curries deadens the taste buds to the subtleties of wine. This seems to have lead to a renewed appreciation of wines with stronger tastes that can compete with the spices. Another cultural import, the use of sweet sauces, characteristic of some Chinese dishes, may herald a renewed appreciation of semi-sweet wines with food in Western cuisine.

Use

Basic roles

At its simplest, wine acts to cleanse the palate. This is primarily effected by its washing action. In tannic wines, though, part of this results from phenolics enhancing saliva production (Hyde and Pangborn, 1978). Ethanol also increases saliva production (Martin and Pangborn, 1971). Cleansing the palate minimizes sensory fatigue because wine flavors alternate with those of the food. Thus, food maintains its flavor and appeal unabated throughout the course of the meal. Conversely, food helps freshen the palate for the wine.

Wine is often considered a foil for the meal, complementing the central flavors of the food. It is less recognized that food often ameliorates attributes of the wine. For example, the binding of food proteins with acids and tannins softens the expression of the acid and bitter–astringent sensations that typify most white and red wines, respectively. Thus, food may more frequently enhance the appreciation of wine than the reverse. In the process, though, the acidity of white wine tends to freshen the mouth, as well as diminish the perception of oiliness[1], whereas the moderate bitterness and astringency in red wines can enhance the flavor of most red meats. Prolonged maceration and oak maturation can give white wines the flavor and bitterness sufficient to complement more tangy foods than usual.

Wine also has significant solubilizing action. The acids and alcohol in wine may solubilize or volatilize food flavorants. In so doing, wine can accentuate food appreciation. Conversely, the dilution of alcohol by food constituents can promote the liberation of wine aromatics (Fischer *et al.*, 1996; Fig. 3.12). This may be the origin of certain aspects of a wine’s finish.

Despite this, the main reason why people take wine with meals is simply because they enjoy the combination. It slows eating, permitting each morsel to be savored.

[1] The best evidence thus far suggests that fatty acids affect the sensitivity of taste receptors (Gilbertson *et al.*, 1997), rather than acids affecting the sensitivity of fats.

Wine also tends to encourage conversation and the social aspect of dining. The presence of a fine wine raises a biologic need to the level of one of life's greatest delights.

In food preparation

Wine has long been exalted for its capacity to complement a meal. Equally, wine has a long tradition in food preparation. Probably the oldest is as a marinade. Wine acids can hydrolyze proteins, tenderizing meat. The acids also temporarily preserve it. Pickling with wine vinegars is an extreme example of this function. Wine also has been employed to extract or mask the gamey flavor of wild meats. The wine seldom modifies the food's flavor significantly, since the marinade is usually discarded after use.

Another culinary use of wine is as the base for poaching, stewing, or braising. Fine wines are seldom used because cooking dramatically changes the wine's flavor. What is particularly important is that the wine does not adversely affect the food's flavor. Wine color is unimportant, because prolonged heating turns the wine brown.

When poaching or braising, the wine may be reduced to make a sauce. Alternatively, wine may be added to deglaze the pan. Because deglazing exposes the wine to less heating, the sauce will possess more of the natural flavors and color of the wine. The more one wants the original wine flavors to appear in the food, the later the wine should be added. Correspondingly, this requires more care in selecting the wine.

Occasionally, dry wines are used as a fruit marinade, may act as a poaching fluid for firm fruit, be incorporated into a sherbet, or function as a blending medium for creamy custards. Otherwise, only sweet wines are compatible with dessert—notably with fresh, fully mature, low-acid fruits, such as strawberries, peaches, and apricots.

Carbon dioxide escapes from wine even more rapidly than does its alcohol content. Thus, there is little value in using sparkling wine instead of still wine. Cooking promotes the evaporation of ethanol, but its loss is often much slower than generally realized (Table 9.1).

Table 9.1 Comparison of various methods of food preparation on the loss of alcohol from wine[a] (from Jackson, 2000, reproduced by permission)

Preparation method	Alcohol remaining (%)
Flambee	75
Marinade (overnight)	70
Simmered (15 min)	45
Simmered (30 min)	35
Simmered (1 h)	25
Simmered (2 h)	10

[a]Data from Augustin *et al*. (1992).

Types of occasion

Different situations invite different qualities or styles of wines. This is self-evident in the choice of fine wines to complement special meals. There, exquisite tastes demand an exceptional wine. Equally, the light, semi-sweet wine that is a delight in summer may seem inappropriate by the fire in winter. However, the choices people make often seem to reflect more habit than appropriateness. For example, dry wines achieve more balance in combination with food than alone. Nevertheless, such wines are often served by themselves. Cultural habits are often the primary determinant in food, as well as wine selection.

Presentation sequence

Because sensory acuity tends to decline during a meal, the flavor intensity of a series of wines should increase during the meal. An exception to this rule is the choice of a dry sherry at the beginning of a meal. This is ostensibly chosen to stimulate the appetite and activate the secretion of digestive juices. More in keeping with increasing intensity is the choice of a light dry white or sparkling wine before dinner. They equally activate the release of digestive juices, while their subtle flavors do not blunt the appetite. A more intensely flavored white or red wine is typically served to combine with the main course, depending on the character of its principal component. At the end of the meal, a full flavored fortified wine, such as a port or oloroso sherry, may be served before or after dessert.

There is also a convention that the finest wine should be served last. This rationale is based on the view that a fine wine will appear even more so by the comparison. It does have the risk, though, that satiety may dull the senses, reducing appreciation.

There is another tradition that the guests should know what vinous pleasures are in store. This does enhance anticipation, but it also increases expectation. If this comes to fruition, fine. Otherwise, it may require public accolade, but result in personal sensory disappointment. This can be avoided by presenting the wine without acknowledgment. If the guests recognize the wine's quality, one's pleasure is all the greater. Personally, my most memorable vinous experiences have occurred when a seraphic wine was offered, without the prior expectation that heavenly delights were in stock.

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Glossary

Appearance—any visual wine perception

Clarity—degree of brilliance (absence of haze-causing colloids or particulate matter); can vary from *clear* to *dull* to *cloudy*
Color—presence of perceptible amounts of yellow, red or brown particles in solution
Sparkle—chains of carbon dioxide bubbles rising in the wine; *still* refers to their absence, *pearl* refers to slight effervescence, and *sparkling* refers to marked, prolonged effervescence
Spritz—formation of a few bubbles on the sides or bottom of a glass; may generate a just-perceptible prickling on the tongue.

Balance—the perception of harmony, notably between the sweet, sour, bitter, and astringent sensation in the mouth, but clearly influenced by the intensity of the aromatic sensation of the wine; one of the most highly regarded of wine attributes

Finish—the perceptions that linger in the mouth after the wine has been swallowed or expectorated
After-smell—the flavor aspect of finish; usually a highly regarded attribute
After-taste—the taste–mouth-feel aspects of finish

Mouth-feel—perceptions derived from trigeminal receptors in the mouth

Alcoholic—a negative expression indicating the excessive presence of alcohol, relative to other sensory attributes
Astringency—a set of tactile sensations including *dryness*, *puckeriness*, and *dust-in-the-mouth* perceptions; provoked principally by the polyphenolic content of wine, but also induced by acids; *smooth* implies a positive response to astringency; *rough* refers to excessive astringency
Body—a tactile sensation induced primarily by the presence of alcohol, but clearly influence by the presence of sugars, glycerol (in high concentration), and phenolics; *full-bodied* is a positive perception of weight in the mouth; *watery* is the negative perception of the absence of sufficient body
Burning—an intense sensation of heat that can be generated either by high alcohol or very high sugar contents

Heat—a perception of warmth generated by the presence of ethanol
Pain—a sharp sensation occasionally induced by excessive tannin contents, or high carbon dioxide contents under cold conditions
Prickling—the pleasant sensation of pain induced by the bursting of bubbles of carbon dioxide on the tongue

Odor—olfactory perceptions that may come from sniffing the wine (orthonasal) or vapors reaching the nasal passages via the mouth (retronasal)
Aroma—the fragrance derived from grapes; typically some complex of *fruity*, *floral*, *spicy*, or *herbaceous* attributes; see Figure 1.3 for specific descriptors
Bouquet—the fragrance derived either from alcoholic fermentation (i.e., *fruity*, *yeasty*), processing (i.e., *buttery*, *nutty*, *oaky*, *madeirized*), or aging (*i.e., oxidized*, *leathery*, *cigar-box*)
Complexity—a quantitative/qualitative term referring to the perceptible presence of many aromatic compounds, combining to generate pleasure; a highly desirable attribute
Development—the change in the aromatic character during the period in which the wine is sampled; a highly regarded wine attribute
Duration—the length of time the wine maintains its distinctive character, before becoming just vinous (generically wine-like); long duration is a highly regarded attribute
Expression— the relative evolution of the fragrance; *closed-in*, if not apparent in a young wine; *opening*, progressive increase in aromatic intensity; *faded* when absent in an old wine; *well developed* when amply present
Off-odors—the detectable presence of olfactory compounds considered unacceptable or atypical; see Figure 1.4 for specific examples
Stylistic—presence of a fragrance typical of a particular winemaking style (i.e., *carbonic maceration*, *recioto*, *botrytized, flor*, *baked*)
Varietal—presence of an aroma distinctive to as single, or a group of related, grape cultivars; see Tables 7.2 and 7.3

Taste—oral perceptions derived from the taste buds

Acidity—a sour perception derived as a complex response to organic acids, wine pH, and the sensory impact of other sapid substance, notably sugars, ethanol, and phenolic compounds; *flat* refers to the absence of sufficient acidity, the opposite of *acidic*; *tart* usually denotes an appropriate, pleasant acidic perception
Bitter—a perception induced primarily by the presence of low-molecular-weight phenolic compounds that is influenced marginally by the presence of sugars, ethanol and acids
Sweet—the perception of sweetness; a complex response to compounds such as sugars, glycerol and ethanol, as influenced by sensations to the acidic and phenolic compounds in the wine; *cloying* refers to an intense, unpleasant sensation of sweetness; the opposite is *dry*

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Note:, All entries relate to wine, unless otherwise noted. This index is sorted in word-by-word order, whereby spaces and hyphens between words are given sorting value.

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