Wine Tasting: A Professional Handbook
Second Edition
Food Science and Technology
International Series

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Wine Tasting:  
A Professional Handbook  

Second Edition

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Dedication

To my wife, Suzanne Ouellet
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Preface

Wine tasting means different things to different people. For this text, it primarily refers to critical wine assessment. Thus, it attempts to differentiate between perception (the human response to sensation) and sensation itself. It is searching for *tangible* reality. Training and experience are usually required to separate subjective response from objective evaluation. Usually, however, wine tasting is more concerned with the *perception* of reality. That is what sells wine. Thus, most wine tastings are conducted under conditions that favor positive assessment. This is not a criticism but a reflection of the diverse functions of wine tasting. Each has its purpose and merit, with none being inherently more appropriate than another.

Winemakers have their particular interests in wine tasting: facilitating wine production in a particular style and checking for sensory defects before they become serious or irreversible. Wholesalers and retailers are interested in selecting wines that suit the desires of their clients and in avoiding faulty wines. For most connoisseurs, tasting wine is intended to enhance appreciation, either by itself or in combination with food. This is the clientele for whom most boutique or premium wine producers aim their products. For even a larger group of individuals, notably in Europe, wine is simply the standard food beverage – tasting with discernment being reserved for special occasions. For others, wine consumption is a status symbol or an affirmation of cultural heritage. Although the thrust of this text is scientific, selected sections can be used by any wine taster. Correspondingly, applied aspects are noted separately to facilitate their use by those less interested in tasting’s academic aspects.

In addition to differences in how people interpret wine tasting, the term *taste* has multiple meanings. Technically it refers to specific chemosenses detected by modified epithelial cells located in taste buds. In common usage, however, it incorporates the somatosensory sensations of mouth-feel and olfaction. As a verb, it refers to the process of sampling beverages and foods, usually in a conscious assessing mode. The terms “organoleptic” and “degustation” specifically refer to aspects of this process, but for various reasons have not been espoused in either the scientific or popular literature.
The complexities surrounding the terms “taste” and “tasting” underscore a fundamental duality. Gustatory, olfactory and mouth-feel sensations, as well as associated visual and auditory sensations are derived from different physical locations. However, the responses, initially analyzed in distinct areas of the brain, are combined and integrated for final interpretation in a central location – the orbitofrontal cortex. These multisensory perceptions, and the memory traces they encrypt, generate what is termed “flavor.” It is a cerebral construct. Examples of this illusion are the sweet “taste” of many fruity odors, the “loss” of flavor from gum as its sugar content declines, and the “nutty” aspect of cracked-wheat bread. The association with intake probably explains, at least partially, why the brain “locates” flavor as originating in the mouth and with “tasting.”

The techniques described are primarily designed for professional tasters – those involved in assessing wine attributes, relative quality, or conformity to traditional varietal or regional styles. These skills are required not only for critical wine evaluation, but also for successful wine making. Although analytic, these procedures can be adapted by the restaurateur or wine merchant, as well as individuals desiring to fully appreciate a wine’s sensory attributes.

Small wineries rarely employ the detailed sensory evaluation procedures noted in the text. Their wines are produced “on the palate of the wine-maker”—the wine being considered a creative, artisanal product, not designed for a mass market. Their wines sell because sufficient customers accept the winemaker’s perceptions. It also helps that most consumers are not particularly discriminating or demanding. Customers are often easily persuaded by the opinions of others. This is not a disparaging comment on consumers or small wineries, just an affirmation of reality. Some small wine estates produce absolutely superior wines and their winemakers are exceptionally skilled. The same procedures, in less competent hands, can produce eminently forgettable wines. The situation is quite different for large wineries. Their wines are sold internationally, produced in million-liter plus quantities, face extensive and stiff competition, and are sold continents away from any personal contact with the winery staff. Successful brands are created using selective blending techniques that require the use of some of the most sensitive and critical sensory evaluation procedures available. Millions of dollars and shareholder profits ride on the decisions made not only by grape growers, winemakers, marketers, but also sensory evaluation experts. There is little margin for personal error. Quality control is critical.
In the text, the reader is first guided through the steps of wine tasting. 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 selecting 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 discussion of what can confidently be said about wine and food pairing.

Although significant strides in our understanding of sensory perception have occurred in the past few years, it is also becoming clear that perception is relative, with few absolutes. What individuals perceive depends not only on their genetics, but also on their upbringing, current emotional and physical health, and the context in which the tasting occurs. Within limits, the latter can be more important to perception than the quality of the wine. Dogmatism concerning wine quality is as obsolete as the model-T Ford.

Because of historical and cultural connections between food and wine, and its popularity among wine aficionados, the topic has received more extensive expansion and revision than any other chapter. Despite this, the best wines usually express their finest qualities more clearly when sampled in the absence of food. For example, the development and finish of a wine are seldom detectable when consumed with food. The time required for their expression rarely being available or appropriate during a meal. To facilitate their detection, wine aficionados often analyze fine table wines prior to eating, or consume the wine slowly and conscientiously with simply prepared food (minimal flavoring). Aperitif and dessert wines are more amenable to full appreciation as they are frequently taken alone.

As with the appreciation of other art forms, the feeling of status and well-being, associated with sampling fine wines with delicately and exquisitely prepared food, is its primary appeal. This is especially evident in the elaborate surroundings of fine dining establishments. This is one of the advantages of surplus income, where the pleasures of eating can be divorced from simply abating hunger pangs. In addition, pairing wine with food helps avoid monotony at the table. Except where the suggestions of experts are followed slavishly, just the act of wine selection can give pleasure and a sense of intrigue.

Wine can act as a wonderful accompaniment to a meal, helping to cleanse the palate while providing a distinct and gratifying sensation, and elevate mealtime to a sublime celebration of life. In turn, food freshens the palate to receive anew the flavors of the wine. Compatibility rests primarily in their differences, not on their similarities. In this regard, wine can be considered a food condiment. Correspondingly, a central tenet of
food and wine combination is that the attributes of the wine should neither clash with the food, nor be excessively mild or intense, in comparison with the predominant food flavors. This is all, of course, based on the flavor sensitivities of the individual, and acceptance of the concept of balance as desirable in wine and food combination. Although an interesting and endless topic of conversation, undue concern about pairing can overshadow what should be a pleasurable and relaxed occasion to nourish the body as well as the soul.

Hopefully, the information contained herein will give the reader the ability to strip away the influences of context and experience that too often afflict wine tasting, precluding valid and fair assessments. As often as not, you should question your own perceptions as much as the views of others. Investigations have clearly demonstrated how powerful expectation or suggestion can be, not only on the higher cognitive centers of the brain, but also on how they impact the responsiveness of receptor neurons. Knowing how the brain can potentially “deceive” us gives us the power to select what contextual or experience-based influences we permit to affect perception. It is always better to be in the driver’s seat than to be driven.

References included in the text are provided as a guide to further investigation, rather than attempting to be all-inclusive. Suggested Readings supply a list of major texts and reviews.

If anything, I hope that from time to time you will relax and fully contemplate the sensory intricacies of wine and how they can complement a meal. They can embellish our short span on this small speck of the universe with wonders that make life fully worth living.

R. S. Jackson
Acknowledgments

Without the dedication of innumerable researchers, the complexities of human sensory acuity and perception would remain mysteries and this book would have been impossible.

Many thanks go to my students, participants of sensory panel tests, MLCC External Tasting Panel, the Manitoba Liquor Control Commission and Academic Press for providing the opportunity to gain access to both the practical and theoretical sides of wine assessment.

Finally, but certainly not least, I must express my thanks to the assistance provided by staff at Elsevier, notably Nancy Maragioglio and Christie Jozwiak. Their help and encouragement have been critical in bringing this book to fruition.
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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 the 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 and Applications, 3e (2008), Conserve Water Drink Wine (1997), several technical reviews, and annual articles in Tom Stevenson’s The Wine Report. Dr. Jackson has retired from teaching to devote his time to writing, but remains allied with the Cool Climate Oenology and Viticulture Institute, Brock University. He may be reached at Elsevier, 525 B Street Suite 1900, San Diego, CA 92101-4495.
As befits one of life’s finest pleasures, wine deserves serious attention. Nevertheless, no wine tasting procedure has achieved universal adoption. Most experienced wine tasters have their own preferred procedure. Although essential for critical tasting, those described here are too detailed for the dinner table. The difference is equivalent to score analysis versus music appreciation. 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, due to the distractions of conversation and the interference of food flavors, the concentration involved in wine analysis can greatly enhance appreciation.

**TASTING PROCESS**

The technique discussed here (Fig. 1.1) is a synopsis of experience gained from assessing tasters, but is a reasonable starting point. No technique is ideal for everyone. Probably the most essential property of a serious taster is the willingness, desire, and ability to focus his or her attention on the wine’s characteristics.

Peynaud (1987) advocates rinsing the mouth with wine before embarking on serious tasting. Where tasters are unfamiliar with the characteristics of the
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* (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 and 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 perceived, 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.

* 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 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 pleasurable, 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.

FIGURE 1.1 Cont’d

wines to be tasted, it can familiarize the senses to the basic attributes of the wines. However, the introductory sample must be chosen with care to avoid setting an inappropriate standard and distorting expectations. Peynaud also cautions against rinsing the palate between samples. He feels that it may alter sensitivity, and complicate comparing wines. In this recommendation, Peynaud is at variance with other authorities. Only when the palate seems fatigued does he support palate cleansing. Leaving palate cleansing up to individual tasters assumes that they can judge accurately when their senses are beginning to show adaptation. Since this is a dubious assumption, it is safer to encourage tasters to cleanse their palate between each sample. In contrast, olfactory adaptation may have an advantage. For example, it may “unmask” the presence of other aromatic compounds (Goyert et al., 2007). It is a frequent observation that the quality and intensity of a wine’s aromatic characteristics change as it is being sampled. This occurs not only over the full course of a tasting (up to 30 min), but also during any particular sampling. Investigation of the complex interaction of aromatics on perception is still in its infancy (Brossard et al., 2007).

Most wines are best sampled in clear, tulip-shaped goblets (Fig. 1.2; Plate 5.11). The primary exception involves sparkling wines. These are normally judged in elongated, flute-shaped glasses (Plate 5.13). 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 tastings. Not only are small volumes economic, but they facilitate holding the glass at a steep angle...
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 better assessed.

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. An example of the influence of wine coloration on perceived quality is illustrated in Fig. 2.6. It is also well known that a deep red color increases perceived quality, even when assessed by seasoned judges. Thus, visual clues must be assessed with caution to avoid unfair prejudgment of the wine.

Clarity

All wine should be brilliantly clear. The haziness often obvious in barrel samples is of little concern. It is eliminated before bottling. Cloudiness in bottled wine is another issue. It is always considered unacceptable, despite its seldom affecting the wine’s taste or aromatic character. Because most sources of cloudiness are understood and controllable, the presence of haziness in commercial wine is uncommon. The major exception may involve some well-aged red wines that eventually “throw” sediment. However, careful decanting can avoid resuspending this material.
**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 and intensity 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 overmature grapes may generate yellowish wines. Increased maturity often enhances the potential color intensity of red wine. The extent to which these tendencies are realized largely depends on the duration of maceration (skin contact). Maturation in oak cooperage enhances age-related color changes, but temporarily augments 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 often inappropriate to be too dogmatic about the significance of any particular shade. Only if the wine’s origin, style, and age are known, may color indicate its “correctness.” An atypical color can be a sign of several faults. The less known about a particular wine, the less significant color becomes in assessing quality. If color is too likely to be prejudicial, visual clues can be hidden by techniques such as using black glasses.

Tilting the glass has the advantage of creating a gradation of wine depths. Viewed against a bright background, the variation in depth creates a range of hues and density attributes. Pridmore et al. (2005) give a detailed discussion of these phenomena. The rim of the wine provides one of the better measures of a wine’s relative age. A purplish to mauve hue is an indicator of youth in a red wine. A brickish tint along the rim is often the first sign of aging. By 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 in words. 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 comparative value, it does not even temporarily preserve an accurate record of the wine’s color.

Until a practical standard is available, use of a few simple terms is probably preferable. 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. These terms are fairly self-explanatory and provide an element of effective communication.
Viscosity
Wine viscosity refers to its resistance to flow. Factors such as the sugar, glycerol, and alcohol content affect this property. Typically, though, perceptible differences in viscosity are detectable 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 sides and bottom of a glass, or the slight effervescence seen or detected in the mouth. Active and continuous bubbling is generally found only in sparkling wines. In the latter case, the size, number, and duration of the bubbles are important quality features.

Slight effervescence is typically a consequence of early bottling, before the excess, dissolved, carbon dioxide in newly fermented wine has had a chance to escape. Infrequently, a slight spritz may result from the occurrence of malolactic fermentation 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 the glass following swirling. They are little more than a crude indicator of a wine’s alcohol content. Other than for the intrigue or visual amusement they may inspire, tears are sensory trivia.

Odor
When one is assessing a wine’s fragrance, several characteristics are assessed. They include its quality, intensity, and temporal attributes. Quality refers to how the odor is described, usually in terms of other aromatic objects (e.g., rose, apple, truffle), classes of objects (e.g., flowers, fruit, vegetables), experiences (grandmother’s pumpkin pie, East Indian store, barnyard), or emotional responses (elegant, subtle, perfumed). Intensity refers to the relative magnitude of the odor. Temporal aspects refer to how the fragrance changes with time, both in quality and intensity.

Orthonasal (in-glass) Odor
Tasters are often counseled to smell the wine before swirling. This exposes the senses to the wine’s most volatile aromatics. When one is comparing several wines, it is often more convenient to position oneself over the glasses than raise each glass to one’s nose. Repeat assessment over several minutes provides the taster with an opportunity to assess one of a wine’s
most ethereal attributes—development, how the fragrance changes over the course of the tasting.

The second and more important phase of olfactory assessment follows swirling of the wine. Although simple, effectively swirling usually requires 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 permits vigorous swirling. As one becomes familiar with the process, start shifting to swirling by wrist action. Once comfortable with this action, raise the glass off the surface to a more normal height for easy smelling. Some connoisseurs hold the glass by the edge of the base. While this approach is effective, its awkwardness seems an affectation. It is simpler, and safer, to hold the glass jointly by its stem and base.

Because the escape of wine aromatics occurs at the air/wine interface, volatilization is a partial function of surface area. By increasing the effective surface area, swirling favors the release of aromatic compounds. In addition, swirling effectively mixes the wine, replenishing the surface layer with aromatics. This is important because of the wine’s small surface area, relative to its volume. Diffusion of aromatics to the surface is slow. For highly volatile compounds (those with high air/liquid partition coefficients—$K_a$), the surface layers may rapidly become depleted of volatile molecules.

The incurved sides of tulip-shaped glasses not only help concentrate released aromatics, but also permit vigorous swirling. Other factors influencing volatilization are the equilibrium between dissolved and weakly bound aromatics, and surface tension effects.

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, involving both inductive and deductive reasoning, is usually required for detecting and recognizing varietal, stylistic, or regional attributes. It often requires several attempts. As the primary source of a wine’s unique character, the study of fragrance merits the attention it requires. Murphy et al. (1977) consider that as much as 80% of the sensory significant information about what we consume comes from olfaction.

Under sensory lab conditions, covers are often placed over the mouth of the glass. These may be watch glasses, small Petri dish covers, or even coffee-cup lids of appropriate diameter. The covers can serve two purposes. With highly fragrant wines, the cover limits aromatic contamination of the immediate environment. Such contamination can complicate the assessment of less aromatic wines. The primary function, though, is to permit especially vigorous swirling (if the lid is held on tightly with the index finger). This can be valuable when the wines are aromatically mild.
No special method of inhalation seems required for odor detection (Laing, 1983). Often, a single sniff is adequate for odor identification (Laing, 1986), at least in simple aromatic solutions. A typical sniff lasts about 1.6 s, has an inhalation velocity of 27 liter/min, and involves approximately 500 cm$^3$ of air (Laing, 1983). The duration and vigor are usually instinctive, being inversely related to odor intensity, unpleasantness, and ease of identification (Frank et al., 2006). Thus, although sniffing for more than half a second rarely improves odor identification, at least of single compounds under laboratory conditions (Laing, 1982), extending sniff duration up to 2 seconds may be helpful with aromatically neutral wines. However, for many wines, prolonged inhalation may only accelerate adaptation and loss of sensitivity.

The action of sniffing by itself activates the cerebral olfactory centers (Sobel 1998). This is similar to the activation of the gustatory cortex with tasteless solutions (Veldhuizen et al., 2007). Nonetheless, because the strength of a sniff differentially affects the efficiency with which various odorants are deposited on the olfactory mucosa (Kent et al., 1996), it may be useful to vary the intensity of sniffing during wine assessment (Mainland and Sobel, 2006). Different odorants adsorb to the mucosa at different rates, analogous to a gas chromatogram. Longer inhalations appear to equalize odorant detection via both nostrils (Sobel et al., 2000), negating any potential affects of the typical differences in flow rate between the nostrils (Zhao et al., 2004).

Although extended inhalation induces adaptation to the most readily detected compounds, it can be informative with some aromatically complex wines, notably ports. As olfactory receptors become adapted to certain constituents, masked or aromatic sensations that take longer to activate may become apparent.

When one is repeatedly sampling the wine, each sniff should ideally 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 to replenish itself (Fischer et al., 1996).

In comparative tastings, the wines should be sampled in sequence. This diminishes the likelihood of odor fatigue developing from sampling the same fragrance over a short period.

Ideally, assessment of a wine’s olfactory features should be spread out over 30 min. This period is necessary to adequately evaluate features such as duration and development. Development is often likened to the unfolding of a flower. Development and the finish (see later in this chapter) 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, it is important to record your impressions clearly and precisely. 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 “the-tip-of-the-nose” phenomenon (Lawless and Engen, 1977). The primary purpose of taking notes is to focus attention on the central aromatic features that distinguish wines. Except in detailed sensory evaluation tests, the actual terms used are, in themselves, less important than the consistent meaning they have for the taster. Dissecting a wine’s sensory attributes is often essential for the winemaker or sensory scientists but does not inherently improve sensory appreciation. Wine appreciation is not a simple sum of its parts any more than poetry appreciation is an arithmetic notation of its similes, alliterations, or rhythmic style. Most complex flavor perceptions are cerebral creations. They start from the detection of separate sensations, but it is their combined interactions that generate odor memories. Only the unique combinations of multiple sensations generate the typical fragrance of an object, be it wine, coffee, lilacs, or fried bacon.

In the sensory analysis of wine, tasters are usually trained, using samples specifically designed for a particular research project. Reference samples for the various terms are commonly provided during tastings (Appendices 5.1 and 5.2). Fragrance and off-odor charts (Figs. 1.3 and 1.4) can assist in developing a common and consistent wine terminology. Terms help codify the aromatic attributes of wine, as particular note patterns characterize the music of specific composers. However, without specific and prolonged training, precise use of the most detailed tier of descriptors (e.g., violet, black currant, truffle) is difficult. In general, middle-level terms (floral, berry, vegetal) seem more applicable, and are more effectively used by the majority of people. At the same time, odor analogy can delude people into believing they can accurately describe a wine’s aromatic features, or discourage them into thinking that they are incapable of appreciating wine. Both situations are equally regrettable.

Stress on descriptive terms can be misinterpreted, especially in wine appreciation courses. Charts should be used only to encourage focusing on a 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 aggravated by the legitimate difficulty people have in verbalizing olfactory sensations. It is generally more advantageous for consumers to concentrate on recognizing the differences that exemplify varietal aromas, production
FIGURE 1.3  Wine fragrance chart (from Jackson, 2000, reproduced by permission).
styles, and an aged bouquet than articulate these in words. Except for research purposes, lexicons of descriptive terms are best left for the purposes for which they were primarily developed—descriptive sensory analysis under laboratory conditions.

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 tasting sheet for wine appreciation courses.
### FIGURE 1.5
General wine tasting sheet (usually enlarged to 11 x 17 inch paper).

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<td>Hazy</td>
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<td>Sprite</td>
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<td>Swirls</td>
<td>Maximum: +/- 1</td>
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<th>WINES</th>
<th>WINES</th>
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<td>Intensity</td>
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<td>Development</td>
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<td>Varietal Character</td>
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<tr>
<td>Fragrance</td>
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<tr>
<td>Tree Fruit</td>
<td>Apple, Afnicot, Banana, Cherry, Guava, Grapefruit, Lemon, Litchi, Peach, Passion Fruit, Quince</td>
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<td>Dry Fruit</td>
<td>Fig, Raisin</td>
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<td>Nuts</td>
<td>Almond, Hazelnut, Walnut</td>
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<td>Vegetable</td>
<td>Asparagus, Beet, Bell pepper, Canned Green beans, Hay, Olives, Tea, Tobacco</td>
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<td>Spice</td>
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<tr>
<td>Roasted</td>
<td>Caramel, Coffee, Smoke, Toast</td>
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<tr>
<td>Other</td>
<td>Buttery, Cheese, Cigar box, Honey, Leather, Mushroom, Oak, Pine, Phenolic, Truffle, Vanilla</td>
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<tr>
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<td>Balance</td>
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<tr>
<td>Specific Aspects</td>
<td>Sweetness, acidity, astringency, bitterness, body, heat, alcohol level, mellowness, spritz (pricking)</td>
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General wine tasting sheet (usually enlarged to 11 x 17 inch paper).
Designed for enlargement to 11 × 17 inch sheets, the circles indicate the placement of six wine glasses. Reduced photocopies of the labels can be placed in the blank spaces above the six comment columns. Alternately, a simple hedonic tasting sheet, such as illustrated in Fig. 1.6, may be adequate. Tasting sheets are discussed further in Chapters 5 and 6. In addition to verbal descriptions, a line drawn on a hypothetical scale can visually illustrate shifts in flavor intensity throughout a 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.

![FIGURE 1.6 Hedonic wine tasting sheet for quality assessment (from Jackson, 2008, reproduced by permission).](image)

<table>
<thead>
<tr>
<th>Sample Number:</th>
<th>Wine Category:</th>
<th>Exceptional</th>
<th>Very Good</th>
<th>Above Average</th>
<th>Below Average</th>
<th>Poor</th>
<th>Faulty</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Visual</td>
<td>Clarity</td>
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<td>Odor (orthonasal)</td>
<td>Intensity*</td>
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<td></td>
<td>Duration**</td>
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<td></td>
<td>Quality***</td>
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<tr>
<td>Flavor (taste, mouth-feel, retronasal odor)</td>
<td>Intensity</td>
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<tr>
<td>Finish (after-taste and lingering flavor)</td>
<td>Duration</td>
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<tr>
<td>Conclusion</td>
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* _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.
In-mouth Sensations
Taste and Mouth-feel

After an initial assessment of fragrance, attention turns to taste and mouth-feel. As with odor, several modalities are assessed. They may include their quality, intensity, as well as temporal and spacial pattern. Quality refers to the type of taste or mouth-feel sensation (e.g., sweetness, sourness, bitterness, astringency). Intensity pertains to the perceived strength of the sensation. The temporal pattern relates to how quality and intensity change over time. The spatial pattern concerns the location of the sensations on the tongue, cheeks, palate, and throat. The time-intensity curve and spatial pattern can be important in assessing the qualitative attributes of a sensation. The differences between sucrose and artificial sweeteners provide a familiar example of these four sensory attributes. More applicable, but less understood, are the qualitative differences and time-intensity profile of the various organic acids and tannins in wine.

Tasting commences with sipping about 6 to 10 ml of the wine. As far as feasible, the volume of each sampling should be kept equivalent to permit valid comparison among samples. Active churning (chewing) brings wine in contact with all regions in the oral cavity.

The first taste sensations potentially recognized are those of sweetness and sourness. Sweetness (if detectable) is initially and generally most noticeable at the tip of the tongue. In contrast, sourness is more evident along the sides of the tongue and insides of the cheeks, depending on the individual. The sharp aspect of acidity typically lingers considerably longer than the perceptions of mild 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 seconds before bitterness reaches its peak, usually most detectable within the central, posterior portion of the tongue. Thus, it is advisable to retain the wine in the mouth for at least 15 s. Subsequently, the taster tends to concentrate on mouth-feel sensations, such as the dry, chalky, rough, dust-in-the-mouth aspects 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 noted, temporal differences in the sequence of detection usually can aid identification [Kuznicki and Turner, 1986]. This capacity is, however, partially dependent on the taster’s approach [Prescott *et al.*, 2004]. That is, analytic (conscious concentration of specific sensations), vs. synthetic (a holistic response to the integration of sensations in the mouth). Identification is also dependent on intensity differences and the number of distinct sensations [Marshall *et al.*, 2005]. The upper limit for identification is usually three [Laing *et al.*, 2002]. In contrast, the duration of 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 and recognizing individual sapid sensations is less important than focusing on how they integrate to form holistic perceptions such as **balance**, **flavor**, and **body**. These perceptions arise from multiple sensory inputs, often including taste, mouth-feel, and fragrance. For example, the creaminess of dairy products is dependent not only on mouth-feel and fat-particle size, but also on aroma [Kilcast and Clegg, 2002].

The integration of multiple sensory inputs often occurs unconsciously. Examples are the association of sweetness with fruity odors and the increased flavor of intensely colored solutions. These associations form instinctively—thus, the illusion of sweetness found in dry white wines possessing a fruity fragrance, or the perception of increased flavor in more intensely colored wines. Although a natural phenomenon, their effects appear to be offset by cognitively focusing on individual aspects of complex sensations [van der Klaauw and Frank, 1996; Prescott, 1999]. It is up to the individual (or experimenter) to decide whether a more natural (integrated/holistic) approach or a more analytic (dissective) approach to wine evaluation is desired. Perceived reality, as in other aspects of life, often depends on past experience and the context in which it is detected [Fig. 6.4]. All is relative.

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 initial bitter and astringent perception. 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 food. 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.

This problem becomes more serious when a series of red wines is tasted in fairly quick succession. To avoid carry-over influences, due to residual tannin effects, tasters are usually provided with a palate cleanser. Recently, several studies have investigated the effectiveness of palate cleansers. For example, Colonna et al. (2004) found that a weak solution of pectin (1 g/liter) was more effective than several traditional palate cleansers. Pectins have been shown to limit tannin-protein polymerization [Hayashi et al., 2005]. This tendency applies particularly to ionic carbohydrates, notably xanthans, but also to pectins and gum arabic [Mateus et al., 2004]. Polymerization is most marked with galloylated flavonols [Hayashi et al., 2005], and becomes less effective as tannin polymer size increases [Mateus et al., 2004]. Brannan et al. (2001) provide additional information on palate cleansers, suggesting 0.55% carboxymethyl cellulose, [1%], due to its low residual effect in the mouth. The presence of acidic, grape-derived polysaccharides (rhamnogalacturonans) in wine may have a similar effect in reducing wine astringency [Carvalho et al., 2006]. In another study, comparing crackers, pectin [1%], carboxymethyl cellulose [1%], and water, the perceived intensity of red wine astringency was found most effectively reduced by crackers [Ross et al., 2007]. Water was found to be the least effective in all studies.

**Odor—Retronasal**

As with orthonasal odor, tasters should concentrate on the relative intensity, identity, and qualitative changes over the full duration of the tasting. Transfer of aromatics in the mouth and back of the throat into the nasal cavity is most marked after swallowing (or expectoration). Intentional concentration on slow deliberate exhalation apparently improves retronasal identification [Pierce and Halpern, 1996]. Correspondingly, tasters should especially concentrate on the in-mouth (retronasal) aspects of fragrance during expiration.

To enhance retronasal detection, tasters frequently aspirate the wine in the mouth. This involves tightening the jaws, contracting the cheek muscles (to pull the lips slightly ajar), and slowly drawing air through the wine. Alternatively, some tasters purse the lips before drawing air through the wine. Either procedure favors volatilization by increasing surface area contact (analogous to swirling wine in a glass), as well as atomizing the wine.
Although less effective, vigorous agitation of the wine in the mouth has a somewhat similar effect (de Wijk et al., 2003).

Odor perception detected retronasally is often qualitatively different from that detected orthonasally (Negoias et al., 2008). This distinction is well recognized from the frequent and often distinct character of cheeses smelled versus sampled in the mouth. This phenomenon probably has several origins. The concentration of aromatics reaching the olfactory patches is considerably less, at least partially due to the diminished volume of air flow. Correspondingly, some constituents may not be present at above threshold values when assessed retronasally. Additional factors potentially involved include the higher temperature of the mouth (modifying volatilization) and the action of enzymes (both salivary and microbial). The latter may either degrade or liberate volatile compounds. Compounds may also be perceived differently relative to the direction of air flow—a phenomenon that is independent of air flow rate (Small et al., 2005). This may relate to the spacial location of different receptors in the olfactory patches, selective removal of odorants as they pass over the olfactory patches, and generation of a different temporal sequence of receptor activation. This may be analogous to playing a segment of music backward, or in the holistic versus analytic interpretation of faces viewed normally or upside down (Murray, 2004).

Although retronasal olfaction is important by itself, it is primarily in its integration with taste and mouth-feel sensations that it has its greatest (usually unrecognized) influence. This integration generates the perception of flavor. The importance of retronasal olfaction to flavor is easily demonstrated by clamping the nose, limiting the access of aromatics in the mouth to the nasal passages. Foods and beverages lose most of the identifiable attributes when the retronasal component is missing.

Some tasters complete their assessment of the fragrance with a prolonged aspiration. Following inhalation, the wine is swallowed, and the vapors slowly exhaled through the nose. This aspect is often referred to as 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, if twenty or more wines are sampled, as in wine competitions or technical tastings, consumption must be assiduously avoided. Scholten (1987) has shown that expectoration avoids significant amounts of alcohol accumulating in the blood. Nonetheless, sufficient tannic material may be consumed to induce a headache. To avoid this, taking a
prostaglandin synthesis inhibitor (acetylsalicylic acid, acetaminophen, or ibuprofen) an hour or more before the tasting may limit certain types of headache development. This and other occupational hazards of wine tasting are discussed at greater length at the end of Chapter 5.

**Finish**

Once the sample is swallowed (or expectorated), concentration switches to the **finish**. Finish (persistence) refers to the lingering sapid, but primarily aromatic, sensations in the mouth. It is the vinous equivalent of a sunset. Some tasters consider its duration a major indicator of quality. Depending on the characteristics of the wine, the finish may last but a few seconds to several minutes (Buettner, 2004). Its duration, measured in seconds, is termed its *cauladie*.

The finish appears to depend on the thin film of wine that coats the mouth and throat, as well as compounds that absorb and are slowly released from the mucous lining of the throat (Bücking, 2000) and nasal passages. Transfer of aromatics to the nose arises from two interrelated but distinct mechanisms (Normand *et al.*, 2004). These are the same as noted concerning retronasal olfaction—punctuated surges of air from the throat (associated with swallowing) and the more tranquil outflow of air associated with exhalation (Fig. 1.8). Both draw aromatics from the oral cavity into the nose. The pattern of flow can be regulated by adjusting swallowing (Fig. 1.8C), varying the breathing cycle, and tilting the head forward. These actions affect the opening of the velum (soft palate). During swallowing, the velum and uvula form a tight seal at the back of the nasopharynx, preventing the passage of odorants into the nose (Buettner *et al.*, 2001). After swallowing, the velum returns to its normal position, allowing volatiles to re-enter the nasal passages.

The finish tends to be subtle and fleeting, due to the progressive loss of aromatics and their low concentration. In addition, only those compounds able to persist in and subsequently escape from the saliva and/or mucus are likely to be detected. Learned associations of odor/taste combinations also significantly affect perceived odor intensity, independent of the concentration of aromatics in the nose (Hollowood *et al.*, 2002). Thus, experience can play a significant role in the perception of a wine’s finish.

Most table wines possess a relatively short finish, lasting rarely more than several seconds. In contrast, fortified wines, possessing more intense flavors, exhibit a much longer finish. Exceptions to the generally desirable nature of a long finish are features such as a persistent metallic aspect, the presence of off-odors, or excessively acidic, bitter, and astringent sensations.
Overall Quality

After the sensory aspects have been studied individually, attention shifts to the integration of their effects—the wine’s overall quality. As noted by Amerine and Roessler (1983), it is far easier to detect a wine’s quality than define it. This presumably involves aspects of conformity with, and distinctiveness within, regional, varietal, or stylistic norms\(^1\); the development, duration, and complexity of the fragrance; the duration and character of the finish; the uniqueness of the tasting experience; and taster perceptive acuity.

\(^1\)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.
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. Balance without character is bland, but when dynamic and refined, it donates an almost otherworldly feeling of elegance. The complex interaction of sensory perceptions involved in this percept is evident in the reduced fruitiness of red wines possessing excessive astringency, or the hollowness of a sweet wine lacking sufficient fragrance or acidity. Balance often seems to be easier to achieve in white wines, due to their lower phenolic content. However, their reduced aromatic complexity often leaves white wines less inspiring than red wines. Thus, in reality, achieving refined balance in a white wine is no easier than in red wines. Occasionally, individual aspects may be sufficiently intense to give the impression that balance is on the brink of collapse. In 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 the taster’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 often not specifically stated, is the requirement for both **power** and **elegance**. Without these attributes, attractiveness is short-lived. If the overall sensation is sufficiently remarkable, the experience becomes unforgettable, an attribute Amerine and Roessler (1983) term **memorableness**. This is the quintessential feature of any great wine. It is almost always associated with surprise. Never have I knowingly sampled a prestigious wine that truly awed me and made me feel that the “heavens had opened.” Memorableness, even when less stunning, is particularly important in the training of tasters and directing future expectations (Mojet and Köster, 2005). The importance of surprise to pleasure has been directly detected with functional magnetic resonance imaging ([fMRI]) (Berns et al., 2001). Unpredictability greatly enhances the “reward” stimulus associated with activation of the cerebral orbitofrontal cortex.

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 England and the New World, where artistic merit tends to be considered more highly than compliance with regional dictates.

Postscript

The full assessment of a wine’s sensory attributes takes time. Thus, it is usually employed only in comparative tastings. For individual wines, it is worth the effort only when the wine is of very fine quality—their expression of a wide range of sensory attributes justifying the time spent.

Despite the clear advantages of a systematic approach to wine assessment, permitted by the technique described in the preceding text, few professional tasters appear to utilize such a disciplined approach (Brochet and Dubourdieu, 2001). This is clear from even a cursory look at most tasting notes. This paradox stems from most wine writers (and consumers) having no need to analyze the wine critically—tasting being conducted holistically, concentrating on general qualities, such as balance, complexity, and depth. Notes primarily give the subjective reaction of the taster. Rarely do the terms have verifiable or easily defined meanings. In addition, each taster tends to possess his or her own unique lexicon. This presumably has meaning for the person who uses it. However, it rarely effectively describes the wine’s actual sensory attributes. At best, descriptors express overall perceptions, or the norms attributed to regional, stylistic, or varietal wines. Ranking typically concentrates on how well, or poorly, wines express features desired by, or considered important to the taster.

Holistic expressions often reflect more the characteristics and experiences of the taster than the wine. Integral wine assessment appears to reflect selective activation of the brain’s right hemisphere (Dade et al., 1998, 2002; Herz et al., 1999). This region principally deals with ideographic and emotive aspects of expression (the reverse often occurs in lefthanded individuals). This contrasts with the left hemisphere, where verbal aspects of language tend to be concentrated (Deppe et al., 2000; Knecht et al., 2000). Whether the tendency to express wine attributes in holistic terms reflects a lack of training in youth, or a genetic predisposition is unknown. Either way, selective activation of the right hemisphere, and the small area of the brain set aside for processing olfactory information, may explain why humans have such a pauperized odor lexicon. Thus, when pressed, people tend to describe their sensory responses in terms of other objects or experiences, such as fruit, flowers, or spices, etc., or the emotions they engender.

Regrettably, sampling wine holistically often robs the taster from detecting some of the wine’s finest subtleties and attributes. For example, without
concentration, features such as development and duration or the length of the finish are missed. Only a programmed set of steps permits the taster to detect and appreciate all the joys (or failings) that a wine may demonstrate.

"Wine drinking is basically an aesthetic experience, or at least it is to the people who write wine books."

Lehrer (1975)

REFERENCES


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 more fully investigated.

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 (about 300 to 700 nm). For example, the pigments in red wine reflect (and absorb) specific wavelengths. Their reflection and transmission of primarily long wavelengths
induce reactions in the retina that are interpreted by the brain as red. The color intensity and hue of the wine depend on the amount and chemical state of the pigments present, and correspondingly the quantity and quality of light reflected. Color purity 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 in Fig. 2.1).

Although such characteristics can be accurately measured with a spectrophotometer, 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. The 6 to 7 million cones are densely arranged in the central portion of the retina, with the nearly 120 million rods positioned on the walls of the eye surrounding the cones. The number and distribution of the types of cones are distinct, as is their range of sensitivity. The least common (S) are those that respond with a peak sensitivity in the short (blue) wavelength region. Far more common are cones responding optimally in the middle and long wavelength regions, respectively termed L and M cones. Although there is considerable variation in their proportion among individuals, it does not appear to markedly affect color perception (Brainard et al., 2000). The pigments in the latter two cone types (L and M) show considerable overlap in their absorption spectra. In contrast, the rods react primarily to low intensity light of medium to short wavelength, and respond relatively slowly to intensity change. Color perception results from the combined impulses from the three types of cones, whereas 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 of the relative constancy in color

**FIGURE 2.1**
Absorbance scans of a single cultivar port (Touriga Nacional, 1981) at different ages (from Bakker and Timberlake, 1986, reproduced by permission).
perception that occurs under most daily changes in sunlight spectral quality (Brou et al., 1986). Thus, color perception of natural objects is a learned construct from multiple stimuli, not a simple reaction to individual wavelengths or their respective intensities (Kaiser and Boynton, 1996; Squire et al., 2008).

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, it is probably best to keep the number of color terms limited and simple to facilitate consistent use. Color terms ideally should incorporate aspects of hue (wavelength purity), saturation (grayness), and brightness (capacity to reflect or transmit light). However, their typical integration reflects the difficulty people have in differentiating these aspects. For example, brown commonly would be described as a hue. 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 red. Figure 2.3 illustrates the three recognized color attributes—hue, saturation, and brightness.

The availability of a standard for 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, it does not fully represent the range of human color vision. Genetic variability in color perception also limits its applicability as 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 absorbency to perceived color (Kuehni, 2002), simple techniques can often yield useful data. For example, the color of red wines is often assessed by its absorbency at 420 nm and 520 nm (Somers and Evans, 1977).

FIGURE 2.2 Coefficients of consistency for the selections made to 233 color names (from Chapanis, 1965).
The sum of these values is a measure of color depth (density), while their ratio estimates tint (hue). Absorbency at 420 nm provides an indicator of a brownish cast, while absorbency at 520 nm assesses redness. As red wines age, the level of yellowish polymeric pigments increases, and the impact of monomeric red anthocyanins decreases. Young red wines often have ratios of 0.4 to 0.5, whereas old reds frequently show values in the range of 0.8 to 0.9. An alternate method incorporates absorbency at 620 nm (Glories, 1984). Problems associated with turbidity may be adjusted for by measurements taken at 700 nm (Mazza et al., 1999), or following sample centrifugation (Birse, 2007).

Additional information may be derived from estimates of the proportion of colored (ionized) monomeric anthocyanins, total anthocyanin and phenol contents. The proportion of anthocyanins complexed to various phenolic polymers can 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).

Despite these adjustments, these measures do not represent the presence of important red pigments such as pyranoanthocyanins. In addition, besides the resulting shift toward brown, aging of red wines is associated with pigment loss and reduction in color depth.

In white wines, absorbency is typically measured at 420 nm. It is used to give an indicator of browning (Fig. 2.4). To facilitate assessing the color of bottled wines, Skouroumounis et al. (2003) have developed a means of spectrophotometrically assessing the degree of browning in situ. As with
simple color measurements in red wines, the values derived may, however, miss subtleties that may be important (Skouroumounis et al., 2005).

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 require complicated mathematical transformations. Tristimulus colorimeters directly translate the reading into tristimulus measurements. Estimates of brightness (light/dark), saturation or chroma (degree of grayness), and hue (basic color) are generated. These are the three parameters normally used in defining color.

However, the most accurate means of measuring wine color is to assess absorbency over the full range of the visible spectrum. The CIELab system designed by La Commission Internationale de l’Eclairage uses these measurements to derive values for \( L^* \) (relative lightness), \( a^* \) (relative redness, on a red-green axis), and \( b^* \) (relative yellowness, on a yellow-blue axis). The values are typically calculated with software packages that accompany the spectrophotometer. The calculations approximate human color vision, where lightness is largely derived from a selective combination of L and M cone inputs, and hue derived from comparison of impulses from L and M cones (red-green axis), and a comparison of impulses from S cones with the sum of L and M responses (blue-yellow axis) (Gegenfurtner and Kiper, 2003).

CIELab measurements can also be used to derive the values required to reproduce color using software such as Adobe® Photoshop® (\( L \), luminosity; \( C \), chroma \( C^* = \sqrt{a^{*2} + b^{*2}} \)) and \( H \), hue \( H^* = \tan^{-1} \left( \frac{a^*}{b^*} \right) \). Hue often reflects the dominant wavelength of the light, but not consistently. For example, a yellow color may originate from light in the yellow range, or a combination of light in the red and green ranges.

CIELab measurements 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 has found little use in wine assessment. Pérez-Magariño and

**FIGURE 2.4** Percentage of 31 assessors rating wines with various levels of browning as visually unacceptable (from Peng et al., 1999, reproduced by permission).
González-San José (2002) have proposed simple absorbance measurements to predict CIELab values for wineries, without the equipment and software normally necessary.

One of the problems in associating such measurements with human perception relates to the marked differences in how assessments may be conducted. In spectrophotometric measurements, wines (often diluted) are placed in cuvettes (usually 1 or 2 mm for undiluted red wine, or 10 mm if diluted). In contrast, visual evaluation of wine occurs in a glass under poorly regulated light conditions. In the latter situation, there can be considerable light scattering and marked differences in color noted as the depth of the wine changes on slanting the glass. These differences have recently been described analytically by Huertas et al. (2003). Finally, different combinations of pigments in various stages of oxidation and polymerization may give rise to the same subjective color impression.

An alternative technique for color assessment being investigated is digital photography. By computerized assessment of the image, pixel-by-pixel, better correlation with human perception has been reported (Pointer et al., 2002; Brosnan and Sun, 2004; Cheung et al., 2005). Digital photography is less expensive than the purchase and operation of a spectrophotometer, is easier to use, assesses a larger surface area (useful where the color is non-homogenous), is rapid, and the data can easily be transferred to a computer for analysis (Yam and Papadakis, 2004; León et al., 2006). An example of digital camera analysis used to evaluate wine color is given by Martin et al. (2007).

**Significance in Tasting**

Color often affects quality perception (Fig. 2.5, Fig. 2.6), as well as taste and odor perception [Maga, 1974; Clydesdale et al., 1992]. For red wines, flavor intensity (and wine quality) has 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. Occasionally, wines are sampled in black wine glasses, or under low-intensity red light, to obviate any possible color bias.

Color is such a critical element in sensory memory that identification may become markedly distorted without it. For example, people usually correctly identify cola-flavored beverages when colored dark brown, but frequently misidentified the solution as orange or tea when it was colored orange (Sakai et al., 2005). In another example, cherry-flavored beverages were frequently misidentified as lime when colored green (DuBose et al., 1980). In wine, the influence of color has been clearly demonstrated by Morrot et al. (2001). The addition of tasteless anthocyanin (red) pigments to a white wine induced tasters to describe the wine in terms typical of a red wine (objects of a red or somber color). This distortion may be less pronounced with expert tasters, at least when the color seriously conflicts with other sensory attributes (Parr et al., 2003). In the Morrot study, the white wine (Sauvignon blanc), that had been colored red, has several aromatic similarities to Cabernet Sauvignon, wines of which the enology students frequently sampled.

Color depth has also been shown to enhance perceived flavor intensity (Zellner and Whitten, 1999). The influence has even been observed at the neuronal level (Österbauer et al., 2005). Showing a color typically associated with a particular fragrance (e.g., red with strawberry) enhances the response in the orbitofrontal complex. This is the cerebral region known to integrate sensory impulses. The reverse occurs with inappropriate colors (e.g., blue with strawberry). That this influence is not just a laboratory phenomenon is indicated by the effect of an oxidized color on wine quality (Fig. 2.5) and acceptability (Fig. 2.6).

Although wine color can affect wine assessment, not all tasters are equally influenced (Williams et al., 1984b). Interestingly, this feature
seemed to be independent of taster experience. This may relate to the manner in which tasters assess the wines. It is known from other studies on sensory interaction [taste-taste or taste-odor] that these influences are most marked when assessments are requested to be holistic, and least evident when assessments are conducted attribute-by-attribute. Specific directions to ignore color in assessment may result in tasters disregarding color in their evaluation [Williams et al., 1984a].

Consumers and tasters alike usually come to associate particular colors with certain wines. For example, 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. More golden colors often arise following prolonged maturation in oak barrels, extended bottle aging, or indicate the presence of a sweet botrytised wine. Sherries vary from pale straw to dark golden-brown, depending on the style [finos the lightest, olorosos the darkest]. Rosé wines are expected to be pale to light pinkish rose colored, without shades of blue. Red wines vary from deep purple to tawny red. Initially, most red wines possess a purplish-red hue, especially noticeable at the edge of the glass. Subsequently, the wine loses its color depth and increasingly takes on a brickish hue. Red ports, depending on the style, may be deep red, ruby, or tawny colored.

Because all wines eventually take on brownish hues, browning is often used as an indicator of age. This feature is indicated by a lowering of the E420/E520 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 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 a process-produced browning. Because most wines fail to develop a desirable aged bouquet, brown casts often mean that the wine is oxidized or "over the hill."

**Origin and Characteristics**

**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 increases both chemical stability and water solubility. The glucoside may also associate with acetic, coumaric, or caffeic acids.

Five classes of anthocyanins occur in grapes: cyanins, delphinins, malvins, peonins, and petunins. They are differentiated based on the number
Table 2.1 Anthocyanins Occurring in Wine

<table>
<thead>
<tr>
<th>Specific Name</th>
<th>$R_3$</th>
<th>$R_4$</th>
<th>$R_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanidin</td>
<td>OH</td>
<td>OH</td>
<td></td>
</tr>
<tr>
<td>Peonidin</td>
<td>OCH$_3$</td>
<td>OH</td>
<td></td>
</tr>
<tr>
<td>Delphinidin</td>
<td>OH</td>
<td>OH</td>
<td>OH</td>
</tr>
<tr>
<td>Petunidin</td>
<td>OCH$_3$</td>
<td>OH</td>
<td>OH</td>
</tr>
<tr>
<td>Malvidin</td>
<td>OCH$_3$</td>
<td>OH</td>
<td>OCH$_3$</td>
</tr>
</tbody>
</table>

|| 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) |


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 between cultivars and with growing conditions [Wenzel et al., 1987]. The hydroxylation pattern of the B ring primarily controls color hue and 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. Thus, wine with a high proportion of malvin or peonin, neither of which possesses $o$-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. Four are free forms and one is bound to sulfur dioxide [Fig. 2.7]. Most are colorless within the pH range of wine. Those that exist in the flavylum 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 sulfur dioxide content of the wine. Low pH enhances redness (favors the flavylum state), whereas high pH generates a blue-mauve cast (by favoring the quinoidal state).
Color density is also affected. Bleaching of anthocyanins by sulfur dioxide (either due to addition or production by yeasts during fermentation) can diminish color depth.

In grapes, anthocyanins exist primarily in stacked conglomerates. These occur primarily as hydrophobic interactions between individual anthocyanins (self-association), or between anthocyanins and other phenolic compounds (co-pigmentation). 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 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 copigmentation complexes may survive, and form during fermentation, to contribute to 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 both more susceptible to irreversible oxidation (browning), as well as conversion of the colored flavylum state to colorless hemiacetals. To limit these events, it is important that the wine contain significant quantities of flavonoids: catechins, proanthocyanidins (dimers, trimers, and tetramers of catechins), and their polymers (condensed tannin). These combine with free anthocyanins to form stable polymers. The polymers also extend light absorption into the blue region. This partially explains the brownish shift that occurs during aging.

The concurrent extraction of flavonoids with anthocyanins during fermentation is crucial 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 anthocyanin content may exist polymerized with tannins. This can rise to about 40% within 1 year in oak cooperage (Somers, 1982). Subsequent polymerization continues more slowly, and may approach 100% within several years (Fig. 2.8). Thus, red color reflects not only the amount, nature, and states of the anthocyanin in wine, but also the types and amounts of flavonoids extracted and retained during and after vinification (Jackson, 2008). The poor color stability of most red muscadine wines appears to derive from the absence of appropriate tannins and acylated anthocyanins in muscadine grapes (Sims and Morris, 1986). A somewhat similar situation with Pinot noir may explain the generally poor coloration of its wines.

Polymerization protects the anthocyanin molecule from oxidation or other chemical modifications. Incidentally, polymerization also increases solubility, minimizing both tannin and pigment loss by precipitation. In addition, more anthocyanin molecules are in a colored state in tannin

![FIGURE 2.8](image)

*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).*
complexes, due to increases in the proportion of both 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 (Fig. 2.9). The yellow-brown flavylium and quinoidal anthocyanin–tannin polymers are generally thought to generate most of the age-related brickish shades.

Polymerization of anthocyanins with flavonoids occurs slowly in the absence of oxygen. Nevertheless, polymerization is promoted during maturation by the oxygen inadvertently absorbed during racking. This has led to the development of microoxygenation systems to provide the winemaker with control over the rate and degree of oxygenation, especially when using inert cooperage.

The small amounts of peroxide generated, as oxygen reacts with tannins, oxidizes ethanol to acetaldehyde. The subsequent reaction between acetaldehyde and anthocyanins promotes their polymerization with flavonoids. The initially small anthocyanin-acetaldehyde-flavonoid polymers are thought to enhance 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 proanthocyanidins.

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, may also complex with 4-vinylphenol, generating red-orange pigments (Fulcrand et al., 1997). These and related compounds are termed pyranoanthocyanins. For details, see the recent review by Rentzche et al. (2007) or Jackson (2008). In addition, internal rearrangements of anthocyanins and other flavonoids produce yellow-orange xanthylium products. Colorless flavonoids also generate brownish products upon oxidation. Thus, although the color of red wines starts out primarily produced by anthocyanins, the aged color of red wines is a complex of anthocyanin-tannin polymers, oxidized
Tannins, pyranoanthocyanins, and xanthylum products and polymers. Its complexity is such that even more sophisticated analytical instruments than currently exist may be needed to discover the critical and decisive events involved in the evolution of wine color. Table 2.2 highlights some of the various forms producing yellow, yellow-red, yellow-brown, red, and violet shades. The reduction in color density that also accompanies aging results from oxidation, structural changes in anthocyanin–tannin polymers, and their precipitation with tartrate salts or soluble proteins.

Red wines can vary from deep red-purple to pale tawny red. As noted, the purplish-red hue of young red wines may be due to the continuing presence of anthocyanin complexes and anthocyanin-acetaldehyde-flavonoid polymers, but may also indicate that the wine’s pH 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. Späthburgunder wines from Germany are typically so pale as to often resemble a dark rosé. Cool climatic conditions are 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 Shiraz 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. Because older vinification procedures favor the uptake of high levels

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Source: "From Ribereau-Gayon and Glories (1987), reproduced by permission.

$^a$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."
of tannins, they generate bitter/astringent sensations that can take decades to soften. This can be avoided by modern techniques, notably treatments such as the use of rotary fermentors. These favor the early extraction of berry flavors and intense coloration, before tannin uptake reaches high levels. Even with standard fermentors, shorter skin-contact time during fermentation can generate milder but still highly flavored, deeply colored wines.

Most red wines begin to take on a noticeable brickish cast within a few years, especially when long aged in oak cooperage (Fig. 2.1). Brickish or tawny red colors are acceptable only if associated with 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 might be associated with a baked odor) or a faulty closure (and associated with an 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 can be characteristic of some rosés made 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 wines. 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, if used, can add to the color of white wines. The deepening yellow-gold of older white wines probably comes from the oxidation of phenols or galacturonic acid (a breakdown product of pectins from grape cell walls).

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 some white wines. For example, the pinking of *Sauvignon blanc* wines derives from the incidental oxidation of dehydrated leucoanthocyanins (flavan-3,4-diols). However, the pinkish
coloration of some Gewürztraminer wines comes from trace amounts of anthocyanins extracted from the skins of pinkish-red clones of the cultivar. Some so-called white (blush) wines, such as white Zinfandel, come from red grapes pressed early to minimize color extraction. In fortified sweet wines, much of the color comes from either oxidation of phenolics in the wine, or from melanoid pigments formed during heating of the wine or in concentrating grape juice used for sweetening.

Typically, young, dry, white wines range from nearly colorless to pale straw. 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 oxidized 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 reduced 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 may result from 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) due to 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, consumers have come to expect a clear product with long shelf-life. This does demand considerable effort to achieve.

**Crystals**

Young wines typically are 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, 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 (cream of tartar). Given sufficient time, the salt crystals precipitate spontaneously. In northern regions, the low temperatures found in unheated cellars can 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 due to the slow oxidation of ferrous oxalate to the unstable ferric form. After dissociation from the metal, oxalic acid may bond 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 may form insoluble calcium salts. Calcium mucate is often the source of the yellowish particles occasionally found in bottles of Sauternes.

Although comparatively rare, the presence of tartrate salt crystals is not a legitimate cause for consumer rejection. The crystals are tasteless and usually remain in the bottle with any sediment that may have developed during aging. Alternatively, tartrate crystals may form on 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 have been known to 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 a complex of polymerized anthocyanins, tannins, proteins, and tartrate crystals. Depending on their chemical composition, sediment may have a bitter or chalky taste. To some wine aficionados, 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 an uncommon source of wine rejection, protein haze can still cause considerable economic loss in bottle returns. Proteinaceous haze results from the clumping of dissolved proteins into light-dispersing particles. Its formation is enhanced by the presence of sulfites, heating, and the presence of tannins and trace amounts of metal ions. Proanthocyanins (oligomers of catechin flavonoids) bind well with proteins containing proline [Siebert, 2006]. However, these typically precipitate during fermentation, maturation, or fining. Thus, they are not the problem they can be in beer [Asano et al., 1984]. The proteins that appear to be the principal source of problems in bottled wine are the pathogenesis-related (PR) proteins, chitinase, and acid-stable thaumatin-like proteins [Waters et al., 1996b; Dambrouck et al., 2003]. They occur in infected grapes and are also produced rapidly in grapes damaged during harvesting [Pocock and Waters, 1998]. Although yeast mannoproteins and grape arabinogalactan–protein complexes may promote heat-induced protein haze, specific members can also reduce its formation [Pellerin et al., 1994; Dupin et al., 2000].

Phenolic Haze

Excessive use of oak-chips in wine maturation or the accidental incorporation of leaf material during grape crushing [Somers and Ziemelis, 1985] can occasionally induce rare forms of phenolic haze. The first situation results from the excessive extraction of ellagic acid, leading to their formation of fine, off-white to fawn-colored crystals. Fine, yellow, quercetin crystals, extracted from leaf material during crushing, can induce a flavonol haze in white wines. This is particularly likely if the wine is bottled before the crystals have had a chance to settle sufficiently [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 can generate haziness in bottled wine (casse). The most important are induced by iron (Fe$^{3+}$ and Fe$^{2+}$) and copper (Cu$^{2+}$ and Cu$^{+}$) ions. The primary source of troublesome concentrations of these metal ions comes from corroded winery equipment.

Two forms of ferric casse are recognized. 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 can also occur in rosé wines.

**Deposits on Bottle Surfaces**

Occasionally, sediment adheres tightly to the inner surfaces of the bottle. This can generate an elongated, elliptical deposit on the lower side of the bottle. Less frequently, a lacquer-like deposit may form in 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 its 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) after the second, in-bottle fermentation (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 flocculent 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 is associated with vinegary (*Z. bailii*) or mousy, barnyardy (*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—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. In addition, even trace amounts of oxygen incorporated in procedures such as racking or battonage can activate growth. If they multiply in wine, they can form a haziness associated with the development of 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 slight haziness.

**VISCOITY**

The viscosity of wine is an in-mouth perception, largely dependent on its sugar, ethanol, glycerol, and soluble polysaccharide contents. If mentioned, it is usually due to obvious reduced fluidity. This is discernible only at unusually high sugar and/or alcohol contents—when glycerol content exceeds 25 g/liter (as in botrytised wines); or in the presence of mucopolysaccharides produced by bacteria (in cases of wines showing ropiness or tourne).

Although glycerol has usually been mentioned in relation to increased wine viscosity, lower sugar contents (15 g fructose/5 g glucose) can generate about the same degree of perceived viscosity as 25 g glycerol [Nurgel and Pickering, 2005]. At these concentrations, viscosity values reach about 1.5 cP (mPa). At and above this level, detectable difference begins to become perceptible. Besides affecting fluidity, viscosity at or above 1.5 cP reduces the perception of astringency and sourness (Smith and Noble, 1998). It may also reduce the perceived intensity of aromatic compounds [Cook et al., 2003]. However, the latter phenomenon appears to occur at the viscosity values typical of food or desserts, not wine. Thus, its potential relevance may relate more to how wine pairs with food than on the perception of wine itself.
SPIRITZ

Still wines may retain sufficient carbon dioxide after fermentation to form bubbles along the sides and bottom of the glass. This usually occurs if the wine is bottled early, before supersaturated carbon dioxide in the wine has escaped. This is not uncommonly seen in bottles of *Beaujolais nouveau* and some young white wines.

Bubbles may also come from carbon dioxide produced by bacterial metabolism. This may develop as a consequence of malolactic fermentation occurring after bottling. Producers apply various procedures to prevent this from occurring. It is associated with the formation of a fine, haze-producing sediment. Light spritz may also result from the action of spoilage bacteria, as in the case of wine showing tourne.

In most instances, marked effervescence is intentional. The size, association, and duration of bubbling are considered important quality features in sparkling wines. Slow, continuous effervescence is favored by prolonged contact between yeast lees and the wine. After several months, yeasts autolysis (self-digestion) releases cell-wall constituents (colloidal mannoproteins) into the wine. The weak bonds formed between carbon dioxide and these proteins are thought essential to the production of a steady stream of bubbles following opening. Whether the sound of bursting bubbles has sensory significance to the perceived quality of sparkling wines, as it does in carbonated beverages (Zampini and Spence, 2005), has yet to be studied.

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 the wine is 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/liter to 2 g/liter. This initiates the release of approximately 5 liters of gas (from a 750 ml bottle). In the absence of agitation, there is insufficient free energy for the CO₂ to escape immediately. It enters a metastable state from which it is slowly liberated.

Carbon dioxide escapes from the wine by several mechanisms (Fig. 2.10). The initial foaming associated with pouring is activated by free energy liberated by pouring. Pouring also generates microbubbles that slowly escape. However, the continuous chains of bubbles, so desired in sparkling wine, are produced by heterogenous nucleation. Most bubbles develop as carbon dioxide diffuses into microscopic gas pockets in fibrous contaminants on the sides of the glass. This particulate material usually consists of cellulosic fragments left following glass drying, or that have fallen out of the air as dust (Liger-Belair et al., 2002). Those few bubble
chains that form in the body of the wine probably originate from micro gas-pockets associated with minute suspended crystals of potassium bitartrate or cellulosic fragments. Gas pockets in these particles probably form during the initial burst of homogenous fizzing that occurs as the wine is poured into the glass. As the bubbles are released and begin to rise, they enlarge and their physical dispersion becomes more pronounced. The slow, progressive release of bubbles is the principal, and desirable, means by which CO₂ escapes from the wine.

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 bubbles reach a critical size, they incorporate more CO₂ than they lose, enlarging as they rise. In addition, semi-stabilized 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 wine is the accumulation of a small mound of bubbles on the surface of the wine 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 (such as soluble proteins, polyphenols, and polysaccharides). They decrease surface tension, easing bubble fusion. This results as gravity removes fluid from between the bubbles, inducing them to fuse and take on angular shapes. As their size increases, so does their tendency to break.
Natural surfactants 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 CO₂-producing fermentation. Contaminant surfactants, notably soap or detergent residues left after glass washing, can effectively dampen bubble formation. These residues coat the particles that are essential for the initiation [nucleation] step in bubble formation. This can be readily demonstrated with a washed but poorly rinsed champagne flute.

TEARS

Droplets form and slide down the sides of the glass after swirling (Fig. 2.11). These have been variously termed “tears,” “legs,” or “rivulets.” They form when alcohol evaporates from the film of wine coating the inner surfaces of the glass. Because ethanol volatilizes more rapidly than water, the surface tension of the film increases. This induces water molecules in the film to pull together more tightly, resulting in droplet formation. As their mass increases, the droplets 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 slowly descends, eventually reaching the level of the meniscus around the sides of the glass.

After swirling, the increased surface tension of the film, created by alcohol evaporation, may induce wine to flow up the sides of the glass (Neogi, 1985). In addition, cooling produced by alcohol evaporation activates the generation of convection currents that facilitate this flow. The duration of tears formation depends on factors affecting the rate of evaporation, such as temperature, alcohol content, and the liquid/air interface. Movement of wine up the sides of the glass can be demonstrated by adding a drop of food coloring, or nonwettable powder such as Lycopodium powder, to wine after tears have begun to form. Contrary to common belief, glycerol neither significantly affects nor is required for formation of tears.
SUGGESTED READINGS


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# Olfactory Sensations

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OLFACTORY SYSTEM

Nasal Passages

The olfactory region consists of two small patches recessed in the upper portion of the nasal passages (Fig. 3.1). Volatile compounds reach the olfactory epithelium either directly, via the nostrils (orthonasally), or indirectly, from the back of the throat (retronasally). The latter route is important in generation of what is termed “flavor”—the cerebral construct from the modalities of taste, touch, olfaction, and vision.

The nasal passages are bilaterally divided by a central septum into right and left halves. The olfactory patches (epithelium) cover a small portion of the nasal cavity below the cribriform plate, on either side of the septum, just behind the eyes and midway between the ears. The receptor cells in each patch send signals, via perforations in the skull (cribriform plate), to
corresponding halves of the olfactory bulb. The olfactory bulb is located directly above the olfactory epithelium, at the base of the skull.

Some experiments suggest that the right hemisphere may possess greater odor discrimination than the left hemisphere (Zucco and Tressoldi, 1988). Alternatively, this may result more from the better air flow past the olfactory patches in the right than left nostril (Zhao et al., 2004).

Each nasal passage is further incompletely subdivided transversely by three outgrowths, the turbinate bones (Zhao et al., 2004). These increase contact between the epithelial lining of the nasal passages and incoming air. These baffle-like bones induce turbulence, warming, and cleaning of the air, but also restrict air flow to the olfactory regions (located above the superior turbinate). It is estimated that during ordinary breathing, only about 5 to 10% of inhaled air passes over the olfactory patches (Hahn et al., 1993; Zhao et al., 2004). 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 affect perceived odor intensity. The

**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, 1983, Natural sniffing gives optimum odour perception for humans. Perception 12, 99–117, Pion Limited, London, reproduced by permission).
usual recommendation to take short, swift sniffs probably has more to do with avoiding odor adaptation than enhancing odor perception.

Only a fraction of the aromatic molecules that reach the olfactory patches is 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. These enzymes may also interact with olfactory UDP glucuronosyl transferase to catalyze reactions hypothesized to terminate olfactory activation [Lazard et al., 1991]. The mucous layer is thought to be recycled about every 10 min.

Olfactory Epithelium, Receptor Neurons, and Cerebral Connections

The olfactory epithelium consists of a thin layer of tissue covering an area of about 2.5 cm² 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 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]. A major constituent of the mucous matrix is olfactomedin. This protein is thought to act as a neurotrophic factor, activating growth and differentiation of olfactory neurons.
Another protein typically found in the mucus is an odorant-binding protein (OBP). It is a soluble lipophilic protein produced by Bowman's glands. It possesses selective specificity for reversibly binding with a range of odorants (Briand et al., 2002). The solubility of the complex is thought to assist the transport of hydrophobic odorants across the mucus to receptor sites on olfactory cilia (Fig. 3.5). They may also assist in the deactivation of odorants. Its presence may partially explain the concentration of odorant molecules (10^3- to 10^4-fold) higher in the nasal mucus than in the inflowing air stream (Senf et al., 1980). Although humans appear to produce only a single OBP, other animals may produce several (rats, rabbits, and pigs produce three, whereas porcupines produce eight). Their enzymatic activity may also limit microbial growth and their access to the brain via the cribriform plate.

Basal cells differentiate into receptor neurons and replace them as they degenerate. Receptor neurons remain active for an indifferent period, averaging about 60 days, but possibly functioning for up to 1 year. Differentiating basal cells produce extensions that grow upward through the cribriform plate to connect with the olfactory bulb at the base of the brain. These non-myelinated 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. Supporting cells electrically isolate adjacent receptor cells and are thought to maintain normal function.

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**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).

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1Evidence is accumulating that nerve growth also occurs in the adult human brain.
Olfactory neurons show a common cellular structure. Thus, odor quality, the unique perceived characteristics of an odorant, is not associated with any obvious cellular differentiation of receptor neurons. Odorant/receptor interaction is believed to occur on the dendritic extensions (cilia) that develop on the surface of receptor cells (Fig. 3.5A). The cilia project from a terminal swelling of the receptor cell, termed the “olfactory knob” (Fig. 3.5B). Each knob possesses up to twenty 1 to 2 μm-long, hair-like cilia. These markedly increase the surface area over which odorants can react with odor-binding proteins on the receptor membrane. Odorant molecules may bind to one (or more) different types of olfactory receptor (OR) proteins. The OR proteins are located in and transverse the membrane of the receptor neuron. Binding of the odorant with an OR protein activates adenylate cyclase, liberating cyclic AMP. It, in turn, activates the opening of ion channels in the membrane, resulting in an influx of Na\(^+\) and Ca\(^{2+}\) (Murrell and Hunter, 1999). This initiates membrane depolarization and impulse transmission along the nerve fiber, eventually activating the olfactory centers in the brain.

The distinctive character (quality) of a particular odor is thought to arise from the differential sensitivity of receptor neurons and the learning of their response pattern. Sensitivity reflects the presence of a unique family of odor-binding proteins produced by the olfactory epithelium (Buck and Axel, 1991). Each receptor cell expresses one of about 340 different odorant receptor genes\(^2\) (Malnic et al., 2004). Thus, each receptor neuron produces but a single type of OR protein. The olfactory receptor gene cluster constitutes the largest known gene family in mammals (Fuchs et al., 2001) and may constitute about 1 to 2% of the human genome (Buck, 1996). The proteins possess seven domains, each of which spans the cell membrane. Their presence on the olfactory cilia ideally positions them to associate with odorants. Each odor-binding protein bears several variable regions (domains), which may act jointly to bind a particular reactive grouping (ligand)—for example, a ring or hydroxyl structure. That individual receptor proteins possess several domains means that each receptor cell can potentially be simultaneously activated by different odorants possessing the same ligand. Correspondingly, different ligands of an odorant may activate sites on more than one type of receptor neuron (Fig. 3.6). Depending on the compound, odor quality may depend on the combination (Fig. 3.7) and activation sequence of several different receptor neurons. Thus, for most aromatics,

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\(^2\)There are also about 600 OR pseudogenes—inactive gene sequences having similarity to and probably derived from active equivalents.
there is no simple correlation between odorant chemical structure and odor quality. Odor quality seems analogous to playing a piano scale. The sequence of notes and their intensity generate a distinctive pattern. The memory of this pattern appears to be encoded in the piriform cortex. In addition, changing the concentration of a compound may modify the pattern of receptor activation, altering its perceived quality (Gross-Isseroff and Lancet, 1988). Although there are probably limits to discrimination, it appears that the primary controlling factor is “need” (Li et al., 2008)—enhanced significance can lead to improved discriminatory ability.

Receptors for specific chemical structures tend to be organized into spatially distinct, but overlapping regions in the olfactory epithelium (Johnson and Leon, 2007). The selective reproduction of special subsets of receptor cells is thought to account for the increased sensitivity to an odorant on repeat exposure (Wysocki et al., 1989). This property is apparently a general characteristic of women (during the childbearing years), but uncommon in men (Fig. 3.8).

On stimulation, the electrical impulse rapidly moves along the filamentous extensions of the receptor neuron toward the olfactory bulb. They 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 (Fig. 3.1B). Most evidence indicates that the axons enervating a particular glomerulus come from olfactory receptors activated by the same ligand (Tozaki et al., 2004). The spacial distribution of these glomeruli appear to reproduce the pattern of olfactory receptors in the olfactory epithelium (Johnson and Leon, 2007). 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 information received from receptor cells in the nose. This initially seems to involve the action of granule cells, to which mitral and tufted cells connect. They are thought to be involved in feedback inhibition of receptor neurons, as well as being activated by feedback responses from higher centers in the brain. This modulation may partially explain why the qualities of odor mixtures may differ from that of their individual components (Christensen et al., 2000). Intriguingly, granule cells show relative survival rates based on exposure to particular odors (Lledo and Gheusi, 2003). These changes appear to partially explain why memory of wine odors improves with frequent exposure, but may subsequently deteriorate. Mitral cell development in the olfactory cortex is also associated with odor learning (Wilson et al., 2004).

From the olfactory bulb, impulses are sent posteriorly, via the lateral olfactory tract, to the piriform (olfactory) cortex. In the latter, mitral cells from different glomeruli converge, combining the impulses from multiple receptor types (Zou et al., 2001). The convergence is enhanced by an elaborate system of interconnections. For example, odorant mixtures can stimulate neurons in the piriform cortex not activated by their individual components (Zou and Buck, 2006). This may also play a role in explaining

**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 (from Malnic et al., 1999, reproduced by permission).
why odorant mixtures may possess odor qualities distinct from their component constituents.

Extended exposure to an odorant tends to result in adaptation. This apparently involves inactivation of firing in the piriform and orbitofrontal cortex [Fig. 3.9]. By suppressing the perception of persistent [background] odors [Best and Wilson, 2004], adaptation has the benefit of facilitating the detection of aromatic changes in the environment [Kadohisa and Wilson, 2006].

The multiple synaptic connections in the olfactory [piriform] cortex is thought to facilitate the developing and encoding odor memories. Identification appears to take place in the anterior portion, whereas qualitative groupings, such as fruity/floral, edible versus nonedible, appears to be localized in the posterior portion [Gottfried et al., 2006].

From the olfactory cortex, signals pass to and from the thalamus {an integrator}, the amygdala {associated emotion-related memories and social interactions}, the entorhinal cortex {involved in memory consolidation}, and on to 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 converge and interact [Fig. 3.10]—what is termed “multisensory perception.” Nerve cells develop expanded synaptic connections based on repeat, coincident, activation [the “fire together, wire together” concept]. When an olfactory pattern is recognized, it simultaneously recalls other memories with which it developed—for example, the affiliation of vanilla with sweetness, the smell of Gewürztraminer with litchi nuts, or the fragrance of thyme with Christmas turkey.

In the past few years, clear evidence has established that such associations are learned [Prescott, 2004]. Stevenson et al. [1999] showed that odorants with the strongest connection with sweetness have the greatest

![Gender effects of repeated test exposures to benzaldehyde on mean benzaldehyde and control thresholds. Although initial thresholds for naive and experienced volunteers differed, the changes over trials did not, and thus data from the two groups were combined. Two-way, repeated-measures ANOVAs with gender as the between-group factor showed a significant interaction between group and time (F (9.90) = 3.29; p < 0.001) [reprinted by permission from Macmillan Publishers Ltd: Nature Neurosci., Dalton, P., Doolittle, N., and Breslin, P. A. S. (2002). Gender-specific induction of enhanced sensitivity to odors. 5, 199–200].](image)
influence on enhancing the sweet taste of sugars. The same aromatics also had the greatest influence in reducing the perceived sourness of citric acid. Figure 3.11 illustrates the effect of strawberry odor on sweetness. Conversely, sweetness and other tastants can influence the perception of fruitiness in aromatic compounds (Cook et al., 2003). However, as with other learned linkages, lack of repeat stimulation, or disassociation of integrated sensations in the future exposures, can lead to a breakdown of the neuronal connections between sensory modalities.

The integration of sensory modalities into the holistic percept called flavor appears to occur in the orbitofrontal cortex. The stability of such affiliations (Stevenson et al., 2003) probably explains why identification of tastants in gustatory–odor mixtures may be poorer when critical components are missing (Laing et al., 2002), why aromatic compounds may appear to possess gustatory attributes, and tastants influence perceived aroma intensity (Dalton et al., 2000). Connections to the amygdala probably generate the emotional memories often associated with certain odors—for example, those connected with childhood recollections. Individual cortical neurons can be associated with both specific odor memories and their perceived quality (Rolls et al., 1996). The neuroanatomy and psychophysiology of flavor perception are currently very active and dynamic areas of research (Wilson and Stevenson, 2006).
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 with cellular constituents and dissociate readily.

More difficult than explaining aromaticity is odor quality. Odors may be generated by single compounds or be the overall reaction to many compounds. The latter is typical for natural objects, such as flowers and fruit. Wine, for example, may possess more than fifty compounds that occur at sufficiently high concentrations to directly affect its odor. As noted, odor memories appear to be stored as holistic integrated patterns (its odor *gestalt*), based on experience, context, attention, expectation, and intensity; not on a collection of readily separable sensations (Wilson and Stevenson, 2003). Wine fragrance and flavor are much more than just the sum of their parts. They are cerebral constructs. For example, we learn to associate certain olfactory sensations with particular colors and wine types. Subsequently, knowing the varietal nature of a wine will induce a search for (and possibly distort) sensory inputs to match expectations. Tasters may use the reverse process to confirm suspected varietal, regional or stylistic origins of a wine. Depending on the degree-of-fit, tasters will have varying degrees of success in recognizing a wine’s origin. The relative degree of similarity appears to explain the frequent addition of the suffix “-like” or “-y” to wine descriptors—for example, rose-like, apple-like, grassy, barnyardy. They evoke similarities, but usually not exact identities. This is the equivalent of searching for recognizable patterns in images (Fig. 3.12) or the diversity of objects that can be imagined in an ink blot or cloud. The ability of the mind to interpret the same data differently (Figs. 3.13 and 6.4) may also explain why the same wine may alternately show a diversity of apparently distinct fragrances.
It appears that several molecular properties may be involved in olfactory stimulation (Ohloff, 1986). They 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 stereoisomers possess spearmint-like and caraway-like qualities, respectively.

Compounds belonging to the same chemical group may show competitive inhibition, despite possessing different odor qualities (Pierce et al., 1995). This phenomenon, called cross-adaptation, results in suppressed detection of one odorant by prior (or simultaneous) exposure to a related odorant. The phenomenon tends to dissipate with extended exposure (Lawless, 1984a). This can result in the “unmasking” of compound(s) whose presence was suppressed. This phenomenon and/or progressive changes in the composition of headspace gases are presumably involved in the development of a wine’s aromatic attributes throughout the course of a tasting. As the aromatic composition of a wine changes and sensitivity of the olfactory receptors changes, the aroma profile generated may trigger different odor memory patterns, resulting in the recognition of new attributes.

Mixtures of aromatic compounds often lose their individual identities or are detected at diminished intensities. Suppression has been shown to occur at the level of olfactory reception in the nose, where members of diverse chemical groups may antagonize activation of specific receptor proteins (Sanz et al., 2006). However, at low concentrations, synergistic effects...
have also been detected (Fig. 3.14). This can benefit detection of desirable aromatics, but may also enhance the perception of off-odors [Laing et al., 1994]. An expression of the complexity of these reactions is given by Piggott and Findlay (1984). They found both synergistic and suppressive influences with different pairs of esters, with even opposite effects appearing at different concentrations. Synergistic effects can even occur across modalities, such that the combination of subthreshold concentrations of olfactory and gustatory compounds can result in detection of both [Dalton et al., 2000]. This phenomenon appears to occur only with sensations that already have been integrated through experience [Breslin et al., 2001]. These reactions, combined with human variability in sensitivity, partially explain why people differ so frequently in their responses to wines.

**CHEMICAL COMPOUNDS INVOLVED**

The major chemical constituents in wine [alcohols, acids, phenolics] tend to generate gustatory rather than olfactory sensations. In contrast, minor or trace constituents donate a wine’s distinctive aromatic characteristics. For example, the most common wine phenolics [e.g., tannins] elicit taste and trigeminal sensations, whereas trace phenolics [e.g., vinyl phenols, syringaldehyde] have aromatic properties. 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 involves the nonvolatile constituents of a wine. For example, mannoproteins may bind important flavorants, such as β-ionone, ethyl hexanoate, and octanal, but enhance the volatility of others, such as ethyl octanoate and ethyl decanoate [Lubbers et al., 1994]. Sugars [Sorrentino et al., 1986], oils [Roberts et al., 2003], various macromolecules [Voilley et al., 1991], polyphenolics [Aronson and Ebeler, 2004], and ethanol [Tsachaki et al., 2005] can also influence volatility.
Acids

The most significant of volatile acids, 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 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 C₆ to C₁₀ carboxylic acids possessing goaty odors. 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. Above its recognition threshold (300 mg/liter), though, it becomes a major fault.

The major wine acids, notably tartaric and malic, are nonvolatile. Lactic acid has a mild odor, but is seldom of sensory significance. These acids may indirectly play a role in wine fragrance by participating 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/liter or less), they may add to the complexity to the bouquet. At higher levels, they increasingly dominate the fragrance. In distilled beverages, such as brandies and whiskeys, fusel alcohols give the beverage much of its distinctive fragrance. It is only in port that a fusel character is considered a positive quality attribute. This property comes from the fortifying spirits added during its production. Although most higher alcohols are yeast byproducts, the fungus B. cinerea produces an important alcohol [1-octen-3-ol] (Rapp and Güntert, 1986). Not too surprisingly, it is characterized by mushroomy odor.

Aldehydes and Ketones

Acetaldehyde is the major vinous aldehyde. It often constitutes more than 90% of the wine’s aldehyde content. Above threshold values in table wines,
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 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 significant amounts in sherry or in brandies.

### Esters

More than 160 esters have been isolated from wine. Because most esters occur only in trace amounts and have either low volatility or mild odors, their importance to wine fragrance is negligible. However, the more common esters may occur at or above their sensory threshold. Because some of them have fruity aspects, they can be an important factor in the bouquet of young wines. Their influence tends to be comparatively short-lived as they break down during aging to their constituent acid and alcoholic components.

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 between ethanol and acetic acid, is the most significant ester in wine. In sound wines, its concentration is generally below 50 to 100 mg/liter. At low levels (< 50 mg/liter), it may add to a wine’s complexity. At contents above 150 mg/liter, ethyl acetate generates an acetone-like off-odor (Amerine and Roessler, 1983). It is a metabolic byproduct of microbial metabolism (both yeast and bacterial) and can form abiotically by a reaction between acetic acid and ethanol.

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, and benzyl acetate an apple-like aspect. They play a significant role in the bouquet of young wines, notably white wines (Vernin et al., 1986). As the length of the hydrocarbon chain of the acid 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, heptyl acetate and ethyl octanoate—has occasionally been considered an indicator of red wine quality (Marais et al., 1979).

Esters of the major fixed acids in wine (tartaric, malic, and lactic) 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 may be found in grapes. The phenolic ester, methyl anthranilate, is a prime example. It contributes to the grapy essence of most V. labrusca varieties. Another is ethyl 9-hydroxy-nonenanoate, 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 and sulfur-containing organics generally occur only in trace amounts in bottled wine—thankfully so. 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 [H_{2}S] is a common byproduct 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.

Exposure to light 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 organosulfur compounds were first recognized as sources of off-odors, an increasing number have been found crucial to varietal aroma of several grape cultivars. For example, several thiols contribute to the aroma of Sauvignon blanc wines. These include 4-mercapto-4-methylpentan-2-ol, 3-mercaptohexan-1-ol, 4-mercapto-4-methylpentan-2-one, 3-mercaptohexyl acetate, and 3-mercapto-3-methylbutan-1-ol (Tominaga et al., 1996, 1998). 4-Mercapto-4-methylpentan-2-ol also plays a central role in the characteristic aroma of Scheurebe (Guth, 1997b) and Maccabeo (Escudero et al., 2004) wines. Often these constituents occur as nonvolatile complexes in grapes. It is the enzymic action of yeasts during fermentation that liberates the active ingredient. Another example of an important aromatic organosulfur compound is 3-mercaptohexan-1-ol. It is central to the fruity aroma of many rosé wines (Murat, 2005).

**Hydrocarbon Derivatives**

Several hydrocarbons in grapes generate important volatile degradation products. Examples are β-damascenone (floral-like), α- and β-ionone (violet-like), vitispirane (eucalyptus–camphor-like), and 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN). Several are derived from the hydrolytic degradation of carotenoids.

Possibly the most significant hydrocarbon derivative is the norisoprenoid, TDN. After several years of in-bottle aging, the concentration of TDN can rise to 40 ppb (Rapp and Güntert, 1986) or above. At above 20 ppb it donates a smoky, kerosene, bottle-aged fragrance (Simpson, 1978).

A cyclic hydrocarbon occasionally found in wine is styrene. It can produce 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 varietal odors. However, one exception is 2-vinyl-2-methyltetrahydrofuran-5-one. It has been proposed as contributing to 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 sun-dried grapes may come from lactones such as 2-pentenoic acid-\(\gamma\)-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 \(\beta\)-methyl-\(\gamma\)-octalactone). Yeasts may also synthesize them in small amounts. They possess oaky, coconut-like odors.

Among other heterocyclic compounds, vitispirane appears to be the most significant (Etievant, 1991). Vitispirane forms slowly during aging, reaching concentrations of 20 to 100 ppb. Its two isomers have different odors. The \(\text{cis}\)-isomer has a chrysanthemum flower-fruity odor, whereas \(\text{trans}\)-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 [see Rapp, 1998]. A sesquiterpene, rotundone, has recently been identified as the source of the peppery aroma that frequently characterizes the aroma of Shiraz wines (Wood et al., 2008). Other cultivars produce terpenes, but they appear to play little role in their varietal distinctiveness (Strauss et al., 1987b).

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 minimal varietal character of most botrytised 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 in
sensory impact results from the breakdown of glycosidic bonds, losses due to oxidation are more common. In the latter reactions, most monoterpenic alcohols are converted to 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.

During aging, additional 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 a major aroma component of most Vitis labrusca varieties. Another significant volatile phenolic is 2-phenylethanol. It produces the rose-like fragrance typical of some V. rotundifolia cultivars. In many V. vinifera cultivars, it is part of the complex of aromatic compounds found in their wines.

Although phenolics may contribute to the varietal aroma of a few cultivars, the most significant are the hydroxycinnamic esters generated during fermentation or derived 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/liter, or 725 μg/liter for vinylphenols. Eugenol, another clove-like derivative, can also occur in wine. At usual concentrations, eugenol adds only a general 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 are also important to the varietal aroma of several grape cultivars. 2-Methoxy-3-isobutylpyrazine plays a major role in the bell (green) pepper odor often detectable in *Cabernet Sauvignon* and related cultivars, such as *Sauvignon blanc* and *Merlot*. At concentrations of about 8–20 ng/liter, methoxybutylpyrazine may be desirable, but, at above these values, it starts to generate an overpowering vegetative, herbaceous aroma. Related pyrazines are present but 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, 2-ethyl-tetrahydropyridine, and 2-acetyl-1-pyrroline (Heresztyn, 1986; Grbin *et al.*, 1996). They are produced by some strains of *Brettanomyces*.

**SENSATIONS FROM TRIGEMINAL NERVE**

Unlike the concentration of olfactory receptors, free nerve endings of the trigeminal nerve occur throughout the nasal epithelium (excepting the olfactory patches). The location and sensitivity of these receptors throughout the nasal passages is poorly understood but appears to be nonuniform (Frasnelli *et al.*, 2004). The nerve endings respond primarily to low concentrations of a wide range of pungent and irritant chemicals. However, most odorant molecules can activate trigeminal receptors, usually at suprathreshold concentrations (Ohloff, 1994). Examples are benzaldehyde (cherry/almond) and iso-amyl acetate (banana). Vanillin is apparently an exception (Savic *et al.*, 2002). Odorants with trigeminal activity can potentially stimulate trigeminal receptors in the mouth as well. Both oral and nasal stimulation of trigeminal receptors by odorants may, thus, occasionally play a role in flavor identification during wine tasting.
Trigeminal receptors are generally 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 (—SH) or disulfide (—S–S—) bridges 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).

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). Their stimulation elicits sensations such as irritation, burning, stinging, tingling, pain, and the general perceptions of temperature, viscosity, weight, and freshness. Not surprisingly, activation of free nerve endings can also modify the perceived quality of an odorant, making it unpleasant at high concentrations. For example, indole is jasmine-like at low concentrations, but fecal-like at higher levels (Kleene, 1986), and small amounts of sulfur dioxide can be pleasing, but at high concentrations are strongly irritant. Similarly, hydrogen sulfide contributes to a yeasty bouquet and fruitiness at low concentrations (~1 μg/liter) (MacRostie, 1974), but at slightly higher concentrations donates a putrid, rotten-egg odor.

Trigeminal stimulants also tend to suppress the perception of “pure” olfactory compounds (those that do not stimulate trigeminal nerve endings). For example, carbon dioxide can suppress the detection of vanillin (Kobal and Hummel, 1988). The importance of this phenomenon, if any, to the perception of sparkling wines appears to be unknown.

VOMERONASAL ORGAN

The vomeronasal organ consists of a pair of small tubular cavities lined by chemoreceptive cells, near the opening of the nostrils (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 vestiges. They are found infrequently, and when present are highly morphologically variable (Abolmaali et al., 2001). They appear to be nonfunctional in humans (Trotier et al., 2000). Correspondingly, it seems highly unlikely that the vomeronasal organ plays any role in wine perception.
ODOR PERCEPTION

Differences in odorant perception have long been known; what is now clearer is the extent of this variation (Pangborn, 1981). Variation can affect the 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. Measurements given in the literature generally refer to when just over 50% of the test subjects detect the compound at about chance. Human sensitivity to various odorants varies over 10 orders of magnitude, from ethane at about $2 \times 10^{-2}$ M to between $10^{-10}$ and $10^{-12}$ M for mercaptans. Even sensitivity to the same (Fig. 3.15) or chemically related compounds may show tremendous variation. For example, the individual detection thresholds of trichloroanisole (TCA) and pyrazines span 4 and 9 orders of magnitude (Seifert et al., 1970). Examples of the thresholds of several important aromatics in wine are given in Table 3.1.

Threshold values are significantly influenced by the solvent—for example, water versus ethanol. Ethanol (10%) has been found to increase the detection threshold of ethyl isobutanoate from 0.03 μg/liter (in water) to 15 μg/liter (Guth and Sies, 2002). This has been noted in the increased fruity and floral aspects of some esters at alcohol content below 8% (Guth, 1998). This may partially explain the more floral nature of Riesling wine from Germany (often produced at alcohol contents significantly below the 11 to 13% typical of most table wines).

These effects are often highly specific (Table 3.2), presumably involving modification of their respective partition constants. Because enhanced volatility appears most marked at low alcohol contents (Fig. 3.16), its significance, relative to ester detection, may be limited to the finish and in-mouth sensations. At this point, the alcohol content may have fallen sufficiently to increase volatility. Equally, evaporation of alcohol from wine coating the sides of the glass following swirling may also affect the release of aromatics.

![FIGURE 3.15](image) Frequency distribution for individual 2,4,6-trichloroanisole thresholds in Sauvignon blanc wine (from Suprenant and Butzke, 1996, reproduced by permission).
Table 3.1 Detection Thresholds of Some Aromatic Compounds Found in Wine

<table>
<thead>
<tr>
<th>Compound</th>
<th>Threshold (μg/liter)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic acid</td>
<td>200,000</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>1,732</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Decanoic acid</td>
<td>1,000; 15,000</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>420; 3000</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Isobutyric acid</td>
<td>2,300; 10,000</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>33</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Octanoic acid</td>
<td>500</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Propanoic acid</td>
<td>420</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td><strong>Alcohols</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>2.8 to 90 x 10^9</td>
<td>Meilgaard and Reid (1979)</td>
</tr>
<tr>
<td>1-Hexanol</td>
<td>8,000</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>3-Hexenol</td>
<td>400</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>Isobutanol</td>
<td>40,000</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>Isoamyl alcohol</td>
<td>30,000</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>Methionol</td>
<td>1000</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td><strong>Aldehydes &amp; Ketones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>500</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Acetoin</td>
<td>150,000</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Diacetyl</td>
<td>100</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td><strong>Esters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>12,200; 7,500</td>
<td>Etiévant (1991); Guth (1997b)</td>
</tr>
<tr>
<td>Ethyl butyrate</td>
<td>14; 20</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Ethyl decanoate</td>
<td>200</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Ethyl hexanoate</td>
<td>14; 5</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Ethyl isobutyrate</td>
<td>15</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>Ethyl isovalerate</td>
<td>3</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Ethyl 2-methylbutyrate</td>
<td>18; 1</td>
<td>Ferreira <em>et al.</em> (2000); Guth (1997b)</td>
</tr>
<tr>
<td>Ethyl octanoate</td>
<td>5; 2</td>
<td>Ferreira <em>et al.</em> (2000), Guth (1997b)</td>
</tr>
<tr>
<td>Isoamyl acetate</td>
<td>30</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>3-Methylbutyl acetate</td>
<td>30</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td><strong>Lactones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ-Decalactone</td>
<td>88; 0.7</td>
<td>Etiévant (1991); Ferreira <em>et al.</em> (2004)</td>
</tr>
<tr>
<td>γ-Dodecalactone</td>
<td>7</td>
<td>Ferreira <em>et al.</em> (2004)</td>
</tr>
<tr>
<td>Z-6-Dodecenoic acid γ-lactone</td>
<td>0.1</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>4-Hydroxy-2,5-dimethyl-3-(2H)-furanone</td>
<td>5</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>cis-Oak lactone</td>
<td>67</td>
<td>Etiévant (1991)</td>
</tr>
<tr>
<td>Sotolon</td>
<td>5</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td><strong>Norisoprenoids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>β-Damascenone</td>
<td>0.05</td>
<td>Guth (1997b)</td>
</tr>
<tr>
<td>β-Ionone</td>
<td>0.09</td>
<td>Ferreira <em>et al.</em> (2000)</td>
</tr>
</tbody>
</table>

(Continued)
Guth and Sies (2002) considered that suppression of fruitiness by increasing alcohol content resulted primarily from its effect on perception, not volatilization. However, Escalona et al. (1999) found that increasing alcohol content progressively decreased the volatility of several higher alcohol and aldehydes, as did Conner et al. (1998) for some ethyl esters. The likely complex interaction of alcohol and other wine constituents on wine flavor has been highlighted by Le Berre et al. (2007). They found both synergy and suppression among β-methyl-γ-octalactone (oak lactone), isoamyl
acetate, and alcohol content. A caveat to these interpretations, relative to wine, may be indicated by the work of Tsachaki et al. (2005). They found that effects like those noted previously were markedly affected by the conditions of the experiment. Most studies have been conducted under equilibrium conditions (when the net transfer of aromatics between the wine and headspace are equal). However, under normal tasting conditions, the situation is dynamic, with more aromatic compounds leaving the wine than returning. An example of results under dynamic conditions is illustrated in Fig. 3.17.

Numerous other wine constituents can influence aromatic volatility. For example, grape and yeast polysaccharides influence the liberation of esters, higher alcohols, and diacetyl (Dufour and Bayonove, 1999a), flavonoids affect the release of various esters and aldehydes (Dufour and Bayonove, 1999b), and anthocyanins

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Table 3.2 Effect of Ethanol on the Odor Threshold of Some Wine Aromatics in Air (Ethanol in the Gas Phase 55.6 mg/liter)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Without Ethanol (a)</th>
<th>With Ethanol (b)</th>
<th>Factor b/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl isobutanoate</td>
<td>0.3</td>
<td>38</td>
<td>127</td>
</tr>
<tr>
<td>Ethyl butanoate</td>
<td>2.5</td>
<td>200</td>
<td>80</td>
</tr>
<tr>
<td>Ethyl hexanoate</td>
<td>9</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Methylpropanol</td>
<td>640</td>
<td>200,000</td>
<td>312</td>
</tr>
<tr>
<td>3-Methylbutanol</td>
<td>125</td>
<td>6,300</td>
<td>50</td>
</tr>
</tbody>
</table>


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3Rhamnogalacturonas and arabinogalactan-proteins (grape-derived) and mannoproteins (yeast-derived).
bind volatile phenolics, such as vanillin (Dufour and Sauvaitre, 2000). Thus, it is not surprising that the detection threshold of the same compound can vary considerably depending on the wine in which it occurs. For example, the detection threshold of diacetyl was found to vary from 0.2 mg/liter in Chardonnay to 0.9 mg/liter in Pinot noir and 2.8 mg/liter in Cabernet Sauvignon (Martineau et al., 1995). Even subthreshold concentrations of tastants may reduce the threshold of aromatics (Dalton et al., 2000; Pfeiffer et al., 2005). Such effects appear to be largely the result of learned associations but may also have a physicochemical component. For example, at low sugar concentrations (1%), the volatility of ethyl acetate and ethanol are enhanced (Nawar, 1971), but can reduce the volatility (and detection) of acetaldehyde (Maier, 1970). At higher concentrations (>10%), sugars may increase the volatilization of some aromatics (Taylor, 1998). Modification of the equilibrium between solubility and volatility may be the source of these effects.

Many of the effects noted previously probably arise from the multisensory nature of flavor memory. For example, learned association probably explains why Chardonnay wines were better identified when sampled globally (normal tasting) than orthonasally (only by smell) (Ballester et al., 2005); or why sucrose can be critical to the perceived flavor intensity of peppermint in gum (Cook et al., 2003). In addition, reducing the alcohol content can increase a wine’s perceived acidity and astringency (Guth, 1998). As noted by Hort and Hollowood (2004), cross-modal interactions can be highly individualistic. This reflects both the individuality of sensitivity as well as experience.
Saliva is an additional factor potentially affecting the release and perception of aromatic compounds. Wine tends to increase saliva production, potentially diluting the wine’s ethanol content. In addition, enzymes in the saliva could modify the chemical nature (and volatility) of wine aromatics. For example, saliva can degrade esters and thiols (Buettner, 2002a), as well as reduce aldehydes to their corresponding alcohols (Buettner, 2002b). Enzymes could also degrade nonvolatile aroma complexes, liberating them for release. Although not marked within the normal time frame of sampling a wine (<60 s), such effects could affect the perception of its finish. Because salivary chemistry is not constant, even in the same individual, saliva variability is another source of the idiosyncratic nature of human sensory perception.

The saliva also contains enzymes released by the oral microbial flora. These also could participate in the release flavorants from nonvolatile glycosidic associations. This begins to take effect within 20 s (Fig. 3.18). Although their activity is reduced in the presence of alcohol, this influence may be limited by dilution in the mouth. Thus, there is the possibility that the enzymatic breakdown of glycosidically bound aromatics may, under certain conditions, contribute to the finish of some wines.

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 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-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 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. Reduced mucous production in the nasal passages may be associated with hyperosmia.

The origin of the limited odor identification 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 15 cm² in surface area (containing about 200 million receptor cells), whereas the olfactory patches in humans cover about 2 to 5 cm² (Moran et al., 1982) and possess an estimated 6 to 10 million receptors (Dobbs, 1989). Considering the effective olfactory area (the cilia), dogs may have 7 m² (Moulton, 1977) in comparison to the 22 cm² for humans (Doty, 1998). Comparative measurements of the odor thresholds in dogs and humans suggest that dogs are at least 100 times more sensitive than humans (Moulton et al., 1960). However, this does not apply to all odorants. For example, humans are as sensitive, or slightly better, than dogs with some aliphatic aldehydes (Laska et al., 2000). As far as functional olfactory genes, dogs possess about 970 (Olender et al., 2004), mice about 913 (Godfrey et al., 2004), but humans only about 340 (Malnic et al., 2004). This likely accounts for some of our limited identification ability.

Additional reasons may involve the suggestion by Stoddart (1986). He suggested that repression of odor sensitivity was selected during human evolution to minimize conflict associated with our gregarious lifestyle and the development of nuclear families. However, the process of inactivation of olfactory genes (65% in humans) appears to have started earlier, correlating with the development of tricolor vision in our primate ancestors (Gilad et al., 2004), and continuing in association with movement of the eyes forward to facilitate stereoscopic vision. Thus, our current state of olfactory incompetence may stem more from increased reliance on vision than a need to reduce territoriality in tribal groupings.

Although in human evolution, there has been a loss of olfactory structures and receptor proteins, there has been an enrichment in cerebral processing. Our responses to odors are largely learned, not hardwired. Thus, combined with our remarkable capacity for memory and language, our discriminatory powers concerning odors are still remarkable. What is generally
lacking is training. There may also be a critical period to odor learning, similar to that of language acquisition.

Two other olfactory thresholds are generally recognized: recognition and differentiation. 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 important to distinguish identification (in isolation) from differentiation (by direct comparison). The former is far more difficult than the latter. It is the equivalent of differentiating shades of color side-by-side from recognizing these shades when presented separately, especially several days later.

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. For example, Jones (1968) estimated that perfumers were able to identify from 100 to 200 odorants. Although sensory skills obviously differ, whether wine professionals, such as sommeliers and Masters of Wine, possess abilities as acute as assumed is unsubstantiated (Noble et al., 1984; Morrot, 2004). In addition, even if such superior skills were to exist, what relevance would it have to the majority of us who are mere mortals? Even winemakers frequently fail to recognize their own wines in blind tastings, and experienced wine professionals frequently misidentify the varietal and geographical origin of wines (Morrot, 2004). Although not correlating with the public impression, it is easy to comprehend in the face of the marked variability that exists within regional and varietal wines (Fig. 3.19). What is surprising is the comparative success tasters may have. For example, experienced tasters at Davis, California, correctly identified the varietal origin of more than 40% of the experimental wines sampled (Winton et al., 1975). As expected, the most easily recognized were those from familiar cultivars with pronounced aromas.

**FIGURE 3.19** 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., 1984a, reproduced with permission).
(e.g., Cabernet Sauvignon, Petit Sirah, Zinfandel, Muscat, Gewürztraminer, and Riesling). What superior tasters exhibit may be above normal olfactory memory, combined with better acuity, superior motivation, and years of experience (Ross, 2006).

The problems of odor identification become compounded when they occur in mixtures (Jinks and Laing, 2001). Because individual receptors may respond differentially to several odorants (possessing a common ligand), and the same odorants activate several distinct receptors, depending on their concentration (Malnic et al., 1999), odor recognition is primarily based on learned pattern recognition, such as with facial recognition (Murray, 2004). Thus, the stimulation of several receptors (some of which may be the same) by an odorant mixture increasingly complicates identification of individual components (Laing, 1994), but does not necessarily prevent identification of the mixture (Jinks and Laing, 2001). The same situation presumably occurs with wines possessing multiple aromatics at or above their individual threshold levels. Correspondingly, identification of varietal or regional wine styles is thought to be primarily based on the holistic response to the pattern generated by multiple aromatics and tastants, not individual components. Since tasters differ in sensitivity and experience, it is not surprising that the odor memories (and the descriptors used to describe them) vary widely. Brochet and Dubourdieu (2001) found evidence suggesting the experience affects the memories (and terms) used. For example, wine critics tend to use quality-related expressions, whereas winemakers are more likely to use enology-related terms. Nevertheless, with training, most tasters come to agree on common attributes. Those that remain idiosyncratic or inconsistent in term use are typically eliminated from a panel. Training tends to level out differences in olfactory experience that can complicate differentiation of particular aromatic combinations (Case et al., 2004).

In most tests of odor recall, the sample contains a single compound or, if a mixture, the task is simple: name the source (e.g., a particular fruit). However, studies of the ability to name individual components of a mixture are rare. Figure 3.20 illustrates the difficulty of the task. This undoubtedly partially explains why identifying off-odors differs depending on the wine in which it occurs (Fig. 3.21). Trained professionals are somewhat

FIGURE 3.20 Percent correct identification of the constituents of mixtures containing up to five odorous chemicals by untrained (▪), trained (◊), and expert subjects (○) (from Laing, 1995, reproduced by permission).
better at identifying components of a mixture, but their ability tends to decline with more than four components [Livermore and Laing, 1996]. Perfumers may appear to have superior skills in this regard because their assessments are based on paper wicks dipped into the perfume. As different components dissipate, the process generates the rough equivalent of a gas chromatographic separation. Somewhat equivalently, identification of components improves when people are first allowed to become adapted to specific constituents prior to testing (Goyert et al., 2007).

Odors are often classified by origin (e.g., floral, vegetal, smoky), or associated with specific events or locations (e.g., Christmas, barbecuing, bonfires, hospitals). Thus, odor terms typically are concrete, referring to an object or experience, and not to the olfactory perception itself. Usually, 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, left versus right, respectively [Herz et al., 1999]. People also have difficulty envisaging odor sensations, in contrast to the ease of conjuring up visual and auditory memories. Verbal or contextual clues improve identification [de Wijk and Cain, 1994], in the same way that suggestion can influence what can be “seen” in cloud formations. Pronouncing the name of a cultivar or an odor often induces its detection, even in its absence. Suggestion seems to reorganize 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]. Thus, it is important that tasters be actively involved in developing a common odor lexicon so that communication can be effective [Gardiner et al., 1996; Herz

![FIGURE 3.21 Detection of off-odors in different wines: □, white wine; ■, red wine; ethyl acetate (60 mg/liter); 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.](image-url)
and Engen, 1996). In contrast, the terms most consumers and wine critics use express more their holistic or 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 in identifying odors than men (Fig. 3.22; Choudhury et al., 2003). This presumably relates to women becoming more sensitive to odors upon repeat exposure—by up to 5 orders of magnitude (Dalton et al., 2002). In addition, the cerebral activity of women on exposure to odors is considerably more marked than men (Yousem et al., 1999). 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 olfactory discrimination, correlated with cyclical hormonal changes (see Doty, 1986). However, the most significant factor differentiating people in sensory skill may be the remarkable genetic diversity between individuals, relative to their olfactory receptor (OR) genes (Menashe et al., 2003). Each person tested had a distinctive OR gene pattern. Their results also indicate that ethnic groups may differ in general olfactory sensitivity.

Age also influences olfactory acuity. This may express itself in increased detection, identification, and discrimination thresholds (Lehrner et al., 1999a). There is also a reported 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. Nevertheless, considerable diversity exists in all age groups (Doty et al., 1984). This probably reflects the incidence of extenuating factors such as medication, smoking, and a history of nasal problems. The latter has been found to significantly influence olfactory function, especially in those more than 65 years old (Mackay-Sim et al., 2006). Cognitive status and health were found particularly important to olfactory function in centenarians (Elsner, 2001).

Reduction in the regeneration of receptor neurons probably explains additional age-related olfactory loss (Doty and Snow, 1988). However, neuronal degeneration of the olfactory bulb and connections to the 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 viewed as 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 volume, especially in the area of the olfactory epithelium, can influence olfactory acuity (Damm et al., 2002). This is well known from the short-term loss of smell associated with massive increases in mucus secretion caused by nasal and sinus infections. This effectively blocks air access to the olfactory regions (Fig. 3.23) and diffusion to receptor neurons. In addition, infection may also accelerate certain degenerative changes, producing long-term acuity loss.

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 syndrome (deficiency in gonadotropin-releasing hormone). Many medications and drugs affect smell (Doty and Bromley, 2004). Cocaine, for example, disrupts the olfactory epithelium.
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 reactivity of the olfactory bulb and cerebral cortex (Freeman, 1991).

Smoking produces both short- and long-term impairment of olfactory skills (Fig. 3.24). Thus, smoking is not permitted in tasting rooms. Nonetheless, smoking has not prevented some individuals, notably André Tchelistcheff, from becoming highly skilled winemakers and cellar masters.

Adaptation is an additional source of altered olfactory perception (Fig. 3.25). 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 olfactory adaptation occurs rapidly (occasionally within 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; the odorants need not even be seemingly related (Fig. 3.14). This may have considerable importance in wine, where hundreds of compounds occur at or below their respective detection thresholds. Although strongly suspected to occur in wine, it has yet to be confirmed experimentally (Grosch, 2001). Of equal importance, but
also little investigated, is the role of odor masking. This refers to the reduced detection of one odorant in the presence of another (Guth, 1998; Czerny and Grosch, 2000). Cross-adaptation is a related phenomenon, where prior exposure to an odorant increases the detection threshold to another. Masking is not always via cross-adaptation, as in the case with SO2. In this instance, as sulfur dioxide oxidizes or escapes from the wine, the rupture of sulfonate linkages releases compounds to which sulfate was bound. An example is the liberation and volatilization of diacetyl [Nielsen and Richelieu, 1999].

The perception of aromatic compounds can also be influenced by other wine constituents. The effect of sugar in augmenting perceived fruitiness is well known, as is the influence of acidity on reducing perceived fruitiness (von Sydow et al., 1974). For example, removal of citric and malic acids from a mixture of strawberry flavor and sucrose resulted in an increase in perceived fruitiness (Cook et al., 2003). These influences, which are learned associations, undoubtedly play a role in wine tasting and its pairing with food.

Despite its importance to the sensory perception of wine, the interaction of food flavors with wine has been little studied. To date, few studies have investigated the interaction of wine and cheese (Nygren et al., 2003a, b). In most instances, the interaction is similar to those of other complex mixtures—a reduction in perceived intensity, notably the wine but also the cheese. The decrease in perception may result from reduced volatilization of wine aromatics (through absorption by lipids in the cheese). Fats coating taste receptors in the mouth may also be involved. A similar effect has been noted with Hollandaise sauce (Nygren et al., 2001). In a separate investigation, Hersleth et al. (2003) showed that taking food with wine enhanced its appreciation, especially those with a buttery flavor.

The interaction of various sensory modalities appears to depend on how the person assesses the combination. For example, interactions are less marked or are absent if the person analyzes taste and olfactory sensations individually, rather than concentrating on holistic perceptions (Frank A

FIGURE 3.25 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).
et al., 1993). Thus, how the brain accesses odor memories and/or evaluates sensory data seems almost as important as the actual stimuli.

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 are clearly affected by pre- and postnatal experiences (Mennella et al., 2001) and tend to mature most noticeably between the ages of 6 and 12 (Garb and Stunkard, 1974), with further significant changes occurring as one ages (Moncreiff, 1967). There are equivalent age-related changes in wine partiality (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 noted earlier are clearly involved. For example, people generally fall into one of three classes relative to androstenone: those detecting androstenone 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 also support a genetic component, with identical twins showing similar responses, whereas fraternal twins often differ (Beauchamp, 1987). Hormonal or developmental factors may be involved in the higher proportion of women detecting androstenone than men.

Contextual factors, such as taste (Zampini et al., 2008), color intensity (Iland and Marquis, 1993; Zellner and Whitten, 1999), and other visual clues (Sakai et al., 2005) can potentially influence odor perception. The experiment of coloring a white wine with anthocyanins is now famous (Fig. 3.26). It induced enology students to describe the white wine in terms typically ascribed to red wines. This influence occurred despite both control and colored samples being tasted together. Although striking, since the wine involved was a Sauvignon blanc, possessing aromatic similarities to Bordeaux reds they often tried, the result is more understandable. In a somewhat similar investigation, where the panelists did not have the same expectations as in the Bordeaux study, experienced tasters were less biased by wine coloration (Parr et al., 2003). Brochet and Morrot (1999) and Lange et al. (2002) have also presented revealing studies on the influence of contextual (label) knowledge on perception. Changes in preference, based on source knowledge are common in almost all consumer goods. Such context effects are often the result of contrast (e.g., a good wine

![FIGURE 3.26](image.png)
appearing better when associated with poorer wines, but poorer when tasted with better wines). These influences are not caused by adaptation as they occur independently of their position in a wine tasting.

Comments from tasters have long been suspected to influence perception. For example, the suggestion of the presence of a hazelnut odor often engenders similar remarks. Familiarity with an odor term also tends to increase perceived intensity and hedonic response to its presence [Distel and Hudson, 2001]. With some odors, correct identification influences the emotional response. For example, recognizing lavender as such increased its perceived pleasantness [Degel et al., 2001]. In addition, the qualitative attributes ascribed to an odor is often affected by the emotional connotation of the term applied to it [Herz and von Clef, 2001]. This has often been thought to be purely psychological, but certainly has a neurological basis. Because odor identification depends on the recall of olfactory receptor patterns, mention of a term associated with an odor can favor its recognition. If these psychological influences enhance appreciation, they may be beneficial—they certainly influence wine sales. Conversely, it can also result in disappointment, as in the case of tasting a wine at home without the accompanying ambiance of the bistro by the beach on vacation. Memories often incorporate incidental associated aspects—a reflection of the holistic experience, not just the wine.

Experience tends to generate idiotypic recollections, against which new wines are compared [Hughson and Boakes, 2002]. In this absence, novice tasters generally use sensory attributes, such as sweetness, on which to base judgements [Solomon, 1988]. The involvement of olfactory memory in wine assessment by wine professionals is supported by functional magnetic resonance imaging (fMRI). For example, sommeliers showed greater activity in left insula and orbitofrontal complex than novice tasters. The principal areas activated in novice tasters were the primary gustatory cortex and regions associated with emotional processing [Castriota-Scanderbeg et al., 2005]. Further evidence of preconditioning has been obtained by McClure et al. (2004). fMRI imaging was used to follow the activity of different parts of the brain when subjects tasted different cola drinks. Without brand knowledge, response was similar for both brands. However, when brand identification was provided, the response pattern changed considerably, affecting not only sensory regions but also emotional, reward, and memory centers of the brain. Thus, brand marketing can change brain response, even when sensory clues are insufficient to permit discrimination.

Although it is usual to think primarily of “smelling” in relation to olfaction, retronasal olfaction is also an important component [Figs. 3.27 and 3.28]. However, clear differentiation between these distinct olfactory
sensations can be complicated, especially when odorants possess gustatory and trigeminal attributes. In addition, orthonasal and retronasal olfaction differ in fundamental aspects (Halpern, 2004; Negoias et al., 2008). Not only is identification of odorants poorer retronasally (Fig. 3.29), but threshold values are generally higher. Retronasal versus orthonasal activation also generates temporally different response patterns in the brain (Frasnelli et al., 2005; Small et al., 2005). This reflects the long-held hypothesis that sensation in the nose resembles a gas chromatogram. Response to different ligands (the reactive structure of an aromatic compound) is spatially distributed along the olfactory patches. Furthermore, retronasal olfaction selectively activates the central sulcus, a site associated with impulses from the oral cavity. This may partially explain why flavors are thought to generate in the mouth. In an absolute sense they do, the olfactory component of flavor originates in the mouth and progresses into the nose via the pharynx.

The difference in response pattern between orthonasal and retronasal administration of odors is particularly distinct between food- or non-food-related odors. This is likely related to learned, integrated, multisensory response patterns. Even color has a different effect on perceived odor intensity, depending on how it is provided. It can affect orthonasal detection but
does not influence retronasal sensation (Koza et al., 2005). The difference between orthonasal and retronasal perception has been confirmed in clinical studies. Landis et al. (2005) demonstrated that a loss of orthonasal smell does not necessarily result in an equivalent loss of retronasal smell, suggesting a distinct processing mechanism. With such differences, it is not surprising that the in-glass fragrance of a wine is often different from its in-mouth sensation.

As might be expected, the concentration of aromatics supplied retronasally is lower than that via the nose (about 1/8th) (Linforth et al., 2002). Aspiration or other oral agitation in the mouth facilitates the continued liberation of aromatics, based on their relative volatility. The more rapidly a compound volatilizes, the more rapidly it needs to be replenished at the air/wine interface. Their study also showed that dilution by saliva did not appear to significantly affect retronasal concentration of the compounds studied. The rate of air flow out the nose appeared to be the most important factor, followed by dilution in the nasal passages, and adsorption by the nasal mucosa. However, studies by Heilmann and Hummel (2004) suggest that flow rate alone does not explain lower retronasal odor detection. This may relate to retronasal olfaction involving differential processing, as noted previously.

Swallowing is a major factor in directing air flow into the nasal passages and, therefore, the concentration of volatiles present (Hodgson et al., 2005).
Exhalation is the other principal source of the intermittent (pulsed) air flow that supplies aromatics to the nasal passages. That flow is pulsed and the concentration significantly lower, the phenomenon of adaptation is presumably less significant than during prolonged orthonasal smelling (Cook et al., 2003).

The most significant contribution of retronasal olfaction in wine tasting is its involvement in the perception of the “finish.” The vapor pressure differences between aromatics, their relative absorption in and/or destruction by saliva enzymes, rates of absorption in the pharynx and nasal mucosa, and destruction by mucosal enzymes influence the perceived duration and intensity of the finish. These effects are illustrated in Figs. 3.30 and 3.31. Additional factors include the reversible association of aromatics in nonvolatile complexes with wine constituents, such as mannoproteins. The molecular structure of such nonvolatile complexes is unknown, but may be similar to the incorporation of molecules in cyclodextrin micelles. They possess hydrophobic interiors and hydrophilic exteriors. Learned associations further complicate issues, as where changes in the perceived

![FIGURE 3.30](image.png)

**Breath-by-breath profiles for the consumption of an aqueous solution containing anethole (A) and p-cymene (B). The solution was consumed at 0 min, and the signal intensity for each compound was followed for 0.5 min thereafter. The maximum signal intensity has been normalized to 100% for each compound (from Linforth and Taylor, 2000, reproduced by permission).**
FIGURE 3.31
Time-resolved retronasal evaluation of the intensities of odor attributes and their overall odor intensities (middle graph) after intraoral application and expectoration of two Chardonnay wines (from Buettner, 2004, reproduced by permission).
intensity of a tastant can influence the perceived intensity of an aromatic, without changing its actual concentration in the nose (Hollowood et al., 2002).

**ODOR ASSESSMENT IN WINE TASTING**

The assessment of fragrance is one of the most difficult and discriminative aspects of wine tasting. Olfaction generates the most diverse and complex perceptions in wine. The distinctive varietal, stylistic, and aging characteristics of wines are largely aromatic in nature. 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 specialist market appeal.

In wine tasting, connoisseurs 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. Unfortunately, samples are a nuisance to prepare, maintain, and standardize. Even pure chemicals can contain contaminants that alter odor quality (Meilgaard et al., 1982). Microencapsulated (“scratch-and-sniff”) strips would be ideal and efficient, but are commercially unavailable. In critical tasting, though, only a few descriptors are usually necessary to differentiate (versus identify) between similar groups of wines (Lawless, 1984b).

The distinction of two categories of wine fragrance, *aroma* and *bouquet*, is of long standing. Their differentiation is based on origin. Aroma traditionally 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 sunburning, 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 *gout 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 distilled wine (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, this distinction is difficult to employ in practice. Similar or identical compounds may be derived from grape, yeast, or bacterial metabolism, or be generated by abiotic chemical reactions. In addition, only with long experience can the aroma aspects of a wine’s fragrance be distinguished from its bouquet.

OFF-ODORS

In the absence of a clear definition of quality, it is not surprising that more is known about the chemical nature of wine faults than wines’ positive attributes. The following section briefly summarizes the characteristics of several important wine off-odors. Appendix 5.2 gives directions for preparing faulty wine samples for training purposes.

Quick and accurate identification of off-odors is advantageous to winemaker and wine merchant alike. For the winemaker, early remedial action can often correct the problem, before the fault becomes more serious or intractable. For the wine merchant, avoiding losses associated with faulty wines improves the profit margin. Consumers should also know more about wine faults, but use it wisely and with discretion. Rejection should be based only on genuinely recognized faults—not unfamiliarity, inappropriate expectations, the presence of bitartrate crystals, or dryness (often incorrectly termed “vinegary”).

No precise definition of what constitutes a wine fault exists—human perception is too variable. Wine faults are like grammar errors—designated by general consensus of groups of experts. Nevertheless, off-odors tend to have a common property. They tend to mask the wine’s fragrance. For example, the suppression of a wine’s fresh fragrance by corked (TCA) or “Brett” taints (Licker et al., 1999). Surprisingly, some compounds considered faults at above-detection thresholds may be desirable at or near their detection thresholds. Examples are acetic acid and diacetyl. Thus, depending on personal sensitivity, what may be desirable to one may be repulsive to another. In addition, when aromatically delicate, they may be an essential and traditional element in certain wines. Examples are the oxidized bouquets of sherries and the fusel odor of ports. In other instances, off-odors such as barnyardy may be considered part of the goût de terroir of certain wines, and as such be highly appreciated. Even aspects considered normally desirable may be considered a fault to some—for example, the oakiness of
some Chardonnay wines. It is the equivalent to whether there is too much or too little pepper in a recipe. Prestige of the wine may also to suppress the perception of a fault, such as the noticeable ethyl acetate character to several Sauternes.

**Acetic Acid (Volatile Acidity)**

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 for ethyl acetate. Vinegary wines typically are sharply acidic, with an irritating odor derived from the combined effects of acetic acid and ethyl acetate. Acetic acid concentrations in wine should not exceed 0.7 g per liter. Frequently, people unfamiliar to wine mistake the acidic attribute of many table wines with vinegar.

**Baked**

Some 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. It involves a series of thermal degradation reactions, often involving sugars (notably fructose) and amino acids. Reactions of this type generate what are usually termed “Maillard products.”

**Buttery**

Diacetyl usually is found in wine at low concentrations as a result of yeast and bacterial metabolism. It may also be an oxidative byproduct of maturation in oak barrels. Although typically considered to possess a butter-like odor, diacetyl is a negative quality factor significantly above its recognition threshold. For some individuals [the author included], other constituents accompanying diacetyl give it a crushed earthworm (decomposing hemoglobin) odor.

Bartowsky et al. (2002) have shown that wine possessing a buttery character may have diacetyl contents below its detection threshold. Thus, other compounds, such as acetoin and 2,3-pentanedione, may play a role in contributing to the buttery attribute.

**Corky/Moldy**

Wines may show corky or moldy odors due to the presence of a range of compounds. One of the most common is 2,4,6-trichloroanisole (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. Its detection is often influenced by the type of wine [Mazzoleni and Maggi, 2007]. Other corky off-odors may come from the presence of 2,4,6-tribromoanisoles [Chatonnet et al. 2004], or 2-methoxy-3,5-dimethylpyrazine [Simpson et al., 2004]. Musty off-odors in cork may also originate from sesquiterpenes produced by filamentous bacteria, such as *Streptomyces*. Additional moldy odors in cork can result from the production of guaiacol and geosmin by fungi such as *Penicillium* and *Aspergillus*. Although most moldy (corky) taints come from cork, oak cooperage or moldy grapes can also be sources of similar off-odors.

**Ethyl Acetate**

Wines spoiled by the presence of ethyl acetate are far less common than in the past [Sudraud, 1978]. At concentrations below 50 mg/liter, ethyl acetate may add a subtle fragrance. However, above about 100 mg/liter, it begins to have a negative influence, possibly due to suppression of the fragrance of other aromatic compounds such as fruit esters [Piggott and Findlay, 1984]. At above 150 mg/liter, ethyl acetate generates an obvious acetone-(Cutex® Remover) like off-odor. Threshold values vary with the type and intensity of the wine’s fragrance. Correspondingly, it is more readily apparent in white than red wines. Spoilage microbes are the most common source of ethyl acetate off-odors. Nonetheless, it can accumulate abiotically from the esterification of ethanol in the presence of acetic acid.

**Ethyl Phenols**

Ethyl phenols can donate a variety of off-odors, depending primarily on their concentration. These can vary from smoky, spicy, phenolic, to medicinal attributes, at near threshold values, to sweaty, leather, barnyardy, or manure taints at higher concentrations. This variation, combined with individual sensitivity, may partially explain why some winemakers consider them desirable and part of the distinctive characteristics of their wines. In contrast, others find them revolting enough to make the wine “undrinkable.”

The odors develop primarily as a consequence of the growth of *Brettanomyces*. The yeast can contaminate wine, converting several hydroxycinnamic acids [nonflavonoid phenolics] into their corresponding ethyl phenols. Consequently, red wines tend to experience “Brett” odors more than white wines. Different strains of *Brettanomyces* possess different enzymatic abilities to oxidize hydroxycinnamic acids to vinyl and subsequently ethyl phenols.
Contamination of wine can occur when the wine is stored in insufficiently disinfected cooperage or passes through contaminated transfer connections. The yeast can grow on even minute remnants of wine. Upon contamination, the yeast can generate ethyl phenols either in cooperage or in-bottle.

**Fusel**

During fermentation, yeasts produce limited amounts of higher (fusel) alcohols. At concentrations close to their detection thresholds, they can add to the aromatic complexity of a wine. If these alcohols accumulate to levels greater than about 300 mg/liter, they generally are considered 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 distillation in the production of the largely unrectified wine spirits used to fortify port.

**Geranium-like**

The distinctive off-odor known as geranium-like occasionally tainted wine in the past, due to 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 odor resembling scented geranium. As a consequence, sorbate is currently rarely used in wine preservation.

**Light Struck**

Light-struck (*goût de lumière*) refers to a series of off-odors that can develop in wine exposed to light. In champagne, it apparently results from the generation of dimethyl sulfide, methyl mercaptan, and dimethyl disulfide (Charpentier and Maujean, 1981). However, D'Auria *et al.* (2003) failed to confirm this, finding instead an increased presence of 2-methylpropanol (a fusel alcohol) and a significant modification of, as well as reduction in, the presence of many fruit esters.

**Mousy**

Several lactic acid bacteria and *Brettanomyces* yeasts generate mousy taints. The odor is caused by the synthesis of several tetrahydropyridines and related compounds. Because they are not readily volatile at wine pH values, their presence is seldom detected on smelling the wine. Their odors become evident only on tasting. Winemakers often put a small amount of wine on their hands and use the “palm and sniff” technique for quick detection of a mousy taint. Sensitivity to this taint can vary by 2 orders of magnitude (Grbin *et al.*, 1996).
Oxidation

Presence of an obviously oxidized aspect is now comparatively rare in commercial table wine. Oxidation produces a “flat” sensation, which at the extreme may possess a range of aldehyde-like odors. This is often associated with browning in white wines and the development of premature brickish hues in red wines. Nevertheless, short-term oxidation does not appear to be correlated with the accumulation of acetaldehyde [Escudero et al., 2002]. This apparent anomaly may result from the low concentration of o-diphenols in most white wines. Their oxidation is the most significant source of the peroxide that generates aldehydes in bottled wines. Sherries possess a complex oxidized odor, due primarily to the presence of acetaldehyde and branched [methyl] aldehydes [Culleré et al., 2007]. The latter tend to possess dried fruit to orange-like flavors. In contrast, oxidized table wines possess few branched aldehydes but significant amounts of 2-alkenals [unbranched aldehydes with a double carbon bond on the second carbon] [Culleré et al., 2007]. Important examples are 2-nonenal, 2-octenal, methional, and phenylacetaldehyde. These may express a range of odor qualities, variously described as cooked vegetable, pungent, earthy, moldy, and rancid. In aged wine, both branched and unbranched aldehydes accumulate. However, the branched forms appear to suppress the perception of the undesirable, unbranched forms [Culleré et al., 2007].

The early expression of oxidation in table wine appears to be associated with the use of faulty corks or improper cork insertion. In addition, cork stoppers may contain sufficient oxygen to induce detectable oxidative browning in white wine [Caloghiris et al., 1997]. Oxygen can also seep into the wine through the cork or probably more frequently between it and the bottle neck. Rapid temperature changes can favor the latter by loosening the seal (due to pressure on the cork caused by alternate expansion and constriction in wine volume). Leaving a bottle standing upright for an extended period can result in cork shrinkage (due to drying), followed by oxygen ingress. Nevertheless, even under seemingly acceptable storage conditions, most white wines often begin to show obvious signs of browning within 4 to 5 years.

The most well-known reaction associated with wine oxidation involves the production of hydrogen peroxide, from the interaction of oxygen and wine phenolics. Hydrogen peroxide subsequently reacts with other wine constituents, such as alcohols, fatty acids, esters, and terpenes. Because ethanol is the reactant occurring in the highest concentration, the principal byproduct of wine oxidation is acetaldehyde. However, its rapid binding to other constituents tends to keep the free acetaldehyde content below its detection threshold. Only after extensive oxidation does acetaldehyde accumulate to the point that it can influence wine fragrance. The precise mechanism by which other aldehydes form in wine has yet to be investigated.
As noted, oxidative reactions with other wine constituents progressively reduce the varietal character of the wine. Oxidation and subsequent polymerization of wine phenolics lead to the formation of brown pigments. Although browning occurs in both red and white wines, it becomes apparent earlier in white wines due to their paler color. White wines, although possessing fewer phenolic compounds than red wines, are also less able to inactivate molecular oxygen (limiting other forms of oxidation). Peng et al. (1998) have shown that browning can affect the acceptance ratings of white wines. What is unclear is how important it is to the “average” consumer under nonlaboratory conditions.

In contrast to the slow oxidative changes in bottled wine, wine placed in bag-in-box packages often oxidize within a year. This results from the slow infiltration of air around or through the spigot. New advancements in spigot design and manufacture may limit this deficiency in an otherwise consumer-friendly package.

Oxidation problems can occur at any stage in wine production. However, for consumers, oxidation is primarily of concern following bottle opening. During the normal time frame of consumption, this does not appear to have a detectable sensory significance (Russell et al., 2005). However, if the wine is not fully consumed within a few hours, it begins to lose its original flavor. Surprisingly, this does not involve the production of significant concentrations of acetaldehyde. What appears more important is the rapid loss in ethyl and acetate esters (Roussis et al., 2005).

Because oxygen uptake is significantly retarded at cold temperatures, minimizing the duration of exposure to air and storage at refrigerator temperatures should delay oxidative deterioration after bottle opening. For example, air/wine contact is about 0.4 cm²/100 ml in a 750 ml bottle at opening. Pouring about half the contents increases the surface area/volume ratio by about 20 times (7.5 cm²/100 ml). Because the air in the bottle would contain about 120 mg oxygen, it should be reduced as much as possible (by vacuum or preferably flushing with an inert gas such as carbon dioxide, nitrogen, or argon).

A phenomenon, termed “bottle sickness,” refers to development of a short-lived off-odor that may develop in wines bottled without prior flushing with carbon dioxide. The off-odor usually dissipates within several weeks.

**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, if present, can usually be eliminated quickly by mild aeration.
Unfortunately, aeration does not as rapidly eliminate the off-odors generated by most volatile organosulfur compounds. Mercaptans, which impart off-odors reminiscent of farmyard manure, rotten onions, etc., may slowly oxidize to disulfides. Although having thresholds about 30 times higher than their corresponding mercaptans, disulfides still possess unpleasant cooked-cabbage to shrimp-like odors. Many other 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.

**Sulfur Odor**

Sulfur dioxide is typically added at one or more points during wine making, maturation, or at bottling. It is also generated by yeast metabolism. Nevertheless, a reduction in its use means that sulfur dioxide seldom occurs at above threshold concentrations, where its presence would produce an irritating, burnt-match odor. Even at above threshold levels, its odor usually dissipates quickly. It rapidly escapes from the wine during swirling.

**Unypical Aging Flavor (untypischen Alterungsnote, UTA)**

The off-odor known as untypical aging flavor or untypischen Alterungsnote (UTA) possesses a naphthalene-like aspect. It has been proposed to be due to the synthesis of 2-aminoacetophenone (Rapp et al., 1993). 2-Aminoacetophenone is a breakdown product of tryptophan or its byproduct IAA. It tends to develop one to several years after bottling and is correlated with the presence of unfavorable seasonal growing conditions, notably water deficit and/or a shortage of nitrogen. The appearance of a similar phenomenon in New York State has been correlated with the presence of TDN, and the loss of volatile terpenes (Henick-Kling et al., 2005). The accumulation of TDN, possessing a kerosene-like odor, also occurs during the aging of several white wines. In some countries, it appears to be associated with exposure to high-intensity sunlight and warm growing conditions (Rapp, 1998). Whether these two atypical aging phenomena are various expressions of the same physiological problem or distinct disorders remains to be clarified (Sponholz and Hühn, 1996). An unrelated source of a naphthalene off-odor may come from naphthalene derived from winery equipment or absorbed by cork from the environment.

**Vegetative Odors**

Several herbaceous off-odors have been detected in wines. The best known are those associated with the presence of “leaf” (C₆) aldehydes and alcohols. Additional sources of vegetative to herbal odors come from the presence of
several methoxypyrazines, notably those that characterize many *Cabernet Sauvignon* and *Sauvignon blanc* wines.

**Other Off-Odors**

Additional recognized off-odors include those produced by butanoic acid (spoiled butter) and propanoic acid (goaty); the raisined aspect derived from sun-dried grapes; the cooked flavor of wines fermented at high temperatures; the stemmy feature produced by the presence of green grape stems during fermentation; and the rancid character of old oxidized red wines. Off-odors of unknown identities or origins are rubbery (likely a thiol), weedy (possibly a synonym for vegetal), and earthy (perhaps one or more sesquiterpenes).

**CHEMICAL NATURE OF VARIETAL AROMAS**

The presence of a distinctive varietal aroma is one of a wine’s premium quality features. Unfortunately, distinctive varietal attributes are not consistently expressed. They vary with the clone, environmental and wine making conditions (Fig. 3.32), cultivation, as well as the production skills of the winemaker.

For several cultivars, specific aromatic attributes tend to epitomize their essential varietal character (Tables 7.2 and 7.3). In a few cases, these can be correlated with the presence of a particular compound. With other cultivars, the varietal aroma is associated with the relative concentrations of several volatile compounds. In most instances, though, no particular compound or group of compounds appears to have singular importance. This may be because there are no unique impact compounds, or they have as yet to be discovered. Based on the recent discovery of the importance of thiol compounds and sesquiterpenes in several cultivars, which occur in ng amounts, many crucial impact compounds may still be awaiting discovery.

Determining the chemical nature of a varietal aroma is fraught with difficulty. Not only must the compound(s) exist in forms unmodified by current extraction techniques, but they must occur in concentrations that make isolation and identification
possible. Isolation is easier when the compound[s] 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 detecting certain groups [e.g., aldehydes bound to sulfur dioxide]. The situation is even more demanding when impact compounds are labile or occur in trace amounts.

Simple presence does not necessarily signify sensory importance. It is estimated that less than 5% of the volatile compounds in food are of sensory significance (Grosch, 2001). The situation with wine appears similar. Determining sensory impact requires detailed analysis, involving its concentration, how that relates to its threshold, and direct confirmation of its role in model wines—either by addition or omission. Because compounds can jointly activate similar receptors in the nose, their effects may be synergistic, or combine to produce a qualitative response distinct from that generated by the individual compounds.

For comparative purposes, volatile ingredients are often grouped into subjective categories, termed “impact,” “contributing,” or “insignificant.” Impact compounds elicit distinctive fragrances—the equivalent of Cyrano’s nose. Contributing compounds add complexity but are not by themselves varietally unique. Examples are the acetate esters of higher alcohols that impart the fruity odor to most young white wines (Ferreira et al., 1995). Components of an aged bouquet would also be considered contributing compounds. Insignificant compounds constitute the vast majority of volatile constituents. They occur at concentrations insufficient to significantly alter the aroma or bouquet.

Most grape varieties are not known to possess a distinctive varietal aroma. This may result from few varieties having been studied sufficiently to know whether they possess a distinctive aroma. For example, were the fame of Pinot noir 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-mercaptopyropionate (Kolor, 1983), N-[N-hydroxy-N-methyl-γ-aminobutyryl]glycin (Boison and Tomlinson, 1988), or 2-aminoaceto-phenone (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 (Capsicum) character of some Cabernet Sauvignon (Boison and Tomlinson, 1990) and Sauvignon blanc (Lacey et al., 1991) wines is primarily due to 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 black currant fragrance of some Cabernet Sauvignon wines is unknown but may be related to the presence of β-damascenone and eugenol, and the absence of fruit esters such as ethyl butanoate and ethyl octanoate (Guth and Sies, 2002). Another possible source of this attribute is 4-mercapto-4-methyl-pentan-2-one (4MMP). At low concentrations, this thiol is described as resembling black currant or box tree.

Another source of a peppery aspect in wine, in this case black pepper (Piper nigrum), is a quaiane-type sesquiterpene, rotundone (Wood et al., 2008). It donates the peppery aroma to Shiraz wines. It also may contribute to the flavor of cultivars such as Mourvèdre and Durif, in which it may also occur at above-threshold values. It can be detected at a few parts per trillion (ng/L) by the majority of people. As usual, there is considerable variation in sensitivity, with some 20% of those tested being essentially anosmic to the compound. Not surprisingly, rotundone donates much of the distinctive character to black pepper, in which it occurs at much higher concentrations.

Several complex thiols have recently been implicated as crucial impact compounds in varietal aromas. The first group of cultivars in which their significance was discovered were the Carmenets (Cabernet Sauvignon, Merlot, Sauvignon blanc, etc.) (Bouchilloux et al., 1998; Tominaga et al., 1998, 2004). Examples are 4-mercapto-4-methylpentan-2-one, 3-mercaptohexyl acetate, 4-mercapto-4-methylpentan-2-ol, and 3-mercaptohexan-1-ol. The first two are considered to 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 has also been found to be central to the aroma of Scheurebe (Guth, 1997b), Colombard (du Plessis and Augustyn, 1981), and Maccabeo (Escudero et al., 2004).

The intensely aromatic character of Gewürztraminer 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, 1997b; Ong and Acree, 1999). Interestingly, the same compounds that give litchi nuts their distinctive aroma are found in Gewürztraminer wines, giving credence to the presence of a litchi-like fragrance.

Muscat varieties are distinguished by the prominence of monoterpene alcohols and C_{13}-norisoprenoids 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 [Rapp, 1998]. Thiols may also contribute significantly to their varietal distinctiveness [Tominaga et al., 2000].

Occasionally, impact compounds are fermentation byproducts, for example, 2-phenylethanol. It is also an aroma compound central to the distinctive fragrance of muscadine wines [Lamikanra et al., 1996]. Another likely example is isoamyl acetate, a distinctive flavorant of Pinotage wines [van Wyk et al., 1979]. Alternatively, yeast enzymes may release impact compounds from bound forms. An example is 3-mercaptohexanol-1-ol, derived from a cysteinylated precursor in grapes. This thiol compound is suggested to donate much of the fruity character to some rosé wines [Murat, 2005].

Several well-known, aromatically distinctive cultivars, such as Chardonnay [Lorrain et al., 2006] and Pinot noir [Fang and Qian, 2005], appear to possess no distinctive impact compounds. Their varietal distinctiveness may arise from quantitative, rather than qualitative aromatic attributes [Le Fur et al., 1996; Ferreira et al., 1998]. For example, β-damascenone is a prominent component in the aroma profile of Chardonnay and Riesling wines [Simpson and Miller, 1984; Strauss et al., 1987a], β-ionone typical of Muscat wines [Étiévant et al., 1983], and α-ionone and benzaldehyde characteristic of Pinot noir and Gamay wines, respectively [Dubois, 1983].

Particular combinations have been considered to generate varietal characteristics. For example, Moio and Étiévant [1995] have suggested that four esters, ethyl anthranilate, ethyl cinnamate, 2,3-dihydrocinnamate, and methyl anthranilate, donate the central varietal flavor to Pinot noir wines.

Although grapes are the principal source of impact compounds, even if they may be released by yeast action or during maturation, there are other sources of important wine flavorants. Yeast derived esters and some volatile phenolics have already been mentioned. Another, but little recognized source of impact compounds, involves oak. For example, several oak constituents are similar to grape flavorants. This may explain why the “varietal” expression of certain wines is enhanced by maturation in oak [Sefton et al., 1993].

Although hundreds of aromatic compounds have been isolated from wine, assessing their relative significance to a particular wine's aroma and bouquet is far from simple. The task has partially been simplified by estimating the odor activity value (OAV) of each compound. This is the concentration of a compound divided by its detection threshold. A listing of olfactory thresholds and ranges of concentration in wines is found in Table 3.1. Additional information has been compiled by Francis and Newton (2005). Compounds with an OAV greater than 1 have a much greater
potential of influencing a wine’s fragrance than those possessing OAVs less than unity. Unfortunately, there is no direct correlation between the OAV and sensory impact. The perceived intensity of various compounds at their threshold and above differ markedly. In addition, interpretation of the data is complicated by the multimodal interaction among wine constituents. This can either reduce or augment a compound’s potential significance. Finally, threshold values are an average, based on the specific group involved and the conditions under which it was assessed. Nonetheless, the OAV is a good starting point in investigating a compound’s potential significance.

Several techniques have been developed to further clarify the sensory significance of particular compounds. An example is aroma extract dilution analysis (AEDA) (Grosch, 2001). It involves adding compounds with OAVs greater than unity to model wines and assessing their character relative to a particular varietal wine. Its use is likely to require a reassessment of the presumed significance of many compounds. It has already been used to demonstrate the importance of certain flavorants to varietal wines such as Grenache (Ferreira et al., 1998) and the existence of a significant difference between the Cabernet Sauvignon and Merlot wines. The latter is apparently characterized by a distinguishing caramel odor. It is suspected to be due to a difference in the concentration of 4-hydroxy-2,5-dimethylfuran-3(2H)-one and 4-hydroxy-2(or 5)-ethyl-5(or 2)-methylfuran-3(2H)-one (Kotseridis et al., 2000). It has also supplied evidence for the probable methoxypyrazine origin of the pronounced stemmy character in Cabernet Sauvignon and Chardonnay wines fermented with stems (Hashizume and Samata, 1997). The technique has further demonstrated that the characteristic flavor of Gewürztraminer and Scheurebe wine could be reproduced, respectively, by the 29 and 42 flavorants that occurred at above threshold values in their respective wines (Guth, 1998). Nonetheless, presence of cis-rose oxide and 4-mercapto-4-methylpentan-2-one were essential, respectively, to the distinctive Gewürztraminer and Scheurebe character of model wines. In contrast, elimination of compounds such as acetaldehyde, β-damascenone, and geraniol had little effect. Addition of 13 other aromatics, occurring at below their threshold value in the original wine, did not affect the aroma characteristics of the model wine.

Another technique, APCI-MS [atmospheric pressure chemical ionization mass spectroscopy or MS-Nose], provides real-time analysis of volatile constituents in the nose (Taylor et al., 2000). Although it has limited identification power, it has proven particularly useful in studying the dynamic change in aromatics following release from food (Taylor et al., 2000). It has seen little use with wine due to disruption of ionization in solutions containing more than 4% ethanol. However, it presumably could
be used in assessing the dynamics of aroma release associated with a wine’s finish, or the influence of food on wine flavor. Nonetheless, the technique has already demonstrated that it is not the absolute content of aromatics in food that is critical, but changes in their concentration that tend to influence perceived odor intensity (Linforth & Taylor, 2000). It has also confirmed the continued liberation of aromatic compounds from the oral cavity minutes after swallowing (Wright et al., 2003; Hodgson et al., 2005). The duration of a particular compound’s presence is markedly affected by its partition coefficient \(K_{al}\). Those with low coefficients are liberated more slowly, but over a longer period. Using another technique, **Buccal Odor Screening System** (BOSS) has indicated that the fruity character of *Chardonnay* wines disappears more rapidly from the oral cavity than more slowly volatilized oak flavorants (Fig. 3.33).

**FIGURE 3.33** Comparative BOSS analysis illustrating how long various aromatics from two different Chardonnay wines remained in the oral cavity after expectoration. (from Buettner, 2004, reproduced by permission).
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CHAPTER 3: Olfactory Sensations


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Taste and Mouth-Feel Sensations

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Two types of oral chemoreceptors generate the perceptions of taste and mouth-feel. Specialized receptor cells generate taste (gustatory) perceptions, notably sweet, sour, salt, bitter, and umami (savory), and are grouped in cavities within taste buds. Free-nerve endings generate the mouth-feel (tactile, haptic) perceptions of astringency, touch, dryness, viscosity, burning, heat, coolness, body, prickling, and pain, and are scattered throughout the oral cavity. The combination of these modalities, with those from the nose, produces the construct perception termed flavor. The olfactory component comes from volatile compounds that enter the nasal passages via the nose (orthonasally) and back of the mouth (retronasally) (Chapter 3).

By themselves, taste and mouth-feel modalities are comparatively monolithic. This feature is evident when a head cold clogs the nasal passages. Because odorants cannot reach the olfactory patches, food and wine lose most of their usual sensory appeal. Nevertheless, achieving balance between the oral, gustatory, and haptic sensations of a wine is one of the most demanding tasks for a winemaker. A distinguishing feature of superior wines is the harmony that exists among these diverse sensations. Imbalances created by excessive acidity, astringency, bitterness, etc., are often the first faults noted by a judge. Thus, although sensorially simple, gustatory and haptic sensations are critical to the perception of wine quality.

In contrast to olfactory sensations (Chapter 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 at parts per trillion.

**TASTE**

Gustatory sensations are detected by nerve-like, modified, epidermal cells. These cells are located in 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 either differentiating or degenerating receptor cells. Cranial nerve fibers enter the base of the taste buds and synapse with one or more receptor cells. About two-thirds of taste buds are located on the tongue, where they are found on the sides of raised growths called papillae. The remainder occur primarily on the soft palate and epiglottis (Schiffman, 1983). A few taste buds 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, especially at the tip and sides. Fungiform papillae are sufficiently critical to gustation that their density has been directly correlated with taste acuity [Miller and Reedy, 1990; 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. They are more evident in children than adults. Filiform papillae are the most common class but contain no taste buds. Their tapering, fibrous extensions give the tongue its characteristic rough texture. The absence of significant numbers of taste buds in the central regions of the tongue means that it is essentially nonsensitive to gustatory sensations.

Gustatory receptor cells usually remain active for only a few days, being replaced by differentiating adjacent neuroepithelial cells. Each receptor cell culminates in a receptive dendrite or many fine extensions [microvilli]. These project into the saliva 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 elicits 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 taste bud integrity. 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). Nevertheless, the differences are comparatively small (Fig. 4.3) and impede differentiation among taste modalities in complex solutions such as wine.

The neurons that enervate 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. 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 taste buds of the epiglottis, larynx, and upper reaches of the esophagus.

Impulses from 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, five taste modalities are clearly recognized: sweet, sour, salty, bitter, and umami.
The latter is a response to some L-amino acids, notably glutamate and aspartate, as well as 5’-ribonucleotides, notably inosinate and guanylate (Rolls et al., 1998). A receptor for fatty acids (Chale-Rush et al., 2007; Laugerette et al., 2007) appears to occur. However, neither umami nor fatty acid receptors are likely to have direct relevance to wine tasting, with the exception of its association with food. The metallic attribute occasionally found in wine appears to be an unrecognized odor (Hettinger et al., 1990; Lawless, 2004). Closing the noses with the fingers usually results in the disappearance of the metallic sensation.

Sensitivity to the various taste modalities appears to be associated with specific receptor proteins or their combination (Gilbertson and Boughter, 2003). Specific receptor cells produce only one or a select pair of receptor proteins. Thus, each receptor may generate impulses to one or a few related modal qualities. In contrast, individual taste buds appear to respond to most taste modalities. Nonetheless, there is a degree of specialization, as noted in Fig. 4.3. This view is supported with genetically modified animal studies (Zhao et al., 2003). In addition, the brain appears to respond to signals from certain regions in programmed patterns, regardless of the actual stimulus (Mueller et al., 2005).
Response to modalities, such as sweet, umami, and bitter, is associated with a group of about 30 related TAS (taste) genes. Sour and salty sensations are associated with an unrelated group of genes. These encode for ion channel transporters and respond to either $H^+$ ions or metallic ions, notably $Na^+$.

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), and an inability to taste L-glutamate (umami) (Lugaz et al., 2002). 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).

Several studies have indicated that receptors of similar sensitivity tend to be grouped together (Scott and Giza, 1987). Nonetheless, individual receptor neurons may react differentially to more than one sapid compound (Scott and Chang, 1984). These factors probably account for limited taste localization with complex solutions such as wine. In addition, touch can redirect localization of perceived sensations—a form of taste referral (Green, 2002). This phenomenon may also partially explain why flavor (integration of retronasal odor, taste, and mouth-feel) appears to be located in the mouth.

Taste acuity has been correlated with the number of taste pores on the tongue. Average tasters have about 70 fungiform papillae per cm$^2$ (at the front of the tongue). In contrast, those with significantly enhanced sensitivity to a bitter tastant (PTC/PROP$^1$) possess more 100/cm$^2$, whereas those with significantly reduced sensitivity have about 50/cm$^2$ (Bartoshuk et al., 1994). This approximates to about 350, 670, and 120 taste pores per cm$^2$ for normal, enhanced (hypertaster$^2$), and reduced (hypotaster) categories, respectively. The fungiform papillae of hypertasters are smaller but have more taste pores than those of hypotasters. The taste buds of hypertasters may also have significantly greater enervation by trigeminal nerves and are correspondingly more responsive to chemosensory and touch sensation, such as the burning sensation of capsaicin. Lim et al. (2008) have suggested what appear to be better criteria for these categories, which relate to a more general heightened (or reduced) sensitivity to taste responses.

Hypertasters, as might be suspected, often prefer foods with more subtle tastes. In contrast, hypotasters are relatively insensitive to most sapid

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$^1$PTC (propylthiocarbamide); PROP (6-n-propylthiouracil).

$^2$Hypertaster and hypotaster categories have been used instead of supertasters and nontasters as used by Bartoshuk for relative sensitivity to PTC/PROP.
substances and tend to prefer foods or beverages with more intense flavors. These differences in taste sensitivity appear to be controlled by a single gene. Hypertasters are homozygous (TT) for a developmental gene (both allelic copies being functional); average tasters are heterozygous (Tt), possessing one each of the functional and nonfunctional alleles; whereas hypotasters are homozygous (tt) for the nonfunctional allele. Environmental factors and/or epigenetic phenomena probably account for most of the variability in the number of papillae and taste pores among individuals. Additional genetic factors may be 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 people, it is a moot point whether they are the best wine tasters. Being especially sensitive to sapid substances, they might reject or downgrade excessively those 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 possessing especially acute sensitivity to sapid and olfactory sensations are probably preferable. However, if data relative to average consumer acceptance is desired, then tasters reflecting the norm of human sensitivity would be more appropriate. At present, there appears no evidence that gustatory sensitivity is related to olfactory acuity.

**Sweet, Umami, and Bitter Tastes**

Although the sweet, umami, and bitter perceptions may appear unrelated, they have similar molecular modes of activation (Fig. 4.6). They also depend
partially on the formation of van der Waals attractions between hydrogen bonds and receptors on gustatory receptors (Beidler and Tonosaki, 1985). The genes that encode for their response proteins fall into two subgroups (TAS1R and TAS2R). The TAS1R group consists of three genes that encode proteins sensitive to sweet and/or savory (umami) tastants. Expression of TAS1R3 generates a low-level response to sugar; joint expression of TAS1R2 with TAS1R3 provides high sensitivity to sugars, a wide range of artificial sweeteners, and a few amino acids (Li et al., 2002); whereas joint expression of TAS1R1 and TAS1R3 produces a receptor for umami activators, such as L-amino acids, notably monosodium glutamate (MSG) (Nelson et al., 2002; Matsunami and Amrein, 2004). Various allelic forms of TAS1R3 exist. They may be partially involved in the qualitative difference perceived among different sweet tastants.
The TAS2R gene group consists of 25 functional genes (there are also nonfunctional pseudogenes). These code for receptor proteins that react with a diverse range of bitter tasting compounds (Behrens and Meyerhof, 2006). These can include certain acetylated sugars, alkaloids, amines, amino acids, carbamates, ionic salts, isohumulones, phenolics, and ureas/thioureas. Receptor cells responsive to bitter tastants occur primarily in taste buds at the back of the tongue and palate, but sporadically elsewhere in the oral cavity. Individual receptors cells may co-express several TAS2R gene transcripts and presumably respond to several classes of bitter tastants. Nevertheless, there appears to be at least some specialization in receptor sensitivity to particular chemical subgroupings. For example, alkaloid-induced bitterness can be detected well on the tip of the tongue, but not the bitterness associated with iso-\(\alpha\)-amino acids. All cells expressing TAS2R genes also express the gustatory G-protein, \(\beta\)-gustaducin, important in the sensation of bitterness. There may also exist a second bitter sensing mechanism. It appears to involve compounds that can penetrate taste receptor cells, directly activating the cells and generating a lingering bitter aftertaste (Sawano et al., 2005). Age-related loss in bitterness sensitivity appears to be chemical specific (Cowart et al., 1994).

Each TAS receptor protein is associated with guanosine triphosphate (GTP). Correspondingly, TAS proteins may also be classified as G-proteins. Reaction with the tastant indirectly induces depolarization of the cell membrane, associated with activation of adenylate cyclase. This modifies \(K^+\) conductance and intracellular free calcium concentration (Gilbertson and Boughter, 2003). This results in the release of neurotransmitters that initiates impulse transmission to the brain.

There is considerably more genetic diversity within the bitter, TAS2R loci than would be expected based on the variation in other human genes (Kim et al., 2005). This situation seems to mimic the variation in odor sensitivity that also exists throughout the human population.

Slight structural changes in many sweet- and bitter-tasting compounds can change their taste quality from sweet to bitter, or vice versa. The change in taste quality appears partially due to their ability to jointly activate members of both receptor groups. For example, the sweet tastant, saccharine, is perceived to have a bitterish aspect by many people. This presumably results from its activation of the bitter receptors TAS2R43 and TAS2R44 (Kuhn et al., 2004). Bitter- and sweet-tasting compounds are also well known to mask the perception of each other's intensity, without modifying their individual sensory modality. The molecular origins of this phenomenon are presently unknown.

The primary sources of sweet sensations in wine are glucose and fructose. The perception of sweetness is enhanced by the presence of glycerol
and ethanol. By comparison, there is no significant concentration of umami tastants in wine.

The primary bitter tastants in wine have normally been viewed to be flavonoid phenolics, notably catechins (tannin monomers) (Kielhorn and Thorngate, 1999). Catechins (flavan-3-ols) are more bitter than astringent (the reverse of their polymers, condensed tannins) (Robichaud and Noble, 1990). In red wines, bitterness is often confused with (Lee and Lawless, 1991), or potentially masked by, the astringency of tannins (Arnold and Noble, 1978). Nonetheless, the importance ascribed to catechins may be exaggerated. Recent studies have identified ethyl esters of hydroxybenzoic and hydroxycinnamic acids (nonflavonoid phenolics) as potentially more significant than catechins as bitter tastants (Hufnagel and Hofmann, 2008).

During aging, wine often loses some of its bitterness, presumably as phenolics polymerize and/or precipitate. However, if smaller phenolics remain in solution, or larger tannins hydrolyze to their monomers, perceived bitterness may increase during aging.

Several glycosides, amines, triterpenes, and alkaloids may occasionally elicit bitter sensations in wine. Examples include the bitter terpene glycosides found in Muscat wines (Noble et al., 1988) and the bitter flavanone glycoside, naringin, found in Riesling wines. Tyrosol, produced by yeasts during fermentation, may also occasionally contribute to wine bitterness. Additional bitter substances may come from pine resin (added to retsina), or herbs and barks, used in the flavoring of vermouth. Occasionally, bitterness may result from the growth of certain spoilage bacteria in red wines. They produce acrolein that donates a bitter taste in the presence of tannins.

Many amino acids possess a variety of taste sensations but occur in wine at concentrations unlikely to have perceptible influence. Fatty acids also activate particular receptors cells, but as with amino acids, they occur in wine at contents below detectable levels.

**Sour and Salty Tastes (ASIC and ENaC Channels)**

Sourness and saltiness are commonly called the electrolytic tastes. In both instances, small soluble inorganic cations (positively charged ions) are the stimulants (Fig. 4.7). For acids, free H\(^+\) ions are selectively transported across the cell membrane (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. In both cases, the influx of ions induces a membrane depolarization that triggers the release of neurotransmitters from axonal endings. Since related ion channels are involved in both instances, it is not too surprising
that acids frequently express some saltiness, and some salts show a mild sour aspect (Ossebaard et al., 1997).

Both sensations are regulated by a pair of related genes. Acid detection is based on an ion channel encoded by the ASIC2 gene (Gilbertson and Bough-ter, 2003). It is highly expressed in mammalian taste buds and is particularly sensitive to H\(^+\) ions. Salt detection is associated with a related gene (ENaC) that encodes another ion-sensitive channel. In addition to activating H\(^+\) ion receptors in taste buds, acids can also stimulate nocio(pain)receptors connected to trigeminal nerve endings. This produces the sharp sensation found in excessively acidic wines.

The tendency of acids to dissociate into ions is influenced both by the anionic (negatively charged) component of the molecule and pH. Thus, both factors significantly affect the perception of sourness. Although undisassociated acid molecules do not effectively stimulate receptor neurons, they can affect perceived acidity (Ganzevles and Kroeze, 1987). The major wine acids affecting perceived sourness are tartaric, malic, and lactic acids. These acids can also induce astringency, presumably by denaturing saliva proteins (Sowalsky and Noble, 1998), but also possibly by enhancing the astringency of phenolcs normally found in the saliva (Siebert and Euzen, 2008). Conversely, wine phenolics, the principal agents of astringency in wine, significantly enhance the sourness of acids (Peleg et al., 1998). Additional acids occur in wine but, with the exception of acetic acid, rarely 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, Na\(^+\), 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, as well as delaying reaction time.

**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 (from Kinnamon, 1996, reproduced by permission).
The major salts in wine possess large organic anions (e.g., tartrates and bitartrates). Because these dissociate weakly at wine pH values, their common cations (K\(^+\) and Ca\(^{2+}\)) do not effectively 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 due to H\(^+\) ions activating salt receptors.

**FACTORS INFLUENCING TASTE PERCEPTION**

Many factors affect the ability to detect and identify taste sensations. These may be conveniently divided into four categories: physicochemical, chemical, biologic, and psychologic.

**Physicochemical**

After a century of investigation, the role of temperature on 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

**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) (from Portmann et al., 1992, reproduced by permission).
bitterness (and astringency) of tannins is well known to be more evident at cool temperatures. This apparent anomaly may relate to the different receptors involved in tannin and alkaloid bitterness.

Another important factor affecting taste perception is pH. It both directly influences the ionization of salts and acids, and indirectly affects 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 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 Finlay, 1990). In addition, members of a group inducing one modality can affect the perception of compounds inducing another modality. At low concentrations, the interaction may enhance perceived intensity. At moderate concentrations, the effect tends to be additive, whereas at high concentration, suppression is the norm. Nevertheless, the interactions are often complex and vary with the compounds involved (Keast and Breslin, 2003).

It is hypothesized that these intermodal influences may arise from the enervation of taste buds and their receptors. Responses from receptors detecting different modalities may travel along the same neuron, and experience subtle and intricate feedback suppression, locally and from higher brain centers. A common example of interaction is the suppression of bitterness, astringency, and sourness by sugar (Lyman and Green, 1990; Smith et al., 1996). The saltiness of some cheeses can equally suppress the bitterness of red wines. These influences may or may not affect response time, duration, and maximum perceived intensity (Figs. 4.9 vs. 4.10). Although suppression is common, ethanol enhances the perception of sugar-induced sweetness and flavonoid-induced bitterness (Noble, 1994), while suppressing the astringency and sourness of some acids. Another example is the increase in perceived bitterness and astringency of tannins in the presence of acids.

Although sapid substances are well known to influence olfactory perception (Voilley et al., 1991), the reverse is also true (Dalton et al., 2000; Labbe et al., 2007). Of particular interest is the influence of aromatics on the perception of the sweetness of sugar. Thus, the fragrance of a wine may not only evoke the perception of sweetness, but also increase the perceived intensity of any sweetness induced by sugars.

Sapid substances often have more than one sensory modality. For example, small tannin polymers may be both bitter and astringent, as well as possess a
FIGURE 4.9  Effect of the astringency of tannins (○ low, 1300 GAE; ● high, 1800 GAE) on sweetness perception (A) maximum intensity, (B) time to maximum intensity, and (C) total duration. (GAE, gallic acid equivalents) (from Ishikawa and Noble, 1995, reproduced by permission).

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) (from Ishikawa and Noble, 1995, reproduced by permission).
fragrance\(^3\); glucose can be sweet and mildly tart; acids show both sour and astringent properties; potassium salts be salty and bitter; and alcohol possess a sweet taste and generate the mouth-feel perceptions of burning and weight. In mixtures, these side-tastes can significantly affect overall taste quality (Kroeze, 1982). The perceived intensity of a mixture generally reflects the intensity of the dominant component, not a summation of their individual effects (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 both dilutes and modifies wine chemistry. The proline-rich proteins of saliva, which make up about 70% of salivary proteins, effectively bind tannin. Saliva histatins also react with polyphenolics (Wróblewski et al., 2001). These reactions not only reduce bitterness (by lowering their ability to react with bitter-sensing receptor proteins), but also affect the generation of an astringent mouth-feel (Glendinning, 1992). Because saliva chemistry changes throughout the day (affecting its buffering action) and often differs between individuals, it is difficult to predict the specific effects of saliva production on taste. People also differ in their saliva flow rates. This can affect how quickly an individual may react to tastants (Fischer et al., 1994). Condelli et al. (2006) have also shown that increased gustatory sensitivity appears to be associated with reduced saliva flow rate.

**Biologic**

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 declines past middle age. Nevertheless, age-related sensory loss is not known to seriously limit wine tasting ability.

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\(^3\)This may, however, come from co-occurring aromatics in commercial tannin samples.
Certain medications also reduce taste sensitivity (Schiffman, 1983), generate their own tastes, and produce a variety of distorted taste responses (Doty and Bromley, 2004). For example, acetazolamide blocks the response of nerve fibers to carbonation, eliminating the prickling sensation of sparkling wine (Komai and Bryant, 1993). In addition, taste perception can be disrupted by various household products. A familiar example is the alteration 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 those with dentures. Acuity loss also complicates identification of sapid substances in mixtures (Stevens and Cain, 1993).

Recessive genetic traits produce specific taste deficiencies, such as with the \texttt{TAS2R38} gene that affects perception of PTC and PROP. These are related, standard bitter tastants frequently used in sensory studies. Inability to detect PROP has also been correlated with reduced sensitivity of the acidity, bitterness, and astringency in red wines (Pickering et al., 2004). However, more subtle individual variations in taste acuity are even more common (Fig. 4.12; Delwiche et al., 2002; Drewnowski et al., 2001).
The origins of these differences are unclear but probably involve variations in the number of taste buds, as well as phenotypic differences resulting from dissimilar allelic complements. Cultural influences, such as family upbringing and peer pressure, can modify some of the genetic underpinning of personal preference (Barker, 1982; Mennella et al., 2001). Whether these modifications are related to stable differences in how the primary taste cortex responds to taste stimuli is unknown (Schoenfeld et al., 2004). Nonetheless, any or all of 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 PTC 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 complete. Correspondingly, it is usually recommended that wine tasters cleanse their palate between samples.

Cross-adaptation refers to the effect of adaptation to one compound affecting perception of 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 (in the absence of any apparent bitterness) (McBurney and Bartoshuk, 1973).

**Psychologic**

The conditions of a tasting (its context) has long been known to influence perception. The example of color’s effect on wine perception has already been mentioned (Chapter 2). The influence of context on food acceptance is also well known (Clydesdale, 1993; Francis, 1995). Most evidence suggests that these influences arise from coincident learned associations.

Several aromatic compounds do have a taste component, such as butyl acetate (Cain, 1974). It stimulates both olfactory and gustatory receptors. However, most instances of cross-modal associations originate from incidental connections based on joint taste-olfactory experience. These multimodal perceptions arise in the orbitofrontal cortex (Rolls et al., 1998; Prescott et al., 2004). Even the verbal suggestion of a fragrance can affect the perception of a tastant (Djordjevic et al., 2004). Nonetheless, independently assessing the fragrant and gustatory aspects of a mixture or holding the nose during tasting can minimize or eliminate cross-modal influences (Frank et al., 1989).
The development of these associations often has a cultural origin, expressed in ethnic differences in odor/taste judgments (Barker, 1982; Chrea et al., 2004). The oft-mentioned affinity between regional cuisines and local wines is probably no more than the embodiment of cultural habituation or the holistic remembrance of vacationing in a charming locale.

**MOUTH-FEEL**

Mouth-feel refers to sapid sensations activated by free-nerve-endings of the trigeminal nerve. Trigeminal nerve endings primarily surround taste buds (Whitehead et al., 1985), but also occur nonuniformly throughout the oral cavity. For example, those responsive to capsaicin (chili peppers) and piperine (black pepper) have different distributions in the mouth (Rentmeister-Bryant and Green, 1997). In addition, receptors particularly sensitive to burning irritants are clustered primarily at the tip and along the sides of the tongue. Nonetheless, these somatosensory receptors typically generate diffuse, poorly localized sensations throughout the mouth. In wine, mouth-feel involves perceptions such as astringency, burning, prickling, viscosity, body, and temperature.

Most mouth-feel sensations originate from stimulation of one or more of the four types of trigeminal receptors. These are categorized as mechanoreceptors (touch, pressure, vibration), thermoreceptors (heat and cold), nocioreceptors (pain), and proprioceptors (texture, movement, and position). Although there is a degree of specialization in these receptors, it is incomplete. For example, some nocioreceptors also elicit the perception of heat; carbon dioxide can trigger nocioreceptors, inducing pain; and alkylamides can activate proprioceptors (see Green, 2004). Some receptors are also clearly multimodal. In addition, either joint activation or other trigeminal receptors are involved in generating the range of modalities grouped under the term “astringency.”

Unlike gustatory and olfactory sensations, activation occurs slowly. This probably arises because most of the receptors are buried within or beneath the mucosal epithelium. Adaptation is also slow or may not develop. The latter is particularly evident in the increased intensity of astringent sensations on repeat exposure to red wines—correspondingly the use of palate cleansers during tasting. However, for many food irritants, such as capsaicin, sensitization is replaced by desensitization. This occurs when the interval between exposures is extended (> 10 min). This phenomenon does not occur with all irritants, for example, menthol.
Astringency

Astringency is probably a series of related sensations variously described as dry, puckery, rough, or dust-in-the-mouth. These attributes typify most red wines (Lawless et al., 1994; Francis et al., 2002), less so for white wines. The sensation is primarily induced by flavonoid tannins that come from grape seeds and skins. Anthocyanins can enhance the perceived astringency of tannins but do not contribute to wine bitterness (Brossaud et al., 2001). Maturation in oak cooperage can also add tannins. However, these are predominantly hydrolyzable tannins. They are more likely to induce bitterness than astringency.

Astringency is not uncommonly confused with bitterness (Lee and Lawless, 1991)—both usually being induced by related compounds. Adding to the potential confusion is the similar nature of their time-intensity profiles, both perceptions developing comparatively slowly and possessing lingering aftertastes (Figs. 4.13 and 4.14). The strong astringency of tannins may partially mask their bitterness (Arnold and Noble, 1978). When requested, trained tasters appear to differentiate between these sensations. Without an objective measure for both sensations, how well tasters succeed in this task is a moot point. Data from Ross and Weller (2008) suggest that astringency is more often confused with bitterness than the reverse. Figure 4.15 illustrates the relative intensities for astringency versus bitterness of several phenolics found in wine.

Astringency is thought to result from the binding and precipitation of proline-rich salivary proteins and glycoproteins with phenolic compounds (Haslam and Lilley, 1988; Kielhorn and Thorngate, 1999). As measured by turbidity, this reaction occurs optimally at about pH 4 (Siebert and Euzen, 2008). The main reaction appears to involve the —NH₂ and —SH groups of proteins, with o-quinone tannin sites (Haslam et al., 1992). In the binding of tannins with proteins, their mass, shape, and electrical properties change, frequently resulting in precipitation. Other tannin-protein reactions are known but are apparently of little significance in wine (Guinard et al., 1986b).

An important factor influencing astringency is pH (Fontoin et al., 2008; Fig. 4.16). Hydrogen ion
concentration affects protein hydration, and both phenol and protein ionization. In very acidic wines, low pH can alone induce salivary glycoprotein precipitation (Dawes, 1964), eliciting astringency (Corrigan Thomas and Lawless, 1995). High ethanol content has been found to reduce the perception of astringency (Fontoin et al., 2008). This may accrue from alcohol limiting the binding of tannins to saliva proteins (Serafini et al., 1997).

As tannins bind with salivary proteins (mostly proline- and histidine-rich proteins, histatins, and glycoproteins, notably α-amylase), salivary viscosity is reduced and friction increases. Both factors reduce the lubricating properties of saliva, inducing a rough sensation (Prinz and Lucas,

FIGURE 4.14  Average time-intensity curve for astringency of 5 g/liter 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) catechin, (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)].
In addition, the precipitation of protein–tannin complexes likely forces water away from the cell surface, simulating dryness. Precipitated salivary proteins also coat the teeth, producing the characteristic rough texture associated with astringency. Inadequately investigated are reactions between tannins (and/or low pH) on denaturing the glycoproteins and phospholipids of the mucous membrane. Malfunctioning of the plasma membrane, such as disruption of catechol amine methylation, could play a role in the perception of astringency. This might explain why catechin content correlates more with astringency than precipitating saliva proteins (Kallithraka et al., 2000). However, data from Guest et al. (2008) do not support this interpretation. In addition, the relatedness of certain tannin constituents to adrenaline and noradrenaline could stimulate localized blood vessel constriction, further enhancing the dry, puckery sensation.

Astringency is one of the slowest of in-mouth sensations to develop. Depending on the concentration and types of tannins, astringency can take up to 15 s before reaching maximal intensity (Fig. 4.14). The decline in perceived intensity occurs even more slowly. Tasters have similar but distinctive response curves to specific tannins. These tend to remain stable over time (Valentová et al., 2002).

The intensity and duration of an astringent response often increases with repeat sampling (Guinard et al., 1986a). This phenomenon is less likely to occur when the wine is consumed with food, owing to reactions between tannins and proteins in the food, as well as due to dilution. However, when one is tasting wine by itself, an increase in apparent astringency could produce sequence errors 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 insufficiently rapid or marked to limit the increase in perceived astringency.

One of the more important factors known to influence tannin-induced astringency is molecular size. Catechins (flavan-3-ol monomers) bond weakly to proline-rich salivary proteins and do not detectably bind to
Bonding is roughly correlated with molecular size (polymerization). However, at above 3400 Da, the molecules lose conformational flexibility. Steric hindrance limits the availability of binding sites. Thus, polymerization is correlated with increased astringency, up to the point where the polymers precipitate or no longer can bind to proteins. The result is a decline in astringency.

The precipitation of saliva proteins has been the most studied molecular aspect of astringency. However, by itself it does not explain all aspects of astringency. For example, proanthocyanidins and their catechin monomers poorly precipitate saliva proteins but generate astringency. However, Kielhorn and Thorngate (1999) question the use of the term “astringency” for the sensation induced by low-molecular-weight flavonols. In addition, the increase in astringency, usually associated with the successive tasting of red wines, does not correlate well with the activation of saliva production. Finally, several authors have described and illustrated distinct astringent modalities (Gawel et al., 2000, 2001). Increasing polymerization of procyanidins augments drying, chalky, grainy, puckery attributes, whereas increased galloylation (flavanols esterified with gallic acid) particularly accentuates rough or coarse attributes as well as dryness (Vidal et al., 2003). Galloylated tannins are particularly common in seed tannins. The epigallocatechin content of tannins (the least common of the grape flavanols) correlates with reduced astringency.

The condensation between flavanols and anthocyanins (either direct or ethyl-linked) also affects perceived astringency. Possibly indicative of the complexity of the interactions, these polymers have been variously found to either enhance (Brossaud et al., 2001) or decrease (Vidal et al., 2004b) astringency.

Although current research is beginning to unravel the various roles of tannin subgroups relative to astringency, much still needs to be learned before a clear picture of its complexities develops. This partially reflects the extreme structural complexity of tannins, their age-induced modifications, and the variety of sensory reactions induced. Flavonoid and nonflavonoid monomers can polymerize to form dimers, trimers, and a diversity of higher oligomers and polymers. They also bond with anthocyanins, acetaldehyde, pyruvic acid derivatives, and various sugars. How these products relate to the so-called “soft” and “hard” tannins of winemakers remains to be clarified.

Recently, attention has been directed to the role of nonflavonoids, notably the ethyl esters of hydroxybenzoic and hydroxycinnamic acids, in wine astringency (Hufnagel and Hofmann, 2008). In addition, the velvety astringency occasionally detected in red wines has been associated with flavonol
glycosides, especially those of quercetin, syringetin, and dihydrokaempferol. What is required is a correlation between the concentration and sensory thresholds of the various constituents, similar to the olfactory activity index (OAV) for aromatic compounds. Addition and subtraction tests would also illuminate the relative importance of the various phenolics to wine astringency.

Although phenolics and organic acids are the main inducers of wine astringency, other compounds may evoke astringency, notably high ethanol concentrations. 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 contents produce a burning sensation in the mouth, especially noticeable at the back of the throat. Some phenolics and sesquiterpenes also produce a peppery, burning irritation in wines. These perceptions probably result from the activation of polymodal vanilloid receptors (TRPV1). These respond to a variety of stimuli, including heat, cuts, pinching, acids, and chemicals such as capsaicin. Although the burning sensation arises from the activation of several types of primarily heat-sensitive pain receptors, there are differences in receptor sensitivity throughout the buccal and oral cavities. These probably give rise to the qualitative differences between the sensations of various irritants, such as mustard, horseradish, chilies, and black pepper. Wines particularly high in sugar content (e.g., eisweins and Tokaji Eszencia) may also generate a burning sensation.

**Temperature**

Another trigeminal receptor important to wine assessment, TRPM8, responds to cool temperatures and chemicals such as menthol. It may also be associated with the burning and stinging sensation associated with cold beverages. This should not be too surprising, as it is closely related to heat-activated receptors.

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 have usually been found to suppress the perception of sweetness (Green and Frankmann, 1988), but augment that of bitterness and astringency. This has usually been given as the
rationale for serving red wines at between 18 and 22°C. Although these views are not supported by data from Ross and Weller (2008; Fig. 4.18), this may result from the low tannin level of the wine used in their study. Their results do support, however, the effect of increased serving temperature on enhanced aroma, presumably by facilitating volatilization. Some of the effects previously reported for temperature on gustatory sensation (Cruz and Green, 2000) may arise from direct effects on trigeminal receptors. Tasteless solutions have been found to induce a variety of perceptions, depending on the part of the tongue stimulated and its temperature. Despite these effects, the preferred serving temperature may primarily be a reflection of habituation (Zellner et al., 1988). This could explain the now-odd nineteenth-century preference for serving red wines cool (Saintsbury, 1920).

Prickling

Bubbles bursting in the mouth produce a prickling, tingling, and occasionally painful burning sensation. This phenomenon does not arise from the bubbles of gas directly, but from the carbonic acid formed as CO₂ dissolves in the saliva (Dessirier et al., 2000). The feeling is elicited in wines containing more than 3 to 5% carbon dioxide, and is affected by bubble size and temperature. In addition, bubbles donate a textural sensation. It is not as marked as the difference between whipping and whipped cream produced by air bubbles, but is equally scalar in nature. Carbon dioxide also possesses a slightly sour taste (from the formation of carbonic acid), as well as bitter and salty side-tastes (Cowart, 1998). Carbon dioxide may modify the perception of sapid compounds (Cowart, 1998), notably those with sweet, sour, and salty modalities. It reduces the sensation of sweetness but enhances saltiness. Its effect on wine sourness appears more complex. Carbon dioxide increases sourness in the presence of sugar but decreases the perceived sourness of acids. The effect of CO₂ on bitterness also seems complex. Carbon dioxide enhances the perceived intensity of low contents of quinine sulfate but reduces it at higher concentrations (Cometto-Muñiz et al., 1987). In addition, carbonation significantly augments perceived coldness in the mouth and vice versa (Green, 1992).
Although carbon dioxide promotes the evaporation of some volatile compounds, the prickling sensation of CO₂ in the nose can suppress (divert) the detection of other aromatics (Cain and Murphy, 1980). This may explain the reduced “foxy” aspect of sparkling wines produced from Concord grapes.

The bursting of bubbles in a glass also produces auditory stimuli. These stimuli can enhance the perceived degree of carbonation of a beverage (Zampini and Spence, 2005). Whether this is sufficient to affect the perception of sparkling wines appears not to have been investigated.

**Body (Weight)**

Despite the importance of body to the overall quality of wines, its precise origin remains unclear. Gawel *et al.* (2007) found a correlation between higher ratings for flavor and/or perceived viscosity with body. In sweet wines, body is often viewed as being roughly correlated with sugar content. In dry wines, it has often been associated with alcohol content. These views are not
inconsistent with data presented by Pickering et al. (1998) and Yanniotis et al. (2007). Although glycerol can increase the perception of body, its normal concentration is usually too low to have a noticeable effect.

There is also evidence that the macromolecular content of wines may play a role in the overall perception of body (Vidal et al., 2004a, b). Model wines (made from the major chemical constituents in wines—ethanol, acids, and tannins) do not generate sensations close to those of real wines. Yeast proteins and polysaccharides are probably involved in this difference.

The complexity of many wine perceptions is indicated by contextual factors. Features such as a wine’s fragrance can influence the perception of body, and conversely, increasing the sugar content can increase the perception of fragrance.

**Metallic**

A metallic sensation is occasionally found in dry wines, and particularly in the aftertaste in some sparkling wines. The origin of this sensation is unknown. Iron and copper ions can generate a metallic taste, but at concentrations at or above those typically found in wine (>20 and 2 mg/liter, respectively). Nonetheless, 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 oxidation, they may be responsible for the formation of oct-1-en-3-one from lipids in the mouth (Forss, 1969). Other metallic-like lipid oxidation byproducts have been noted by Lawless et al. (2004). 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; Lawless et al., 2004).

**CHEMICAL COMPOUNDS INVOLVED**

**Sugars**

Sweetness in wines is primarily due to the presence of sugars, notably residual amounts of unfermented glucose and fructose. Additional unfermented sugars typically include arabinose, galactose, rhamnose, ribose, and xylose. They are derived from grapes but are not fermented by wine yeasts. Although most possess a sweet taste, they generally occur in trace amounts
and are not known to contribute to the sweet taste of wines. Of common sugars, fructose is the sweetest, especially at low concentrations.

Sugar concentrations above 0.2% are generally required to exhibit 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 is usually due to the presence of a noticeable fruity fragrance. Coincidental association between fruity odors and sweetness has trained the mind to instinctively affiliate the presence of fruity odors with sweetness, even in its absence (Prescott, 2004).

Sugars begin to have a pronounced influence on sweetness and affect the perception of body at concentration at or above 0.5%. At high concentrations, sugars can generate a cloying sensation, as well as a burning mouth-feel. This is particularly noticeable in the absence of sufficient acidity. Sugars can diminish the harsh aspects of wines 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, slightly 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 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 (Fig. 4.19).

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/liter) (Noble and Bursick, 1984). The relative insignificance of glycerol to perceived viscosity has been confirmed by Nurgel and Pickering (2005). 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/liter). 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 slightly influence the sensation of body.

**Acids**

As a group, carboxylic acids are as essential to the sensory attributes of wines as alcohol. They generate its refreshingly tart taste (or sourness, if in excess); it can induce both sharp and astringent touch sensations; influence wine coloration (and stability); and modify the perception of other sapid compounds. The effect of acidity in diminishing perceived sweetness appears less marked than that of sugar in suppressing the perception of acidity (Ross and Weller, 2008). In addition, the release of acids from cell vacuoles during crushing initiates an acid-induced hydrolytic release of aromatics from the fruit (Winterhalter et al., 1990). Several important aroma compounds, such as monoterpenes, phenolics, C\textsubscript{13} norisoprenoids, benzyl alcohol, and 2-phenylethanol often occur in grapes as acid-labile, nonvolatile glycosides (Strauss et al., 1987).
By maintaining a low pH, acids are crucial to the color stability of red wines. As the pH rises, anthocyanins decolorize and may eventually turn blue. Acidity also affects the ionization of phenolic compounds. Ionized (phenolate) phenolics are more readily oxidized than their non-ionized 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 acids to deionize in wine—a complex function of the acid’s structure, the pH, and the concentration of various metal and metalloid anions (notably K\(^+\) and Ca\(^{2+}\)). Because of the partial nonspecificity of gustatory receptors, and variability in the reaction of trigeminal nerve endings to acids, it is not surprising that people respond idiosyncratically to wine acidity and that perceived sourness cannot easily be predicted from the wine’s pH or its acid content.

Of the common carbonic acids found in wine, malic acid is the most sour tasting, whereas lactic acid is the least sour (Amerine et al., 1965). One of the prime advantages of the conversion of malic acid to lactic acid, during malolactic fermentation, is a reduction in perceived sourness. Because malic acid does not markedly affect the pH, this conversion does not significantly (and undesirably) increase wine pH. Tartaric acid is in between malic and lactic acids in sourness.

Although the acid taste of wine is predominantly induced by grape-derived carbonic acids, it is a fatty acid (acetic acid) that is most associated with a sour (vinegary) character. The vinegary odor is usually a combination of both acetic acid and its ester with ethanol, ethyl acetate. Acetic acid can be derived from acetic acid bacteria growing on infected grapes; be produced during yeast fermentation; and arise from the breakdown of oak constituents during maturation in barrels. Nonetheless, a detectable vinegary character is usually the consequence of bacterial contamination after fermentation. Lactic acid bacteria may be involved, but usually acetic acid (vinegar) bacteria are the causal agents.

**Phenolics**

The predominant phenolics in wine are either flavonoids (phenylpropanoids possessing two phenol groups joined by a pyran ring) or nonflavonoids (phenyl compounds possessing at least one phenolic group). Their differences are illustrated in Table 4.1. Both groups exert a marked influence on taste and mouth-feel. Alone or in combination, they generate a very large group of polymers, grouped together under the general term
### Table 4.1 Phenolic and Related Substances in Grapes and Wine

(from Jackson, 2008, reproduced by permission)

<table>
<thead>
<tr>
<th>General Type</th>
<th>General Structure</th>
<th>Examples</th>
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<td>Benzaldehyde</td>
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<td>Benzaldehyde</td>
<td>G, O, Y</td>
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<tr>
<td>Vanillin</td>
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<td>Vanillin</td>
<td>O</td>
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<td>Syringaldehyde</td>
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<td>Syringaldehyde</td>
<td>O</td>
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<tr>
<td><strong>Cinnamic acid</strong></td>
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<td>p-Coumaric acid</td>
<td>G, O</td>
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<td>Ferulic acid</td>
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<td>G, O</td>
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<td>Chlorogenic acid</td>
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<td>Caffeic acid</td>
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<tr>
<td><strong>Cinnamaldehyde</strong></td>
<td><img src="image" alt="Cinnamaldehyde" /></td>
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<td>O</td>
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<td>Sinapaldehyde</td>
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<td>Sinapaldehyde</td>
<td>O</td>
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<tr>
<td><strong>Tyrosol</strong></td>
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<td>Tyrosol</td>
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<td><strong>Flavonoids</strong></td>
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<td>Flavonols</td>
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<td>Kaempferol</td>
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<td>G</td>
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<tr>
<td>Myricetin</td>
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*Continued*
“tannins.” In wine, they can elicit bitter and astringent sensations, as well as contribute to its color, body, and flavor. Their individual influences depend on the constituent phenolic, its oxidation state, ionization, and polymerization with other phenolics, 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 may 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,” Chapter 8).

Flavonoids are derived primarily from grape skins and seeds, less frequently from the stems. Flavonols, such as quercetin and anthocyanins, commonly collect in cellular vacuoles of the skin. Flavonols may also be deposited in stem tissue. In contrast, flavan-3-ols (catechins) are produced

### Table 4.1 Phenolic and Related Substances in Grapes and Wine

<table>
<thead>
<tr>
<th>General Type</th>
<th>General Structure</th>
<th>Examples</th>
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<tr>
<td>Anthocyanins</td>
<td></td>
<td>Cyanin</td>
<td>G</td>
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<td></td>
<td></td>
<td>Delphinin</td>
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<td></td>
<td></td>
<td>Petunin</td>
<td>G</td>
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<td></td>
<td></td>
<td>Peonin</td>
<td>G</td>
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<tr>
<td></td>
<td></td>
<td>Malvin</td>
<td>G</td>
</tr>
<tr>
<td>Flavan-3-ols</td>
<td></td>
<td>Catechin</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Epicatechin</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gallocatechin</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Procyanidins</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Condensed tannins</td>
<td>G</td>
</tr>
</tbody>
</table>

Source: Data from Amerine and Ough (1980) and Ribereau-Gayon (1964).

\(^a\)G, grape; \(O\), oak; \(Y\), yeast.
primarily in stems and seeds. They commonly occur in polymerized complexes (tannins). They consist primarily of catechin, epicatechin, and gallate epicatechin subunits. Those tannins that occur in the skin are characterized by a higher degree of polymerization and greater epigallocatechin contents.

Flavanols and their polymers (procyanidins and condensed tannins) have generally been viewed as generating the majority of bitter and astringent sensations in red wines. However, this view is being challenged (Hufnagel and Hofmann, 2008). Hufnagel and Hofmann have presented data suggesting the importance of nonflavonoids to astringency, notably ethyl esters of hydroxybenzoic and hydroxycinnamic acids. They also indicate that the velvety astringency, occasionally detected in red wines, is associated with flavonol glycosides, especially of quercetin, syringetin, and dihydrokaempferol.

Of flavonoids, flavan-3-ol monomers are more bitter than astringent, whereas different groups of condensed tannins donate various rough, grainy, puckery, and dry dust-in-the-mouth sensations. The gallic acid constituent of seed tannins seems to generate a coarseness and dryness not found with skin tannins (Francis et al., 2002). Figure 4.20 illustrates one researcher’s views as to the relative effects of different phenolics on taste and mouth-feel.

The largest tannin polymers are too massive to react effectively with taste receptors or saliva proteins. Because these tasteless polymers form

---

**FIGURE 4.20**

Influence of flavonoid polymerization on their sensory attributes: 1, catechins and simple procyanidins; 2, oligomeric procyanidins; 3, procyanidin polymers; 4, anthocyanins; 5, stalk tannins (from Glories, 1981, unpublished, reproduced in Ribéreau-Gayon et al., 2006, reproduced by permission).
slowly during aging, they probably explain much of the usual, progressive loss in the roughness of tannic red wines. If they precipitate, the sediment generated affects mouth-feel only if 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 white wines, nonflavonoids are the predominant phenolic tastants. For example, caffeoyl tartrate (caftaric acid) can induce a bitter sensation (Ong and Nagel, 1978), whereas benzoic acid derivatives may confer a range of perceptions, including astringency, bitterness, sourness, and even sweetness (Peleg and Noble, 1995). The small amounts of catechins (flavan-3-ols) and leucoanthocyanins (flavan-3,4-diols) present in white wines may contribute to the wine’s body. The classification of German wines, customarily based on fruit ripeness, has also been correlated with increased flavonoid content (Dittrich et al., 1974). Nevertheless, their role in browning and bitterness (> 40 mg/liter) 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, most occur at concentrations below their detection thresholds (Singleton and Noble, 1976). In combination, though, they can influence the perception of wine. 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 oak. Degradation of oak lignins liberates various cinnamaldehyde and benzaldehyde derivatives.

Hydrolyzable tannins apparently 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 effect is particularly noticeable in sparkling wines. Tyrosol level increases considerably during the second in-bottle fermentation that characterizes the production of most sparkling wines. Even in still white wines, tyrosol can donate bitterness at typical concentrations (~25 mg/liter).

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 expression of a varietal aroma.

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

**Polysaccharides**

The majority of wine polysaccharides are grape- and yeast-derived substances. Although present in small amounts, their role in wine is usually important in relation to delaying the release of aromatics from wine (Chapter 3). Nonetheless, they may also play a role in reducing the astringency of wine phenolics. Exactly how they have this action is unclear, but it may involve solubilization of protein-tannin aggregates (de Freitas et al., 2003) or disruption of their binding (Ozawa et al., 1987). Yeast-derived manno-proteins are also considered important in the slow release of carbon dioxide from sparkling wine (Senée et al., 1999), helping to give it the effervescent attributes for which it is famous.

**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. Their release is most marked early during autolysis. Several ribonucleotides, especially in the presence of monosodium glutamate, can enhance flavor perception. Glutamate acts in conjunction with olfactory compounds to elicit flavor enhancement (McCabe and Rolls, 2007). Thus, some interest has been shown in their potential sensory significance (Courtis et al., 1998), despite their low concentration in wines.
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 the various aspects of astringency. Their time-intensity curves can be useful in confirming identification (Kuznicki and Turner, 1986). Spatial localization in the mouth or on the tongue can also occasionally help affirm taste identification. The wine’s fragrance cannot only influence the apparent presence of taste sensations, but also reduce the time taken to identify specific sensations (White and Prescott, 2001).

Sweetness is probably the most rapidly detected taste sensation but may last little more than 30 s (Portmann et al., 1992). Physicochemical sensitivity to sweetness is optimal at the tip of the tongue but also occurs elsewhere in the mouth (Fig. 4.3). Possibly because sugar content is typically low, sweetness tends to be the first taste sensation to show adaptation. Except for sweet wines, lingering sensations of sweetness are probably due to learned associations with particular odors, and not due to direct stimulation of sweetness receptors on the tongue. The perception of sweetness 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 detected rapidly. The rate of adaptation is usually slower than for sugar, and may represent the primary aftertaste in dry white wines. Acid detection is commonly strongest along the sides of the tongue, but varies considerably among individuals. Some people detect sourness more distinctly on the insides of the cheeks or lips. The perception of sourness likely involves both stimulation of receptors in the taste buds, as well as activation of trigeminal receptors. 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 (Smith and Noble, 1998).

Perception of bitterness usually follows, if present, taking several seconds for detection to commence. Peak intensity may take from 10 to 15 s (Fig. 4.13). On expectoration, the sensation declines gradually and 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 more (or initially) perceived on the soft palate and front of the tongue (Boudreau et al., 1979). This feature is rarely noted in wine because the bitterness of phenolics develops more rapidly (McBurney, 1978). Also, few bitter alkaloids occur in table wines.
Wine bitterness is more difficult to assess when the wine is also markedly astringent. High levels of astringency seem to diminish or partially mask the perception of bitterness. In addition, noticeable sweetness reduces (Schiffman et al., 1994), whereas alcohol enhances (Noble, 1994) bitterness.

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 wine with a meal. Others consider that judging astringency should occur only after several samplings, when the modifying affects 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 are more appropriately minimized by assuring adequate palate cleansing between samples.

Although in-mouth sensations are relatively few, they appear to be particularly important to consumer acceptance. Unlike professionals, most consumers essentially disregard the wine’s fragrance. Thus, taste and haptic sensations are far more important to overall appreciation. Even for the connoisseur, one of the ultimate expressions of finesse is the holistic impression of fullness and balance. These are phenomena principally derived from gustatory and tactile sensations, combined with retronasal olfactory stimuli. Producing a wine with a fine, complex, and interesting fragrance is often a significant challenge for the winemaker. Assuring that the wine also possesses a rich, full, and balanced in-mouth impression is the ultimate challenge.

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 described below was developed by Linda Bartoshuk, Yale University.
Subjects swab the tip of their tongue with a cotton swab (e.g., 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 the following diagram). 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 waxed 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 cm² is obtained by dividing the number of papillae counted by the surface area (πr²) of the observation hole.

An alternative and more rapid approach is described by Shahbake et al. (2005). It uses a digital camera (4 megapixel or greater) to photograph the tongue. The tongue is pat-dried, stained by placing a 6 cm circular section of Whatman filter paper (No. 1) impregnated with methylene blue, and the tongue redried. After the digital photograph is transferred to a computer, the number of fungiform papillae can be counted by zooming in on the stained region of the image.

**SUGGESTED READINGS**


REFERENCES


Quantitative (Technical) Wine Assessment

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This chapter deals primarily with what could have been titled “sensory evaluation.” The phrase has not been used, as it is more restrictive than what is normally encompassed within the expression “wine tasting.” Sensory evaluation typically involves the assessment of products designed for particular consumer groups (Lawless and Heymann, 1999; Stone and Sidel, 2004; Meilgaard et al., 2006). As such, it typically involves foods with a much narrower range of competition than wines that are produced on an industrial scale—for example, breakfast cereal, ketchup, and cookies. Typically, the assessment relates to how existing products compare with the competition and how formula changes may affect purchase response. This situation is atypical of the wine industry, where artisan winemakers are the norm, and consumer choice may involve hundreds of products, even in small retail outlets. Only for the largest wineries, dealing with many thousands of cases, does traditional sensory analysis apply (ISO, 1994). Even here, most standard procedures are not particularly well adapted to wine assessment. Wine attributes typically vary from year-to-year and change in character during aging. Evaluation is more applicable to detecting faults, such as excess volatile acidity, corky off-odors, and oxidation, or brand or stylistic consistency. These usually involve procedures such as discrimination testing or descriptive analysis.

Even though sensory evaluation procedures yield data on the attributes that distinguish a series of wines, they rarely clarify their relative importance to a wine’s perceived quality. Equally, ranking wines by experts provides data on the perceived qualities, but does not specify those attributes that were central to making the decisions. Novel approaches to integrate quantitative and qualitative techniques have been proposed recently by Bécue-Bertaut et al. (2008) and Perrin et al. (2008). Regrettably, both are labor intensive and involve complicated statistical manipulation and assumptions that are not intuitive or readily verifiable. A simpler approach
might involve superimposing graphic representations of the sensory attributes that characterize a series of wines (e.g., Figs. 5.20 and 5.21) over scaled quality attributes provided by expert tasters. However, it should be acknowledged that there may be no direct correlation between sensory attributes and quality indicators. Just because trained sensory evaluators and traditional wine judges detect the same sensory input does not mean that these data are processed similarly. Earlier chapters in the book noted how experience directs the way sensory information is processed by the brain. It is undoubtedly the same for the even more integrated perceptions of wine quality, especially where select information about the wines being sampled is known.

Strict sensory analysis may also be relatively insignificant when it comes to consumer wine perception. Consumers rarely possess a clear or consistent concept of wine quality. Nor do they have a well-developed odor memory of wine styles or varietal attributes. Consumers often believe that such subtleties are beyond their abilities. Alternatively, they may explain their inability to detect traditional attributes due to a poor vintage or bottle-to-bottle variation. The opinion of wine authorities often takes precedence. Furthermore, the majority of wine purchasers assess wines holistically, rather than dissecting them critically, attribute-by-attribute. Other than a cursory look at the label and a symbolic sip, purchases may give the wine’s properties little notice, quickly shifting their attention to food or conversation. Although regrettable, this is often to the benefit of wine retailers—very astute consumers will not accept repute in place of quality. Furthermore, if one wine does not satisfy, there are thousands of others to try, and memory is often short. Although this is emotionally disappointing to the ego of cellar masters, it does permit the sale of wine, albeit to a largely nondiscriminating audience. For the majority of purchasers, features such as convenience, price, brand recognition, and cultural identity are often of greater significance to purchase choice than sensory quality.

Despite the general lack of a highly discriminating clientele, the minimum requirement for winery sensory analysis is ascertaining the absence of faults. Because trained panel members typically possess (develop) higher sensitivities than the majority of purchasers, panels act as a safety net, minimizing the likelihood of aberrant wines reaching the public. More detailed assessments have their principal value in studying the sensory attributes that distinguish wines. For example, sensory analysis may be used to investigate why, to what extent, and in what respects, various consumer groups prefer particular wines; in studying those attributes that may be quality limiting, to determine what production procedures result in desirable modifications of wine quality; or in establishing whether and in what ways wine from particular regions can be sensorially distinguished.
Depending on the purpose of the analysis, the choice and training of tasters are likely to change. For example, in descriptive sensory analysis, the panel is essentially functioning as an analytical instrument. Figure 5.1 illustrates how effective humans can occasionally be in this regard. If people were always consistent and precise, only one sufficiently skilled person would be essential. However, individual and daily variability requires that a panel be available to mollify this inherent variation. Panel members are trained to develop a common lexicon as well as assessed for consistency in its use. In contrast, in consumer testing, interest is focused as much on how a group differentiates among samples as on the degree of variation within the group. In this situation, the analogy to an analytic instrument no longer holds.

Commercial wine tastings (discussed in Chapter 6) are primarily designed to promote wine sales and showcase wines to the news media. They also allow producers to subsequently display awards received to the public. Although it would be desirable to have strict controls on how such tastings are conducted (as with descriptive sensory analysis), this is usually not the case. The view that these tastings are impartial and use skilled (“expert”) tasters is usually unjustified. This comment may seem harsh. It is not intended to be a condemnation, simply an acknowledgment of
reality. Why go to great lengths when publicity is the principal goal? In addition, the results are unlikely to be used to influence production procedures or commercial decisions.

In contrast, wine tastings conducted by winery staff do have utilitarian goals. Regrettably, in small (and occasionally large) wineries, sensory assessment is the prerogative of one or a few individuals (the chief winemaker and his or her assistants). As will be noted later, this is inadequate for legitimate sensory evaluation. Human perceptive ability is too variable and limited for one or a few people to assess wine attributes both adequately and accurately. Individual sampling may be acceptable for the artisan wine producer, where wines are made to his or her specification. Even champagne and port blends are often based on the opinions of a few individuals. However, this is rapidly becoming archaic in most large, modern wineries. It is far too risky to leave decision making up to a few individuals. Stockholders or bankers are not interested in taking that much of an economic gamble. Sensory analysis also plays a major role in university and government research. This research is often designed to investigate the psychophysiology of human sensory perception, or to study how modifying viticultural or enologic factors influences wine attributes. These latter aspects are the subject of the current chapter.

The principal benefit of sensory analysis is uncovering the physical, chemical, biological, and psychological bases of perceived quality. With this knowledge, grape growers and winemakers have the potential to improve wine quality. That expensive wine provides a few with a feeling of prestige and exclusivity is fine. However, quality wine should not be the preserve of the wealthy. Sensory evaluation has helped the egalitarian goal of increasing the quality of “everyday” wine, bringing fine wine within the reach of everyone who desires it.

Quantitative wine assessment usually entails one of two components: evaluation or analysis. Evaluation involves the differentiation and/or ranking of wines. It can vary from large consumer tastings, intended to assess purchaser preference, to trained panels designed to assess differences generated by experimental treatments, or to choose the formula for a blend. Occasionally, expert panels may go further in assigning a monetary value to the ranking. In contrast, wine analysis involves detailed investigation of a wine’s sensory attributes. Its intent may be to examine aspects such as the magnitude of differences that distinguish a series of wines, the features that lead to preferences among wines, or the psychophysics (nature and dynamics) of sensory perception as it relates to wine. Alternatively, analysis may function as a quality control procedure. Sensory evaluation may or may not use trained panels, whereas sensory analysis essentially always uses panels specifically trained for the task. Because quantitative wine analysis is primarily a research/developmental tool, it is essential that the
assessment be conducted in a quiet, neutral environment, devoid of taster interaction or prior knowledge of the sample’s origin.

The purpose of the analysis dictates the type or types of sensory tests appropriate, the degree of training required, and the number of members necessary. If the only question is whether two or more samples are detectably different, then one of a number of discrimination tests may be performed. For consumer panels, orientation and habitual use are all that is required. Where a more critical approach is needed, fewer attributes are typically assessed, but the degree of acuity required is enhanced. Panelists must be tested for the necessary level of sensitivity, trained in the use of precise descriptive language, and assessed for consistent and reliable analyses.

Although sensory evaluation has helped clarify issues facilitating the more consistent production of better wine, there remains a gap in correlating sensory attributes with wine chemistry. New techniques such as gas chromatography combined with olfactometry (Leland et al., 2001), aroma extract dilution analysis (AEDA) (Grosch, 2001), and atmospheric pressure chemical ionization mass spectroscopy (APCI-MS) (Linforth et al., 1998) are finally starting to tackle this thorny issue.

**SELECTION AND TRAINING OF TASTERS**

**Basis Requirements**

In most instances, participation is (or should be) voluntary. It is only for winemakers, négociants, or wine critics that tasting is part of their job description. Thus, possibly the most critical requirement for membership is motivation. It provides the genuine desire required for both effective learning and consistent attendance. Without a sincere interest in wine, it is unlikely that members will retain the dedication needed for the arduous concentration that often occurs periodically for weeks, months, or years. General good health is also a criterion, not only because medical problems such as frequent colds or migraines disrupt sensory acuity, but also because many common medications distort sensory perception (Doty and Bromley, 2004). Examples are diuretics disrupting ion channels in receptor cells, antifungal agents suppressing cytochrome P450-dependent enzymes, and chemotherapeutic agents affecting receptor cell regeneration.

For consistency, it is desirable to retain a common nucleus of members. Therefore, the selection process includes many more candidates than required. Often no more than 60% of potential candidates possess the necessary sensory skills. If a high degree of discrimination is required, an even larger number of candidates will need to be tested. Tact is often required in rejecting candidates, especially those eager to participate or who feel their
experience justifies inclusion. In the latter case, rejection could be viewed as snub to their self-esteem and skill. For employees of a wine store or winery, this could be particularly discouraging. In such a situation, selection as part of a backup group or forming several panels with different (simpler or less significant) tasks could be part of a diplomatic solution.

To maintain enthusiasm and attendance, the panel members need to have a clear indication of the importance of their work. 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 as well as educational. Finally, depending on legal issues and appropriateness, presentation of vouchers for wine is another tangible expression of value.

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, can serve as indicators of consistency. Analysis of variance can also indicate whether panel members are individually or collectively using a score sheet uniformly. Although tasters show fluctuations in sensory skill, this should be minimal, if subtle differences are to be detected. Because tasters are, in essence, substitute analytic instruments, their responses to sensory features should 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 minimal 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, of course, assumes that the nature of the sensory variation in the target group is known.

A property often expected of professional tasters is extensive experience with traditionally accepted norms. In several studies, it is the presence of a working knowledge of varietal or stylistic percepts, discrimination, and a more consistent and standard use of terms that characterizes various types of expert tasters (Bende and Nordin, 1997; Ballester *et al.*, 2008). Adequate but not necessarily refined acuity is all that is usually a prerequisite. An extensive memory base is especially important when rating varietal or stylistic expression. However, the abilities of experts, such as Masters of Wine or sommeliers, should not be taken for granted. Several studies have shown they may be considerably less skilled at distinguishing among regional wines than normally thought (Winton *et al.*, 1975; Noble *et al.*, 1984; Morrot, 2004). Depending on the difficulty of the task, tasting experience, and training in term use, tasters may or may not recognize wines based
on their own or collective descriptions (Lawless, 1985; Gawel, 1997; Hughson and Boakes, 2002; Lehrer, 2009; Fig. 5.5). Regardless, professional tasters should be able to describe wine attributes independent of personal preferences. This requires training, experience, and an honest and dedicated analytic concentration.

Although enthusiasm, experience, and an extensive knowledge of wine are desirable, these aspects alone cannot be used as a shortcut to selecting tasters (Frost and Noble, 2002). They do not indicate the presence of serious sensory idiosyncrasies. Each sensory attribute is an independent entity that, where essential, must be measured separately. In most instances, adequate acuity, consistency, and an excellent odor memory are the principal sensory requisites of a superior taster.

As noted, sensitivity to particular characteristics can influence panelist suitability. For example, in descriptive sensory analysis, high acuity to particular attributes may be required. In such instances, there is no need or intention for the panel to represent the average consumer. In most situations, panel members need only average sensitivity to sensory modalities. For example, a panel composed of individuals hypersensitive to bitterness and astringency may unduly downgrade young red wines, but be required if the effect of skin contact on these attributes is under investigation. 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 most important critical attributes.

Because the features preferred by trained tasters (and most aficionados) typically differ from those of most wine consumers, panel rankings rarely reflect consumer preference (Table 5.1). This is reflected in the preferences shown by various age groups or possessing different drinking habits (Tables 5.2 and 5.3). Consumers tend to concentrate primarily on gustatory

<table>
<thead>
<tr>
<th>Table 5.1</th>
<th>Correlation between Overall Acceptability and Hedonic Scores for General Wine Attributes (from Williams et al., 1982, reproduced by permission)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General Public</td>
</tr>
<tr>
<td></td>
<td>As Commercial Product</td>
</tr>
<tr>
<td>Appearance</td>
<td>–</td>
</tr>
<tr>
<td>Color</td>
<td>0.54</td>
</tr>
<tr>
<td>Aroma</td>
<td>0.40</td>
</tr>
<tr>
<td>Flavor by mouth</td>
<td>0.91</td>
</tr>
</tbody>
</table>
attributes (Solomon, 1997). They generally prefer wines with minimal astringency, bitterness, or sourness. They also have a preference for wines possessing some detectable sweetness and/or pétillance. Thus, if taste panels are used in marketing studies, careful selection of members showing equivalent preferences is essential. Forced consensus and data aggregation can lead to false confidence in understanding the rationale of consumer preferences.

Tasting conditions are in some ways simpler where the tasting panel consists of wine purchasers. However, it is important to avoid laboratory-like conditions; otherwise, the context is likely to seriously distort the findings. Individuals should also be used only once, to avoid entrainment. Other than the inducement of sampling wine, consumers deserve a full explanation of the value of their participation, and they should be presented with some small token of appreciation. This may involve a monetary reward or, where permissible, a bottle of the wine they preferred in the tasting. Selection should clearly favor representatives of actual potential purchasers, not just passersby. Careful scrutiny of the spread and potential data clumping may

<table>
<thead>
<tr>
<th>Table 5.2</th>
<th>Correlation between Overall Acceptability and Hedonic Scores for General Wine Attributes within Population Subsets (from Williams et al., 1982, reproduced by permission)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>18–24</td>
</tr>
<tr>
<td>Color</td>
<td>0.40</td>
</tr>
<tr>
<td>Aroma</td>
<td>0.17</td>
</tr>
<tr>
<td>Mouth flavor</td>
<td>0.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5.3</th>
<th>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)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Wine: Drinking Habits</td>
<td>&lt;£2 per Bottle</td>
</tr>
<tr>
<td>Frequent Drinkers</td>
<td>Infrequent Drinkers</td>
</tr>
<tr>
<td>Color</td>
<td>0.42</td>
</tr>
<tr>
<td>Aroma</td>
<td>0.63</td>
</tr>
<tr>
<td>Mouth flavor</td>
<td>0.88</td>
</tr>
</tbody>
</table>
highlight unsuspected consumer subgroupings. This could be very useful. Novice wine consumers are no more homogenous than are connoisseurs.

It is a common finding that women generally do better at aroma recognition than men [Fig. 3.22]. On this basis, women potentially should be better (more acute) wine tasters. However, in our modern, equal-opportunity, political environment, excluding men from a role on taste panels would undoubtedly be considered sexist. It also would probably skew results unduly toward higher levels of sensitivity.

**Identification of Potential Wine Panelists**

Because of the considerable time and expense involved in training, it is judicious to screen potential tasters for the requisite skills. No known series of tests can infallibly identify the tasting potential of a candidate. This reflects as much the variety of skills required (olfactory acuity and memory, and the ability to objectively assess quality attributes), as it does the efficacy of the testing procedure. Possibly, a finely tuned ability to discriminate among wines is the most critical attribute of a taster. Unfortunately, discrimination is probably based as much on odor memory (that accumulates with experience) as on sensory acuity. Thus, this property may not be readily recognizable in novice candidates. Nevertheless, indications of tasting capacity, such as sensory acuity (detection thresholds); odor and flavor memory; term use and recall; scoring consistency; as well as existent ability to discriminate, recognize, and identify wines can be measured. These measures can act as indicators of the skills candidates possess or may need to develop. Other potential qualities are more difficult to quantify. They include the potential for recognizing and ranking wine based on traditional standards. These facilities are inherently subjective and based on experience, and the effective use of both deductive and inductive reasoning. Detection of wine origin and quality usually involves assessment of attributes both present and absent. In general, it appears that exceptional memory, rather than phenomenal perceptual acuteness, is what distinguishes the greatest tasters.

Examples of screening tests that might be used are noted in the following sections. The skills measured indicate aptitude for sensory analysis, as well as demonstrate individual strengths and weaknesses. The degree of proficiency required in each test will naturally depend on the skills demanded. Sensory assessment is markedly different from assessing quality in manufactured goods. In the latter, quality standards are usually precise and can be 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 quick succession. Thus, 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 the variety or type. Repute or previous acceptability is no substitute for prior sampling. Price should not be a condition for either selection or exclusion.

Testing and Training

In the past, wine evaluation was conducted primarily by winemakers or wine merchants. Their training tended to focus on recognizing accepted regional (varietal) norms. This established a frame of reference for judging quality, and acceptance in accordance with traditional or stylistic attributes. One of the problems with this approach is that it accentuates the importance of the norm (Helson, 1964). In addition, these paradigms are not fixed, changing in response to recent experience or modifications in preference. Although personal opinion may be acceptable in the wine trade, individual biases and sensory deficiencies can limit taster suitability. To offset such inherent prejudices, most critical wine evaluations are 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.

As noted, extraordinary olfactory acuity is rarely required. In addition, initial skill in recognizing odors is typically of little significance, as it simply reflects personal experience (Cain, 1979). Training (repeat exposure) often improves detection (Stevens and O’Connell, 1995; Dalton et al., 2002). It also tends to improve verbal recognition (Clapperton and Piggott, 1978). Conversely, the presence of descriptors facilitates recognition (Gardiner et al., 1996; Lehrner et al., 1999). Thus, measures of learning ability tend to be more important than initial verbal odor recognition (Stahl and Einstein, 1973). The experience of training appears to generate changes in how the piriform (olfactory) cortex responds to odors—the brain reacting differently to familiar versus nonfamiliar odors (Wilson, 2003). Categorization and identification appear to be dependent on experience-based neural plasticity in both the piriform and orbitofrontal cortices (Li et al., 2006). Qualitative learning occurs as an integrative process, subsequent to chemical-based identification in the olfactory bulb.

Instructions during training (and subsequent assessment) affect whether sensations are integrated into single multimodal attributes (e.g., vanilla...
associated with sweetness) or retain their individual modal identities (Prescott et al., 2004). Thus, training for sensory analysis aims at avoiding sensory integration, concentrating on individual sensations, whereas training for regional, stylistic, or varietal characteristics focuses on sensory integration.

Humans show remarkable ability to differentiate thousands of odorants (compared side-by-side), but have considerable difficulty recognizing (naming) even common odors without visual or contextual clues. Even perfumers seem to recognize only about 100 to 200 odors individually (Jones, 1968). In laboratory studies, the ability of people to identify the components of an odor mixture is usually poor (Fig. 3.20). Nonetheless, this apparent inability may be artifactual, due to the components of recognizable odors (themselves usually a mix of aromatic constituents) rarely occurring alone in pure form. In addition, the dynamically changing concentration of aromatics escaping over the duration of a tasting may temporally separate recognizable odor-memory patterns. Direct evidence of the neuronal interconnection between various cognitive centers of the brain during smelling has been obtained using fMRI imaging (Gottfried and Dolan, 2003).

Training has its primary role in enlarging the odor-memory base. It may also result in enhanced intrinsic sensitivity (Dalton et al., 2002). Where intended, specific training can also promote the separation of individual attributes of multimodal sensations (e.g., taste-taste or taste-odor interaction) (Bingham et al., 1990).

Although training usually concentrates on olfactory and holistic memories, it may be extended to taste, mouth-feel, and visual attributes. Because they are rarely deemed of sufficient importance in most tasting situations, only a few training exercises are included here. Additional training/testing exercises of this type are supplied in Chapter 6.

Training is normally incorporated into the process of selecting panel members. Subsequently, further training is usually required and should be provided periodically to refresh and reinforce embedded memories. This is especially required, as these memories do not have the support of visual and contextual clues that typically contribute to and consolidate odor memories.

Beyond learning to recognize individual sensory attributes, panel members may need to become adept in recognizing the properties that traditionally characterize wine quality. Thus, training may include exposure to an extensive selection of varietal, regional, and stylistic wine types (idiotypic learning). This is particularly important in evaluative assessments. For this, samples should express as fully as reasonably possible not only paradigms of the type, but also the range that can be ordinarily 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. In contrast, training concentrates primarily on the appropriate and
consistent use of a descriptive language in descriptive sensory analysis. This often involves discussion and negotiation on the terms to use and their meaning, as it relates to the specific task involved. Alternatively, definitions with standards may be supplied for training to avoid meaning ambivalence. Candidates showing insufficient precision and consistency are removed.

As noted, candidates without the desired consistency are typically eliminated. Natural variation can be a nuisance and disrupt the fine distinction that may be desired. Alternatively, the effects of such variation may be minimized by statistical procedures such as Procrustes analysis [see later in this chapter]. Nonetheless, in so doing, there is the risk of jeopardizing the validity of the results, as they may be based on false assumptions. In addition, investigation of the sources of consumer variation and their distribution may be as important as understanding the sources of variation among wines. As with training, the appropriate means of data analysis often depends on the intent of the task. For further discussion of these issues, see Stevens (1996).

With the availability of computerized data accumulation and analysis, candidates can receive data on their abilities almost as soon as testing is complete. Rapid feedback, usually in graphic form, permits the trainees to realize their status relative to others, and to learn where they are both skilled and deficient. The former can provide a psychological reward, reinforcing training and enhance motivation. It also provides an opportunity for candidates to access remedial help in the areas where they are below standard. Both aspects appear to speed training. Findlay et al. (2007) provide a specific example of how rapid feedback is used. Rapid feedback also can help the experimenter/trainer to see where training may be deficient and need revamping.

For economy and convenience, aspects of grape varietal aromas may be simulated by producing odor samples [see Appendix 5.1]. These samples have the advantage of being continuously available for reference. Standards may be prepared in a neutral or artificial wine base, stored under paraffin in sample bottles (Williams, 1975 and 1978) or in a cyclodextrin solution. Because pure compounds may contain trace impurities, which can modify odor quality, it may be necessary to conduct initial purification before use (Meilgaard et al., 1982).

In addition to recognition of wine odors, identification of off-odors 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 always be available [see Appendix 5.2]. In addition, prepared samples have the advantage of being available in any wine and at any desired intensity level.

Training also tends to include a few taste samples, prepared either in water or wine. As with odor training, gustatory tests have the advantage of disclosing personal idiosyncrasies in sensitivity and perception.
Basic Selection Tests
The tests described in the following sections have been used in selecting panelists. Their applicability will depend on the tasks required. They are provided as a point of departure for preparing selection tests that are pertinent to the needs of wine professionals.

Taste Recognition
As noted, fine discrimination of taste sensations is seldom a criterion for wine tasting. This does not imply insignificance, merely a lack of clear standards of acceptance. In addition, mixtures of tastants and odorants (as in wine) can significantly modify the perception of individual gustatory attributes. Thus, the tests mentioned are primarily for the benefit of the participants—to give them an opportunity to discover their own taste particularities. This can help panelists gain personal insight into human sensory variability, as well as how context (water versus wine) influences perception.

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 both 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/touch sensations (Appendix 5.3) and record the intensity of the most dominant sensation along the scale-line supplied.

Participants should record where each sensation occurs most prominently, especially with the aqueous samples. This permits individual

<table>
<thead>
<tr>
<th>Sample (Solution)</th>
<th>Amount (per 750 ml Water or Wine)</th>
<th>Sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>15 g sucrose</td>
<td>sweet</td>
</tr>
<tr>
<td>Acid</td>
<td>2 g tartaric acid</td>
<td>sour</td>
</tr>
<tr>
<td>Bitter</td>
<td>10 mg quinine sulfate</td>
<td>bitter</td>
</tr>
<tr>
<td>Astringent</td>
<td>1 g tannic acid</td>
<td>astringent, woody</td>
</tr>
<tr>
<td>Alcohol</td>
<td>48 ml ethanol</td>
<td>sweet, hot, body, alcoholic odor</td>
</tr>
</tbody>
</table>
localization of the distribution of sensitivity throughout the mouth. Subsequent samples examine the ability to recognize taste and touch stimuli in the context of a white or red wine. These abilities often differ significantly from those in water.

Figure 5.2 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 or crossover sensations from the previous

Table 5.5: The Variation in Responses of 27 People to Taste Sensations in Water: Sucrose (15 g/liter), Tartaric Acid (2 g/liter), Quinine Sulfate (10 mg/liter), Tannic Acid (1 g/liter) and Ethanol (48 ml/liter)

<table>
<thead>
<tr>
<th>Solution</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
<th>Astringent</th>
<th>Alcoholic</th>
<th>Dry</th>
<th>Salty</th>
<th>Nothing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>94</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tartaric acid</td>
<td>3</td>
<td>47</td>
<td>17</td>
<td>12</td>
<td>3</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Quinine</td>
<td>0</td>
<td>15</td>
<td>40</td>
<td>15</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Tannic acid</td>
<td>0</td>
<td>16</td>
<td>25</td>
<td>47</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Ethanol</td>
<td>7</td>
<td>6</td>
<td>12</td>
<td>1</td>
<td>74</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>7</td>
<td>15</td>
<td>7</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>57</td>
</tr>
</tbody>
</table>
sample or the belief that some sensation must be present. Participants were not instructed to expect a water blank. Figure 5.3 demonstrates how the solute (water or wine) can influence response to a tastant.

Relative Sensitivity (Sweetness)
To assess relative sweetness, dissolve 2.25, 4.5, 9, and 18 g sucrose in separate 750 ml wine samples. Provide a 0.5% pectin solution or unsalted crackers as a palate cleanser. Have participants familiarize themselves

**FIGURE 5.3**
Variation of responses of 15 people to the presence of quinine sulfate (10 mg/liter) in A, water; B, Cabernet Sauvignon wine; C, Sémillon/Chardonnay wine.
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 could be conducted using citric or tartaric acids for sourness (5, 10, 20, 40 g/liter), quinine or caffeine for bitterness (2.5, 5, 10, 20 mg/liter), and tannic acid for bitterness and astringency (5, 10, 20, 40 g/liter). To present astringency, without an accompanying bitterness, testers can use alum (aluminum potassium sulfate) at 2.5, 5, 10, 20 g/liter.

Although a common element in training, taste testing is unnecessary in most instances. Rarely are tasters required to assess separately the basic taste modalities of a wine. In addition, the perception of these aspects is, to varying degrees, influenced by other wine constituents. This is particularly significant in the perception of sweetness and sourness. For example, perceived sweetness in dry wines is typically a reflection of the wine’s aromatics influencing how the orbitofrontal cortex interprets sensory impulses.

### Threshold Assessment

Because of the time and labor involved in threshold measurement, the specific recording of individual threshold values is seldom conducted, unless there is some rationale for selecting panelists based on sensitivity to particular compounds. Where of interest, it is more usual to assess the detection and/or recognition thresholds of the panel as a whole.

Threshold detection has been primarily used in studies investigating the relative significance of particular compounds to wine’s varietal aroma. Typically, only those compounds occurring at or above their threshold value significantly affect the aroma. Threshold determination is also important in assessing the concentration at which off-odors begin to affect wine rejection. From a more

---

**Table 5.6** Sweetness Sensitivity Test

<table>
<thead>
<tr>
<th>Session 1 Chardonnay</th>
<th>Session 2 Valpolicella</th>
<th>Session 3 Riesling</th>
</tr>
</thead>
<tbody>
<tr>
<td>#5&lt;sup&gt;a&lt;/sup&gt; (A)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>#5 (E)</td>
<td>#1 (E)</td>
</tr>
<tr>
<td>#3 (B)</td>
<td>#3 (D)</td>
<td>#4 (D)</td>
</tr>
<tr>
<td>#2 (D)</td>
<td>#4 (C)</td>
<td>#2 (C)</td>
</tr>
<tr>
<td>#1 (C)</td>
<td>#2 (B)</td>
<td>#3 (A)</td>
</tr>
<tr>
<td>#4 (E)</td>
<td>#1 (A)</td>
<td>#5 (B)</td>
</tr>
</tbody>
</table>

<sup>a</sup># 1–5 Label identifying the sample.

<sup>b</sup>A, control (0 g/l sucrose); B, 3 g/l; C, 6 g/l; D, 12 g/l; E, 24 g/l.
Theoretical point of view, threshold studies have been used to study the dynamics of how perceived intensity or quality change with concentration.

Threshold determination is complicated by issues such as individual variation and the influence of physicochemical factors on solubility and/or volatility. A detailed discussion of the theory and practice of threshold measurement can be found in standard texts such as Lawless and Heymann (1999), or articles by Bi and Ennis (1998) and Walker et al. (2003).

A simple procedure for determining thresholds is as follows. A series of concentrations of the compound in question is prepared in water (or some other appropriate solvent, such as a dilute ethanol solution or wine). The number of samples should cover a wide range of concentrations. In assessing taste sensitivity, for example, concentrations of 0, 1, 2, 3, 4, 5, 6, and 7 g/liter glucose, or 0.03, 0.07, 0.10, and 0.15 g/liter tartaric acid might be used for sweetness and acidity, respectively. If more precision were desired, once the rough threshold range has been established, additional sets could more precisely bracket the threshold value. For example, if the rough threshold were between 0.40% and 0.50% glucose, concentrations such as 0.40%, 0.42%, 0.44%, 0.46%, 0.48%, and 0.50% might be appropriate.

Each sample concentration is paired with a control solution. The samples are arranged and marked so that the control sample is tasted first, followed by the tastant or another control sample. Participants note whether the second sample is the same or different from the control. This type of procedure is called an A-not-A test. Each concentration pair should appear at random at least six times, but usually more. Chance alone should produce about 50% correct responses at below threshold. Detection of a legitimate differentiation among samples is normally considered to have occurred when a correct response rate of >75% (50% above chance) occurs. The samples should be presented in random order to avoid panelists anticipating an increase or decrease in concentration. Having the panelists do the test slowly and in a random sequence helps minimize adaptation or fatigue. In the example given in Table 5.7, the participant would have a detection threshold of between 0.4% and 0.5% glucose.

<table>
<thead>
<tr>
<th>Sample (% glucose)</th>
<th>Control</th>
<th>0.2%</th>
<th>0.3%</th>
<th>0.4%</th>
<th>0.5%</th>
<th>0.7%</th>
<th>0.9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct responses</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Percent correct</td>
<td>50</td>
<td>66.7</td>
<td>50</td>
<td>66.7</td>
<td>83.3</td>
<td>83.3</td>
<td>83.3</td>
</tr>
</tbody>
</table>

*Total number of responses = 6.
Odor Recognition Tests
Fragrance (Aroma and Bouquet)

The fragrance test measures the identification of several odors often viewed as being characteristic of wine aromas. Appendix 5.1 gives an example of sample preparation. Because learning is often a component of the test, samples should be presented for familiarization before each test.

Cover the glass openings 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). Participants should be instructed only to smell the samples, tasting being unnecessary. By avoiding tasting, preparation (number of samples required) and cost are minimized.

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 their preparation). Substitute some odor samples with control samples in each test session. This helps to minimize identification by a process of elimination.

The answer sheet lists all samples as well as 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 to aid learning. Three training–testing sessions may be sufficient to judge ability to learn fragrance samples but are inadequate to train a panel to use the terms accurately and consistently.

Figure 5.4 illustrates a typical set of data from this type of test. When participants misidentify samples, they frequently (but not consistently) choose a term in the same category of odors, for example, bell pepper for herbaceous. This may relate to how olfaction is encoded in the brain. Experience-based learning with aromatic compounds in a category may facilitate differentiating other members of the same group. For example, exposure to phenylethyl alcohol (possessing a floral odor) enhanced subsequent differentiation between other floral odors (Li et al., 2006). This training effect did not extend to unrelated odorants.

Off-Odors: Basic Test

The off-odors test assesses ability to learn and identify several characteristic odor faults. Appendix 5.2 gives an example of the preparation of off-odor
samples. Training sessions with the samples should be held at least a few hours prior to the test. During training, encourage the participants to record their impressions to help them recognize the off-odors during the subsequent test situation.

The answer sheet lists all the off-odors, 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 odor contamination of the surroundings. Present the samples in dark-colored wine-tasting glasses (or under red light). In some off-odor samples, appearance can give a clear clue as to the fault.

Three training-testing sessions are usually adequate to screen people for their ability to detect off-odors and initiate the learning of each. Additional training sessions should be provided to stabilize their odor memory, as well as periodic retraining to maintain proficiency. Figure 5.5 illustrates a typical set of responses from 15 participants. When misidentified, they are often selectively confused—for example, baked and oxidized, mercaptan and goût de lumière; guaiacol and TCA; and ethyl acetate with acetic acid, fusel alcohols, or plastic.
Off-Odors in Different Wines

The basic off-odors test presents off-odors at a single concentration and in a relatively neutral-flavored wine. To provide a more realistic indication of identification ability, a test of off-odors in different wines presents the faults at two concentrations (closer to those that might occur naturally) and in both a white and red wine base. Wine type can affect both perception and recognition of off-odors (Martineau et al., 1995; Mazzoleni and Maggi, 2007).

In the test design given in Appendix 5.4, only a selection of the more important and easily prepared off-odors is used. Participants smell 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 spaces set aside for controls.

Figure 3.21 illustrates results from this type of test. Off-odors tend to be more readily detected in white than red wines, presumably because of the less intense fragrance typical of white wines. Intriguingly, almost half the control samples are identified as having an off-odor, even though participants sampled the base wines before the test. This is probably an example of how anticipation can sway 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.
Having five sets of three glasses at each dilution is the minimum requirement. Pour diluted (or undiluted) wine into two of the three glasses. The remaining glass holds the undiluted (or diluted) sample. Each triplet has one different sample, but not consistently the diluted or undiluted (control). This testing procedure is called the triangle test. Arrange the sets at random. Table 5.8 illustrates an example of a setup for this type.

<table>
<thead>
<tr>
<th>Dilution Fraction&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Green</th>
<th>Yellow</th>
<th>Purple</th>
<th>Most Different&lt;sup&gt;b&lt;/sup&gt; Sample</th>
<th>Sample Sequence</th>
<th>#1&lt;sup&gt;c&lt;/sup&gt;</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4%</td>
<td>c&lt;sup&gt;d&lt;/sup&gt;</td>
<td>x</td>
<td>c</td>
<td>y</td>
<td>1</td>
<td>15</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>x</td>
<td>c</td>
<td>c</td>
<td>g</td>
<td>8</td>
<td>18</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>c</td>
<td>c</td>
<td>x</td>
<td>p</td>
<td>13</td>
<td>5</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>x</td>
<td>c</td>
<td>x</td>
<td>y</td>
<td>6</td>
<td>12</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>c</td>
<td>c</td>
<td>x</td>
<td>p</td>
<td>19</td>
<td>1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>c</td>
<td>x</td>
<td>c</td>
<td>y</td>
<td>12</td>
<td>20</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>c</td>
<td>x</td>
<td>x</td>
<td>g</td>
<td>17</td>
<td>13</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>x</td>
<td>c</td>
<td>x</td>
<td>y</td>
<td>5</td>
<td>4</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>x</td>
<td>c</td>
<td>c</td>
<td>g</td>
<td>18</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>c</td>
<td>x</td>
<td>c</td>
<td>y</td>
<td>9</td>
<td>3</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>c</td>
<td>c</td>
<td>x</td>
<td>p</td>
<td>11</td>
<td>11</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>x</td>
<td>c</td>
<td>x</td>
<td>y</td>
<td>2</td>
<td>16</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>c</td>
<td>x</td>
<td>x</td>
<td>g</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>c</td>
<td>c</td>
<td>x</td>
<td>p</td>
<td>16</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>c</td>
<td>x</td>
<td>c</td>
<td>y</td>
<td>14</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>32%</td>
<td>c</td>
<td>x</td>
<td>x</td>
<td>g</td>
<td>4</td>
<td>19</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>32%</td>
<td>c</td>
<td>c</td>
<td>x</td>
<td>p</td>
<td>7</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>32%</td>
<td>c</td>
<td>x</td>
<td>c</td>
<td>y</td>
<td>15</td>
<td>14</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>32%</td>
<td>c</td>
<td>x</td>
<td>x</td>
<td>g</td>
<td>3</td>
<td>17</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>32%</td>
<td>x</td>
<td>c</td>
<td>x</td>
<td>y</td>
<td>20</td>
<td>8</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>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 " "<br>
<sup>b</sup>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.<br>
<sup>c</sup>Sessions #1: Cabernet Sauvignon, #2: Zinfandel, #3: Chardonnay.<br>
<sup>d</sup>c, control (undiluted) sample; x, diluted sample.

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.
Participants move past each set of glasses, remove the covers, and smell each sample. They record 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” samples may have come from separate bottles, they may not be as equivalent as one might desire. This approach 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.

Although wines are not usually assessed only orthonasally (as in this test), data from Aubry et al. (1999) suggest that for at least Pinot noir it can be almost as discriminatory as by in-mouth sampling.

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), the participants must correctly identify four out of the five replicates to accept differentiation.

Although the test is designed to distinguish the sensory skills of individuals, group results are also informative. Some individuals may be able to detect all levels of dilution at above chance, but personal experience has indicated that successful differentiation by groups seldom exceeds 60%, even at the highest level of dilution employed.

**Varietal Differentiation**

The varietal differentiation test assesses the ability to distinguish between similar varietal wines. As in the varietal dilution test, the triangle procedure is used.

Choose distinctive pairs of varietal wines. For each pair, prepare ten 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 dies may eliminate the color differences. If so done, this fact should be mentioned to the panelists. Otherwise, their responses may be influenced by the color. Random positioning of the sets minimizes the likelihood of identical pairs occurring in sequence (Table 5.9 gives an example using three varietal wine pairs). With ten replicates of each set of wines, the participant must obtain seven correct responses to signify identification above chance ($p = 0.05$) (see Appendix 5.5).

Participants should assess each of the wine pairs before the test. This minimizes prior experience from being a major determinant in differentiation.
This is equally important if participants are asked to identify the varietal origin of the wine sets.

The test is particularly valuable in assessing tasting ability. Tasters are required to recognize the subtle differences that distinguish similar wines. Correspondingly, samples must be chosen carefully to demonstrate distinguishing characteristics. In addition, the samples should be at least sufficiently distinct to be differentiable by the preparers of the test.

Figure 5.6 illustrates the types of group results one might expect. For example, participants had more difficulty separating the two Beaujolais varieties:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Position#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sangiovese</td>
<td>1</td>
</tr>
<tr>
<td>(1, Melini Chianti; 2, Ruffino Chianti)</td>
<td>5</td>
</tr>
<tr>
<td>Cabernet Sauvignon</td>
<td>4</td>
</tr>
<tr>
<td>(1, Santa Rita; 2, Santa Carolina)</td>
<td>8</td>
</tr>
<tr>
<td>Pinot noir</td>
<td>6</td>
</tr>
<tr>
<td>(1, Drouhin; 2, Pedauque)</td>
<td>9</td>
</tr>
</tbody>
</table>

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

Although seemingly simple, experience has shown this to be one of the most challenging of screening tests.

Taster Training

In some of the screening tests noted in the preceding sections, training is incorporated into the testing procedure. In most cases, though, specific training follows selection. Part of this includes sessions on how to taste wines critically. For some panelists, this step may be unnecessary but can be useful as a refresher. Part of training also involves the use of the specific wine evaluation sheet used by the employer or experimenter. If scaling is used, developing experience in how to properly and consistently use the scale is essential.

A critical component of many training sessions involves practice in using a set of standard terms correctly and consistently. Occasionally, this may be preceded by sessions in which the panelists generate and subsequently select the terms to be used in actual sensory trials. This especially applies to descriptive sensory analysis. The influence of training on term use is illustrated in Fig. 5.7.

**FIGURE 5.7** Mean profiles of data for a trained panel and two untrained panels. [Reproduced from Lawless, H. T. (1999). Descriptive analysis of complex odors: Reality, model or illusion? Food Qual. Pref. 10, 325–332, with permission from Elsevier].

There will also tend to be some training relative to particular varietal, regional, or stylistic types. The extent and duration of such training will depend on the task demanded of the panel. No specific recommendations can be supplied here, as it is too dependent on what the panel is expected to do and local wine availability.

**Assessing Taster and Panel Accuracy**

Critical to the function of any panel is the accuracy and consistency of its members. At its simplest, this may involve comparing the results of each taster with the group average. Analysis of variance can provide additional information. In general, consistency and score stability are the measures of most concern to those conducting tastings. Consistency refers to the ability to repeatedly generate similar ratings of a particular attribute or wine, whereas stability refers to the ability to score wines or attributes similarly to other panelists. Although many procedures have been suggested to assess features such as consistency, stability, reliability, and discrimination, no consensus has arisen as to the most appropriate technique. Recent examples of statistical tests suggested are Rossi (2001), Stone and Sidel (2004), McEwan *et al.* (2002), Alvelos and Cabral (2005), and Latreille *et al.* (2006). Some, such as Vaamonde *et al.* (2000), King *et al.* (2001), and Bi (2003), provide working examples. Deterioration in skill may indicate the need for retraining, declining interest, or some other factor that needs discovery and correction.

Because of the additional effort involved in making these assessments, they have seldom been performed on a regular basis. With the introduction of computer-based, automated data entry, there is now little excuse not to conduct regular member assessment. More difficult, though, is the decision on what constitutes a minimal level for acceptable performance. Here, statistics are of no avail.

Consistency in all aspects of critical tasting is essential. In descriptive sensory analysis, near homogeneous use of descriptive terms is obligatory. Continuous monitoring of term use during training can be analyzed to determine if there is low taster × term variance. For evaluation-type tasting, random repeat tasting of a few wines over several weeks or months can provide similar data (for an example, see Gawel and Godden, 2008). Variance that is insignificant, or small values obtained from measuring standard deviation or tests of skewness, suggest taster consistency. In the latter assessment, it is important that the wines given repeatedly not be easily recognized. If wines are particularly distinctive, tasters will soon detect this, realize why the same wine[s] 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 set up to perform analyses of variance.

Table 5.10A presents hypothetical tasting results from which data are used to assess taster consistency. In the 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

\[
LSD = t_a \sqrt{2v/n} \tag{Eq. 1}
\]

where \(t_a\) is the \(t\) value with error degrees of freedom (available from standard statistics charts), at a specific significance level \((\alpha)\); \(v\) 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

\[
\text{LSD} = 2.91 \sqrt{2(0.983)/5} = 1.916
\]

(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 indicates 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): 

\[
A_1 - B_1 = 8.6 - 6.2 = 2.4
\]

(Eq.3)

\[
A_1 - B_2 = 8.6 - 5.8 = 2.8 \quad (\text{Eq.4})
\]

\[
A_2 - B_1 = 8.8 - 6.2 = 2.6 \quad (\text{Eq.5})
\]

\[
A_2 - B_2 = 8.8 - 5.8 = 3.0
\]

(Eq.6)

Similar results are obtained directly from the analysis of variance table (Table 5.10B). The \( F \) value from the two wines (\( F = 12.52 \)) shows the wines were differentiated by the tasters at the 0.1% level of significance, while the replicate scores from the same wines were insignificant (\( F = 0.46 < F_{.05} = 3.26 \)).

**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 clear and definitive 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 differences among score averages for several wines probably indicate real differences among the wines. Table 5.11A provides data on the ranking of four wines assessed by five tasters.

In the 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 $F_{.05}$

**Table 5.11A** Data on the Score for Four Wines Tasted by Five Panelists

<table>
<thead>
<tr>
<th>Tasters</th>
<th>$W_1$</th>
<th>$W_2$</th>
<th>$W_3$</th>
<th>$W_4$</th>
<th>Sum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>9</td>
<td>15</td>
<td>12</td>
<td>51</td>
<td>12.8</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>10</td>
<td>12</td>
<td>13</td>
<td>51</td>
<td>12.8</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>52</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>11</td>
<td>14</td>
<td>12</td>
<td>56</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>12</td>
<td>13</td>
<td>15</td>
<td>57</td>
<td>14.3</td>
</tr>
<tr>
<td>Sum</td>
<td>85</td>
<td>52</td>
<td>67</td>
<td>63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>17</td>
<td>10.4</td>
<td>13.4</td>
<td>12.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.11B** Analysis of Variance Table

<table>
<thead>
<tr>
<th>Source</th>
<th>$SS$</th>
<th>$df$</th>
<th>$ms$</th>
<th>$F$</th>
<th>$F_{.05}$</th>
<th>$F_{.01}$</th>
<th>$F_{.001}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>142.55</td>
<td>19</td>
<td>7.56</td>
<td>21.21</td>
<td>3.49</td>
<td>5.95</td>
<td>10.8</td>
</tr>
<tr>
<td>Wines</td>
<td>112.95</td>
<td>3</td>
<td>37.65</td>
<td>21.21</td>
<td>3.49</td>
<td>5.95</td>
<td>10.8</td>
</tr>
<tr>
<td>Tasters</td>
<td>8.30</td>
<td>4</td>
<td>2.08</td>
<td>1.17</td>
<td>3.26</td>
<td>5.41</td>
<td>9.36</td>
</tr>
<tr>
<td>Error</td>
<td>21.30</td>
<td>12</td>
<td>1.77</td>
<td>1.17</td>
<td>3.26</td>
<td>5.41</td>
<td>9.36</td>
</tr>
</tbody>
</table>
statistic \(3.26\). This indicates group scoring similarity (at least for those wines on that particular occasion).

Analysis of variance can also suggest whether a panel possesses 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 \(F_{0.05}\) 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 than the \(F_{0.05}\) 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 either unfamiliar with that type of wine, inconsistent in scoring, or possessing 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.

**Table 5.12A**

<table>
<thead>
<tr>
<th>Tasters</th>
<th>(W_1)</th>
<th>(W_2)</th>
<th>(W_3)</th>
<th>(W_4)</th>
<th>(W_5)</th>
<th>Sum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>26</td>
<td>5.2</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>31</td>
<td>6.2</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>23</td>
<td>4.6</td>
</tr>
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<td>4</td>
<td>7</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>31</td>
<td>6.2</td>
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<tr>
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<td>6</td>
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<td>4</td>
<td>5</td>
<td>6</td>
<td>26</td>
<td>5.2</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>35</td>
<td>7</td>
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**Table 5.12B**

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Summary

Current evidence suggests that becoming a good taster requires considerable training plus experience; both are essential. One cannot substitute for the other. Although exceptionally acute sensitivity is not essential, it can be a desirable attribute. What appears more essential is the ability to develop an extensive memory for the odor and taste attributes that distinguish wines. Additional requirements are the abilities to consistently describe and rank wines, relative to standard norms; development of a standard lexicon of wine descriptive terms; recognition of subtle differences between similar wines; assessment of wine attributes independent of personal preferences; being healthy; and dedication to attendance at tasting. A further property that many tasters desire, but usually not necessary for panel membership, is the ability to identify wine origin. This usually involves not only the properties the wine expresses, but also the attributes it does not express.

What is lacking is a clear understanding of how best to achieve these goals. Clearly, motivation is required, but how is this accomplished? Neither do we know the meaning of motivation at the molecular and neuronal level, nor do we know what environmental stimuli are required for its stimulation. It is also uncertain how memories are established. Are there fundamental differences between incidental learning (e.g., the association of color, texture, and flavor in the recognition of fruit) and attentive, declarative learning (e.g., language acquisition and memory of events), or are their apparent differences just an illusion and they are simply designated zones along a spectrum? It seems that the more emotionally significant the learning situation, the better the encoded memory trace. Were these fundamental aspects better known, presumably we could provide a better and more effective learning experience.

Clearly, few people will be blessed with, or develop, all these desirable traits, or express them consistently. For this reason, if for no other, a panel is required.

PRE-TASTING ORGANIZATION

Tasting Area

Indirect natural lighting is often preferred when assessing wine color, possibly because of its apparent uniform intensity and bluish cast. However, the apparent spectral uniformity of diffuse sunlight is an illusion (Fig. 5.8). Even if skylight were spectrally constant, it is rarely possible to provide such illumination under tasting conditions. Most tasting rooms possess only
artificial lighting, with little if any natural illumination. Of light sources, fluorescent tubes provide more uniform illumination. Ideally, daylight tubes should be used. In most instances, though, cool-white fluorescent tubes are adequate. The mind adjusts color perception within a fairly wide range of natural 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 fluorescent illumination are more important than its spectral qualities. Alternatively, recessed or track halogen lights can provide individual, brilliant, full-spectrum, or low-intensity red illumination (Plate 5.4) at each station. In contrast, standard incandescent lighting is less uniform and has an excessively high yellow component. Color distortion can be further minimized by having tasting rooms painted in clear, neutral (white or off-white) colors and having counters or tabletops matte-white.

When the influence of color on perception needs to be avoided, to enhance discrimination based solely on gustatory or olfactory sensations, low-intensity red light is often used. This distorts color perception to a point that it negates color-based clues. Alternatively, blue-, red-, or black-colored (Plate 5.10) wine glasses may be used. Either procedure is probably as effective, the choice being a matter of preference or availability. Personally, my preference is for colored glasses. They seem to minimize the “laboratory” feeling. In contrast, red lighting enhances the already contrived context of the tasting experience.

Under most circumstances, as near to natural illumination is desirable to minimize the inherently artificial ambiance of most tastings. Color is a normal component of a wine’s gestalt—how it is recorded in memory (Morrot et al., 2001; Österbauer et al., 2005). This is especially important if the results are intended to have any relevance to the marketplace, consumer preferences, or identification. In the latter instance, it is somewhat equivalent to asking a person to identify someone wearing a mask. The question of the appropriateness of a truly blind tasting usually relates to the relative importance of pure olfactory or gustatory discrimination versus the naturalness of the tasting situation.
Tasting rooms should ideally be air-conditioned, or at least, well ventilated. This is not only for the comfort of the panel, but also to prevent odor accumulation. Positive air pressure not only creates good ventilation, but also prevents the entrance of extraneous odors from surrounding rooms. This can be especially important where the tasting room is close to a wine cellar or wine storage area. Tasters become adapted to mild background odors, but if these odors are stale or possess off-odors, they may compromise the fairness of wine assessments. Thus, it is essential to avoid any potential sources of olfactory distraction.

When air-conditioning or adequate ventilation is not available, air purifiers can help provide an aromatically neutral tasting environment. As part of reducing the presence of odors, wine glasses are often covered to prevent their odors escaping and accumulating in the room. This also applies to cuspidors. Tasting rooms equally need to be free of annoying sounds that could disrupt concentration.

Tasting stations should be physically isolated to prevent taster interaction. Research has confirmed the widely held belief that comments can modify perception (Herz and von Clef, 2001; Herz, 2003). Thus, in deference to Shakespeare:

“A rose by any other name may not smell as sweet.”

Ideally, the tasting room should be set up specifically for that purpose, with separate tasting booths (Fig. 5.9; Plates 5.1 and 5.2). Typically, the back of each booth opens onto a preparation room (Plate 5.3). Alternate lighting permits the use of white or low-intensity red lighting (Plate 5.4). A passthrough permits samples to be easily presented and removed. A counterbalanced sliding guillotine model is highly efficient, resilient, and easy to use. Nonetheless, a small catch to hold the door up when open is less expensive and as effective. For easy maintenance, the door should be produced from some opaque, readily cleaned material such as plastic or plexiglass. An opening about 20 cm high and 25 cm wide should be adequate for most tastings. Viewing into the preparation area can be avoided by construction of a box (with its own door) on the preparation side of each booth. Other models are discussed in sensory evaluation texts noted in “Suggested Reading” at the end of this chapter. Where considered of value (frequent presentation of a series of samples), some means of easy communication between panelists and servers should be included. In addition, an adjacent waiting/discussion room is often included in the design of a tasting facility.

Where the tasting room is multipurpose, folding partitions can be constructed as tasting booth dividers. Partitions can be easily constructed
from 3/8” white melamine (easily cleaned). The sections should be about 1 m \times 1 m (allowing about 50 cm to extend over the edge of the counter or table). Two long hinges (one set inside one end panel and the other set outside on the other end panel) permit the panels to be conveniently folded for storage. If tasting locations cannot be compartmentalized, separate and random presentation of the samples to each taster can reduce the likelihood of significant taster interaction. Even with silence, facial expressions can be very communicative.

Chairs or stools should be adjustable as well as comfortable. Panel members may be spending hours concentrating on the difficult tasks of identification, differentiation, or evaluation. Every effort should be made to make the working environment as pleasant and comfortable 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 liter opaque plastic buckets can act as substitutes. These buckets need to be voided frequently or possess a cover to limit odor contamination of the surroundings during a tasting.

Pitchers of water or preferably samples of dry, unsalted, white bread or crackers are typically available for palate cleansing. Recent studies have reached varying conclusions as to the optimal palate cleanser, being either unsalted crackers, 1% pectin, or 0.55% carboxymethyl cellulose solutions (see Chapter 1). Water is generally the least effective palate cleanser. Cleansing the palate before and between each sample is encouraged to minimize 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 touch screen monitors, incorporating the tasting sheet, frees the
tasting surface of the clutter of writing materials or a mouse. If notation
demands more than just checking items, a keyboard installed on a slide rail
under the counter could be installed. It eliminates problems that frequently
arise from illegible handwriting.

The preparation area should be provided with a series of refrigerated
units so that wines can be brought to and kept at a desirable temperature.
Cool-temperature laboratory incubators contain more wine and are less
expensive than commercial, refrigerated, wine storage units. Refrigerated
units are also useful for storing tasting reference standards. There also
needs to be ample cupboard space for glass storage as well as other equip-
ment such as microbalances, beakers, and graduated cylinders. The con-
struction material should be neutral in odor, so as not to contaminate the
glasses during storage. Industrial dishwashers 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.
There also needs to be ample counter space for sample preparation to facili-
tate the transfer of wines to panelists. In addition, an adequate supply of
odorless, tasteless water is needed. In large research centers, this is usually
supplied from a double distiller. Where this is impossible, the ready avail-
ability of under-counter reverse-osmosis units can usually supply an ade-
quate supply of flavorless water.

Number of Samples

There is no generally accepted number of samples appropriate for a tasting.
If the samples are similar, only a few wines should be tasted. For accurate
evaluation, the taster must be able to simultaneously remember the attri-
butes of each sample—no easy task. Also, if description as well as rating
are involved, the more detailed the tasting, the fewer the number of wines
that can be adequately evaluated concurrently.

If the samples are markedly different, relatively large numbers of wines
can often be evaluated. Nevertheless, six wines tend to be the limit that
can be jointly compared adequately. In contrast, wine tasters in commercial
competitions are often expected to sample more than 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 dura-
tion of the wine’s fragrance is not feasible. Typically, the wines are judged
on an overall quality ranking. Although rapid, this approach 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, some repeats should be incorporated to assess taster reliability and consistency. Replicates are also useful if substitutes are needed to replace faulty samples.

Typically, established panels provide fairly consistent scoring. However, when the results show atypical variation, it suggests that the panel may consist of significant subgroups relative to a particular attribute. Some members may be detecting an unexpected problem. In this situation, reassessment of the wines is warranted.

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 somewhere in-between. Besides these general guidelines, there is little precise agreement among authorities.

The recommended cool temperature for white wines can vary from 8 to 12°C, with the upper end of the range being more frequent. Anywhere within this range is usually appropriate. What is more important is that all wines be served at the same temperature. As with other aspects of tasting, it is essential that wines be sampled under, as close as possible, 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, since 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 at about 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 extends 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 enhance the metallic perception occasionally found in 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 ports be taken at temperatures near the lower range for red wines.

Although temperature preferences partially reflect habituation, corresponding to expectation (Zellner et al., 1988), they also embody empirical observations on the effects of temperature on volatilility, solubility, and gustatory sensitivity. It is well known that aromatic compounds tend to become more volatile as the temperature rises (there is more free-energy for volatilization from the wine’s surface). Nonetheless, this generality glosses over important subtleties in the response of individual compounds to temperature. Because temperature’s effect on volatilility varies with the compound, the relative proportion of aromatics in the air above the wine is not easily predicted from its temperature. Consequently, temperature change may 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. Because the alcohol content of this fraction falls rapidly, the relative volatibilility of its aromatic constituents will change even further.

Temperature has marked effects on taste and mouth-feel. Cool temperatures reduce the sensitivity to sugars but enhance responsiveness 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 warmth of summer. In contrast, reduced bitterness and astringency help explain 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. These may be subdivided to maintain wines at different temperatures. Alternatively, wines may be immersed in water at the desired temperature or stored in a cool-temperature incubator, a refrigerator, or cool room until the desired temperature is reached. Figure 5.10 provides examples of the rates of

![Figure 5.10](image)
temperature change in a 750 ml bottle of wine in air and water, respectively. Temperature adjustment is about five 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 a short period in well-insulated containers.

Because the wine begins to warm after pouring, it is often advisable to present 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 are to be 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 may require considerable force for cork extraction. Double action models are preferable [Plate 5.5]. They both sink the screw into the cork as well as subsequently remove the cork. A lever model is available in several models for restaurant or home use [Plate 5.6].

Regardless of design, most corkscrews have difficulty removing old corks. With time, corks lose their resiliency and tend to tear apart on removal. In this situation, a two-prong, U-shaped device, occasionally called the Ah-So [Fig. 6.2A], or a hand pump connected to a long hollow needle can prove invaluable. There are also a series of devices that facilitate the removal of corks that accidentally get pushed into the bottle [Fig. 6.2B].

Decanting and Pouring

Decanting is valuable when sampling older wines that have developed sediment. It also permits early detection of off-odors. In the process, though, the wine is exposed to air. This is of little concern if the wine is tasted shortly after opening. Nonetheless, the decanter or glasses should be covered immediately after pouring, and sampling should occur as soon as possible. For very old wines [rarely studied critically under laboratory conditions], tasting should occur immediately after decanting. These wines rapidly lose whatever fragrance they may still possess. Covering the mouth of the decanter with a watch glass or petri dish top only retards aromatic loss. Because most modern wines are sufficiently stabilized to prevent sediment formation, it is now rare that wines need decanting.

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

**Sample Volume**

The volume of each wine sampled should be identical. Depending on the purpose of the tasting, an adequate volume 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 desired, volumes in the 50 to 60 ml range are more appropriate. With volumes in the 50 ml range, a 750 ml bottle can serve 12 to 14 tasters.

**Dispensers**

Wine dispensers are usually refrigerated units holding various numbers of bottles. They may possess separate compartments for keeping both red and white wines at appropriate temperatures (Plate 5.7). Each bottle is separately connected to a gas cylinder containing an inert gas, usually nitrogen. It usually supplies the pressure to dispense wine when the spigot is pushed (Plate 5.8). Originally designed for commercial wine bars, these dispensers also have particular value in training sessions. Wines can be economically sampled over several days or weeks, without significant oxidation or most other forms of deterioration. If refrigeration is less important, almost any number of samples can be supplied with individual spigots connected to a common gas cylinder (Plate 5.9). This relatively inexpensive option is especially useful where reference samples are kept available over an extended period. The presence of standard odor samples is particularly important in maintaining consistent term use in descriptive sensory analysis. Since the emotional context of the learning experience is minimal, repeat exposure is essential to consolidating odor/term memories (see Li et al., 2008).

**Representative Samples**

When one is dealing with bottled wine, a single bottle is generally assumed to exemplify the characteristics of the wine it represents. 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 distinct zones experiencing different maturation conditions.
Bottom samples are likely to be cloudy and tainted with hydrogen sulfide or mercaptans, due to the low redox potential that can develop in the collected sediment. Regions next to oak may have higher concentrations of wood extractives. Thus, 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, due to their smaller size. Nevertheless, barrel-to-barrel differences can be even greater than those that arise in large tanks. These variations can develop due to 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 fully representative sample is not required. Barrel tastings are usually used only as a check for faults or to follow development of the wine.

In either case, the samples should be placed in sealable containers and transported immediately to a tasting room for assessment—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 minimizes the possibility of oxidative changes 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 to accurately observe the wine’s appearance. The bowl should have sufficient capacity and shape to permit vigorous swirling of between 35 and 60 ml of wine. The glass should also be wider at the base than the top. 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; Front Cover). The broad base and sloped sides facilitate viewing and vigorous swirling, whereas the narrow mouth (giving the glass its tulip shape) helps to concentrate aromatics released by the wine. The latter is particularly useful in detecting subtle fragrances.

Most ISO glasses are slim crystal. Although this enhances elegance, they are too fragile for regular cleaning in commercial dishwashers. In addition, dishwashers often cause scratches and may slowly result in the buildup of a whitish, film-like, cloudy patina on the glass. Thus, less expensive, thicker-glass versions (such as those available from Durand and Libbey) are preferable. In addition, they may come in a range of sizes—for example,
215 and 310 ml (7.3 and 10.2 oz) capacities for the Luigi Bormioli Wine Tasting Glasses from Libbey. Alternate versions are illustrated in Plate 5.11. Where they are used solely for in-house tastings, a circular line may be etched around the glass to denote an adequate fill level. This is of particular importance where panelists fill their own glasses. Most stores that do engraving will etch glasses for a nominal fee.

For special tastings, where the biasing influence of color must be avoided, colored wine glasses may be used, for example, when panelists are being trained to recognize standard odor samples [they often differ in color and clarity], or where wines are being assessed for the presence of oxidative odors [observation of slight browning could significantly skew the results]. Black-colored ISO glasses can be obtained from Älghult Glassworks, Sweden (Plate 5.10). Reidel in Austria also produces a black tasting glass, but of larger volume than the typical ISO glass. Blue glasses are available from Libbey and possibly other producers. Standard wine glasses can be painted black. Unfortunately, they must be hand-washed to avoid removing the paint. An alternative technique, of untried efficacy, is to instruct the panelists to purposely disregard the wine’s color in making their analysis. Holistic versus attribute-by-attribute analyses of the same wine frequently differ.

Although ISO glasses have generally been assumed to be optimal for wine tasting, only recently has the influence of glass shape on wine assessment been investigated. These studies require elaborate precautions to avoid the participant from detecting the shape of the glass (Plate 5.12). Cliff (2001) confirmed the efficacy of the ISO glass, as well as its superiority in color discrimination. Other studies on the effect of glass shape on perception can be found in Delwiche and Pelchat (2002), Fischer (2000), Hummel et al. (2003), and Russell et al. (2005).

Unfortunately, none of the studies have addressed the physicochemical reasons for the differences detected. The sources are most likely to be a complex function of several factors, such as

\[
\text{surface area of the wine in the glass} = \pi r_w^2 \quad (\text{Eq.7})
\]

\[
\text{surface area of the wine adhering to the sides of the glass following swirling} = 2\pi r_s dh_1 \quad (\text{Eq.8})
\]

\[
\text{volume of headspace gas in the glass above the wine} = \pi r_s^2 h_2 \quad (\text{Eq.9})
\]

\[
\text{diameter of the mouth of the glass} = \pi r_m^2 \quad (\text{Eq.10})
\]
where \( r_w \) = radius of the wine surface in the glass; \( r_s \) = variable radius of sides of glass covered by wine following swirling; \( r_m \) = radius of the mouth of the glass; \( h_1 \) = height from the surface of the wine (meniscus) to the top of wine film adhering to the sides of the glass; \( h_2 \) = height from surface of the wine to the opening of the glass; \( \pi \) = mathematical constant (3.14159).

The first two equations refer to the escape of volatiles from the wine into the glass headspace. The headspace volume sets a limit on the equilibrium between volatiles in the wine and the headspace. The surface area of the mouth regulates the escape of volatiles from the headspace into the surrounding air. What the equations do not address is the dynamics of how different aromatics escape from the wine.

The surface area of film of wine on the sides of the glass often changes, decreasing as gravity draws it down into the main volume of wine after swirling, and increasing as a result of swirling. The evaporation of ethanol (and other volatiles) changes the dynamics of their partial pressures and, therefore, volatilization. Those compounds with higher partial pressures are the most immediately affected. They tend to volatilize more rapidly than they are supplied from the wine to the static surface. Those with lower partial pressures build up in concentration in the headspace more slowly, but more consistently. Changes in surface tension also undoubtedly affect volatility. As compounds escape, the dissociation constants between dissolved volatiles and their weakly bound forms in the wine change. As compounds in the headspace above the wine dissipate into the surrounding air, the equilibrium between the composition of the headspace volatiles and their dissolved forms in the wine continue to change. The latter is primarily influenced by the surface area of the mouth. For a critical measurement of glass shape on volatilization, continuous assessment of headspace gas composition with a combination of analytic instruments is required.

For sparkling wines, tall, slender, flute-shaped glasses are typically used (Plate 5.13). 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). Similar blue-colored versions of these glasses are available from Libbey.

Industrial dishwashers not only effectively clean but also sterilize. 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
is stored in cardboard boxes (a poor idea). Hanging stemware upside down may be acceptable in restaurants, where they are constantly being reused, but is ill advised in cabinetry.

**Number of Tasters**

Up to a point, the larger the number of tasters, the greater is the probability of obtaining valid data (Lawless and Heymann, 1999), or the data being more representative of the clientele for whom panelists may be intended to exemplify. In practice, though, as few tasters as possible are used. The number chosen often reflects the nature of the tasting and the need for accuracy. A few panel members can be acceptable if they are known to be skilled and consistent. This minimizes both costs as well as statistical analysis. This is also benefitted when only a few specific attributes are involved.

In most instances, a nucleus of 15 to 20 trained tasters is an appropriate minimum. This should provide at least 12 tasters for any one tasting. The greater the importance of the test results, the larger the number of panelists, repeat tasting, and/or higher the minimum acuity level required of the panelists. In some ways, it is an advantage that wines vary so much from vintage to vintage. Rough approximations may be all that is necessary.

Because tasters are occasionally out-of-form, continuous monitoring of taster function is advisable. However, designing a simple effective test for sensory adequacy depends on the task the panel is designed to perform. It is usually more effective, and polite, to request panel members to excuse themselves if they are not feeling up-to-par.

For quality control work, the number of tasters may be low (the winemaker). Nevertheless, it is far better for several people to be involved. Daily variation in perception is often too marked to leave critical decisions up to a single person, no matter how skilled. Only when immediate attention to some problem is required, and there is no time to convene a panel, should the decision be left to a single person or a few people.

With small groups (≤5), valid statistical analysis is essentially impossible. Thus, tasters should be known to be sufficiently acute for the task and be very consistent. It is also important that assessments be done individually, not by consensus. A consensus too often reflects the views of the most dominant member.

Ideally, quality control programs should retain samples that represent the range of acceptability desired for the wine[s] involved. These should be continuously available as standards for the panel members. Clearly, the panel needs to be well trained and of adequate size (>10) to provide for adequate statistical analysis. In addition, there should be a well-established
protocol of sample preparation and tasting under suitable conditions. Finally, there needs to be provision for reporting and archiving of the results. The latter is required for assessing procedural and panel performance.

Because individual tasters perceive tastes and odors differently (analogous to fingerprint uniqueness), sufficient tasters should be available to buffer these idiosyncrasies, or sufficiently trained and selected to provide adequate consistency. Which approach is preferred will depend on the intent and nature of the tasting. As noted, members showing the diversity of a particular subcategory of consumers may be desirable in wine evaluation, but be unacceptable for descriptive sensory analysis.

TASTING DESIGN

Tastings have a diversity of purposes—strict sensory analysis, ranking, consumer preference, etc. Correspondingly, their design must reflect this intent. Most of what is discussed in this chapter relates to analytical wine assessment. Consumer preference studies and related tasting situations are quite distinct. Various aspects of these are dealt with in Chapter 6.

Information Provided

Beyond specifics that need to be withheld, the general details of what is expected and how the test is to be conducted need to be clearly specified. It is up to the coordinator to determine the level of direction required. Where the tasting procedure is new or its intent different than usual, instructions should be given both verbally, prior to the tasting, and in print form at the tasting station. Tastings are not designed to assess memory for instructions. Even when panelists have considerable experience with the test, it may be best to err on the side of caution. It is far easier to provide adequate instruction initially than to redo the test.

Wines assessed critically must have their identity withheld. Precise knowledge of the wine’s origin, price, or prestige can severely influence perception. For example, in a study in Bordeaux, enology students were presented a wine for assessment but permitted to observe what appeared to the empty wine bottle nearby. When the wine was presumed to be a vin de table, term use was skewed toward faults, in contrast to predominantly positive comments given when an empty bottle of grand cru classé was in evidence (Brochet and Morrot, 1999). In a similar mode, Lange et al., (2002) found that knowledgeable consumers in the Champagne region seldom distinguished between champagne grades in a blind-tasting situation. However, when the bottles (and labels) were in clear evidence, ranking
and estimated monetary value coincided with traditional perceptions. Contextual effects on perception have been directly observed in modified brain activity (McClure et al., 2004; Plassmann et al., 2008). Despite the modifying influence of knowledge, providing some general information is essential. For example, if conformity with particular varietal or regional norms is being measured, tasters clearly need to know this. Panelists cannot be expected to be mind readers. However, in some situations, indicating the style or requesting specific information about a particular attribute can prejudice the assessment (Lawless and Schlegel, 1984). For example, requesting that panelists check for specific off-odors tends to enhance (exaggerate?) their perceived presence. Conversely, if this aspect is not noted, the presence of faults may go under-recorded. Because the information provided or requested can influence panelist response (Lawless and Clark, 1992), it is important that the experimenter weight seriously the pros and cons before deciding what instructions should or need to be provided.

Preparing Samples
Prepouring in marked glasses (or carafes) effectively obscures wine identity. This has several additional advantages beyond concealing identity. It assures that samples do not contain sediment that might have developed in the bottle, and permits prior detection and substitution of unrepresentative samples. If black glasses are used, prepouring is essential to avoid panelists' recognizing the wine's basic color.

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 this approach is 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.

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 if 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 comparatively sweeter. Equally, a wine tasted after a faulty sample will probably be perceived better than it would have had it followed a faultless 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 occurrence of this form of sequence error.

The effect of sequence errors can also be partially reduced by allowing sufficient time (at least 2 min) between each sample and adequate palate cleansing between wines. In addition, repeatedly sampling a series of wines over several minutes may negate sequence errors due to incidental randomization of samplings. However, these procedures may not be practical, or possible, in most tasting situations. Therefore, it is preferable to present the wines to each taster in a different sequence. One method of achieving a completely randomized design is using the Latin Square (Table 5.13) or its modifications. This method works well for situations in which all panelists taste all samples, a typical situation when evaluating wines. Where this is not possible, an incomplete block design or other treatment may be required. See Lawless and Heymann (1999) for details.

Subliminal numerical bias can be minimized by giving each wine a randomly generated three-digit code. Such codes may be easily obtained from several Internet sites such as


or

http://warms.vba.va.gov/admin20/m20_2/Appc.doc

<table>
<thead>
<tr>
<th>Taster</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>5</td>
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<tr>
<td>B</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>6</td>
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<tr>
<td>C</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>1</td>
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<tr>
<td>D</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>2</td>
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<tr>
<td>E</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
This minimizes the likelihood of psychological influences associated with particular numbers. Marking glasses is usually done with a permanent marking pen directly on the glass, but may also be done using small colored coding labels, such as Avery® #579x.

Other problems can be avoided (or arise) depending on the information provided. Stating that identical samples might be present could condition tasters to not exaggerate differences. However, the same information may induce tasters to ignore legitimate differences. Thus, as noted, it is essential that much forethought go into the design of critical tastings. The potential effect of observing facial reactions has also been noted. The more difficult the tasting, the more likely tasters may be swayed by suggestion. Mention of odor-related terms (but not other words) has been found to activate the piriform (olfactory) cortex and amygdala (González et al., 2006). The terms used can also affect the type of response. For example, isovaleric acid (possessing a sweaty odor) combined with cheese flavor and associated with the words “cheese” or “body odor” elicited markedly different responses from test subjects (Fig. 5.11). Differences were also observed in the areas

![Pleasantness ratings](image)

**FIGURE 5.11** Subjective pleasantness ratings to labeled odors. The means ± SEM across subjects are shown. The corresponding stimulus and label to each bar are listed in the lower part of the figure. Note that the test odor and clean air were paired in different trials with a label of either “cheddar cheese” or “body odor” [reproduced from de Araujo, I. E., Rolls, E. T., Velazco, M. I., Margot, C., and Cayeux, I. (2005). Cognitive modulation of olfactory processing. Neuron 46, 671–679, with permission from Elsevier].
of the brain activated. This suggests intimate connections exist between language, olfactory, and emotional centers in the brain. Expectation is also a significant influencer of taste perception (Pohl et al., 2003). Panel members should be aware of these influences so that they can guard against their undue 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 minimizes sensory fatigue.

Typically, only similar wines are tasted together—for example, regional or varietal wines. 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.

Tasting similar wines as a group tends to force panelists to search for differences. This is a valuable tendency when differentiation is desired. However, it also tends to exaggerate differences that might otherwise go unnoticed. This is termed the range effect (Lawless and Malone, 1986). Thus, comparing equivalent wines alone generates a greater score range than would occur if the wines were sampled with dissimilar wines. This suggests that the ranking of wines is relative and cannot be correlated to the same wines ranked under different circumstances.

Timing

Tastings are commonly held in the late morning, when people are generally at their most alert. Where this is inconvenient, tastings are commonly scheduled in the late afternoon or mid-evening. This usually eliminates any problems that might arise following teeth cleaning. Most toothpastes contain flavorants (such as menthol, thymol, methyl salicylate, eucalyptol, or cinnamaldehyde) or surfactants (such as sodium lauryl sulfate). These flavorants can affect olfactory and gustatory sensations, respectively. Usually, an hour is sufficient to erase any of these sensory distortions (Allison and Chambers, 2005).

Organizing tastings two to three hours after eating also seems to be correlated with more acute sensory skills. Reduced acuity, associated with satiety, partially results from suppression of central nervous system activity (see Rolls, 1995). It may also involve direct suppression of receptor sensitivity. Although not as yet confirmed in human studies, the secretion of the hormone leptin can depolarize taste receptors in animals (Shigemura et al., 2004). Leptin is secreted after eating and elicits a feeling of satiety.
WINE TERMINOLOGY

The popular language of wine is often colorful, poetic, and evocative. This is not too surprising. Impulses from the mouth and nose traverse the emotional centers of the brain before reaching the cognitive regions. Thus, although rich and redolent, most wine memories encode only an impressionistic glimpse of the most distinctive aspects of our responses. Without recording these perceptions in words, they soon morph into one another. As noted in Fig. 5.11, terms can distort our response to odors, as well as potentially directly affect sensory processing. The degree to which this occurs probably relates to personal experience and the emotional loading associated with particular terms.

Regrettably, the terms commonly used in the popular literature poorly articulate the sensory perceptions they are supposed to describe. Odors, unlike tastes, are usually described in terms of other aromatic objects or experiences. These usually involve the addition of an adjectival suffix such as “-like” (e.g., rose-like), or “-y” (e.g., corky). Other suffixes occasionally used include “-ic” (e.g., metallic), “-ful” (e.g., flavorful), and “-ous” (e.g., harmonious). Verb participles may also be used in describing wine qualities, for example, “balanced” or “refreshing.” Only chemists are likely to refer to odors by their chemical name. For natural objects this is essentially impossible. They typically derive their distinctive fragrance from a multitude of aromatic compounds. Experiments have shown that humans are ill adept at distinguishing the individual components of a mixture. This almost assuredly also applies to wine. Thus, there seems little choice but to use comparative representations.

The difficulties of assessing the validity of such descriptors are discussed by Wise et al. (2000). They point out significant liabilities and limitations to their use, notably that these subjective expressions are highly context-, experience-, and culture-sensitive. Requiring people to make precise statements about wine may actually defeat its purpose. Oro-nasal responses are largely implicit and encoded subconsciously.

Terms often develop precise meaning and significance when used repeatedly by a group, but this usually is dependent on specific training or selection. Nonetheless, descriptors rarely give adequate expression to individual differences in perception or experience. Is one person’s “apple-like” the same as another’s? The act of description may appear so foreign as to invalidate its use when dealing with consumer preference studies (Köster, 2003). Worst of all, most terms do not permit precise measurement of qualitative differences. Without confidence in qualitative measurement, the ability to understand the origins of any differences identified is severely
limited. For example, when tasters note a black currant or violet aroma in a Cabernet Sauvignon wine, are people referring to the specific aroma of these items, or is it that experience has taught them to use these descriptors when detecting a Cabernet aroma? Examples of descriptors frequently used to enunciate the characteristic aroma of several cultivars are noted in Tables 7.2 and 7.3. These and the terms used on aroma wheels are only approximations and may reflect more the fragrant experiences and perceptions of the classifiers than the wine attributes themselves. For additional views on these issues, see Lawless (1999).

In descriptive sensory analysis, separation among similar samples is the usual intent, not a complete description of the wine’s sensory attributes. In this case, many of the problems just noted do not arise or can be sidestepped. Terms selected usually refer only to attributes considered discriminatory and that do not overlap. They are typically represented by physical or chemical reference standards. They are used in lexicon training and available during tastings. In addition, panelists are selected for their ability to accurately and consistently use these terms. That laboratory tasting conditions do not reflect consumer tasting situations is not a concern. The intent is discrimination, not preference or quality assessment.

In normal usage, flavor impressions are funneled through the language of odor. Flavor terms often employ general categories, such as fruity, flowery, herbal. Descriptions also tend to include even more general states, such as illusions to size or shape (e.g., big, round), power (e.g., robust, weak), or weight (e.g., heavy, light, watery). The vocabulary frequently evokes broad emotional reactions, such as pleasant, unctuous, vivacious, scintillating.

Increased experience expands the lexicon to include more precise terms, such as tannic, buttery, or mercaptan, but too often becomes increasingly florid (e.g., honey, cherries, truffles, tar) and metaphoric (e.g., heavenly, voluptuous, feminine, nervous). Term usage often closely reflects the cultural, geographic, and specific upbringing of the taster—truffle being commonly identified in wines from the Rhône or northern Italy, or eucalyptus being imagined to be typical of Australian wine. Knowledgeable wine consumers use descriptive terms such as “fruits” and “flowers” much more frequently than teetotalers in describing wines. The latter tend to use terms such as “pungent,” “vinegary,” or “alcoholic” (Fig. 5.12).

Terms may also connote the expectations or overall reaction of the taster—“jammy,” “harmonious,” and “complex” applying to wines that are highly regarded, whereas “unbalanced,” “astringent,” or “simple” often being employed for wines disliked or considered mediocre. Only rarely are specific wine constituents sufficiently distinct to be individually
recognizable—for example, mercaptans, methoxypyrazines, and specific fruit esters or lactones.

Color or color-associated terms (raspberry, cherry, peach, melon, apple) used to describe a wine often reflect the color of the wine. The association of red wine flavors with red to somber-colored objects and white wines with pale to yellow-colored objects is well recognized (Morrot et al., 2001). These learned associations mirror the integration and interpretation of visual, olfactory, and taste sensations in the orbitofrontal cortex (Fig. 3.10) and the dominance of visual over other sensations.

Many of the commonly used terms, especially when ranking wines, denote holistic, idiotypic, or integrated aspects of perception, as well as flavor intensity or their temporal development (Lehrer, 1975, 1983; Brochet and Dubourdieu, 2001). Terms such as “balance,” “dynamism,” “complexity,” “development,” “body,” “finish,” and “memorability” integrate multiple, often independent sensations. Such abstract terms are essential, but impossible to define precisely. The absence of reference samples for these impressions makes evaluation of their consistent use fraught with difficulty.

The difference in how novices and experts express their reactions to wine may depend on which side of the brain is used. For example, the holistic expressions used by most consumers may originate from the selective activation of the right hemisphere (Herz et al., 1999; Savic and Gulyas, 2000). This region typically deals with ideographic aspects of expression. Consumers also tend to show significant activation of the amygdala, an area implicated in emotional processing (Castriotu-Scanderbeg et al., 2005). In contrast, verbalization of knowledge and most analytic processes tend to be concentrated in the left hemisphere, at least in right-handed people (Deppe et al., 2000; Knecht et al., 2000). Odor memory appears to require both hemispheres for optimal recognition (Dade et al., 2002).

Alternatively, poor verbalization of sensory perception may simply reflect a lack of training. Current research on brain plasticity would support this view. Either way, the small portion of the brain set aside for processing olfactory information may partially explain why humans have such a
limited odor lexicon. It also forces people to describe their vinous impressions in terms of familiar objects or the emotions they engender. The specific terms used probably also reflect genetic individuality. For example, most people smelling diacetyl appear to detect a resemblance to butter. Personally, I do not detect this attribute. More frequently, I appear to detect a contaminant that occasionally occurs in association with diacetyl. The contaminant dominates, probably because it reminds me of the crushed earthworms I so often had to dodge, going up a long driveway of the apartment complex in which we stayed during my first sabbatical in Ithaca. Under such conditions, my emotional response to a wine with this aspect is markedly different than that of those who do not detect or recognize this particular odor response pattern.

Language often plays several roles in wine tasting. The writers of wine columns tend to use language at least as much to entertain as to inform. In a home setting, comments typically express overall reactions or are used to seek reassurance from others. Under certain conditions, comments may be used to honor the host or donator of the wine, or simply function to activate social exchange. Regrettably, winespeak may also be used to impress or cajole others into accepting a particular opinion. In tasting clubs, discourse is often used unsuccessfully to describe the sensory attributes of wine. Only with long and concerted training is it possible to approach the semblance of precision in describing the sensory attributes of wine.

For critical analysis, communication should be as precise and accurate as possible, expressing the impressions of the taster in a clear and unambiguous manner. Terms chosen should be readily distinguishable from one another (minimum overlap), be represented by stable chemical or physical standards (present in cases of doubt), facilitate wine differentiation, and ideally permit subsequent wine recognition. Meilgaard et al. (1979) were the first to develop a standardized terminology for an alcoholic beverage (beer). A similar system was later developed for wine (Noble et al., 1987). Regrettably, neither appears to have been subjected to published evaluations for use, effectiveness, appropriateness, or determination if the terms are mutually exclusive. Subsequently, similar proposals have been presented for sparkling wines (Noble and Howe, 1990) and brandies (Jolly and Hattingh, 2001). Gawel et al. (2000) proposed a set of mouthfeel terms. The latter seems to have even more problems than those for olfaction (King et al., 2003). Effective mouth-feel standards do not exist and many definitions overlap (being gradations of the same sensation), while others combine several independent sensations. Despite these difficulties, prolonged training apparently generates panelists who can use the terms consistently (Gawel et al., 2001). The proposal has been used to
differentiate among the various attributes of different wine-tannin frac-
tions (Francis et al., 2002).

Most of these collections of terms have been prepared in the form of
wheels. In contrast, the versions provided in Figures 1.3 and 1.4 are
prepared in chart form. This is to obviate the frequent complaint of having
to repeatedly rotate the sheet to easily read the terms.

There is extensive practical evidence that training improves precise term
use. Data from Rabin and Cain (1984) suggest that this results from develop-
ing familiarity with specific odors and associating its receptor activation
pattern with particular terms. For familiar odors, it may take several trials
to achieve recognition in the absence of visual clues (Cain, 1979). In
learning new odors, concentration on verbal memorization (rather than
their sensory attributes) seems initially to retard odor memory development
(Melcher and Schooler, 1996; Köster, 2005). In addition, familiarity with
complex odors (based on several aromatic compounds) may complicate
identification of their individual components (Case et al., 2004). Odor
memory, at least memories encoded incidentally during life (without active
concentration), seems more designed to detect “significant” changes in the
environment than identification. For example, rapid detection of a predator
is more important than its precise identification.

Although developing a common lexicon is important, odor training also
tends to selectively direct attention to the attributes named (Deliza and
MacFie, 1996). This can be valuable in certain circumstances, such as
searching for faults or specific attributes, but may induce exaggeration of
their presence.

The success in learning a specific lexicon often depends on the absence
of preexisting associations for the odors involved. Existing (encoded) asso-
ciations are often stable and resistant to recoding (Lawless and Engen,
1977; Stevenson et al., 2003). Most odor memories are long-lasting, develop
incidentally (without intentional learning or naming), and are associated
with particular experiences. This may explain why some trainees fail to
establish the desired skills and are eliminated. Although selection for con-
sistency generates better statistical results, it reflects data from a specific
subset of individuals who perceive similarly. This is desirable for distinction
but certainly does not represent consumer diversity. That wine consumers
fall into different groups is self-evident, but only recently have the factors
affecting how this affects wine purchasing habits (Goodman et al., 2006)
and by whom (Hughson et al., 2004) attracted study. As previously noted,
which approach to panel selection (consistency or representativeness) is
preferable depends on the purpose of the tasting.
Although experts use descriptive language more precisely, it may not significantly improve their ability to identify wine origin (Lehrer, 1983). Various studies have tried to assess the differences between expert and novice tasters (Lawless, 1984; Solomon, 1990; Hughson and Boakes, 2002; Parr et al., 2002). The issue is complicated by having no objective measure of the difference among wines, or for what constitutes an “expert.” Nonetheless, ability to differentiate appears to depend primarily on experience, both sensory and verbal, not on superior acuity.

In the research on wine language, participants are often divided into novices and experts. While novices are often consumers with little knowledge of or experience with wine, experts generally fall into two relatively distinct categories. These roughly correlate with those who have expensive, experience-based expertise, and those who have been specifically trained in sensory analysis, what I term “training-based expertise.” This is similar to a distinction proposed by the ISO (1992). Examples of experience-based experts are sommeliers, the majority of wine writers, and many winemakers. Training-based experts include members of panels used in descriptive sensory analysis and the majority of university-trained winemakers. Experience-based experts tend to have extensive practice in assessing the relative quality of varietal, regional, and stylistic wine types. The more people experience particular groups of wine, the more they learn to focus on the features that distinguish them, aspects that may not necessarily be obvious to the novice. This seems equivalent to how a botanist can distinguish among tree species, whereas many laymen say: “After you’ve seen one tree, you’ve seen ’em all.” Each taster tends to use a comparatively limited descriptive lexicon, but an extensive range of emotive expressions that are idiosyncratic. There is little commonality in the terminology used by these experts. In contrast, training-based experts tend to use a standard (panel-based) lexicon of descriptive terms. These usually refer to specific reference samples with which they have been trained. Emotive language is discouraged. These training-based experts may or may not have extensive experience in recognizing the features that may characterize varietal, regional, or stylistically distinctive wines.

Each type of expert has his or her rightful place in wine tasting, a phenomenon that includes a very wide range of situations, each with its own particular rationale. Thus, neither is intuitively “better” than the other. Their respective values depend on what is desired. Nonetheless, when one is looking at studies on wine language usage, it is important to discern that the relevance of the study depends on whether it is investigating experience-based expertise or training-based expertise. Without recognizing
this difference, comparing studies could easily lead to the impression that their conclusions are as often in conflict as in agreement.

Simple taste and touch sensations are easier to differentiate than odors. This may result from our language possessing terms that exclusively refer to these sensations. In contrast, our vocabulary of uniquely 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 primarily on reference to objects or situations that, through individual experience, have become associated with a particular odor.

Although a universal, precise language for wine would be desirable, no such system has yet evolved. It is also unlikely that it will arise any time soon, due to human variability. People even have difficulty correctly naming common household odors (devoid of visual clues), let alone anything more complex. Figure 5.13 illustrates the extent of the problem. It may be that the “need” to name wine fragrances develops so late in life that it is far easier to relate them to those we already recognize and can name. In addition,
personal designations are variable and may change from day to day (Ishii et al., 1997). This probably explains why people have such difficulty in recognizing wines from verbal descriptions, even their own (Lawless, 1984; Duerr, 1988). Thus, that personal terminology is often idiosyncratic and reflects familial, cultural, and geographic contexts should not be surprising. The chemical diversity of wine aroma and the lack of childhood odor training make it almost unavoidable that the terms used will be individualistic and reflect personal experience.

For sensory evaluation, terms are usually provided on a prepared tasting sheet. Nevertheless, use consistency is usually superior when these terms are self-generated. In addition, if the terms provided do not permit adequate sensory representation, there is a strong likelihood that existing terms will be expropriated (misused) for their expression. This adds another reason why terms generated by tasters may be preferable to those supplied by experimenters.

**WINE EVALUATION**

**Score Sheets**

With wine tasting encompassing an incredible diversity of events, there is an equivalent multiplicity of score sheets. They span the spectrum from purely academic investigations, such as sensory psychophysiology, to maintaining the constancy of a proprietary blend, to recommending the “best buy” in some category. Also involved may be public and comparative tastings that only rank wines. Ranking may be based on aesthetic principles, with or without the weighting of particular attributes.

Despite their diversity, tasting sheets can be grouped roughly into two categories: **synthetic** and **analytic**. In synthetic versions, wines are assessed holistically and/or hedonically, and the wines’ attributes combined together and assessed on overall qualitative scales, such as balance, complexity, development, duration, etc. Alternatively, or in addition, wines may be assessed relative to the purity of their expression of some established paradigm, such as specific varietal attributes, regional traits, stylistic characteristics, or a combination of these. In analytic versions, individual visual, gustatory, mouth-feel, and olfactory attributes are separately assessed. These are usually rated quantitatively. As noted earlier, accurately assessing individual sensory attributes can be fraught with difficulty, notably due to learned integrated associations. Training can be used to minimize such influences (Bingham et al., 1990), but not necessarily eliminate them (Stevenson and Case, 2003).
For preference rating, sheets recording ordinal divisions may be sufficient (Fig. 5.14). For this function, they may be as effective as detailed assessments (Lawless et al., 1997).

In contrast, most tasting sheets rank particular attributes (Fig. 5.15) 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. 5.16) or emphasize integrated impressions (Fig. 5.17). Detailed score sheets are particularly useful in identifying specific strengths and weaknesses. Most score sheets, however, are deficient in adequately rating intensity characteristics or gauging the negative influences of faults. They also require the taster to give a quantitative estimate of the importance of different and integrated groupings of visual, gustatory, and olfactory sensations. Furthermore, it assumes that wine ranking can be fairly assessed by a sum of its component parts. Exceptionally fine qualities in one category, which may strongly influence the overall impression of the wine, are not permitted to bias the ranking, without having to artificially adjust the ranking in other categories. Statistical analysis is also complicated by the variable number of marks given each category and the usual request that only whole numbers be used. This is particularly limiting when the score range has a maximum of 2. There are also considerable difficulties in consistency of use. Preparing adequately representative standards for “good” versus “poor” may be impossible. Thus, panelists may have differing concepts of what these categories mean and use personal criteria to integrate and quantify complex qualitative judgments. Use of such sheets effectively and consistently requires considerable training and extensive practice. Without this, the data obtained are of little diagnostic value and are not of a quality on which wine production decisions should be made.

To offset these limitations, tasting sheets may be specifically designed for descriptive sensory analysis (e.g., Figs. 5.27 and 5.28). They permit the intensity measurement of individual attributes. The features are usually those that permit discrimination among the wines being analyzed. By avoiding the
FIGURE 5.15  General score sheet based on the Davis model.

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

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* 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

1. attributes derived from treatments given after fermentation is complete.

**FIGURE 5.16** Sparkling wine score sheet.
**FIGURE 5.17** Sensorial analysis tasting sheet for wine judging competitions (from Anonymous, 1994, reproduced by permission).

<table>
<thead>
<tr>
<th>OCCASION</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>COMMISSION</th>
<th>SAMPLE</th>
<th>VINTAGE</th>
<th>NAME OF WINE</th>
<th>PRESENTATION CATEGORY</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TEST</th>
<th>LIMITATION</th>
<th>VERY GOOD</th>
<th>GOOD</th>
<th>FAIR</th>
<th>LEAN</th>
<th>FAIR</th>
<th>POOR</th>
<th>NEGATIVE</th>
<th>EXCESS</th>
<th>LACK</th>
<th>IMBALANCE</th>
<th>DEFECT</th>
<th>NATURE OF DEFECTS</th>
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<td>5</td>
<td>4</td>
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<td>2</td>
<td>1</td>
<td>0</td>
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<tr>
<td></td>
<td>HUE</td>
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<td>5</td>
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<td>3</td>
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<td>0</td>
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<tr>
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<td>INTENSITY</td>
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<td>7</td>
<td>6</td>
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<td>4</td>
<td>2</td>
<td>0</td>
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<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
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<tr>
<td>OVERALL JUDGEMENT</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>0</td>
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<td>PARTIAL TOTALS</td>
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<th>TOTAL</th>
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<th>REMARKS</th>
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<tr>
<th>MEMBERS OF COMMITTEE</th>
<th>SIGNATURE/</th>
</tr>
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<table>
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<tr>
<th>biological</th>
<th>chemical</th>
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<tr>
<th>physical</th>
<th>accidental</th>
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integration of multiple factors into a single or a few qualitative assessments, it is easier to spot particular quality problems (and initiate vineyard or winery solutions). Limitations to the use of descriptive sensory analysis (see below) include the time and expense involved in panel training and data analysis; potential problems of data dumping and halo effects; and its limitation to attributes that are well known (for which standards can be prepared as anchor references).

An interesting alternative that includes some of the benefits of standard score sheets and descriptive sensory analysis has been proposed by Muñoz et al. (1993). It has not been used in wine assessment to my knowledge, but includes some of the qualitative aspects of the former and the intensity scaling of the latter.

Few tasting sheets have been studied to determine how quickly they come to be used effectively. Thus, reliance on the data derived from tasting sheets partially depends on how accurately and consistently tasters use the forms. Generally, the more detailed the score sheet, the longer it takes for it to become used consistently (Ough and Winton, 1976). If the score sheet is too complex, features may be disregarded, and ranking based on preexisting quality concepts (Amerine and Roessler, 1983). Conversely, insufficient choice may result in dumping—the use of unrelated terms to register important perceptions not present on the sheet (Lawless and Clark, 1992; Clark and Lawless, 1994). This can be avoided only by selectively choosing terms that adequately express the important impressions detected by the tasters (Schifferstein, 1996).

Possibly the most widely used scoring system is that based on the UC Davis scorecard (a modification is illustrated in Fig. 5.15). It was developed as a tool to identify wine production defects. Thus, 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 in sparkling wines). Evaluation forms designed for sparkling wines incorporate a special section on effervescence attributes (Fig. 5.16; 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. 5.17 and 5.18). An alternative system employs a letter-grade system, similar to that often used in grading student exams (Fig. 5.19). Whatever the choice, it should be as simple (rapid and easy to use) as possible, consistent with adequate precision, relative to the purpose for which it is used.

The total point range used should be no greater than that which can be used effectively and consistently. In ten-point (decimal) systems, half-points
<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance and color</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>POOR – Dull or slightly off-color</td>
</tr>
<tr>
<td>1</td>
<td>GOOD – Bright with characteristic color</td>
</tr>
<tr>
<td>2</td>
<td>SUPERIOR – Brilliant with characteristic color</td>
</tr>
<tr>
<td><strong>Aroma and bouquet</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>FAULTY – Clear expression of an off-odor</td>
</tr>
<tr>
<td>1</td>
<td>OFF CHARACTER – Marginal expression of an off-odor</td>
</tr>
<tr>
<td>2</td>
<td>ACCEPTABLE – Absence of characteristic varietal-regional stylistic fragrance or bouquet</td>
</tr>
<tr>
<td>3</td>
<td>GOOD – Mild to standard varietal-regional stylistic fragrance or aged bouquet</td>
</tr>
<tr>
<td>4</td>
<td>SUPERIOR – Varietal-regional-stylistic fragrance or aged bouquet distinct and complex</td>
</tr>
<tr>
<td>5</td>
<td>EXCEPTIONAL – Rich, complex traditional fragrance or refined lingering aged bouquet</td>
</tr>
<tr>
<td><strong>Taste and flavor</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>FAULTY – Off-tastes or off-odors so marked as to make the wine distinctly unpleasant</td>
</tr>
<tr>
<td>1</td>
<td>POOR – Absence of varietal, regional or stylistic taste and flavor characteristics</td>
</tr>
<tr>
<td>2</td>
<td>GOOD – Presence of distinctive varietal, regional, or stylistic taste and flavor characteristics</td>
</tr>
<tr>
<td>3</td>
<td>EXCEPTIONAL – Superior varietal, regional or stylistic taste and flavor characteristics</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>POOR – Acid/sweetness ratio inharmonious; excessively bitter and astringent</td>
</tr>
<tr>
<td>1</td>
<td>GOOD – Acid/sweetness ratio adequate; moderate bitterness and astringency</td>
</tr>
<tr>
<td>2</td>
<td>EXCEPTIONAL – Acid/sweetness balance invigorating; smooth mouth-feel</td>
</tr>
<tr>
<td><strong>Development/duration</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>POOR – Fragrance simple, does not develop, of short duration</td>
</tr>
<tr>
<td>1</td>
<td>STANDARD – Fragrance typical, develops in complexity, does not fade during tasting</td>
</tr>
<tr>
<td>2</td>
<td>SUPERIOR – Fragrance improves in intensity and/or character, lasts throughout tasting</td>
</tr>
<tr>
<td>3</td>
<td>EXCEPTIONAL – Rich fragrance, improves in intensity and character, long lasting</td>
</tr>
<tr>
<td><strong>Finish</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>POOR – Little lingering flavor in the mouth; excessive astringency and bitterness</td>
</tr>
<tr>
<td>1</td>
<td>GOOD – Moderate lingering flavor in the mouth, fresh aftertaste</td>
</tr>
<tr>
<td>2</td>
<td>EXCEPTIONAL – Prolonged flavor in the mouth (&gt;10 to 15 s), subtle, refined after-sensations</td>
</tr>
<tr>
<td><strong>Overall quality</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>UNACCEPTABLE – Distinctly off-character</td>
</tr>
<tr>
<td>1</td>
<td>GOOD – Acceptable representation of traditional aspects of the type</td>
</tr>
<tr>
<td>2</td>
<td>SUPERIOR – Clearly better than the majority of the wine type</td>
</tr>
<tr>
<td>3</td>
<td>EXCEPTIONAL – Memorable experience</td>
</tr>
</tbody>
</table>

**FIGURE 5.18** Score sheet assessing aesthetic wine quality.
are often permitted to increase the range to the maximum that can be used effectively. It also increases breadth in the midrange (central tendency)—most tasters avoiding the extremes (Ough and Baker, 1961). Typically, ends of a range are used only when fixed to specific quality designations.

Assuming that wines show a normal distribution of quality, scores should equally show a normal distribution. While generally true, scores may be skewed to the right (Fig. 5.20), reflecting the infrequent appearance of faulty wines. When tasters use the full range, scoring distribution tends to be non-normal (Fig. 5.21). Tasters showing non-normal distributions using the Davis 20-point card demonstrated standard distributions when using fixed-point scales (Ough and Winston, 1976).

Most professional scoring sheets give particular weighting to various sensory categories with surprising uniformity (Table 5.14). They differ primarily where overall impressions are combined with taste/flavor. However,
the similarity may be fortuitous, being based on similar views of the
originators, not research into the relative importance of different attributes
assessed by wine professionals (or consumers). It is also a moot point
whether quality can be quantified adequately by summing the values given
to particular attributes. In addition, experienced judges may not use any of
these sheets as intended, assigning an overall numerical value and then
going backward to assign marks to individual categories to reach the total
chosen.

<table>
<thead>
<tr>
<th>Score Sheet</th>
<th>Appearance</th>
<th>Smell</th>
<th>Taste/ Flavor</th>
<th>Overall/ Typicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associazione Enotecnici Italiani (1975)</td>
<td>16</td>
<td>32</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>Davis scorecard (1983)</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>O. I. V. tasting sheet (1994)</td>
<td>18</td>
<td>30</td>
<td>44</td>
<td>8</td>
</tr>
</tbody>
</table>
Alternate procedures include providing a holistic summation of one’s perception of quality, without the use of any weighting of individual attributes. This avoids the problem of scoring sheets where wines with a serious fault cannot be adequately downgraded. An example of the holistic approach is the 100-point ranking that has become so popular in consumer publications. However, there is no published evidence that people accurately distinguish 100 grading divisions. That the portion of the scale most commonly recorded ranges from 80 to 100 is an indicator of a lack of effective use. Parr et al. (2006) have demonstrated that 100-point systems are no more discriminative than 20-point systems.

Other schemes permit tasters to assign any number they want. In this instance there is no upper limit, and the taster’s ratings are not constrained. Procrustes analysis is used to analyze the data. It is based on the dubious assumption that, although people may use different terms and scales, the attributes are perceived essentially the same way. Procrustes procedures search for common trends, and shrink, expand, or rotate the scales to develop the best data matching. If people’s responses differ fundamentally, and not just by degree, then Procrustes statistics are based on a false premise. The origins of consumer variation, although not of direct concern in wine tasting per se, should be to the interpreters of the data. Conversely, if the variance in perception is due to differences in how tasters understand the task, then this must be corrected by the organizers.

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**—a situation in which 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.

Many studies have shown that the type of task (analytic or synthetic) demanded of panelists can modify significantly the results derived (see Prescott, 2004). Thus, the experimenter must have a clear idea what is desired and how the tasting procedure could bias the results.

**Statistical Analysis**

Statistic analysis provides a degree of confidence in the interpretation of experimental data. Ideally, it provides an objective confirmation of the interpretation, avoiding both type I and II statistical errors—in other words, avoiding accepting a difference when none exists or rejecting a difference when one actually exists. Statistics has its greatest value when interpreting
the interrelationships of complex sets of data where discernment of regulating factors is not readily apparent. This is frequently the situation with descriptive sensory analyses. An additional complicating factor is that human sensory perception is not noted for its consistency and objectivity. Thus, statistical tools improve the ability to detect potentially significant differences, either among wines, tasters, or both, and the attributes that may be the origin of the differences.

Statistical analysis can confirm doubt (without proving it) or provide confidence values for differences detected. When many factors are involved, simple comparison of the data is difficult. Procedures such as Principle Component Analysis may identify those factors leading to differences. Although not perfect, used with caution and interpreted within the limitations of such tests, statistical tests provide an interpretation not easily obtained otherwise. Demonstration of significance is, of course, not proof. This requires further experimentation. Unfortunately, this is too often not performed. This is one of the problems associated with research funding, often on a 3-year basis, and being conducted by graduate students or post-doctoral fellows present only for a few years. Other problems are inherent in the experimental design. Wine assessed analytically in a laboratory setting is very different from that at the dinner table. Thus, significance with a panel of tasters trained and selected for specific skills may have little if any relevance to market conditions. Statistical significance is also dependent on the validity of the assumption on which the test is based and the skills of the tasters involved.

Another fundamental problem, especially for nonstatisticians, is the difficulty of intuitively confirming the conclusions derived from complicated statistical analysis. This limitation, and inappropriate use, probably led the satirist Mark Twain to pen his now famous quip:

“There are three types of lies: lies, damned lies and statistics.”

Except for those with extensive statistical training, it is advisable to seek professional advise in choosing an appropriate tool to analyze data, and help with its proper interpretation. New statistical approaches are constantly being developed. It is not readily apparent which might be the most appropriate. Thus, it is preferable to work with a statistician who has a good working knowledge of sensory evaluation procedures. It is important that statisticians be well aware of the limitations of dealing with using humans as sensory instruments. As noted previously, humans are excellent at differentiating between samples side-by-side but are not as efficient as objective analytical instruments. In addition, it is far too easy to be dazzled by the impressive graphical representation of data analysis readily available in
computer statistical packages. 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 [and appropriate] tasters, and conducted with due concern for the assumptions on which the statistical test is based.

Because an adequate discussion of multivariate procedures is the prerogative of statistical texts, only illustrations of relatively simple statistical examples are provided. More complex statistical tests are noted only relative to their potential use in wine analysis and where their use might be justified. As noted at the beginning of the chapter, such rigor is usually unnecessary. Only in research, or when critical production decisions are involved, is establishing statistical significance warranted and obligatory.

At its simplest, statistical analysis can confirm 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 are 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 any 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 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 of the data (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
recognized as being significantly different from the other wines. In the same manner, were there fifteen tasters of the same skill used, both wines A and E would be differentiated (the highest and lowest ranked wines). Even having a few inconsistent tasters 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 the degree of difference on which separation occurred remains undefined. Ranking wines, based on numerical (versus hierarchal) attributes, helps to minimize the problem. Table 5.16 presents a simple example 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.

| Table 5.15 | Hierarchical Ranking of Six Wines by Five Panelists |

**A. Five Tasters**

<table>
<thead>
<tr>
<th>Taster</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Rank total | 9 | 19 | 20 | 21 | 24 | 12 |
Overall rank | 6 | 4 | 3 | 2 | 1 | 5 |

**B. Ten Tasters**

<table>
<thead>
<tr>
<th>Taster</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Rank total | 18 | 38 | 40 | 42 | 48 | 24 |
Overall rank | 6 | 4 | 3 | 2 | 1 | 5 |
Table 5.16 Results of Five Wines Scored by Seven Panelists

A. Wine Scoring Data

<table>
<thead>
<tr>
<th>Taster</th>
<th>Wines</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>20</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>73</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>18</td>
<td>77</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>18</td>
<td>15</td>
<td>13</td>
<td>17</td>
<td>82</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>18</td>
<td>17</td>
<td>14</td>
<td>18</td>
<td>82</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>16</td>
<td>15</td>
<td>12</td>
<td>19</td>
<td>74</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>14</td>
<td>13</td>
<td>14</td>
<td>17</td>
<td>71</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>17</td>
<td>13</td>
<td>14</td>
<td>16</td>
<td>75</td>
<td>5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Wine A</th>
<th>Wine B</th>
<th>Wine C</th>
<th>Wine D</th>
<th>Wine E</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>14*</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Wine B</td>
<td>6</td>
<td>19*</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Wine C</td>
<td>12</td>
<td>25*</td>
<td>6</td>
<td>25*</td>
</tr>
<tr>
<td>Wine D</td>
<td>14*</td>
<td>1</td>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td>Wine E</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>25*</td>
</tr>
</tbody>
</table>

* significance at the 5% level.

C. Analysis of Variance Table

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>F.05</th>
<th>F.01</th>
<th>F.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>164.2</td>
<td>34</td>
<td></td>
<td>6.74</td>
<td>2.78</td>
<td>4.22</td>
<td>6.59**</td>
</tr>
<tr>
<td>Wines</td>
<td>76.2</td>
<td>4</td>
<td>19.0</td>
<td>6.74</td>
<td>2.78</td>
<td>4.22</td>
<td>6.59**</td>
</tr>
<tr>
<td>Tasters</td>
<td>20.2</td>
<td>6</td>
<td>3.4</td>
<td>1.19</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>67.8</td>
<td>24</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** significance at the 0.1% level.
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 be greater than the product of 0.58 and the sum of score ranges (24)—in this instance, 13.9. Because the range of total scores (26) is greater than the calculated product (13.9), one can conclude that the tasters could distinguish among the wines. Which wines were distinguishable can be determined with the second (lower) statistic in Appendix 5.8 (0.54). It is multiplied by the sum of score ranges, 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 between wine 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:

```
E   B   A   C   D
```

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. This obviates the need for a 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.

**Multivariate Techniques**

For detailed evaluation of tasting results, an analysis of variance (ANOVA) or multivariate analysis of variance (MANOVA) may be useful. In so doing, it permits, for example, appraisal of the likely interaction among various factors in the tasting. ANOVA evaluates different factors (dependent variables) one at a time, whereas MANOVA investigates the interaction among all factors simultaneously. For example, the intensity of several independent attributes may be measured when performing descriptive sensory analysis of wines. In such a situation, MANOVA would assess for the presence of any statistical differences between the wines on any of the attributes. Were a significant F-value obtained, then individual ANOVA of the data could indicate the origin of the statistical difference detected by MANOVA. Without a significant result from MANOVA, performing separate ANOVAs for all the
attributes would be unwarranted. In addition, MANOVA assesses whether combinations of attributes may discriminate among wines, even if single attributes do not. Thus, it detects aspects potentially missed by assessing the significance of individual attributes in isolation.

Other statistical tests, such as discriminant analysis, may be used to separate the wines into groups that are significantly different. It involves an investigation of the variance of data point means {e.g., wine versus attribute}, based on the amount of disagreement between panelists. As usually occurs in descriptive sensory analysis, multiple attributes are involved in wine discrimination. Occasionally, some of these attributes may be correlated. For example, the influence of some aromatic compounds on the perception of sweetness. To investigate this feature and reduce redundancy where various attributes are affected by the same properties, one may perform principal component analysis. It transforms the data into new variables called principal components. These components maximize the variation, and related attributes are grouped together along what are termed components. The first principal component corresponds to those attributes that possess the maximum amount of variance in the data. Subsequent principal components successively account for smaller amounts of the variation that distinguish the wines. When discrimination is based primarily on a few components, the results may be visually represented on a two- or three-dimensional linear graph. In other words, it maps the related attributes (components) spatially. In the hypothetical example represented in Fig. 5.22, the samples were differentiable primarily on their sweetness, sourness, and bitterness, with sweetness and sourness being related but opposed attributes. Occasionally, attributes may group together along a common principal component axis, occurring on the same (+/−) side of the graph. Their location close together suggests related discriminating ability, possibly based on similar or related stimuli (for example, bitterness and astringency). Those components showing the highest loading (values closer to the maximum of + or −1) are the most significant in discrimination.

For free-choice profiling, where tasters may be using terms differently or scaling on personal criteria, Procrustes analysis is the method of choice. It combines sources of variation resembling those generated by principal component analysis. The data are also graphed similarly. The procedure standardizes (centers) each panelist’s score, reducing intrapanel variation. It also searches for common patterns to adjust for idiosyncratic term or scale use. The technique has also been used to compare data from different panels, or where sensory data are compared with corresponding instrumental analysis. Where there is ample justification to believe that the tasters
are perceiving attributes similarly (despite divergent term use or scaling), then Procrustes analysis is appropriate. However, with consumer groups, possessing diverse likes and dislikes, and different perceptive acuities, its use is suspect. In the latter instance, Procrustes analysis may generate fallacious correlations.

An alternative procedure that appears to be more appropriate for data from consumer groups is termed preference mapping. It is particularly valuable in looking at those attributes or wines distinguished by particular groups of tasters. In this regard, it helps identify those features that may be affecting the predisposition of various target groups. This has benefits in providing a better understanding of the desires of different clientele segments. Its principal drawback is that, in the condensation involved in the procedure, important facets of the data may be overlooked. In addition, if the groupings plot close together, it may signify only that the participants were unable to differentiate among the samples, may be making choices based on attributes not noted on the score sheets, or may be inconsistent in their assessment. This method is best combined with other statistical methods, such as an analysis of variance of individual attributes or wines.

Although these techniques require sophisticated calculation, computers have made them available to essentially all those requiring their use. Direct electronic incorporation of data of data. This has developed to the point where computer programs

![Figure 5.22](https://example.com/image.png)
specifically designed for the food and beverage industries are commercially available (e.g., Compusense five®). They can be adjusted to suit the needs of the user.

For a detailed discussion of sensory statistics, see texts such as Bi (2006) and Meullenet et al. (2007) in “Suggested Readings.”

**Pertinence of Tasting Results**

Most of the chapter is based on the assumption that training and selection of tasters provide panels that generate not only more consistent, but also more inherently valid data. However, specific training can both reduce or increase certain halo effects (for example, the influence of wine color on certain taste sensations), as well as exclude natural variance in perception during panel selection. Restricting variance to within sensory norms set by the experimenter is usually the approach used to improve statistical significance (and panel discrimination). Although the influence of natural variation in perception can be adjusted for with Procrustes statistics, it is based on the dubious assumption that individual tasters perceive and respond similarly to identical sensations, despite their diversity in response scaling or terminology. Furthermore, there are those who consider that the laboratory tasting situation, required to avoid psychological influences, invalidates the results. That a wine consumed with a meal will appear different when sampled in the laboratory or in a competitive tasting is without doubt. Equally, wine perception changes depending on the accompanying food, or with the same food on separate days, or under different circumstances (home versus restaurant). It is because environmental and psychological influences so affect perception that wines can be impartially compared only under the admittedly contrived conditions of a critical tasting. Finally, the data obtained are only comparative, not absolute.

Although the techniques used in sensory evaluation and its analysis may be unnatural, they are the best we currently have. They are clearly better than basing decisions on individual perceptions or averaging group results without any analysis of its internal variability. Despite the limitations and artificiality of sensory analysis, it is hoped that conclusions derived from such tastings have relevance to real-life situations. To date, the degree to which this hope is justified 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 discrimination testing, descriptive sensory analysis, time-intensity analysis, and charm analysis. For more detailed discussion of these and other sensory evaluation techniques, see “Suggested Readings.” As with all tests, specific instructions on how the procedure is to be conducted and clear indications of what is expected are essential if the desired results are to be obtained.

**Discrimination Testing**

Of sensory analysis procedures, discrimination testing may have the greatest applicability to daily winery operations. Its intent is to ascertain whether two (or a few) wines can be differentiated, based on one or more attributes. Its use applies to situations in which brands are intended to remain consistent from year to year. This typically applies to large wineries, as well as to most sparkling wine, sherry, and port producers. In such situations, the wines are blended from a series of sources to produce a consistent product. Because of variation in supply, the blend may have to be changed periodically throughout the season, and certainly from year to year. Thus, the producer needs some reliable means of assessing that the new formulation is essentially identical to the existing blend. For this task, the winery needs a panel that is fairly representative of the target purchaser. A panel composed of professionals may be too critical, demanding more similarity than is necessary in the marketplace. Where more than two wines need to be assessed, other procedures such as ranking or scaling may be more appropriate.

Where discrimination testing is used as an indicator of acceptance, preliminary assessment by the winery staff avoids unnecessary use of a panel. If the wine passes the first evaluation, the formulation is assessed by a larger group and under more stringent tasting conditions than in the blending lab. Conversely, discrimination may be used to confirm if a particular blend, to be labeled differently, is detectably distinct. However, in most such situations, the wines will be graded to determine not only if they are differentiable, but also to what degree. This could be particularly useful in determining pricing.

Alternatively, discrimination testing can be used with a group of wines (e.g., Tables 5.11 and 5.12). The degree to which panel members can distinguish different wine pairs is a relatively unbiased measure of the degree to which the wines diverge. It avoids the problems associated with semantic ambiguity, the subjectivity of term use in sensory profiling, or differences in how panelists scale criteria. Figure 5.23 illustrates the importance of training in reducing variability in scale range use by panelists. Contextual
factors are also kept to a minimum. Training also minimizes problems associated with inconsistent or variable score card use. The procedure is also applicable to certain research questions, such as measuring the differences in a homologous series of aromatic compounds (Fig. 5.24).

Various discrimination methodologies are available. The most commonly used procedures are the triangle or duo-trio tests. The simplest of all procedures is the difference test. It is particularly appropriate when one of the samples is likely to possess a lingering effect, such as when one of two wines may possess an off-odor. When employing a simple difference test, the panel is simultaneously provided with a pair of wines—the wines being presented in all possible sequences (AA, BB, AB, BA) an equal number of times. Because the panelists are asked to note only whether the samples are similar or dissimilar, identical pairs (AA and BB) must be included. Panelists tend to anticipate a difference, whether evident or not. In the case of an off-odor, it is probably worth mentioning the possibility of a fault and choose a panel of individuals adequately sensitive to the fault. Although this increases the likelihood of falsely detecting a taint, releasing a wine suspected of possessing an off-odor, without confirming that it is below the detection threshold of sensitive individuals, could lead to expensive recalls. The minimum number of correct answers considered necessary to confirm a detectable difference is given in Appendix 5.9.

A somewhat similar test, called the A-Not-A test, includes an element of memory. The first sample is presented, removed, and replaced by a second. The panelists are asked whether the second sample is the same or different from the first. This test may be particularly useful in studying different wine blend formulations, since it is rare that consumers will have both wines together for comparison in a home setting. Thus, this test more resembles natural tasting conditions.

In the duo-trio test, panelists are simultaneously presented three samples. One is marked as the reference wine. In most instances, the reference sample will be the same in all the test comparisons. The other two samples are coded. The taster is requested to indicate which of the two is more similar to the reference wine. The test samples’ order (AB/BA) should be
presented randomly to the panelists. The minimum number of correct answers considered appropriate to confirm a detectable difference is provided in Appendix 5.9. The duo-trio test is more discriminating because the panelists have a reference against which to compare the two test samples.

The triangle test is probably the most commonly used discrimination procedure. It also presents panelists with three samples, but simultaneously. Two of the samples are identical. The samples are grouped so that the two wines (A and B) occur equally among all the comparisons. In addition, the sequence order (AAB, ABA, BAA, BBA, BAB, and ABB) is arranged to occur an equal number of times and at random. The participants are requested to indicate which of the coded samples is the odd sample. The minimum number of correct answers for considering the samples different is provided in Appendix 5.5. The triangle test can be made more discriminative if the assessors are informed as to what attribute they should use in making their comparisons. The decision is not now which sample is different, but which has a highest or lowest intensity in some particular attribute. In this situation, the triangle test is termed a 3-AFC (three-alternative forced choice).

For more details on discrimination testing, refer to standard sensory evaluation texts identified in “Suggested Readings” or to O’Mahony and Rousseau (2002) and Rousseau (2003).

**Scaling Tests**

The discrimination tests noted in the preceding section are easy to perform and can assess whether there are noticeable differences between samples. However, they do not provide information on the origin or magnitude of the differences detected. Where the origin of the difference is suspected, information on this issue can be obtained by using one of the series of scaling tests. Scaling (quantifying) a sensory experience works well when the attribute involved is simple and based on a single compound, such as with the corked odor produced by TCA. It does not work as well when the attribute is chemically complex. Experience can result in the brain integrating sensory modalities. For example, exposure to a mixture of mushroom and lemon odors can lead to either odor being perceived to possess both qualities.
Another example is wine oxidation, where color and odor are influenced by a wide diversity of compounds, some increasing in concentration, whereas others may decrease.

A common scaling test is ranking. This form of scaling was discussed previously. While ranking is a common procedure in wine tastings, it is seldom used in sensory analysis. Its disadvantage is that it provides no information relative to why or to what degree wines ranked first, second, third, etc., differed. Thus, other, more informative scaling techniques are preferred in sensory analysis. A commonly used version is 9-point, boxed, balanced scale (Fig. 5.25). Alternatively, scaling may be represented along a line, with appropriate phrases placed equidistantly along its length (Fig. 5.26).

The 9-point scale presents a balanced set of values, four on each side of a neutral or central point. It is commonly used to measure the degree to which a product is liked or disliked. Although there is a tendency for people to avoid the extreme categories, the interval between the categories is represented as being equal. This permits the ready numerical conversion of the data (1 through 9) for parametric statistical analysis. In its simplest form, the 9-point hedonic scale is particularly useful in consumer evaluations. Other than basic instruction on how to proceed, no training is required. Where desired, demographic and wine usage data can be collected before testing begins. Detailed study of the results may highlight subcategories in a consumer group for which particular wines may have a special appeal.

**Preference Ranking**

Check the box that best characterizes your overall response to each sample.

Sample number

☐ Like extremely
☐ Like very much
☐ Like moderately
☐ Like slightly
☐ Neither like nor dislike
☐ Dislike slightly
☐ Dislike moderately
☐ Dislike very much
☐ Dislike extremely

**FIGURE 5.25** An example of a 9-point hedonic ranking form.
The 9-point hedonic scale can also be used to derive more specific information concerning particular attributes. When so used, training is typically required. Otherwise, tasters may interpret the attributes in different ways. Depending on the property, a range of anchor points may be required. For example, consumers are unlikely to have a clear and common vision of the meaning of “viscosity” or “body” in wine. “Astringency” is another example of a term that has various aspects of meaning and may be used differently. Although it would be useful to understand the origin of consumer preferences, such tests are rarely used due to the training required. Training itself can modify preferences. Thus, the process of measuring may modify the property studied. This clearly complicates designing wines for particular consumer groups. In addition, consumer perception is unlikely to be the same in a test situation as under home or restaurant conditions. As always, it is important to recognize the potential limitations to any method. Consumer testing is discussed further in Chapter 6.

Alternative measurement techniques are numbered or line scales (Fig. 5.26), where positions along the line can be converted into numbers for statistical analysis. Ends of the line may be designated by terms such as “none” or “very weak,” and “very evident” or “intense.” Alternatively, intensities may be scaled relatively (more or less intense) to some central reference sample considered normal or ideal. It is important not to incorporate or present tasks that demand measuring perceptive intensity with attributes that also generate marked hedonic responses—for example, mercaptans. Otherwise, subjective impressions are likely to distort intensity measurements.
The principal disadvantage with scaling is that it requires more time and concentration on the part of the panelists, especially if several attributes are independently scaled. Additional problems can arise if the attributes are complex, involving features that may change in quality as well as intensity over the expected range. For example, the qualitative perception of hydrogen sulfide and many thiols changes markedly as concentration rises. Finally, it is important to realize that the values derived from interval scales are relative (subjective values of perception), and not likely to represent absolute differences in the attributes scored. In other words, a value of 5 on a scale of 9 is not necessarily twice that of a value of 2.5.

Except for specific properties, scaling tests are rarely used in daily winery practice. Scaling tests are much more applicable to basic research. Here, the time and effort involved in training panel members in their appropriate use is justified. While training is beneficial, it is unlikely to overcome contextual effects, such as contrast between samples and changes in the range of intensities from test to test. Where feasible, context effects can be minimized by repeat sample presentation and providing wines in a random order. For a detailed account of scaling procedures, the reader is directed to the standard sensory evaluation texts noted in “Suggested Readings.”

Line scales are particularly useful in descriptive analysis or in studying single properties. Their application has been greatly facilitated by the introduction of touchscreen monitors. Panelists simply slide a bar along the appropriate line with their finger to indicate the intensity or magnitude of the perceived sensation. Lines for different attributes may be placed one above each other, where rankings of each attribute are desired. More frequently, attribute lines appear only as long as they have not been marked. The computer automatically records and digitally converts the values noted by each participant. Subsequently, the computer collates all the data and performs a variety of computations, such as mean, mode, standard deviation, and any other statistical analyses considered appropriate by the researcher.

It is usual for panelists to be trained using reference samples for each of the anchor points. This gives them a common frame of reference for use of the scale and reduces individual variation. Otherwise, Procrustes analysis becomes necessary.

**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 usually involves features not essential to determining the sources of wine differentiation or the effects of changing production procedures.

In enology, descriptive sensory analysis has primarily been used as a research tool, in distinguishing among similar wines—information important in developing products designed for particular consumer groups. Despite these advantages, it seems to have seen little use in wine production. Producers and consumers alike want wines to be viewed as natural products, not processed-food items. Thus, its use has been largely relegated to 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). When one is studying the effects of production techniques on sensory attributes, it is essential that all other factors be as equivalent as possible. In combination with chemical analysis, sensory analysis can facilitate the identification of compounds responsible for specific sensations. Although not directly involved in assessing quality, sensory analysis can also 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 trained to use a specific set of sensory terms in a common and consistent manner. Where a complete sensory profile is desired, standards for all pertinent sensory modalities need to be prepared. For wine, this would include visual, gustatory, haptic, and olfactory traits. Typically, though, only selected aspects of the aroma or flavor are investigated. Thus, the terms need not adequately describe the wine’s flavor. Only those properties that consistently differentiate among the samples are essential. Quantification involves scoring the perceived intensity of each attribute. Qualitative responses to the attributes are not assessed. Their subjectivity precludes accurate measurement.

Although descriptive analysis is one of the best and most used of tools in sensory analysis, Lawless (1999) has drawn attention to the assumptions upon which it is based: that odor quality can be analyzed and measured as a set of independent olfactory attributes; that each descriptive term be unrelated and perceived separately; and that individual attributes vary in perceived intensity relative to stimulus concentration. Without the
validity of these assumptions, interpretations based on the data may be mendacious.

If current views of olfaction are correct [Wilson and Stevenson, 2006], perception is based on learning particular receptor-activation patterns. Typically, responses to particular odorants are not hardwired [neuronal reflexes]. They develop as subconscious, pattern-based learning. Thus, it differs from learning to read words or music. The latter are typically associated with an analysis of specific arrangements of identifiable letters or notes. Only secondarily do particular patterns come to be associated with particular words or chords. With odor, there is no direct access to the separate responses that generate odor memories, as one has with letters or individual notes. Nonetheless, with training, tasters can come to distinguish the patterns of specific wine impact compounds, off-odors, grape varieties, styles, etc. The majority of aromatic compounds in wine play the role of the secondary harmonics, equivalent to those generated by a musical instrument when a single note or chord is played.

Because people’s experiences and thus odor memory patterns are unique, the olfactory attributes detected in wine typically vary from person to person. Perception may, thus, depend as much on the perceiver as on the wine. This means that the terms used, and the subjective responses they induce, may be disparate. In addition, human ability to assess olfactory intensity may not be up to the demands traditionally expected of sensory analysis [Engen and Pfaffmann, 1959, 1960].

Lawless [1999] has argued that it is better to ask panelists to rate terms on their degree of appropriateness rather than intensity. This is frequently what panelists do, despite instructions. In most situations, the fragrance attributes found in a wine only loosely resemble the olfactory characteristics of descriptors used. Thus, the aroma of a Chardonnay wine may be described in terms of resemblances to apples, melons, and peaches. However, this no more gives a true impression of the Chardonnay aroma than does the verbal description of a person’s nose, eyes, and ears adequately depict the individual’s face. It is an expression of the brain attempting to find a “best fit” to flavor memories developed during a person’s life. The cerebral construct is a blend of actual sensory input and flavor impressions. Memories can also generate the illusion of features that do not exist. A frequent example is the perception of sweetness in a dry wine that has a fruity fragrance.

These concerns do not negate the value of descriptive sensory analysis in differentiating or characterizing wines. Such analysis does indicate, though, that the data generated are unlikely to depict a genuine representation of its human perception.
There are many forms of descriptive sensory analysis. Only the three most common examples are noted here. They are quantitative descriptive analysis, spectrum analysis, and free-choice profiling. For the first two, screening of potential panelists is category-specific, as is subsequent training. In contrast, panel members for free-choice profiling seldom undergo sensory screening, nor are measures of sensory variability determined.

Where training is essential, it typically involves considerable attention to acquiring a common descriptive lexicon. How the language is developed partially differentiates quantitative descriptive analysis from spectrum analysis. In addition, sensory features tend to be grouped into related categories, definitions developed for each attribute, reference samples prepared, and members trained in how to score intensity (or degree of appropriateness). Abstract terms, such as body, balance, and development are not employed because adequate references are unattainable.

With quantitative descriptive analysis, members work toward a consensus on descriptors that adequately represent the wine’s distinctive attributes. For an example, see McDonnell et al. (2001). The duration of training required seems to depend on the degree of differentiation required—the greater the precision, the more extended the training (Chambers et al., 2004).

Civille and Lawless (1986) have discussed the characteristics ideally possessed by descriptors used in sensory analysis. They include independence (lack of redundancy); constitute primary attributes (e.g., apple, litchi, oak, mushroom) versus collective/holistic terms (e.g., balanced, perfumed, rich); permit a clear enunciation of the differences that distinguish the wines; adequately note the attributes that may group wines by type; and can be represented by standards.

Training 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. Although a particular term is attached to a particular standard, a range of descriptive terms may be employed initially to encourage members to search for the central attributes of the descriptor. For example, benzaldehyde may be described as having elements of cherry pits, wild cherry, and almond oil. Homa and Cultice (1984) have noted that panel feedback and diverse descriptive components facilitate learning. Training is usually shorter if members develop their own terms, rather than use unfamiliar technical terms or chemical names.
Subsequently, panelists assess wines using these descriptors to determine their efficacy (lack of confusion or redundancy) and establish which of the terms are the most discriminatory. This typically involves analysis of tasting results after several trials using identical wines. Only then can the number of attributes be reduced to those actually useful. 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.

Table 5.17 illustrates one method of studying term efficacy. 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. These attributes were subsequently eliminated. High levels of individual judge-wine interaction can indicate tasters who are using terms inconsistently.

Another procedure involves correlation matrices. It can highlight the occurrence of term redundancy. For example, Table 5.18 illustrates that attributes such as fresh berry and berry jam; leather and smoke; astringency and bitterness showed highly significant correlation. The latter is certainly not unexpected, as both astringency and bitterness are elicited by similar if not identical compounds. However, in this instance, significant

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**Table 5.17** Analyses of Variance of Attribute Ratings (Seven Judges) for *Pinot Noir* Wines: Degrees of Freedom (df), F-Ratios, and Error Mean Squares (MSE) (from Guinard and Cliff, 1987, reproduced by permission)

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

| df | 6 | 1 | 27 | 6 | 162 | 27 | 162 |

*, **, ***, significant at \(p < 0.05\), \(p < 0.01\), and \(p < 0.001\), respectively.
Table 5.18 Correlation Matrix Among the Descriptive Terms (df = 26) Used for Differentiation of Pinot Noir Wines (from Guinard and Cliff, 1987, reproduced by permission)

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

*, **, ***, significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.
correlation does not indicate term redundancy because both refer to distinct sensory phenomena. 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 in which the discriminatory attributes are known and the wines relatively uniform, 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 (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 descriptors are possible (Solomon, 1991). In an attempt to offset these concerns, free-choice profiling may be used. In it, panelists are allowed to use their own vocabulary to describe wine attributes. Although training is minimal, time is still required for tasters to gain experience with the wines, develop their own terminology, and become familiar with intensity scale use. Similar numbers of terms make analysis simpler, but are not obligatory. It is assumed that panel members experience identical sensations, even though their 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., 1991; Dijksterhuis, 1996), rotation, stretching, and shrinking of the data search for common trends. Thus, the possibility exists that relationships may be generated where none exist (Stone and Sidel, 1993). In addition, relating the generated axes to specific sensory attributes can be difficult. This often requires combination of the data with information derived from sensory profiling or chemical analysis. Nevertheless, free-choice profiling is especially valuable when using consumer panels. In addition, it is more economical in time—there being no need to develop a discriminative terminology, train members in its use, and select those that use the terms consistently. Consistent and uniform use are particularly essential if differences among samples are small.

An alternative approach to consumer idiosyncrasy is to analyze the ranking or scores provided for individual pairs of wines from each participant, rather than simply averaging collective data. The differences can then be analyzed statistically for significance with techniques such as analysis of variance.
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, it can remove important subgroups with different perceptions. Although a legitimate problem, it 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 descriptor. Where present, standards should demonstrate only the property intended, without confusing tasters with additional attributes. They should also 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/liter). Incorporation of cyclodextrin is an additional measure in extending the useful shelf-life of standards.

Reference standards also have use when new panel members are incorporated. They permit the new members 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 with its 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 influence is minimized by averaging results. 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 Figs. 5.27 and 5.28. Figure 5.27 illustrates the use of intensity scales for several sensory attributes. Figure 5.28 involves a simplification
FIGURE 5.27 Example of a descriptive sensory analysis tasting form adjusted for Bordeaux wines.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Relative intensity scale*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flavor</td>
<td>Low</td>
</tr>
<tr>
<td>Berry</td>
<td></td>
</tr>
<tr>
<td>Blackcurrant</td>
<td></td>
</tr>
<tr>
<td>Green bean</td>
<td></td>
</tr>
<tr>
<td>Herbaceous</td>
<td></td>
</tr>
<tr>
<td>Black pepper</td>
<td></td>
</tr>
<tr>
<td>Bell pepper</td>
<td></td>
</tr>
<tr>
<td>Tannic</td>
<td></td>
</tr>
<tr>
<td>Oaky</td>
<td></td>
</tr>
<tr>
<td>Vanilla</td>
<td></td>
</tr>
<tr>
<td>Leather</td>
<td></td>
</tr>
<tr>
<td>Cigar Box</td>
<td></td>
</tr>
<tr>
<td>Taste/Mouth-feel</td>
<td></td>
</tr>
<tr>
<td>Sourness</td>
<td></td>
</tr>
<tr>
<td>Bitterness</td>
<td></td>
</tr>
<tr>
<td>Astringency</td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td></td>
</tr>
<tr>
<td>Balance</td>
<td></td>
</tr>
</tbody>
</table>

* Place a vertical line across the horizontal line at the point which best illustrates how you rate the intensity of the attribute.
for categorizing large numbers of wines—more than can easily be assessed by traditional sensory analysis procedures. In the latter instance, panel members select up to five terms from a list of the ten attributes that most distinguish individual wines. The frequency of use (a measure of appropriateness) is used to characterize the wines.

* 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 5.28** Multiwine descriptive analysis scorecard.
All methods incorporate replicate trials—four to six replicates generally being considered minimally adequate. Most panels consist of between ten and twenty members.

Data generated from these procedures are often visualized as polar (radar, spider, cobweb) plots. The distance from the center represents the mean intensity value for each attribute (Fig. 5.29). Additional information can be shown if correlation coefficients are used to define the angles between the lines connecting the intensity values (Fig. 5.30). This presentation works well for up to five comparisons (especially when presented in different colors), but 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., 2006). 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.

Polar plots have become particularly popular means of representing the results of descriptive analysis. However, caution should be used in a simplistic interpretation of the data. The data represent sensory attributes that the panelists used to distinguish among the wines, not the attributes that necessarily characterize the wines. In that regard they are similar to floral diagrams used in plant taxonomy. The latter highlight the distinguishing features of a flower, but certainly do not do justice to the human perception of the flower. In addition,
the panelists were trained and selected on the basis of their use of a specific set of
terms, usually with precise reference standards. These are rarely available to the
viewer. Thus, their value relative to consumer perception is dubious—consumers
rarely analyze wine, assessing the relative intensities of distinct flavor attributes.

**Principal component analysis** is particularly effective in visualizing cor-
relations between attributes. For example, Figure 5.31 shows that the
peach, floral, and citrus notes of *Chardonnay* wines were closely correlated
(perceived similarly), but negatively correlated (rarely associated) with pep-
pier notes (first principal component). The second principal component
illustrates an independent relationship between sweet and vanilla notes,
which is inversely correlated with the presence of obvious bitterness. These
associations can be detected in conventional histograms, but are less visu-
ally obvious. Histograms also do not present quantitative indicators of cor-
relation. Combination of average data with that of individual wines can
demonstrate whether particular wines cluster with specific flavor character-
istics [Fig. 5.32]. 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. If tasting becomes too arduous, main-
tenance of member enthusiasm may wain and
fatigue set in. Both can result in a qualitative
deterioration of the data. However, if too many
attributes are eliminated, panelists may receive a
negative message, suggesting that the consid-
erable effort expended in preparing the attribute
list was unnecessary. It might imply that some
“hidden” list was expected.

**Cluster analysis** is another statistical tool that
can be used to highlight quantitative relationships
between factors. These often resemble the branches
of a tree. Connections between the branches indi-
cate the degree of correlation. Because this type of
information is rarely of relevance to sensory analy-
sis, 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 associ-
ation of specific fragrances noted in Figure 5.31
could have been particularly informative. Was it

![Figure 5.31](image-url)
due to term redundancy, related chemicals, varietal origin, or a unifying wine-making 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 were correlated with particular aromatic and sapid substances. Relating wine chemistry to consumer preferences could rationalize producing wines designed for particular purchasers. This may not fit the romantic image of winemaking as the expression of artisanal winemakers, but can be highly remunerative. The success “wine coolers” had is a clear example. It can also keep financial wolves from the cellar door.

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 guesstimating how various wines will combine to enhance their positive qualities and minimize any defects. The intense concentration and scrutiny required in descriptive sensory analysis provide a wonderful learning experience for both young and seasoned winemakers alike.

**Time-Intensity (TI) Analysis**

Time-intensity analysis records the temporal dynamics of oral sensations (Overbosch et al., 1986; Lawless and Clark, 1992). The technique requires participants to continually record their perceptions of a particular taste, mouth-feel, or flavor sensation. The procedure has little applicability to
purely aromatic sensations. Their perception develops and vanishes almost instantaneously. The only exceptions are retronasal olfactory sensations (Fig. 3.27), such as those of a wine’s finish. Regrettably, this important feature has been little investigated (Cain, 1979; Mialon and Ebeler, 1997).

Measurements are most easily recorded in real time on a computer using one of several software packages (e.g., CompuSense five®). Formerly, measurements were recorded on strips of perforated chart paper on a rotating drum.

As illustrated in Fig. 5.33, four basic aspects of perception can be distinguished. They 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 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, or wine-like solutions. Thus, it has considerable use in investigations of taste perception. For example, time-intensity studies have clarified the differences between the dynamics of sweet, sour, bitter, and astringent perceptions (at least under controlled laboratory conditions). This technique has also been used extensively in designing foods to have specific taste profiles.

The use of time-intensity methods with wine is more problematic. The complex chemistry of wine often suppresses gustatory sensations (see Chapter 4). Nonetheless, time-intensity studies may provide insights into how various blends can affect the sensory perception of particular consumer groups. A delay in the perception of bitterness and astringency could make a red wine more appealing to clients unused to tannic wines. Time-intensity methods can also reveal how gustatory perceptions of a wine are modified when combined with food. For example, total taste intensity and sweetness were reduced in combination with various constituents that activate oral trigeminal nerves (Lawless et al., 1996).

Generally, concentration has little effect on the time taken to reach maximum perceived intensity, although it does affect its duration. Because
wines are normally expectorated shortly after sampling, this tradition must be modified to study adaptation. In so doing, it has been shown that increasing concentration can delay the onset of adaption (Fig. 5.34). The timing of expectoration must also be changed to study the effect of repeat exposure on features such as astringency (Fig. 5.35). To date, the procedure has been used little to investigate the interaction between sapid substances or the joint influences of sapid and olfactory compounds on flavor perception.

Although providing valuable insights into the nature of perception (see Lawless and Heymann, 1999, for limitations), strict time-intensity procedures are generally not employed in wine tasting. Nonetheless, in a crude and discontinuous form, the procedure has long been used as a rapid and visual means of representing dynamic changes in perceived wine flavor (Fig. 1.7; Vandyke Price, 1975). In addition, differences in the dynamics of how sapid compounds are perceived permit

**FIGURE 5.34** Adaptation during 30 s of the threshold of perception under stimulation with 5% (○), 10% (●), and 15% (▲) sodium chloride solutions. The unadapted threshold $S_0$ 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 5.35** 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).
tasters to more effectively focus on the various perceptions of sweetness, acidity, bitterness, and astringency (see Chapter 1).

For details on training a panel for time-intensity analysis, see Peyvieux and Dijksterhuis (2001) for a case study.

**CHARM Analysis**

CHARM analysis is a technique combining the benefits of gas chromatography with olfactometry (GCO). It is designed to assess the sensory significance of olfactory compounds (Acree and Cottrell, 1985). Gas chromatography effectively separates most aromatic compounds, providing their relative concentration, but supplies no information about their sensory impact. In CHARM analysis, the taster sniffs compounds as they separate and exit the gas chromatograph, and identifies them, by name where possible, and their relative intensity. 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 5.36 illustrates the difference between the data obtained by gas chromatography and charm analysis.

**Finger Span Cross Modality (FSCM) Matching**

Finger span cross modality (FSCM) matching is another gas chromatography-olfactometry (GCO) technique. It is not designed to provide a descriptive analysis of the wine’s aromatics, as with CHARM, but to discriminate between wines (Bernet et al., 2002). Its advantage is that it avoids extensive training to achieve an adequate level of consistency in term usage. The development of polar diagrams of flavor differences is not obtained. This is replaced by scaled intensity measures of specific aroma compounds as they leave the chromatograph. This could be used to provide

![Figure 5.36](image_url)
an indicator of specific chemical differences between the samples. Because of the possibility of connecting emission from the gas chromatograph with NMR and other analytical chemical instrumentation, the technique provides the option to identify the chemicals that may be generating the differences detected among samples. This is a significant limitation in descriptive sensory analysis.

CHEMICAL MEASURES OF WINE QUALITY

Standard Chemical Analyses

In the previous section, emphasis was 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 absorbency values at 420 and 520 nm) is highly correlated with perceived quality. Absorbency at 420 and 520 nm was chosen because both change dramatically during aging. These changes are primarily due to the status of anthocyanins in the wine and their polymerization with other wine constituents (Jackson, 2008). Although visually perceptible differences in color depth were not considered to induce this color-quality correlation, Somers (1975) does not consider the subliminal effects of color on perception. These associations come from experience, usually learned incidentally. Their influence has been frequently noted relative to wine, and initially investigated by André et al. (1970). When a series of rosé wines was separately ranked by color, sampled normally, and tasted blind, the results from the first two conditions were essentially identical. However, when visual cues were absent, ranking was markedly different. The influences of color on sensory perception have already been noted (Fig. 3.26). Color may be far more influential on the perception of red wine quality than has generally been appreciated.

It is not surprising to observe an association between color density and perceived quality because it tends to correlate with grape maturity, flavor development, and the duration of maceration (anthocyanin, tannin, and flavor extraction). However, the association of color with quality develops only with experience and is intimately linked with particular wine styles or varieties. However, it is equally clear that a dark red wine is not consistently highly regarded—for example, the so-called black wines of Cahor. In wine competitions, though, it is usual to group wines by category. Thus, the judges know in advance (even without thinking) what to expect relative to color for particular wines.
Another parameter that seemingly correlates well with assessed wine quality is the proportion of colored anthocyanins (notably ionized flavylvium forms), for example, the deeply pigmented wines made from *Cabernet Sauvignon* and *Shiraz*. In contrast, most studies with white wines have shown no relationship between phenolic content and assessed quality (Somers and Pocock, 1991).

Similar results have been obtained with visible near-infrared spectroscopy (Dambergs *et al.*, 2002; Cozzolino *et al.*, 2008). They appear to confirm the importance to anthocyanins as a major predictor of wine quality, at least with *Shiraz* (Fig. 5.37), as well as with *Cabernet Sauvignon* and Tawny ports (Dambergs *et al.*, 2002). Spectroscopy has been less successful in predicting the assessed quality of white wines.

If spectroscopic techniques can be perfected and simplified to function as an effective indicator of quality, they could greatly assist wineries as well as wine competition organizers. In wineries, they could streamline the grouping of wines in terms of their commercial pricing. In wine competitions, they could be used as a preliminary assessment of quality, retaining only the best samples for human evaluation. The result would be a marked savings in time and judge fatigue. Analytic equipment has many advantages over human assessors. It is objective, accurate, rapid; generates highly reproducible data; and does not suffer from exhaustion or adaptation. However, spectroscopic techniques are still in the early stages of experimentation.

Another potential objective measure of wine and grape quality investigated has been the 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). Thus, a single test might measure potential grape flavor intensity. Disappointingly, after a flurry of activity, its potential to assist researchers, grape growers, and winemakers in predicting wine quality seems not to have been fulfilled.
Electronic Noses

Potentially the most significant advance in objective sensory analysis may come from development of instruments such as electronic noses (e-noses) [Martí et al., 2005; Röck et al., 2008]. Some are already produced in handheld models. Most possess a collection of discs (sensors) composed of an electrical conductor (such as carbon black) homogeneously embedded in a nonconducting 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. 5.38A]. The swelling progressively separates the electrically conductive particles. This results in a rise in electrical resistance. The speed and degree of resistance recorded from each sensor generate a unique fingerprint of the compounds in an odor [Fig. 5.38B]. As the number of sensors increases, so does the potential discriminating power of the instrument. Commercial e-nose systems, such as the Cyranose 320® (Plate 5.14), possess 32 distinct sensors. After each sample, the sensors regain their original size and sensitivity, as the aromatics absorbed escape into and are vented by a flushing gas.

Electronic (e-) tongues are similar in concept, but the receptors respond to chemicals in solution rather than in air. They have been used experimentally to discriminate among white wines [Pigani et al., 2008], monitor maturation in oak cooperage [Parra et al., 2006], and estimate port aging [Rudnitskaya et al., 2007].

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, are typically subjected to one or more statistical recognition tests. These tests usually include principal component analysis and mathematical algorithms. The patterns generated resemble the principal component relationships derived from descriptive sensory analysis [Fig. 5.39]. Computer software supplied with the machine conducts the mathematical analyses automatically.

When the data are combined with computer neural networks [Gopel et al., 1998; Fu et al., 2007], 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, separation, identification, and quantification of individual volatile compounds are 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 nontarget chemicals.

A different e-nose technology is based on flash chromatography. Unlike traditional gas chromatography, in flash chromatography samples can be analyzed in a few seconds, rather than hours. In the zNose® (Plate 5.15), 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-meter long, capillary column to separate the constituent volatiles. When
the chemicals emerge from the column, they are directed onto a 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 msec, 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 zNose models primarily resolve and quantify hydrocarbons. Because wines contain many hydrocarbons, their dominant presence could mask the co-occurrence of significant impact compounds. For example, caprylate and caproate might mask the presence of the off-odor caused by 2,4,6-TCA (Staples, 2000). In addition, certain impact compounds, specific to particular cultivars, cannot currently be resolved. This drawback may disappear as improvements in carrier systems are developed. Nevertheless, current models can readily distinguish between several varietal wines (Fig. 5.40).

Electronic-nose technology is already routine in assaying off-odors in several foods and beverages. Its speed, accuracy, economy, portability, and applicability to almost any task involving odor assessment (including disease detection, crime investigation, and military uses) have greatly spurred its rapid development. 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 predetermined, desired flavor characteristics. Figure 5.41 illustrates the vastly enhanced aromatic complexity of fully ripened fruit. Nonetheless, there is considerable difference between the sensitivity of analytic equipment and the human nose—analytic instruments being better with some constituents, whereas the nose is superior for others.

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), monitoring aroma production during fermentation (Pinheiro et al., 2002), and detecting cork and wine contamination with 2,4,6-TCA. In addition,

**FIGURE 5.40** Example of the differentiation possible between varietal wines using zNose, a chromatographic form of electronic nose technology (courtesy of Electronic Sensor Technology, Newbury Park, CA).

**FIGURE 5.41** Illustration of the significantly increased aromatic complexity of fully ripened fruit (from Do et al., 1969, reproduced by permission).
it has shown some success in differentiating among wines from a single winery (García et al., 2006), or wine from the same cultivar but from different regions (Buratti et al., 2004). Furthermore, some terms used to describe wine attributes correlate with e-nose measurements (Lozano et al., 2007).

Although significant advances are occurring rapidly in this field, there are still significant hurdles in using electronic nose technology in routine wine analysis (e.g., Schäfer et al., 2006). Wines are extremely complex chemically, consisting of hundreds of components, ranging from ng/L to g/L concentrations, and spanning a vast range of polarities, solubilities, volatilities, and pHs. Often extraction and concentration are required to detect the compounds, leading to the possibilities of degradation and artifact production.

Humans will always be needed to assess the sensory significance of taste, mouth-feel, and olfactory sensations, as well as the cerebral constructs of flavor, complexity, balance, and body. The latter are as much associated with cultural experience and individual genetics as with sensory input. However, electronic noses are likely to join panels in many situations in which people have been 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 this goal is achieved, the ease, efficiency, reliability, and accuracy of analytic equipment may replace the expense and imprecision of human panels for objective assessments in many routine areas of sensory evaluation.

**OCCUPATIONAL HAZARDS OF WINE TASTING**

It is uncommon to consider occupational hazards in relation to wine tasting. If any were acknowledged, it would probably be the likelihood of triggering any latent tendency toward alcoholism. While this point is legitimate, the practice of expectoration in formal tastings should minimize such a likelihood. Scholten (1987) reported that expectoration avoided a significant rise in blood alcohol level during wine tasting. Despite this, it is probably advisable for women, desirous of becoming pregnant or knowingly pregnant, to excuse themselves from tastings, as well as anyone with a family history of alcoholism.

Headache induction is another well-known potential hazard of wine tasting, however, usually with excess consumption, not tasting. For some
people, though, consumption of even small amounts of either white or red wines, or sparkling and red wines on the same occasion can activate a migraine. Currently, there seems no explanation for either phenomenon. For others, young red wines are potent activators. In this instance, activation may relate to the relatively high concentration of nonpolymerized phenolics in the wine. Smaller phenolics traverse the intestinal lining and enter the blood stream more easily than do their polymerized versions found in older red wines. Typically, absorbed phenolics are rapidly detoxified (o-methylated or sulfated) by plasma enzymes. However, some phenolics suppress the action of platelet phenol-sulfotransferase (PST) [Jones \textit{et al.}, 1995]. Individuals having low levels of platelet-bound PST are apparently more susceptible to migraine headaches [Alam \textit{et al.}, 1997]. Suppression of PST results in reduced sulfation (detoxification) of a variety of endogenous and xenobiotic (foreign) compounds, including biogenic amines and phenolics. Without inactivation, biogenic amines may activate the liberation of 5-hydroxytryptamine (5-HT, or serotonin), an important neurotransmitter in the brain. 5-HT also promotes platelet aggregation and the dilation of small cerebral blood vessels. Vessel dilation can provoke intercranial pain, which may incite a migraine [Pattichis \textit{et al.}, 1995]. If phenolics are not inactivated rapidly in the blood, they are likely to be oxidized to o-quinones. If these traverse the blood-brain barrier, o-quinones could inhibit the action of catechol-O-methyltransferase (COMT). This limits the breakdown of the neurotransmitter dopamine and the availability of \( \mu \)-opioid (painkilling) receptors. Consequently, the perception of pain associated with cerebral blood vessel dilation may be enhanced. Another potential cause of wine-related headaches involves the release of type E prostaglandins in the brain. These are important chemicals involved in blood vessel dilation. This may explain the action of prostaglandin synthesis inhibitors, such as acetylsalicylic acid, acetaminophen, and ibuprofen on headache prevention. For this benefit, they should be taken in advance of a tasting [Kaufman, 1992]. The author has personal experience with its value in limiting both headache induction and facial flushing associated with assessing multiple wines over a few hours. Small phenolics also prolong the action of potent hormones and nerve transmitters, such as histamine, serotonin, dopamine, adrenalin, and noradrenaline. These could affect headache severity and other allergic reactions.

Although the presence of biogenic amines, such as histamine and tyramine, has been suggested as an activator of headache induction by red wines, double-bind tests with self-professed sensitive individuals have
not supported this contention (Masyczak and Ough, 1983). The levels of biogenic amines in wines are usually lower than those considered sufficient to activate a migraine attack. Nonetheless, alcohol can suppress the action of diamine oxidase, an important intestinal enzyme that inactivates histamine and other biogenic amines (Jarisch and Wantke, 1996). However, this is not consistent with the observation that spirits and sparkling wines are more frequently associated with migraine attacks than other alcoholic beverages (Nicolodi and Sicuteri, 1999). Both are low in histamine content.

The sulfite content of wines has often been considered to induce wine-related headaches but, as yet, there is no scientifically validated evidence of its occurrence. Sulfite could cause problems in some very sensitive asthmatics, but this is another issue. With the continuing reduction in the use of sulfur dioxide, its involvement as an occupational hazard for wine tasters is diminishing.

Potentially the most significant occupational hazard for the professional wine taster is dental erosion (Mok et al., 2001; Mandel, 2005; Chikte et al., 2006). This results from the frequent and extended exposure to wine acids. Dissolving calcium softens the enamel, potentially leading to tooth disfiguration that affects both shape and size. Cupping, a depression in the enamel (exposing dentine at the tip of molar cusps), is a frequent clinical sign. Erosion can also contribute to severe root abrasion at the gum line. Protection is partially achieved by rinsing the mouth with an alkaline mouthwash after tasting, application of a fluoride gel (such as APF), and refraining from tooth brushing for at least one hour after tasting. The delay permits minerals in the saliva to rebind to the enamel. This problem does not affect consumers who take wine with meals. Food and saliva secretion limit, if not prevent, demineralization of tooth enamel.

Another, but unrelated, occupational hazard is a result of changed perspective. You no longer suffer insipid, characterless, or faulty wines, despite their price or repute. Your daily wine must, at least, not insult your sensibilities and, preferably, be interesting and flavorful. Thus, the vast majority of red and many white wines are no longer acceptable, and much effort is required to locate good wines at a modest price. In addition, other than being appreciated by store owners for above-average wine purchases, you may come to be recognized for your frequent return of faulty wines.
Appendix 5.1  Aroma and Bouquet Samples

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

(Continued)
Appendix 5.1  Aroma and Bouquet Samples (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Amount per 300 ml of Base Wine&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrogenous</td>
<td></td>
</tr>
<tr>
<td>Incense</td>
<td>0.5 Stick of Chinese incense</td>
</tr>
<tr>
<td>Smoke</td>
<td>0.5 ml Hickory liquid smoke (Colgin)</td>
</tr>
<tr>
<td>Mushroom</td>
<td></td>
</tr>
<tr>
<td>Agaricus</td>
<td>Juice from 200 g microwaved mushrooms</td>
</tr>
<tr>
<td>Truffle</td>
<td>30 ml Soy sauce</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>Chocolate</td>
<td>3 ml Chocolate liqueur</td>
</tr>
<tr>
<td>Butterscotch</td>
<td>1 ml Butterscotch flavor (Wagner)</td>
</tr>
</tbody>
</table>

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. Where used in research, and purity and consistency of preparations are paramount, details given in Meilgaard et al., 1982 is essential reading. Additional recipes may be found at http://www.nysaes.cornell.edu/fst/faculty/acree/fs430/aromalist/sensorystd.html, or in Lee et al. (2001), Meilgaard (1988), Noble et al. (1987), and Williams (1975). Pure chemicals have the advantage of providing highly reproducible samples, whereas “natural” sources are more complex, but more difficult to standardize. Addition of cyclodextrins may also aid stabilize the compounds and regulate their release. 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. To limit oxidation, about 20 mg of potassium metabisulfite may be added to the samples noted.

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 limit oxygen penetration. Samples stored in a refrigerator usually remain good for several months. Alternately, samples may be stored in hermetically sealed vials in a freezer and opened only as required.

<sup>a</sup>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.

<sup>b</sup>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.
## Appendix 5.2 Basic Off-Odor Samples<sup>abcd</sup>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Amount (per 300 ml Neutral-Flavored Base Wine)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corked</strong></td>
<td></td>
</tr>
<tr>
<td>2,4,6-TCA</td>
<td>3 µg 2,4,6-Trichloroanisole</td>
</tr>
<tr>
<td>Guaiacol</td>
<td>3 mg Guaiacol</td>
</tr>
<tr>
<td>Actinomycete</td>
<td>2 mg Geosmin (an ethanolic extract from a <em>Streptomyces griseus</em> culture&lt;sup&gt;e&lt;/sup&gt;)</td>
</tr>
<tr>
<td>Penicillium</td>
<td>2 mg 3-Octanol (or an ethanolic extract from a <em>Hemigera</em> (Penicillium) culture&lt;sup&gt;f&lt;/sup&gt;)</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td></td>
</tr>
<tr>
<td>Fusel</td>
<td>120 mg Isoamyl and 300 mg isobutyl alcohol</td>
</tr>
<tr>
<td>Geranium-like</td>
<td>40 mg 2,4-Hexadienol</td>
</tr>
<tr>
<td>Buttery</td>
<td>12 mg Diacetyl&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>Plastic</td>
<td>1.5 mg Styrene</td>
</tr>
<tr>
<td><strong>Sulfur</strong></td>
<td></td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>200 mg Potassium metabisulfite</td>
</tr>
<tr>
<td>Gout de Lumière</td>
<td>4 mg Dimethyl sulfide&lt;sup&gt;g&lt;/sup&gt; and 0.4 mg ethanethiol</td>
</tr>
<tr>
<td>Mercaptan</td>
<td>4 mg Ethanethiol</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>2 ml Solution with 1.5 mg Na₂S·9H₂O</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td></td>
</tr>
<tr>
<td>Oxidized</td>
<td>120 mg Acetaldehyde</td>
</tr>
<tr>
<td>Baked</td>
<td>1.2 g Fructose added and baked 4 weeks at 55°C</td>
</tr>
<tr>
<td>Vinegary</td>
<td>3.5 g Acetic acid</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>100 mg Ethyl acetate</td>
</tr>
<tr>
<td>Mousy</td>
<td>Alcoholic extract culture of <em>Brettanomyces</em> (or 2 mg 2-acetyltetrahydropyridines)</td>
</tr>
</tbody>
</table>

<sup>a</sup>To limit oxidation, about 20 mg potassium metabisulfite may be added per 300 ml base wine.

<sup>b</sup>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 limit oxygen penetration. Samples stored in a refrigerator usually remain good for several months.

<sup>c</sup>Other off-odor sample preparations are noted in Meilgaard et al. (1982).

<sup>d</sup>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.

<sup>e</sup>*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.

<sup>f</sup>*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.

<sup>g</sup>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 5.3  
**Response Sheet for Taste/Mouth-Feel Test**

<table>
<thead>
<tr>
<th>Sample#</th>
<th>INTENSITY OF SENSATION</th>
<th>Weak</th>
<th>Medium</th>
<th>Intense</th>
</tr>
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<tbody>
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<td>1</td>
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Name: ______________________  
Session: □□□

### Appendix 5.4  
**Off-Odors in Four Types of Wine at Two Concentrations**

<table>
<thead>
<tr>
<th>Wine</th>
<th>Off-Odor</th>
<th>Chemical Added</th>
<th>Amount (per 300 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gewürztraminer</td>
<td>Oxidized</td>
<td>Acetaldehyde</td>
<td>20, 60 mg</td>
</tr>
<tr>
<td></td>
<td>Sulfur dioxide</td>
<td>Potassium metabisulfite</td>
<td>67, 200 mg</td>
</tr>
<tr>
<td></td>
<td>2,4,6-TCA</td>
<td>2,4,6-Trichloroanisole</td>
<td>2, 10 µg</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td>Styrene</td>
<td>1.5, 4.5 mg</td>
</tr>
<tr>
<td>Sauvignon Blanc</td>
<td>Vinegary</td>
<td>Acetic acid</td>
<td>0.5, 2 g</td>
</tr>
<tr>
<td></td>
<td>Buttery</td>
<td>Diacetyl</td>
<td>2, 6 mg</td>
</tr>
<tr>
<td></td>
<td>Ethyl acetate</td>
<td>Ethyl acetate</td>
<td>40, 100 mg</td>
</tr>
<tr>
<td></td>
<td>Geranium-like</td>
<td>2,4-Hexadienol</td>
<td>10, 40 mg</td>
</tr>
<tr>
<td>Beaujolais</td>
<td>Geranium-like</td>
<td>2,4-Hexadienol</td>
<td>10, 40 mg</td>
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<tr>
<td></td>
<td>Buttery</td>
<td>Diacetyl</td>
<td>5, 24 mg</td>
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<tr>
<td></td>
<td>Ethyl acetate</td>
<td>Ethyl acetate</td>
<td>40, 100 mg</td>
</tr>
<tr>
<td></td>
<td>Oxidized</td>
<td>Acetaldehyde</td>
<td>20, 60 mg</td>
</tr>
<tr>
<td>Pinot Noir</td>
<td>Guaiacol</td>
<td>Guaiacol</td>
<td>0.2, 0.6 mg</td>
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<tr>
<td></td>
<td>Mercaptan</td>
<td>Ethanethiol</td>
<td>5, 24 µg</td>
</tr>
<tr>
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<td>2,4,6-TCA</td>
<td>2,4,6-Trichloroanisole</td>
<td>2, 10 µg</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td>Styrene</td>
<td>1.5, 4.5 mg</td>
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</tbody>
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## Appendix 5.5

Minimum Number of Correct Judgements to Establish Significance at Various Probability Levels for the Triangle Test (One-Tailed, $p = 1/3$)*

<table>
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<th>No. of Trials ($n$)</th>
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<th>0.04</th>
<th>0.03</th>
<th>0.02</th>
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</table>

*(Continued)*
### Appendix 5.5

Minimum Number of Correct Judgements to Establish Significance at Various Probability Levels for the Triangle Test (One-Tailed, \( p = 1/3 \)) * (continued)

<table>
<thead>
<tr>
<th>No. of Trials ((n))</th>
<th>Probability Levels</th>
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<td>0.05</td>
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<td>100</td>
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</table>

*Values \((X)\) not appearing in table may be derived from \(X = (2n + 2.83 \sqrt{n} + 3)/6\).

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

<table>
<thead>
<tr>
<th>Number of Judges</th>
<th>Number of Wines</th>
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<tbody>
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<td>2</td>
</tr>
</tbody>
</table>

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

<table>
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<th>Number of Judges</th>
<th>Number of Wines</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>5–19</td>
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</table>

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

### Appendix 5.8

Multipliers for Estimating Significance of Difference by Range. Two-Way Classification. A, 5% Level; B, 1% Level

<table>
<thead>
<tr>
<th>Number of Judges</th>
<th>Number of Wines</th>
</tr>
</thead>
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</tr>
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<td><strong>A</strong></td>
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<td>1.15</td>
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</tbody>
</table>

(Continued)
### Appendix 5.8

Multipliers for Estimating Significance of Difference by Range. Two-Way Classification. A, 5% Level; B, 1% Level (continued)

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<th>Number of Judges</th>
<th>Number of Wines</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
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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).

### Appendix 5.9
Minimum Numbers of Correct Judgements to Establish Significance at Various Probability Levels for Paired-Difference and Duo-Trio Tests (One-Tailed, $p = 1/2$)

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(Continued)
Appendix 5.9  Minimum Numbers of Correct Judgements to Establish Significance at Various Probability Levels for Paired-Difference and Duo-Trio Tests (One-Tailed, \( p = 1/2 \))^a (continued)

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^a Values (X) not appearing in table may be derived from: \( X = (z\sqrt{n} + n + 1)/2 \). See text.

SUGGESTED READINGS


REFERENCES


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Qualitative Wine Assessment

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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 attributes. This usually involves qualitative ranking. Despite the impression often given by wine critics, detection of these features is often far from easy, and 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. Thus, the search for these traits is often fruitless. Only the best examples clearly show the idiotypic features attributed to a variety or region. Experience provides the knowledge to recognize these features, when they exist, and how 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 properties. General aesthetic 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 essentially 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 water used to rinse glasses used to sample several wines). 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 should be avoided, wherever possible. For example, the presence of winemakers or sales staff may be interesting but can compromise making an honest assessment. The influence of contextual factors on perception has been discussed in earlier chapters of the text. In contrast, if the intent is to enhance appreciation, discussion is encouraged. Participants of wine societies, for example, usually appreciate suggestions and support. In addition, where expensive or rare wines are sampled, cold critical analysis is probably counterproductive. On the negative side, psychological factors may be used to direct opinion.
INFORMATION PROVIDED

Details provided about the wines depend on the objective of the tasting. For example, if varietal or regional differences are being evaluated or illustrated, the tasters require this information. Otherwise, there is considerable likelihood that the essential features of the tasting may be missed. Ideally, precise identification should be withheld to avoid unduly influencing the evaluation. However, if promotion is the primary purpose (e.g., in-store tastings), identity should be provided as the wines are sampled.

If the purpose is to obtain consumer opinion, it is important the questions not be leading. For this, indirect questioning is appropriate. For example, asking which wine is thought to be made by traditional versus modern procedures, or which wine the taster would prefer serving a business colleague or close friend is likely to be less prejudicial and more revealing than simply asking which sample is preferred. Indirect questioning has been used very successfully in detecting subtle differences in beer (Mojet and Köster, 1986) and milk (Wolf-Frandsen et al., 2003).

Wrapping bottles in paper bags is the typical means of concealing wine identity at most informal tastings. Prepouring or decanting is often unwarranted and impractical. However, bagging covers neither bottle color nor 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 technique has the advantage of obtaining copies of the labels. The labels can be reproduced on the tasting sheet or for distribution after the tasting. Because bottles are usually opened during the session, it may be best for the instructor to remove the corks. This approach not only provides an excellent opportunity to demonstrate the proper use of various cork screws, but also avoids having students identify the wines from inscriptions on the cork. 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 can also involve some aged white wines. Although the associated air exposure does not produce noticeable wine oxidation, the interval between decanting and tasting should be kept short, especially for old wines. Their limited fragrance rapidly dissipates upon opening.
Despite the principal function of decanting, much misinformation surrounds its benefits. Most of this misinformation relates to the wine’s incidental exposure to air. During the 1800s, aeration associated with decanting helped dissipate off-odors—the “bottle stink” to which wines of the time were often afflicted. This presumably was due to the presence of hydrogen sulfide (rapidly degrading on exposure to oxygen in air) and mercaptans (more slowly volatilizing or oxidizing to less malodorous disulfides). We can be thankful that modern wines are neither so plagued nor develop copious amounts of sediment. Thus, few modern wines need or benefit from decanting. Despite this, opening bottles in advance is still frequently recommended, even if this involves pulling the cork only a few minutes before pouring. This act is viewed as allowing the wine to “breathe.” However, the surface area of wine exposed to air in an opened 750 ml bottle approximates 3.5 cm². The surface area increases to about 28 cm² after wine is poured into a standard tulip-shaped glass. The surface area at least doubles again during swirling. If one assumes 30 ml in the glass, benefits associated with air contact should occur several hundred times faster in the glass than in the bottle (if based on surface area to volume contact). The increased wine-air contact favors the release of aromatics from the wine, as well as qualitative changes in its character. Both features are part of what is often called the wine’s opening and development. Thus, the benefits of simply pulling the cork before serving are illusionary—probably the equivalent of the placebo effect in medical studies, or maybe it’s a case of “my mind’s made up; don’t confuse me with the facts.” In contrast, it takes several hours of exposure for perceived quality loss to occur (Ribéreau-Gayon and Peynaud, 1961; Roussis et al., 2005).

Unfortunately, there are little objective data on wine aroma changes during tasting. The limited data relate to the effect of air exposure for up to 30 min before sampling (Russell et al., 2005). During this period there were detectable chemical changes in several phenolic compounds, but these changes were not sensorially discernible. Identifiable oxidative changes in aroma have been detected in sound wine only with periods considerably longer than typically experienced during tasting (Roussis et al., 2005).

Although the physicochemistry of the “opening” of a wine’s fragrance is still largely speculation, it probably relates to rapid equilibrium changes between the gaseous, dissolved, and weakly bound states of wine aromatics. 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 weakly bind with aromatics in wine,
making them nonvolatile. Upon opening a bottle of wine, aromatics in the headspace escape into the surrounding air, permitting additional volatilization of dissolved aromatics. This, in turn, shifts the equilibrium between dissolved and fixed forms in the wine. The changing equilibrium will progressively modify the relative concentrations of the various aromatics in the headspace, affecting their individual threshold values. This feature would undoubtedly be enhanced by swirling. For example, ethanol evaporation from the thin film of wine coating the sides of the glass rapidly affects the vapor pressure of wine aromatics (Williams and Rosser, 1981) and surface tension phenomena. Progression of these changes during the tasting is referred to as “development.” Thus, breathing, opening, and development are separately named stages in the same process. Because this is one of the more fascinating features of quality wines, it should not be relegated to transpire undetected in the bottle or a decanter.

Depending on the wine, its 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 still possess. In contrast, young red wines that age well often show a fascinating aromatic development 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 and meticulously so that the incoming air, replacing the wine, flows past the shoulder with minimal turbulence. For this, 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 has the disadvantage of requiring a continual readjustment of the carafe to receive the wine as it pours out. Pouring terminates when sediment reaches the neck. While these devices are effective, anyone with a steady hand can manually decant a bottle of wine as effectively, if performed slowly. Under such conditions, checking for sediment flow toward the neck needs to begin only when about 80% of the wine has been poured. The presence of a candle to see the sediment may appear romantic, but is required only if decanting occurs under dimly lit conditions.

Decanting can be 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. Setting the bottle upright facilitates the settling of loose sediment to the bottom of the bottle.
Temperature

White wines are generally 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 at between 6 and 8°C. This mellows their intense bouquet and diminishes the potential cloying sweetness of some sherries. In contrast, ports are served 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 than warmer temperatures.

Temperature also has pronounced effects on gustatory sensations. Cool temperatures reduce sensitivity to sugars but 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. 5.10B).

Because wine begins to warm after pouring, presenting wine at a temperature lower than 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; Front Cover) fully satisfies these requirements. Its narrow mouth helps to concentrate aromatics, while the broad base and sloped sides expedite viewing and vigorous swirling. Terms for the various part of a glass are illustrated in Fig. 6.1.

The problem with most ISO glasses is their fragility (made of slim crystal). Thus, thicker glass versions may be preferable. Examples are Libbey’s Royal Leerdam #9309RL (Plate 5.11, left), the Durand Viticole Tasting Glass, and the Libbey Citation #8470 (Plate 5.11, right).

For sparkling wines, tall slender flutes (Plate 5.13) 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 (cordon de mousse) around the edge of the glass.

Except for flute-shaped glasses, only tulip-shaped glasses are used for analytic 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 aesthetic appeal as changing the size or design of the chinaware during a 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), all participants should use identical glasses.

Because glasses can 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 surface. For this, only nonperfumed detergents, water-softeners, or anti-static agents should be used. Equally important is adequate rinsing to
remove detergent residues. Hot tap water is usually adequate. If the glasses are hand dried, 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. Odors can seriously adulterate the wine’s fragrance. It is discouraging to think how commonly glassware odors can ruin a wine’s quality.

The removal of detergent residues is particularly important for assessing sparkling wines. 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 primarily of minute dust particles or microscopic rough edges where microbubbles of air form during pouring. Diffusion of carbon dioxide into these nucleation sites requires considerably less activation energy than incipient bubble formation. Detergent residues leave a molecular-thin film that severely limits or prevents carbon dioxide diffusion into nucleation sites and, thereby, bubble enlargement and release. To promote bubble formation, some aficionados etch a star or cross on the bottom of their flutes. Whether this is of actual benefit appears not to have been investigated.

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 is acceptable only for short-term storage. It facilitates glass pickup by the base in restaurants and wine bars. It also reduces the likelihood of marking the glass with fingerprints. The practice of glass inversions in cabinetry should be avoided.

Although not absolutely essential for tasting, wine glasses greatly facilitate wine assessment and donate an aspect of elegance that tumblers do not provide. The finer the glass, the more graceful the experience. Using wine glasses is not elitism, just a means of elevating ordinary occasions into something special. Life is all too short not to accentuate those aspects that bring personal pleasure and do no harm. Whether some consumers accept claims that specific glass shapes enhance the quality perception of particular wines is of little consequence. It is nothing more than another example of expectation influencing perception. If their use increases their appreciation of wine, why should scientific realism spoil their enjoyment?

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 overconsumption. In contrast, where sampling and note taking are brief (large trade tastings), upwards of 30 to more than 100 wines may be available.

Between 35 and 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 facilitates the presentation of equal 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 since the excess is usually discarded. At trade tastings, for example, people usually take only one or two sips, pouring out the rest. 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 generally the easiest and most efficient to use. The waiter’s corkscrew is a classic example. Its major liabilities are the physical effort required to extract the cork and the lack of elegance. Through an adjustment in the design, the same action that forces the screw into the cork also lifts it out of the neck. One of the most popular of this type is the Screwpull® [Plate 5.5]. Its Teflon-coated screw makes cork removal particularly easy. A lever model is available for commercial use [Plate 5.6]. Regardless of design, removing old corks is always a problem. Over time the cork loses its resiliency and tends to split or crumble on extraction. The two-prong, U-shaped Ah-so [Fig. 6.2A] can be invaluable in these situations. If the cork’s adherence to the neck is not too loose, gentle, side-by-side pushing nudges the prongs down between the cork and the neck. Combined twisting and pulling

![FIGURE 6.2](image-url) Illustration of the U-shaped Ah-so (A) and Wine Waiter™ (B) corkscrews (Courtesy of H. Casteleyn).
can usually remove weak corks without significant 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 should be removed, and some other means used to remove the cork. Pushing the needle between the cork and the neck is usually ineffective—it produces a channel through which the pressurized air can escape.

In situations in which the cork crumbles and fragments enter the wine, they may be removed by filtering. Coffee filters are fully adequate but an uneloquent means of removing cork debris. Rinsing the bottle permits its refilling with the filtered wine, if one wishes to serve the wine from its bottle.

A final device in the arsenal of the wine taster is one of several gadgets that can remove corks that inadvertently get pushed into the bottle. One particularly useful model possesses several flexible, plastic, appendage-like flanges attached around a hollow core (Fig. 6.2B). The flanges 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 flanges bite into the cork. Slow steady pulling removes the cork.

The former use of lead-tin capsules occasionally was associated with an accumulation of a crust around the lip of the neck, especially when the wine had been stored in damp cellars. This was typically associated with fungal growth on wine residues or cork dust. This growth 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 (or 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, unsalted crackers, or water are usually provided as palate cleansers. They refresh the mouth for the next sample. Presenting cheese, fruit, and luncheon meat, however, gives the tasting more of 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 unarticulated] focus of the presentation [most public tasting], the presence of food has value. Although food and most cheeses interfere with the detection of subtle differences among wines, they can mask the bitter/astringent sensations of red wines (see Chapter 9).
Language

The deficiencies people have in adequately verbalizing sensory experience were noted in Chapter 5. Odor memory and recognition are based on experience, not neuronal hardwiring. The specific terms applied to odors are typically culturally and environmentally encrypted. This also applies to odor categories (Berglund et al., 1973). Thus, it is not surprising that personal odor lexicons are typically idiosyncratic. Regrettably, this limitation is poorly recognized, or purposely ignored, setting the stage for memory illusions (Melcher and Schooler, 1996). The sophistication level of most wine language is the equivalent of children’s drawing—stick men and ball-and-trunk trees. If this analogy seems harsh, reflect on how many centuries it took humans to develop the skills (or feel the need) to draw lifelike representations of people or physical perspective. For descriptive sensory analysis, the solution has been to develop a specific vocabulary for the wines studied. Despite this, technical descriptors rarely do justice to the hedonic response most consumers experience with wine.

Wine language has been extensively covered by Lehrer (1983, 2009). Amerine and Roessler (1983) and Peynaud (1987) also have reviewed the topic, albeit from markedly different perspectives. Regardless, the primary function of language is to effect clear and precise communication. However, in many situations, its secondary, but unacknowledged, role is social interaction. In most wine clubs, descriptions function more as a vehicle for amiable contact than enunciating the wine’s attributes. At worst, winespeak can veil attempts to purport superior sensory skill or knowledge. Published wine descriptions (magazines, newspapers, Internet web sites) usually incorporate metaphoric, figurative, anthropomorphic, and emotional elements, as well as nonsensory aspects such as vintage, winemaking conditions, geography, and aging potential (Brochet and Dubourdieu, 2001; Silverstein, 2004; Suárez-Torte, 2007). Even seemingly precise terms (“sour,” “bitter”) may refer more to disguised holistic impressions than actual sensations. There is also a preponderance of motion verbs, such as “exploding,” “burst,” “leap,” “unfold,” and “extend” (Caballero, 2007). Frequently, odor memory seems independent of a semantic base (for example, see Parr et al., 2004).

Frequently, published descriptions seem more designed to entertain (avoid reader boredom) than educate. Asher (1989) is likely correct in his assessment that the reader “…wants the writer’s response to the wine, not his analysis of it.” If the florid language on back labels or in wine columns inspires consumers to purchase and appreciate wine, then the poetic imagery employed may not be detrimental. Regrettably, for some consumers, inability to detect the attributes so glowingly described can be
disheartening (Bastian et al., 2005), and discourage a broadening of the consumer base. In most countries, per capita wine consumption is either static or declining (OIV, 2005).

In contrast, trained panels are taught to use specific, nonoverlapping terms (corresponding to physical or chemical standards) and may be coached in the use of general terms, such as “complex,” “balance,” “finish.” The attributes of intensity and duration tend to be expressed simply with adjectives, such as “mild,” “moderate,” “marked,” and “short” versus “long,” respectively. Regrettably, this degree of training and the presence of standards are rarely available outside the laboratory. Figures 1.3 and 1.4 list examples of potential standard reference samples used for fragrance and off-odor terms. Depending on need, panelists may also be trained to recognize the fundamental attributes that distinguish the range of varietal or stylistic wines commonly found in commerce.

Despite the desirability for precision, much of popular wine parlance is anything but, objectivity being cloaked in subjectivity. Wine descriptions rarely permit the originator, let alone anyone else (Lawless, 1984), to recognize the wine. Different tasters presumably detect the same attributes, but rarely describe it similarly. For example, “chalky,” “earthy,” and “metallic” may refer to the same impression. Culture (aromatic experience) and upbringing (social status) also significantly modify what attributes are recognized (Chrea et al., 2004). Thus, it is not surprising that, although wine writers may use their own expressions in a relatively consistent manner, little commonality is found in how they describe wines (Brochet and Dubourdieu, 2001; Sauvageot et al., 2006). What they possess mutually is a tendency to relate description to presumptive type (its paradigm), without clearly enunciating it (Brochet and Dubourdieu, 2001). This view is supported by data from Solomon (1997) and Ballester et al. (2005). For example, when tasters misidentified a Pinot gris wine as Chardonnay, they described it in terms appropriate for a Chardonnay. Sauvageot et al. (2006) suggest that absence of a common lexicon may reflect wine critics viewing themselves as references, not needing referral to external standards.

English possesses few uniquely odor-related terms. Those that exist generally possess emotional connotations, for example, “putrid,” “pungent,” and “acrid.” In most cases, general terms refer to classes of aromatic objects, such as “floral,” “resinous,” “burnt,” “spicy.” A semblance of improved precision is given by the addition of suffixes such as “-like” and “-y.” If tasters agree on and consistently use these terms, then odor communication has the potential to be effective. Typically, this requires considerable training.
and discussion. Experiments have shown that repeat exposure to unfamiliar odors tends to reduce the number and range of qualitative terms used to describe them (Mingo and Stevenson, 2007).

One of the regrettable limitations of wine language is that it does not clearly and precisely enunciate the taster’s response to the wine. These responses are usually buried in the emotional aura of words (Lehrer, 2009). For example, terms such as “acidic,” “vegetal,” “leather,” and “oaky” can have either positive or negative connotations, depending on the user. Equally “tart” and “sharp” refer to the same sensation but may be selectively used to denote the taster’s qualitative reaction to the wine’s acidity/pH. Thus, terms such as “weak” versus “delicate” and “austere” versus “hard,” although appearing to be descriptive, probably signify more the taster’s hedonic response to the wine than describe its attributes. This probably explains why the same odor may generate different responses in terms of pleasantness, depending on whether its identity is known in advance (Bensafi et al., 2007), or is recognized (Degel et al., 2001). This element of description is suggested by the observation that tasters who liked a particular wine described it as fruity, with no mention of any sour or bitter attributes; whereas those who disliked the wine noted its sour or bitter character, without commenting on any fruitiness (Lehrer, 1975). A similar finding has been noted by Lesschaeve and Noble (2005). Because enunciation of hedonic responses is of particular importance to consumers, their expression is vital. This is not surprising, since our oro-olfactory sensations pass through the limbic system, associated with emotional responses, before reaching the higher, cognitive centers of the brain. Thus, the metaphoric, emotive, and often poignant illusions have their legitimate place, despite their inherent imprecision. Silverstein (2003) notes that the ritual of tasting and language use appears to be “culturally eucharistic.” In the process, tasters second unto themselves many of the symbolic qualities of what they imagine in the wine.

Part of the problem associated with obtaining precision in wine description involves the absence of adequately representative terms. Exceptions are the bell pepper and litchi aspects of Cabernet Sauvignon and Gewürztraminer, respectively. More commonly, descriptors only vaguely resemble the odor of the object or experience mentioned. In addition, fruits and flowers, like wines, rarely have a single odor quality. While apples and roses may, respectively, have common olfactory elements, many apple and rose cultivars are aromatically distinguishable. It is the fascinating diversity that gives wine one of its most endearing and captivating, but descriptively irritating properties.
For several widely grown cultivars, their association of particular descriptors has become fairly standard [see Tables 7.2 and 7.3]. Experience in their use may explain the improved ability of trained versus novice tasters to recognize varietal wines [Hughson and Boakes, 2002]. Cultivars with only regional significance are rarely associated with specific descriptors, at least in English. Traditional descriptors also appear to differ from language to language. For example, “black currant” is traditionally associated with *Cabernet Sauvignon* in English, whereas “violet” is more common in French. Some terms also seem to suggest regional cultural/agricultural aspects, such as the use of truffles in referring to some wines from Piedmont. This largely reflects the personal/cultural/regional heritage of the user.

Spider plots, such as those generated by descriptive sensory analysis [Figs. 5.29 and 5.30], have become popular as a means of visualizing wine aromas. However, most are based on data derived from features used to discriminate among similar samples. Thus, they may not include attributes that uniformly characterize the wines and correspondingly not represent the actual sensory perception of the wines [Lawless, 1999]. In addition, the features alluded to by specific descriptors exist within a general vinous background. For white wines, this typically involves a nebulous collection of fruity–floral scents, with occasional herbaceous aspects. In red wines, the aromatic spectrum often possesses aspects of ripe berries and fruit jam, with spicy or peppery overtones. These features may be complexed or partially obscured by oak flavors, or infused with mushroom–truffle, leathery odors as the wine ages.

Most descriptive terms [Fig. 1.3] attempt to delineate aromatic qualities that characterize certain wine fragrances. Regrettably, aroma wheels have too often been viewed as a guide to wine flavors. Many wine lovers have been indoctrinated into believing that their use is the passageway to connoisseurship. Such lists were intended only as memory prompters. In general, precise descriptive terms (e.g., violet, peach, raspberry) do not adequately represent the actual aromatic aspects of a wine, and do injustice to the subjective pleasures and attributes of fine wines. Nonetheless, describing wine fragrance in terms of odor descriptors has become so pervasive that books on the subject have been written [Moisseeff, 2006]. This approach purports to indicate what wines possess what flavors. This deflects attention from what is more valuable: encouraging people to develop an odor memory for the aromatic attributes of distinctive grape cultivars, stylistic features, or any regional differences that may exist. This is hard enough. Stressing the unproductive search for wine descriptors is the equivalent of expecting people to verbally enunciate the flavor of fruits and vegetable in terms of varietal wine aromas. Other than focusing consumer
attention on wine fragrance (its most complex and fascinating attribute), the activity has legitimate value only in descriptive sensory evaluation.

For the majority of consumers, olfactory descriptors act as “trial balloons,” as the originator searches for conformation. They generate encouragement when there is agreement and can be easily disregarded when greeted with skepticism. As noted in de Wijk et al. (1995), labels seem to organize odor perception. As long as the expressions represent honest feelings, they fulfill an obvious psychological need. However, they may also be used to impress rather than inform. As Samuel Johnson noted:

“This is one of the disadvantages of wine, it makes man mistake words for thoughts.”

Terms that are best avoided are those with anthropomorphic connotations, such as “feminine,” “fat,” or “aggressive.” Their potential meanings are so complex and imprecise that their interpretation depends more on the reader than the wine. Nonetheless, expressions such as “body,” “legs,” “nose,” and “aging” have become so entrenched as to be inexorable. In addition, terms such as goût de terroir (to describe flavors supposedly derived from particular vineyard sites) are figments of the imagination. Thankfully so, as anyone who has put his nose to the soil can attest.

Normally, descriptions should be kept short, recording only noteworthy attributes. 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 (see the following section) encourages the economic use of time and words.

WINE SCORE SHEETS

Detailed score sheets (e.g., Figs. 5.15 to 5.18) 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 that illustrated in Fig. 1.5 may be adequate. Figure 6.3 illustrates a variation of this sheet, developed for wine-appreciation courses. 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 illustrated is intended for an introductory course, verbal descriptions of the wines’ characteristics and varietal origin are noted to assist student identification. Initially, the order of wines’ presentation may correspond to the sequence of the descriptions. Subsequently, the presentation sequence is varied from that of the descriptions. This is designed to encourage
FIGURE 6.3  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. Figure 1.5 is a related form without added wine descriptions but ample space for student comments on the wines’ sensory attributes (from Jackson, 2000, reproduced by permission).
students to correlate the wines with the descriptions. Initially, little space is provided for student comments because they usually have difficulty verbally expressing their reactions and write little. In subsequent tastings, description of the wines may be eliminated and more space allotted for comments (Fig. 1.5). If desired, descriptive material may be projected on a screen using overheads or from a computer before, during, or after the tasting, depending on the instructor’s intentions. Quality concepts and flavor descriptors are noted to the left of the sheet (Fig. 1.5) to encourage concentration on the wine’s attributes.

Although most tasting sheets provide space for numerical scoring, caution must be exercised in ascribing undue significance to the values generated. In most cases, repeat sampling generates a different value. Equally, ranking wines out of 100 may give a sense of precision that is rarely if ever justified. In reality, the exercise is as reasonable as ranking music or art out of 100. Why then wine? Grading in terms of letters (Fig. 5.19) probably does less injustice to the relative merits of a wine. It also implies that grading is imprecise.

SENSORY TRAINING EXERCISES

Sensory testing and training for professional tasters were covered in Chapter 5. In this chapter, exercises are provided to help those with little professional experience in recognizing the diversity and complexities of wine tastes. Occasionally, such exercises may also be incorporated into training wine judges.

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. More detailed exercises on the gustatory attributes of wine are found in Appendices 6.1 through 6.4. These are usually followed by a series of exercises to illustrate how these compounds interact with one another, for example, Appendix 6.5. From the author’s experience, a few exercises of this type usually suffice.

Particularly valuable in this category of exercise is an assessment of two sets of samples, where the same concentration (e.g., sugar) is lower in the first set but higher in the second set. This highlights the contextual influence of contrast on perception. The identical sample in the first set will appear less intense than in the second set. In addition, it is well known that taste is often significantly modified by other sensations, both visual and olfactory.

Once students recognize the subtleties and relative nature of most taste sensations, there seems little value in endlessly repeating this observation
with multiple examples. Individual taste sensations in wine are so influenced by other gustatory and olfactory stimuli as to invalidate the significance of measuring the sensitivity of individual tasters to specific taste sensations. For example, sweetness is a function not only of the sugar concentration, but also of acids, glycerol, alcohol, phenolic compounds, aromatic substances, carbon dioxide, and temperature. In addition, individual taste sensations are less important to quality perception than their integration into overall sensations, such as balance and body. Finally, gustatory sensations are also far less complex and interesting than are the perceptions of fragrance and flavor. Nevertheless, it is vital that tasters realize how perceptions can easily be modified by context (for example, Fig. 6.4). Contextual influences equally affect olfactory stimuli and quality perception.

Exercises designed to demonstrate the different perceptions of major flavorants in wine, such as esters, lactones, or pyrazines could be prepared, but are more difficult and expensive to prepare. They also are no more illustrative than tastants. However, for those desiring to prepare such exercises, Aldrich Chemical Co. has prepared kits containing small samples of a variety of aromatic compounds, some of which occur in wine. Aldrich also produces a catalogue specifically dealing with flavors and fragrances. Although less precise, samples prepared from actual items (mushrooms, bell peppers, beets) or commercial fruit and floral essences are a more practical alternative for those without connections to a chemical laboratory. Simpler again, but more limiting, are commercial wine flavor kits such as the Le Nez du Vin.

Staff Training for Medium to Small Wineries

Most small wineries do not have the resources to establish a panel of tasters. Due to the immediate demands of winery function, only the winemaker may be available to make decisions on urgent matters. However, this does run the risk (advantage?) of making the wine on his or her palate. No matter how skilled, everyone has days when his or her acuity is “off.” Thus, it is not only useful, but often essential, to train other staff members. An integral part of this training is the development of a common vocabulary for describing wine sensory attributes. Not only does this permit useful dialogue between staff members at tastings, but also can facilitate consistent communication with clients.
As part of developing a common terminology, training should include sampling standardized taste and odor samples as described in Chapter 5, but especially those terms most appropriate for the cultivars used by the winery. Although it may be traditional in some wineries to sample wines in the cellar, this is not good practice. All training and serious sampling should occur in a brightly lit, quiet, odor-free environment, under comfortable seating conditions.

During term acquisition and training, the staff should sample totally blind (in black glasses). This is especially useful for those who meet the public in their reception/sales room. Every staff member should be able to identify all their wines by smell alone. Not only is this skill useful in responding to questions, but will give customers the desired feeling that they are dealing with professionals. An essential component in staff training is learning to recognize standard faults. This is critical not only for winemakers, but also for other staff members. If a faulty wine is questioned by a client, the staff should be sufficiently knowledgeable to recognize this and replace it with a sound sample. Admittedly, everyone has limits in detecting faults, as with any wine attribute. Thus, it is important that staff members know their limits and those of other staff members. Armed with this knowledge, they can direct customers to the person who is the most capable of responding to some question for which the staff member realizes he or she is unqualified.

As part of training, it might be useful for the staff to become cognizant of the local competition, as well as some of the more popular or reputed wines from other regions. The more knowledgeable the staff, the more they will appear competent and instill the confidence so important in repeat sales. Another aspect of training could relate to the effects of various temperatures on wine attributes, as well as opening wine in advance. This gives everyone actual experience with some of the most frequently asked consumer questions. If time is available and the staff sufficiently inclined, practical experience on the influence of context should be included. For example, wines could be sampled with a few cheeses to determine which appears to balance best with particular wines; white wines could be secretly colored red (with tasteless anthocyanins) to give the staff experience with the biasing influence of color on perception; or wines could be falsely identified (more and less expensive wines exchanged) and their apparent ranking compared. In the latter two examples, it is important to explain the rationale for such exercises. Knowing that they were included only to make staff members aware of how easily people can be influenced by extraneous factors will nullify any embarrassment potentially caused. As the old expression goes, “Forewarned is forearmed.”
Another aspect of training, specifically anyone dealing with customers, is food and wine combination. The general dictum of red with red and white with white is fine, but so imprecise as to be of little practical use. If the staff understands the principles underlying food and wine pairings (Chapter 9), they can adjust their responses to the perceived expertise of the client, without being intrusive or peremptory. Knowledge is a great mitigator, encouraging sensitivity to the needs and feeling of others.

If staff members are part of a tasting panel assessing the relative quality grades of the winery’s wines, it is important that at least some simple statistics be applied to the results. It is important to realize that the “best” wine (highest ranked) may be statistically indistinguishable from the second- or third-ranked wines, despite their apparent rank order. One has to be cautious in applying undue importance to ranking results.

Trained staff can also be employed in analytic procedures during wine production. Examples may involve assessing of the effects of different additives, the benefits of different yeast or lactic acid strains, the level of oaking or micro-oxygenation, and blending formulation. The list of applications is almost endless. Various discriminatory procedures applicable to winery conditions are noted in Chapter 5.

Beyond issues associated with a limited number of tasters is a tendency for the staff to show “parental” pride. This may lead to minimizing problems, possibly due to habituation. For example, frequent exposure to low levels of an off-odor can often lead to its going unnoticed. One technique to offset this situation involves the random inclusion of samples showing known faults; those that are atypical in some manner; or incorporation of samples from adjacent wineries. It is important that these outliers change frequently. Panel members must not become accustomed to and easily detect their presence.

TASTING SITUATIONS

Wine Competitions

Wine tastings have become an important tool in the wine industry. Properly used, they can benefit both consumer and producer. They can be an inexpensive technique in assessing the potential market for a new or modified product. However, the principal rationale for most wine competitions is increasing market awareness—to gain media and consumer exposure. When successful, increased wine sales and recognition are the major benefits [Lockshin et al., 2006].
Government-conducted competitions tend to be more professionally run, as selection of judges and tasting procedures are more regulated. The process for qualifying judges at the California State Fair is an example. Qualifying tests for judges are administered several weeks in advance of the competition. Nonetheless, analysis of the results is discouraging (Hodgson, 2008). Privately run competitions may or may not be conducted in accordance with accepted procedures. Medals may be awarded simply by the competitor's achieving a preset minimum mark or by rank order, with judge selection based on availability and reported tasting experience. In such instances, it is impossible to distinguish between valid rankings and those derived by chance. Although potentially discouraging for tasters (and organizers), it is better to acknowledge reality than accept unsupportable conclusions. Of more general importance is the recognition that appropriate qualification of tasters is essential.

One of the problems associated with qualifying tests, especially for candidates without sensory evaluation training, is the specter of failure. This could deal a serious blow to a critic's public persona, since peers in attendance might realize who failed. A potential solution is to partially base qualifying sensory tests on suggestions supplied by the candidates. With each candidate submitting a potential qualifying sensory test, he or she would feel actively involved in the selection process. This should reduce apprehension about the results or their relevance.

In major wine competitions, the total number of tasters usually required is 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 should 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 in which the experience of the tasters is unknown in advance, this information should be requested to avoid inappropriate assignment.

Although not perfect, wine competitions are one of the best means by which unknown wineries or little-known regions can achieve public awareness. The recognition obtained can significantly affect a winery's reputation (and sales) and, by reflection, the region from which the wine came. An example is the greatly enhanced prestige of Ontario wines following a slate of awards given its ice wines at international competitions. Media reports of these awards have an influence far beyond those garnered by evaluations conducted in research laboratories. In addition, wine competitions act as one of the few venues 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 rarely reflect true merit. Comparison of winners from different competitions seldom correlate with one another. In addition, the best wines may not be entered. Thus, 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 to varying degrees to all tastings.

Wines are typically grouped by category to avoid significant halo effects that can occur when wines of markedly different character or quality are tasted together. When categories contain many representatives, they are further subdivided into groups of no more than ten wines. These may be rapidly sampled to eliminate wines of poor or mediocre quality. Once the number has been reduced to a manageable level, the remaining wines can be reassessed at a more leisurely 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 minimize (by randomization) the influence of sequence errors. In other aspects, the tasting conditions should conform to those outlined 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. In addition, it is advisable that a maximum of one gold, one silver, and one bronze medal be permitted in each category. Although the winners may be statistically indistinguishable, organizers, participants, and the public are accustomed to winners.

Although it is uncommon to analyze the performance of judges in wine competitions, several statistical techniques for this purpose have been proposed. Examples are those provided by Cicchetti (2004) and Scaman et al. (2001).

**Consumer Preference Tastings**

Consumer testing is much more common in the food industry and certain aspects of the beverage industry than with wine. Although it certainly plays a major role in preparing new brands for worldwide distribution, serious investigation of wine preferences is still largely in its infancy. As with other consumer studies, consumer wine testing is complex and may be laden with numerous fallacies and hidden caveats (see Köster, 2003). Surveys are especially sensitive to misinterpretation. Multiple studies have shown that what people say they do may differ significantly from actual practice.
For example, most people acknowledge the benefits of a healthy lifestyle, but only a small portion act upon it. Although consumer preference is essentially holistic, acknowledging this feature can be important in directing detailed sensory wine analyses. The results can guide the actions of wine producers (knowing what attributes various consumers prefer) and the effectiveness of wine marketing. Thus, a brief discussion of consumer testing is appropriate. What is given in this section is based on the situation-oriented approach advocated by Köster (2003).

The approach involves evoking images of natural conditions under which products, such as wine, would be consumed. This often involves the use of visual and/or auditory cues. This is in contrast to tastings done on location, such as in wine stores or in the laboratory. These have an ambiance distinctly alien to that of consuming wine at home or in a restaurant. The intent of situation-oriented sampling is to induce the consumer to conjure up real-life situations appropriate to his or her lifestyle—the importance of context often being equivalent to the difference between touching and being touched.

In the test, the experimenter requests the consumer to rank the appropriateness of a series of wines with the situation imagined. This may be repeated with different situations, such as sampling with guests at home or in a restaurant, on picnics, by itself, or while relaxing on the patio. Of course, it is unnecessary (and probably inappropriate) to relate all wines with all situations. Many would assuredly be considered foreign. The site conditions selected would depend on the type of wine and the subset of consumers studied. The setting chosen would also depend on an assessment of the relative frequency with which the particular situation occurred in the consumer’s life. The questionnaire itself could initiate the recall of personal images of the conditions against which the wines would be ranked.

Evoking the appropriate context usually requires considerable forethought. Simple suggestion is usually inadequate. Experience indicates that imagining the situation demands more effort than most consumers are willing to bestow. Thus, appropriate environmental stimuli are usually required to create the mental virtual reality required. Projection of photos or videos can occasionally be adequate. However, with some situations, such as tasting at home, the photos may be too precise to elicit the appropriate image. In this case, relating a hypothetical story may be more effective and appropriate. Doing so activates the candidate’s imagination, generating the personal details suitable to the situation.

The principal advantage of situation-oriented tasting is that it arouses reactions that relate to real-life conditions. It can also be used to provide
data on the frequency with which consumers would likely purchase similar wines. In addition, the data could be used to direct descriptive and/or chemical analyses to discover those features important to particular consumer preference. Finally, situation-oriented tasting avoids many of the potential pitfalls of consumer research. For example, it does not assume consumer uniformity or consistency; questions are indirect and relate to actual, real-life settings; and it avoids the complications of imprecise term usage.

Preselection of candidates for testing often involves obtaining data about critical factors that tend to influence preference. Cultural background is often the most significant determinant, followed by the degree of education, yearly income, and gender. Were not these factors so crucial to purchase decision, no generalities about feelings or situations would be possible.

For preference studies, adequate representation of consumer diversity requires large numbers of individuals. It is also important to select only appropriate candidates (McDermott, 1990). 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, in moderation. However, conflicting data have been noted by Binders et al. (2004) and Hersleth et al. (2003). The importance of color and aroma to general acceptability increases with consumer age and the frequency of wine consumption. Not surprisingly, experience also influences the words people use to describe wine (Du¨rr, 1984; Solomon, 1990). In addition, nonconsumers may express an opinion, but one that is irrelevant. A questionnaire requesting the frequency and type of wine purchase is a minimum in the selection process.

In wine assessment, a 9-point hedonic ranking scale may be appropriate (Fig. 5.25). Its use is intuitive, permitting the scale to be used without specific training. Another option is a simple questionnaire, where the participants are asked to describe several aspects of the wines they like and dislike (Fig. 6.5). If the number of comments requested is limited (≤3), consumers do not consider the task too arduous or demanding. It highlights those aspects that the participants find especially desirable and undesirable. Such a questionnaire may provide useful insight that other scoring procedures do not provide, or as easily. Its principal limitation is the frequent inability of participants to enunciate their opinions in words. Correspondingly, the more effectively a participant verbalizes his or her views, the less they may represent the views of the target group. Wine consumers rarely possess a well-developed sensory vocabulary. This situation can also affect the interpretation of data from consumer discussion groups, where they attempt to express their views about the wines.
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, with the evening set aside 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 are organized relative to the merchant/producer supplying the wine.

WINE QUESTIONNAIRE

Name: ______________________________       Date: ______________________________
Sample # ______________________________

Describe three (3) aspects of the wine you particularly like:

a) __________________________________________________________________________
b) __________________________________________________________________________
c) __________________________________________________________________________

Describe three (3) aspects of the wine you particularly dislike:

a) __________________________________________________________________________
b) __________________________________________________________________________
c) __________________________________________________________________________

FIGURE 6.5 Descriptive wine questionnaire.

Trade Tastings
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 to emphasize. Typically, only six to ten wines are presented.

In such events, organizers should have a full appreciation of the complex elements that go into wine purchasing. Sensory attributes are particularly important for serious connoisseurs. They are less important for the average consumer. These consumers tend to have little interest in the wine’s inherent sensory qualities. For this large category, convenience of purchase, familiarity, and cost are the major factors influencing buying habits. Wealthy clientele may have refined tastes, but may also primarily desire the prestige associated with the ownership of world-renowned wine. Status significantly influences the purchasing habits of the majority of aficionados, or would-be connoisseurs. Personal prejudices also markedly influence purchase behavior. This can vary from biases concerning red versus white wines to ideological aspects such as a preference for organic wines. Culture also affects wine choice, as the purchaser tries to self-identify with particular historic or cultural paradigms. This feature is particularly strong in the promotion of some European wines. Drouin in Burgundy is reported to have said something to the extent that “when one samples a Burgundy, one is not just drinking a wine but identifying with its history and culture.” Additional factors can involve peer pressure, advertising, and opinions expressed by wine authorities. Thus, to have their major impact, trade tastings must have a clear idea of who will attend and what factors are most significant in these consumers’ future purchases.

**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 used are more appropriate for juice than wine sampling. Regrettably, the personnel typically employed are there only to dispense, not inform. Whether such tastings have real value is dubious.

In contrast, a well-administered in-store tasting can positively affect sales, as well as supply useful information to the clientele. In addition, it can enhance the store’s 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 (and affluent) customers frequent the store. Ideally, tastings should be held at similar times so that regular clients come to know when to expect tastings. Because of the intimate nature of the tasting, only one or two wines should be featured at a 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. Because promoting sales is as important as education, the identity of the wine should be in clear evidence. As has been shown by Lange et al. (2002) and Brochet and Morrot (1999), knowledge of the wine’s presumed quality and price can significantly influence taster opinion. 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 also hold wine appreciation courses in off-hours. Tastings of this nature are discussed next.

**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 plants or birds is incidental to appreciating walking in a forest. Enjoyment requires only the basic rudiments of sensory acuity. Superior skill improves differentiation, but whether they increase appreciation is a moot point. Is the critical assessor the more appreciative? Exceptional acuity is like a two-edged sword: it enhances detection of both the wine’s finest attributes and its faults. It can result in losing satisfaction with the norm.

Except in those instances in which wines are donated, or students are willing to pay high course fees, wines must be selected for their optimal price/quality ratio. They also need to clearly demonstrate the attributes desired. Repeatedly finding excellent representatives, within a limited budget, is one of the most daunting tasks the instructor must perform. 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, one hopes 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 laws, 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 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 Tastings for a Wine Appreciation Course

<table>
<thead>
<tr>
<th>Tasting</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taste detection</td>
<td>Sweet, Acid, Bitter, Astringent, Astringent-Bitter, Heat, Spritz</td>
</tr>
<tr>
<td>Odor detection</td>
<td>Off-doors (e.g., oxidized, sulfur, volatile acidity, fusel, baked, corked, buttery) Fragrance (e.g., fruits, flowers, vegetal, spices, smoky, nuts, woody)</td>
</tr>
<tr>
<td>Quality detection</td>
<td>Pairs of average and superior quality sweeter (e.g., <em>Riesling</em>) and drier (e.g., <em>Chardonnay</em>) white wines and a red wine (e.g., <em>Cabernet Sauvignon</em>)</td>
</tr>
<tr>
<td>White varietals</td>
<td><em>Pinot Grigio</em>, <em>Riesling</em>, <em>Sauvignon Blanc</em>, <em>Chardonnay</em>, <em>Gewürztraminer</em>, Viura</td>
</tr>
<tr>
<td>Red varietals</td>
<td><em>Zinfandel</em>, <em>Sangiovese</em>, <em>Tempranillo</em>, <em>Pinot Noir</em>, <em>Merlot</em>, <em>Shiraz</em></td>
</tr>
<tr>
<td>Varietal variation I</td>
<td>Three examples of different expressions of two white varietals</td>
</tr>
<tr>
<td>Varietal variation II</td>
<td>Three examples of different expressions of two red varietals</td>
</tr>
<tr>
<td>Sparkling wines</td>
<td>Regional expressions (e.g., Champagne, Cava, Sekt, Spumante, Californian, Australian) or production technique (method champenoise, transfer, charmat)</td>
</tr>
<tr>
<td>Fortified wines</td>
<td>Fino, amontillado and oloroso sherries plus ruby, tawny and vintage ports</td>
</tr>
<tr>
<td>Winemaking technique I</td>
<td>Several examples each of the use of procedures such as carbonic maceration (Beaujolais), the recioto process (Amarone), or the governo process (some Chianti)</td>
</tr>
<tr>
<td>Winemaking technique II</td>
<td>Several examples each of the effect of procedures such as oak exposure, sur lies maturation, prolonged in-bottle aging.</td>
</tr>
</tbody>
</table>
Data, such as given in Tables 7.2 and 7.3, can help students recognize various varietal aromas. Students should not view these descriptors 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 memories of qualitatively similar 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 or regional origin of wines more often than they would like to admit.

If a wine too 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 were insufficiently or poorly ripened. Fully ripened fruit of *Cabernet Sauvignon* should yield wines expressing a rich, black currant fragrance, with multiple other subtle flavor complexities. There should be no more than just a hint of bell pepper, usually in the aftertaste.

Wine enthusiasts often want to know how professionals seemingly divine wine origin. The popular press propagates the myth that professionals can identify wine origin, occasionally down to the proverbial north- or south-facing slopes. With experience, testers can detect the basic aspects of style and variety [its gestalt] in better samples. However, because environmental, viticultural, and enologic conditions can markedly affect their expression, it is often impossible to ascertain the origin of the majority of wines simply by tasting.

Despite this, many connoisseurs still seek this utopian goal. Thus, it is important for the instructor to provide guidance and instruction into the strategies used by professionals. Two types of reasoning are involved, usually in combination. Deductive reasoning concentrates on the sensory attributes possessed by the sample, whereas inductive reasoning analyses the properties the wine does not possess. These features primarily entail the fundamental aspects that characterize prototypic examples of a particular variety, style, or region, as well as modifications associated with aging or particular vintages (if the regional source of the sample is known). This is where the combination of sensory acuity, extensive experience, and a well-developed odor memory come into play. Adequate acuity is required to recognize those properties. Once the basic characteristics have been identified, extensive experience and a good memory accomplish the rest. There are no shortcuts. While training can and does improve potential, it cannot substitute for a lack
in inherent sensory acuity, reasoning, and memory. Motivation and practice are essential, but alone will not assure achieving the desired end.

Examples of wines for which it is easier to identify varietal origin are those derived from cultivars such as Cabernet Sauvignon, Shiraz, Riesling, and Gewürztraminer. Many other cultivars produce wines with a unique and distinctive fragrance, but are less easily described in words, or vineyard and winemaking conditions more markedly influence their varietal character. This certainly complicates learning their gestalt. Examples are wines from Negro Amaro, Tempranillo, Pinot noir, and Sangiovese (for reds); and Viura, Sémillon, Trebbiano, Chenin blanc, and Pinot gris (for whites).

One of the difficulties most consumers have in learning the idiotypic characteristics of particular wines is the lack of frequent exposure to good examples. This is where access to a serious wine society can be of immeasurable help. Wine societies provide an opportunity to sample many wines under near optimal conditions. The alternative is to form such a grouping of dedicated tasters. Otherwise, a dispensing machine [Plates 5.7, 9.4], holding upwards of 16 wines, permits the sampling of a series of wines on a schedule at the owner’s discretion.

Surprisingly, current research suggests that active cognitive effort is often not required in learning odor patterns. It is an inherent property of our olfactory brain to search for repeating patterns, possibly in the same way that children learn language. What is central is frequent and repeated sampling to discern common elements and encode this profile in memory. Frequently, the odor percepts contain more than just olfactory memories. They frequently include taste, tactile, and visual aspects. Because such memory traces develop as an entity, identification is optimal when all the components are activated simultaneously. For example, eliminating one (such as masking the color) can seriously deteriorate recognition.

The effects of aging on color and flavor are most easily illustrated if the instructor has collected the same wine over several vintages. This way, other variables such as cultivar composition, geographic origin, and production style are more likely to have remained relatively constant (especially if the wine is a well-known brand and attempts to keep its characteristics constant from year to year). Opening examples covering a 5- to 6-year period for white wines or a 10- to 15-year span for red wines should well illustrate the diagnostic changes that judges use in estimating wine age.

Stylistic differences that apply to winemaking are relatively easily illustrated, for example, oaked versus non-oaked, or wines with and without malolactic fermentation. Red wines matured using standard procedures, in contrast to carbonic maceration (nouveau wines), or having undergone the recioto processing (amarone) can be clearly demonstrated. Some regional
styles, such as sherries, ports, and madeiras, are so distinctive that almost anyone can rapidly come to recognize their basic sensory characteristics. Differences due to geographic origin are more problematic to exemplify clearly. For example, Cabernet wines from Bordeaux tend to be more tannic and possess fewer fruit flavors (at least early in their maturation); Californian versions tend to be as tannic but express their fruit flavors earlier; and South Australian versions tend to show fewer tannins and possess forward fruit flavors. However, these differences may reflect as much stylistic preferences in production as they do geographic origin. Detailed sensory evaluation, conducted under rigorous laboratory conditions, usually can identify subtle variations among wines from different sites within a region (McCloskey, 1996; Schlosser, 2005). The problem is that individual wines from these sites can vary so much that they may not express the regional characteristics, making consistent recognition of regional origin essentially impossible. Thus, it is important to clearly enunciate the difficulties students undoubtedly will experience in identifying wine origin. They should be counseled that everyone has, to varying degrees, the same problem.

In most situations, wines do not express attributes that permit easy identification against their general vinous aromatic background. Thus, tasters frequently resort to a form of inductive reasoning by concentrating on the features the wine lacks. Possible origin is divined as much from what it could not be as what it might be. Although useful, such joint deductive and inductive reasoning often has limited validity and accuracy. For example, Cabernet Sauvignon and Merlot both ideally show a black currant fragrance, but tend to differ in the degree of astringency and the presence of a bell pepper fragrance. In another example, a palish red French wine, possessing a complex fruity but nondistinctive fragrance, might lead a taster to suspect a less than excellent example of a Pinot noir. With this supposition, the taster would then scan his or her odor memory of Pinot noir wines in search of other characteristics for confirmation. The more extensive the taster’s memory bank of wine experiences, the greater are the chances that a reasonable match might be found. Accessory information, such as country of origin, vintage, price, etc., can be used in the process of elimination to reduce the possibilities where these aspects are known.

**Wine Tasting Societies**

Wine societies come in almost as many variants as there are examples. Too frequently, the members are more interested in social contacts and/or gastronomic interests than learning about wine or legitimately assessing their quality. This undoubtedly reflects the reality that a majority of supposed
wine lovers are actually uninterested in objective wine assessment. Nevertheless, that these societies benefit wine sales is without question. They also help to spread consumer interest in wine.

We can be thankful that there are groups that are genuinely dedicated to improving wine knowledge and expertise. These are strict tasting societies. Food is limited to bread or crackers as palate cleansers. Cheese may be present. However, it rarely if ever assists in assessing the actual qualities of the wine. In contrast, cheese tends to interfere or suppress the expression of particular wine attributes. Tastings should always be conducted blind, usually with only the names of the wine noted in advance. In this instance, and to add an element of challenge, participants are encouraged to match the numbered samples with the wines listed. Once everyone has had sufficient time to sample the wines (about 30 min), the wines are ranked according to preference, or some other preset criteria. 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 most can afford. It also has the salutary message that quality is expressed in the sensory attributes of the wine, not in its public accolade, exalted price, vintage, geographic origin, varietal nature, rarity, or venerable age.

To increase the educational value of the tastings, each should be focused relative to a particular theme. There is an endless array of themes, but most fall into one of several categories. A popular theme focuses on differentiating among the varietal characteristics of several cultivars. Such tastings not only act as a useful refresher for seasoned members, but also function as valuable training for new participants. Other popular topics involve comparing examples of a particular cultivar or style; probing the nature of quality; or exploring the expression of a producer’s, a region’s, or a country’s wines. Other tastings may examine the effects of winemaking technique or vintage differences. Specific examples could be a comparison of the various styles of sherry—Sanlúcar de Barrameda versus Jerez de la Frontera finos; variations between nouveau, standard, village, and cru Beaujolais (storing the nouveau at refrigerator temperature to retain its character so that it can be compared with other Beaujolais of the same vintage); or varietal ice wines. Table 6.2 lists other potential tastings. The possibilities are limited only by the imagination of the organizers, wine availability, and, of course, money. Variation in availability obviates the value of presenting numerous precise recommendations. Occasionally, wine stores will sponsor a tasting. However, they may be uneasy about allowing their wines to be tasted blind, devoid of information that may focus opinion in a direction the owners might prefer.
Table 6.2  Examples of Various Tastings for Wine Society Tastings

<table>
<thead>
<tr>
<th>Type</th>
<th>Subtype</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervarietal comparison</td>
<td>White vinifera cultivars</td>
<td>Six samples showing the distinctive varietal aroma of the representative cultivars (e.g., Chardonnay, Riesling, Sauvignon Blanc, Parellada, Gewürztraminer, Rhoditis)</td>
</tr>
<tr>
<td></td>
<td>Geographic expression</td>
<td>German Riesling, Silvaner, Müller-Thurgau, Ehrenfelser, Gewürztraminer, Ortega</td>
</tr>
<tr>
<td></td>
<td>Red vinifera cultivars</td>
<td>Six samples showing the distinctive varietal aroma of the representative cultivars (e.g., Cabernet Sauvignon, Tempranillo, Sangiovese, Nebbiolo, Pinot Noir, Malvasia Nero)</td>
</tr>
<tr>
<td></td>
<td>Red non-vinifera cultivars</td>
<td>Chambourcin, Marechal Foch, Baco noir, de Chaunac, Concord, Norton</td>
</tr>
<tr>
<td>Intravarietal comparison</td>
<td>International</td>
<td>Six similarly priced representatives (e.g., Australian, Californian, French, Italian, Canadian, Bulgarian)</td>
</tr>
<tr>
<td></td>
<td>Regional</td>
<td>Six similarly priced representatives (e.g., Napa, Sonoma, Mendocino, Santa Barbara, Santa Clara, Central Valley)</td>
</tr>
<tr>
<td></td>
<td>Producers</td>
<td>Six regional wines from the same variety but different producers (e.g., Rioja, Chianti, or Bordeaux)</td>
</tr>
<tr>
<td></td>
<td>Vintages</td>
<td>Six different vintage wines from the same producer (e.g., Don Miguel Cabernet Sauvignon, or Wolf Blass Chardonnay)</td>
</tr>
<tr>
<td></td>
<td>Quality</td>
<td>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)</td>
</tr>
<tr>
<td>Winemaking style</td>
<td>White</td>
<td>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$^a$</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>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)</td>
</tr>
</tbody>
</table>

$^a$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.

For the organizer, wine societies provide an excellent opportunity to provide useful enlightenment. A perfect example involves wine off-odors. Admittedly, it is difficult to inspire people about wine faults. However, when complaints arise about the quality of a particular bottle, learning comes effortlessly. Demonstrating what a sound sample smells like, in comparison to the faulty bottle, is a perfect chance for members to learn
from experience. The effects of wine age on color and flavor are other easy examples whereby education can be infused painlessly. Simple examples of how food (especially cheese) influences wine perception provide another learning exercise that is easily incorporated into a tasting. A clear example is the bitterness reduction of tannic red wines following a sampling of salty cheese (e.g., Parmigiano Reggiano).

Depending on the level of wine expertise and the members’ willingness to experiment, a tasting relating to the influence of color on perception could be conducted with white wine colored with tasteless anthocyanins. Malvin is the most frequently occurring wine anthocyanin. It can be purchased from Sigma-Aldrich Chemical and probably other chemical companies. It may also be possible to obtain in some pharmacies or health food stores. Other anthocyanins that could be substituted are delphinin, petunin, cyanin, or peonin. Another informative tasting could involve sampling several wines in both black and clear glasses. The samples in black glasses would be assessable only by odor, whereas those in clear glass would be assessed normally. This would give members experience in how the various sensory aspects of a wine affect its overall perception. Because black glasses, identical to clear versions, are neither readily available nor inexpensive, a solution is to spray the exterior of a set of glasses with black paint. Painting them inverted leaves the inner surfaces unaffected. It usually takes several days for the paint odor to dissipate. The paint is easily removed following the tasting by soaking the glasses in hot, soapy water. Although messy, the educational value of this approach is well worth the effort.

**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 have more to do with guessing than wine assessment. Sampling two or more wines with a meal may be pleasurable, but has little to do with wine evaluation. Food flavors may enhance appreciation, but conflict with objective assessment. Social interaction and alcohol consumption make impartial assessment next to impossible. Thus, the only home tastings that even approach critical assessment are those in which the wines are sampled before the meal. Ideally, these should be sampled blind. Without this precaution, the probability that prior knowledge will prejudice opinion is considerable. Because serious tasting tends to distract from the primary purpose of consumption (pleasure), home tastings may best be 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, 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 byproducts 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.

To demonstrate the relative sweetness of the major sweet-tasting compounds found in wine, prepare aqueous solutions of glucose (20 g/liter), fructose (20 g/liter), ethanol (32 g/liter), and glycerol (20 g/liter). Participants

| Table 6.3 | Typical Concentration 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 | Dry | 70 to 150 |
| | Glycerol | | 3 to 15<sup>a</sup> |
| | Butylene glycol | | up to 0.3 |
| | Inositol | | 0.2 to 0.7 |
| | Sorbitol | | 0.1 |

<sup>a</sup>In botrytized grapes.
arrange the samples (presented at random) in order of ascending relative sweetness. The form given in Table 6.4 can be used to record relative sweetness.

**APPENDIX 6.2 SOURNESS**

Acids are characteristic of all wines, being important to its 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 affect 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 byproducts (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 does not affect either taste or 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/liter), malic acid (1 g/liter), citric acid (1 g/liter), lactic acid (1 g/liter), acetic acid (1 g/liter), and succinic acid (1 g/liter). 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 in Table 6.6.
B. To roughly assess ability to detect differences in acidity, prepare aqueous solutions containing 0, 0.5, 1.0, 2.0, and 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.

### APPENDIX 6.3 PHENOLIC COMPONENTS

#### A. BITTERNESS AND ASTRINGENCY

Phenols and their phenyl derivatives are the principal source of bitter–astringent sensations in wine. As discussed previously 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 break down to their monomers in wine) and generally increase in size during aging. If present in sufficient amounts, they can contribute to the formation of sediment in red

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Additional Taste or Odor Sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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</tbody>
</table>

### Table 6.5 Typical Ranges of Several Acids in Wine

<table>
<thead>
<tr>
<th>Acid</th>
<th>Concentration (g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tartaric</td>
<td>2 to 5</td>
</tr>
<tr>
<td>Malic</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Citric</td>
<td>0 to 0.5</td>
</tr>
<tr>
<td>Gluconic</td>
<td>0 to 2</td>
</tr>
<tr>
<td>Acetic</td>
<td>0.5 to 1</td>
</tr>
<tr>
<td>Lactic</td>
<td>1 to 3</td>
</tr>
<tr>
<td>Succinic</td>
<td>0.5 to 1.5</td>
</tr>
</tbody>
</table>

### Table 6.6 Assessment Sheet for Wine Acidity

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Additional Taste or Odor Sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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</tbody>
</table>
wine. Nonflavonoid-based tannins are less stable in wine and tend to break down 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 do not break down 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 per liter. 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/liter) and gallic acid (100 and 500 mg/liter), respectively.

**B. OAK**

Another informative exercise involves preparing oaked wine samples. Add 10 g/liter oak chips to either unoaked white or red wine. After one week, decant the wine, add 30 mg/liter potassium metabisulfite (as an antioxidant), and store in sealed glass bottles for at least 3 months. During storage, acetaldehyde produced following inadvertent exposure to air reacts with sulfur dioxide or combines with other wine constituents to neutralize any mild oxidized (acetaldehyde) character.

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1. Soak the chips in ethanol for a few minutes before adding to the wine to expel air from the wood.
2. Most inexpensive wines are unoaked.
This exercise can be expanded to include observing the various effects of different oak species (American versus 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. 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 solutions 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).

Table 6.7 Assessment Sheet for Ethanol Sensations (Rank in Ascending Order of Alcohol Concentration)

<table>
<thead>
<tr>
<th>Sample</th>
<th>(Least Alcoholic)</th>
<th>(Most Alcoholic)</th>
<th>Additional Taste or Odor Sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>6</td>
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<tr>
<td>D</td>
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<td>E</td>
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<td></td>
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<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1The negative influence of fusel alcohols is illustrated in the exercise associated with off-odors (Appendix 5.2).
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/liter. 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/liter) [Noble and Bursick, 1984]. At lower concentrations, it may reduce the perception of astringency [Smith et al., 1996] and contribute to the perception of body (Table 6.8).

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.

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.

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 versus 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

<table>
<thead>
<tr>
<th>Table 6.8</th>
<th>Assessment Sheet for Glycerol Sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>None</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
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<tr>
<td>E</td>
<td>5</td>
</tr>
<tr>
<td>F</td>
<td>Maximal</td>
</tr>
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understand their personal sensory biases. This knowledge may encourage
tasters to excuse themselves from certain tastings. Sensory idiosyncrasies
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 con-
taining 1 g/liter grape tannins. The samples also contain 0, 20, 40, and 80
g/liter sucrose. Tasting the samples in random order\(^1\), 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 in 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/liter) can be substituted for grape tannins
if only a bitter sensation is desired (grape tannins induce both bitter and
astringent sensations). The data generated from all participants can be com-
bined 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 solutions will clearly demonstrate the effect of alcohol content on
both the bitter and astringent characteristics of tannins.

<table>
<thead>
<tr>
<th>Table 6.9</th>
<th>Assessment Sheet for Sweet-Bitter Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample</strong></td>
<td><strong>Bitterness</strong></td>
</tr>
<tr>
<td>A</td>
<td>a</td>
</tr>
<tr>
<td>B</td>
<td>a</td>
</tr>
<tr>
<td>C</td>
<td>a</td>
</tr>
<tr>
<td>D</td>
<td>a</td>
</tr>
</tbody>
</table>

\( ^a \text{Scale from 0 to 10.} \)

\( ^1 \text{At least 2 min should separate each tasting to allow the mouth to reestablish its baseline sensitivity.} \)
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 previously. However, it may be more interesting if the procedure is changed.

In this exercise, provide participants with at least six aqueous solutions (Table 6.10). One pair contains sucrose (20 and 40 g/liter), a second pair contains tartaric acid (0.7 and 1.4 g/liter), and the third pair combines different sugar and acid combinations, but at the same ratio (20 g/liter sucrose + 0.7 g/liter tartaric acid, and 40 g/liter sucrose + 1.4 g/liter 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 as provided in 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.

**SUGGESTED READINGS**


References


Organization is a human trait. This is most obvious in language, where objects and ideas are codified in words. However, producing a coherent, logical classification of wine based on either evolution or flavor seems hopeless. Wine covers too wide a range of beverages that have evolved over millennia; in various locations; under a diversity of environmental and cultural heritages; produced from many, distinctly different cultivars; and whose flavor is modified by multiple factors. Modern technical advances and understanding have improved wine quality, at the same time renewed interest in older techniques has resurfaced. The result is an eclectic mix of products, with little inherent commonality by which to organize a rational classification scheme. In its absence, wines have been organized around simple, easily detectable features. Traditionally, this means by color, presence or absence of an obvious effervescence, whether alcohol has been added during or after fermentation (fortification), and origin (geographic and/or varietal).
Although this approach is simplistic, long use has given it familiarity and a sense of accreditation. It does provide the consumer with a crude idea of the wine’s sensory attributes. For example, white wines typically have a milder flavor, often with a fruity/floral aspect. In contrast, red wines tend to be more flavorful and astringent. They are rarely sweet or even semi-sweet, whereas whites may be. The association between anything sparkling and celebration is longstanding and one of the prime reasons why sparkling wines are grouped together in a special category. Identification of a fortified category also has a usage rationale. These wines are consumed in smaller quantities, either before or after a meal. These categorizations have also been used in levying taxes—sparkling and fortified being taxed at a higher rate than still wines.

Designation by grape variety is typical outside Europe. It has particular benefit in that it indicates, regardless of geographic origin, the basic flavor traits that might be expected. In contrast, most European wines have traditionally been identified by regional origin, except in German-speaking regions. Here, varietal origin is usually clearly denoted. While this is now seemingly an oversight, local consumers in European countries were little concerned about varietal origin. All regional wines were made from the same, few, related cultivars, and the wines possessed a fairly consistent character. In addition, they were frequently the only wines available due to poor transport. Adequate differentiation could be based on vineyard or regional origin alone.

Although designation by varietal name has much in its favor, its use may be limited by the various synonyms under which it may go in different countries or subregions. For example Syrah in France is Shiraz in Australia; Cannonau in Sardinia is Garnacha in Spain and Grenache, Alicante, or Carignane in France; Pinot noir in France is Blauerburgunder in Germany and Pinot nero in Italy; and Zinfandel in California is Primitivo in southern Italy and Crljenak kastelanski in Croatia.

Regardless of varietal or regional designation, the consumer must have prior experience with these designations for them to be of benefit. Because most consumers seldom possess this degree of knowledge, designation by country of origin often gives the perception of confidence concerning quality or characteristics (even if unjustified). Color designation is another supposedly “safe” indicator. Regrettably, both give only a rough indication of the wine’s sensory attributes. Although many European wines carry geographic appellations that have become familiar, consistency of style is more an illusion than reality. In many regions, the wine is a blend from several cultivars. The proportional mix can change from producer to producer, as well as vary from year to year, depending on the vintage conditions and the views of the winemaker. In addition, with the spread and adoption of techniques from around the globe, regional distinction has blurred even further.
Geographic origin [appellation] is often subliminally assumed to guarantee quality. In reality, it simply is a certification of geographic origin. Even as a geographic indicator, appellation designation is a major hurdle to many consumers. Typically, the 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. Learning these appellations is often considered a right of passage to connoisseurship. However, wine shops simplify matters for the majority of purchasers by physically organizing their wines by country and subregion.

In the New World, geographic designation is simply that. It is only occasionally associated with a readily distinguishable style—for example, Marborough Sauvignon blanc from New Zealand or ice wines from Canada. Most New World regions (and even wineries) produce a diversity of wines from many different grape varieties. Although not perfect, varietal origin is usually a better indicator of probable flavor characteristics than regional origin.

The former tendency of naming New World wines after European regions has almost disappeared. This not only pleases producers in the named regions, but also removes a source of potential confusion. In addition, it no longer promotes recognition of appellations other than those from which the wine comes. For example, the generic use of “champagne” for “sparkling wines” has encouraged consumers to think of champagne as the standard against which all sparkling wines should be compared. This does benefit only champagne producers.

With the increasing importance of wines from regions other than Europe, geographically based wine classifications are losing much of their former marketing advantage. Thus, the arrangement presented in the following sections is based primarily on stylistic differences. These have broader applicability but still require experience for effective use. Nonetheless, all but the broadest categories are of little value to those with minimal wine experience. This probably explains the popularity of wine columns that suggest best buys and annual wine compendia. These tips help the neophyte develop the experience to a point at which he or she can use wine categories to direct purchases.

**STILL TABLE WINES**

Still table wines constitute the largest grouping of wines and correspondingly requires the most extensive number of subcategories [Table 7.1]. Following tradition, this grouping is initially divided based on color, reflecting major differences in use, flavor, and production technique.
Wines possessing a distinctive varietal aroma generally increase in flavor complexity during the first few years of bottle aging. Correspondingly, they are more highly regarded and command a higher price. Depending on their geographic origin, the label may or may not indicate varietal origin. A recent trend in the New World is a return to the former European tradition—naming wines without denoting varietal origin on the front label. Well-known examples are Opus One, Dominus, Conundrum, and Grange Hermitage. This naming may reflect their desire to indicate that they stand alone, not being just another varietal wine.

As briefly noted in Chapter 8, the most significant factor in wine production is the winemaker. How the wine develops depends on decisions the winemaker makes. However, unless one knows the winemaker and his or her stylistic preferences, this knowledge is of little help in purchase decisions. Beyond the winemaker, the grape variety or varieties set limits to the sensory attributes of a wine. It is the wool, whereas the winemaker is...
the weaver/tailor and the winery equipment the loom. Thus, in a funda-
mental sense, wine classification should be based on the cultivar[s] fer-
mented. Unfortunately, many grape cultivars do not, or are not known to,
possess a readily distinguishable varietal aroma. This may reflect only a his-
toric accident, leading to their not having been grown widely enough, or their
characteristics insufficiently studied in comparison to so-called premium
cultivars. Some of the aromatic attributes of the more widely cultivated
wine-grape varieties are briefly described in the following sections. Examples
of other cultivars that could significantly expand the flavor palate of wine
include Cayuga White, Ehrenfelser, Fiano, Parellada, Rhoditis, Symphony,
Traminette, and Torrontes as whites, and Chambourcin, Dolcetto, Graciano,
Grignolino, Lambrusco, Limberger, Malvasia Nero, Negro Amaro, and Tour-
iga National for reds. This is no more than a personal short list of potential
vinous gems still to be brought to broader attention.

White Cultivars

Chardonnay is probably the most recognized white wine grape. It not only
generates wines with an appealing fruit fragrance, but also tends to do well
under diverse climatic conditions. In addition to producing fine table wines,
it is an important component in the blending of one of the most well-known
sparkling wines, champagne. Under optimal conditions, the wine develops
aspects reminiscent of various fruits, frequently said to resemble apple,
peach, or melon.

Müller-Thurgau is possibly the most widely grown of modern V. vinifera
cultivars, constituting about 30% of German hectarage. It is the progeny of
a cross between Riesling and Madeleine Royale or Chasselas de Courtillier.
Its mild acidity, subtle fruity fragrance, as well as early maturity make it
ideal for producing light wines in cooler climates.

Muscat blanc is one of many members of the Muscat family of cultivars.
Their aroma is so distinctive that it is described in terms of the cultivar
name—muscaty. Because of the intense flavor, slight bitterness, and ten-
dency to oxidize, Muscat grapes have been used most commonly in produc-
ing dessert wines. The reduced bitterness and lower oxidation susceptibility
of Symphony, a new Muscat cultivar, permit the production of dryer wines
with better aging potential. Moscato bianco is the primary cultivar used in
the flourishing sparkling wine industry located in Asti, Italy.

Parellada is a variety distinctive to the Catalanian region of Spain. It pro-
duces an aroma that is apple- to citrus-like, occasionally showing hints of
licorice or cinnamon.
Pinot gris and Pinot blanc are color mutants of Pinot noir. They are both cultivated throughout the cooler climatic regions of Europe for the production of dry, botrytized, and sparkling wines. Pinot gris yields a richer, more fragrant wine, with aspects of passion fruit, whereas Pinot blanc is more subtly fruity, with suggestions of hard cheese.

Riesling is without doubt Germany’s most highly regarded grape variety. It produces fresh, aromatic, well-aged wines, which can vary from dry to sweet. Its complex floral aroma, commonly reminiscent of roses and pine, has made it acclaimed throughout central Europe and much of the world. Outside of Germany, its largest plantings appear to be in California and Australia.

Sauvignon blanc is the most important of white Carmenet varieties in Bordeaux, and the major white cultivar in the upper Loire Valley. It has become popular in California and New Zealand in recent years. Often, its aroma shows elements of green peppers, as well as a herbaceous aspect, especially in cooler climates. Better clones possess a subtly floral character.

Traminer is a distinctively aromatic cultivar grown throughout the cooler regions of Europe and much of the world. Although occasionally possessing a rosé blush in the skin, it produces a white wine. It is fermented to produce both dry and sweet styles, depending on regional preferences. Intensely fragrant, rosé-colored (Gewürztraminer) clones generally possess an aroma resembling litchi fruit.

Viognier has become popular in the USA and Australia, following languishing in the Rhône Valley since the phylloxera epidemic of the late 1800s. The wine matures quickly and is characterized by the development of a fragrant, muscat-like peach to apricot aroma.

Viura is the main white variety cultivated in Rioja. In cooler areas, it produces a fresh wine possessing a subtle floral aroma with aspects of citron. After extended aging in large wood cooperage, it develops a golden color and rich butterscotch to banana fragrance that characterizes the traditional white wines of Rioja.

Red Cultivars

Cabernet Sauvignon is the most well-known member of the Carmenet family of grape cultivars. Its renown comes from its involvement in most Bordeaux wines (and equivalents). Other members of the family include Merlot and Malbec. Their inclusion in Bordeaux blends moderates the tannin content donated primarily by Cabernet Sauvignon. The tendency of Merlot to mature more quickly has made it a popular substitute for
Cabernet Sauvignon. Under optimal conditions, Cabernet Sauvignon yields a fragrant wine possessing a black-currant aroma. Under less favorable conditions, it generates a predominant bell-pepper aroma. Cabernet Sauvignon probably is the offspring of an accidental crossing between grapes related to, if not identical with, Cabernet Franc and Sauvignon blanc.

Gamay noir is the primary, white-juiced, Gamay cultivar. Its reputation has risen in association with the popularity of Beaujolais wines. Crushed and fermented by standard procedures, Gamay produces a light red wine with few distinctive characteristics. However, when processed by carbonic maceration, it yields a distinctively fruity wine. Most of these features come from the grape-berry fermentation phase of carbonic maceration.

Nebbiolo is generally acknowledged as producing the most highly regarded red wine in northwestern Italy. With traditional vinification, it produces a wine high in acid and tannin content that requires years to mellow. The color has a tendency to oxidize rapidly. Common aroma descriptors include tar, violets, and truffles.

Pinot noir is the most famous Noirien grape variety. It is particularly environmentally sensitive, producing its typical fragrance (beets, peppermint, or cherries) only occasionally. The cultivar exists as a varied collection of distinctive clones. Usually, the more prostrate, lower-yielding clones produce the more flavorful wines. The upright, higher-yielding clones are more suited to the production of rosé and sparkling wines. The South African cultivar, Pinotage, is a cross between Pinot noir and Cinsaut.

Sangiovese is an ancient cultivar consisting of many distinctive clones, grown extensively throughout central Italy. It is most well known for the light- to full-bodied wines from Chianti, but also produces many fine red wines elsewhere in Italy. Under optimal conditions, it yields a wine possessing an aroma considered reminiscent of cherries, violets, and licorice. Sangiovese is also labeled under local synonyms, such as Brunello and Prugnolo, used in producing Brunello di Montalcino and Vino Nobile di Montepulciano wines, respectively.

Shiraz (Syrah in France) has become famous for yielding a deep red tannic wine with long aging potential in Australia. This has helped Syrah regain the prominence it once held in the Rhône Valley of France. Its wines are peppery with aspects reminiscent of violets, raspberries, and currants.

Tempranillo is probably the finest Spanish red-grape variety. Under favorable conditions, it yields a delicate, subtle wine that ages well. It is the most important red cultivar in Rioja. Outside Spain, it is primarily grown in Argentina. It usually goes under the name Valdepeñas in...
California. *Tempranillo* generates an aroma distinguished by a complex, berry-jam fragrance, with nuances of citrus and incense.

*Zinfandel* is extensively grown in California. Its precise origin is unknown, but is clearly related to several Austrian, Croatian, and Hungarian varieties (Calò et al., 2008). This variety occurs under a variety of synonyms, such as Primitivo in Italy and Crljencak kastelanski in Croatia. *Zinfandel* is used to produce a wide range of wines, from ports to light blush wines. In rosé versions, it shows a raspberry fragrance, whereas full-bodied red wines possess rich berry flavors.

**Production Procedures**

Cultivar properties set limits on the attributes the wine may possess. However, these properties are often markedly modified by the growing conditions, as well as grape health and maturity at harvest. They can also be modified and transformed by the production procedures chosen by the winemaker. Occasionally, the fermentation conditions have more effect on the characteristics of the finished wine than the cultivar.

Because production procedures have often arisen independently over centuries, there is no evolutionary logic by which they should be organized. For simplicity, they have been grouped relative to their use, either before, during, or after alcoholic fermentation. Many procedures are designed primarily to adjust for deficits in grape or wine attributes. Examples are clarification procedures, the addition of enzymes, hyperoxidation, acidity adjustments, and chaptalization. Since these inherently do not result in stylistic changes, they are not discussed here. What are noted in the following sections are those that principally affect the wine’s stylistic characteristics.

**Prior to Fermentation**

Before the development of efficient stemmer-crushers in the late 1800s, some grapes remained whole throughout much if not all of the fermentation process. Before breaking open and releasing their juice, they underwent a grape-berry fermentation. Although the alcohol content rose to only about 2%, it activated the production of distinctive aromatic compounds. If the grape clusters were collected and piled together without crushing, most of the grapes underwent grape-cell fermentation. This is in essence what occurs in the process now termed carbonic maceration (Fig. 7.1). It is how *Beaujolais* wines are produced and why they possess a distinctive fragrance. Although occasionally used to produce white wines, this procedure is primarily employed in the production of red wines.
Grapes harvested in the heat of the day and whole clusters dumped into wide shallow fermentor

Top of vat sealed loosely and air flushed out with CO₂ (optional), grapes are allowed to self-ferment at temperatures reaching 30°C or above

Some berries break under the weight of those above them, the juice released begins yeast-induced fermentation

Free-run juice/wine drained off

Remaining grapes pressed to obtain the press-run fraction

Ferment fractions separately at cooler temperatures of cellar and blend as desired for style

FIGURE 7.1
Flow diagram of carbonic maceration wine production.
Occasionally, harvested grapes are stored whole for a period of post-maturation. For the production of certain white wines, the grapes are left to partially dry in the sun. This increases their relative sugar content, enhancing their alcohol producing potential. In some locations, this has resulted in the production of fortified wines. A classic example is the sherry-like wine from Montilla, Spain. Partial drying has also been used in the production of red wines. Here, however, the grapes are usually stored under cool, shaded conditions. For the production of old-style Chianti wines, part of the harvest was so stored. These grapes were subsequently crushed and added to the wine derived from the majority of the harvest, inducing a second fermentation. For reasons that are still unclear, this technique produces a lighter wine that can be enjoyed early. The procedure, called governo, produced the jug Chianti that for decades made it synonymous with easy drinking wine.

Partially drying grape clusters or their wings (the smaller side branch of a cluster) are also occasionally used in Veneto and Lombardy, Italy (Fig. 7.2). During the slow drying and over-maturation, nascent Botrytis infections may reactivate [Plate 7.1, Usseglio-Tomasset et al., 1980]. They generate chemical changes that resemble those that occur during the noble-rotting of white grapes in the vineyard. These include marked increases in glycerol, gluconic acid, and sugar content. Surprisingly, the anthocyanin content is not as oxidized as might be expected. Botrytis has the potential to produce a powerful polyphenol oxidase, laccase. Thus, although the color may be more brickish than usual for a red wine of equivalent age, it is not brown. Nonetheless, the sharp tulip and daffodil odor of recioto wines, such as Amarone, probably derives from phenols oxidized by laccase.

Typically, harvested grapes are destemmed and crushed shortly after harvest. The crush is then either allowed to ferment directly (red wines) or kept cool for flavor extraction for up to 24 h prior to pressing (white wines). Occasionally, white grapes are pressed whole (without prior destemming and crushing). This is typical in the production of sparkling and botrytized wines, but is also receiving renewed interest from dry, white wine producers. Its primary benefit is to minimize the extraction of tannins or undesirable constituents found in the skins. Depending on the character of the desired wine, it can also limit the extraction of flavorants.

Before pressing, the juice (or wine) is normally allowed to run free under gravity (free-run). Extra juice (or wine) is subsequently extracted by pressing the remainder (called pomace). There are many methods of extracting the remaining juice or wine (press-run). The method and number of successive pressings affect the release of flavorants, anthocyanin pigments, and tannic substances. It is up to the winemaker to decide what method is most appropriate for the style desired and to determine what proportion of free-
FIGURE 7.2
Flow diagram of recioto wine production.

Selection of fully ripe clusters or wings

Lay clusters/wings in trays to dry under cool conditions for several wks or months

Ferment (warm – amarone; cool – amabile; or produce as a spumante)

Press and collect wine

Mature and then filter

Bottle
press-run juice (or wine) should be used in the finished wine. These procedures affect the attributes of the wine but do not modify the wine’s style as the procedures noted previously.

As noted, crushed white grapes may be left in contact with the seeds and skins for several hours after crushing. The process, termed maceration, helps extract grape flavorants, most of which are located in the skin. To limit the growth of microbes during this period, maceration is usually conducted at cool temperatures. The same procedure may also be used in the production of rosé wines, but this time to limit the extraction of anthocyanins. Cool maceration is also being used with some red wines, notably Pinot noir. In this instance, maceration may last several days. It has been associated with improved coloration and flavor. Why coloration is improved is unclear, but may be associated with the extraction of other phenolics. Because Pinot noir wines tend to be relatively poorly colored, the extra phenolics may help stabilize them from oxidative color loss.

**During Fermentation**

Conditions during fermentation tend to have more significance to the stylistic characteristics of red wine than white wines. This undoubtedly results from differences in the length of contact time between the seeds and skins (pomace) and juice during fermentation. For standard red wines, this duration can vary from 2 to 5 days. Shorter periods are usually associated with more active mixing of the fermenting juice and pomace. Without periodic mixing, most of the pomace floats to the surface, forming a cap. The temperature and alcohol content in the cap can be quite different from that of the main volume of the ferment. Mixing limits or eliminates this difference, as well as facilitates the extraction of anthocyanins and flavorants from the skins. In the past, when mixing of the juice and pomace was less efficient, it was common for wineries to leave the pomace in contact with the fermenting juice until fermentation was complete. Depending on the size of the fermentor, winery temperature, and the temperature of the grapes entering the winery, fermentation might take from a few days up to several weeks. The latter often extracted excessive amounts of tannins, requiring fining to reduce, and prolonged aging, before the wine lost its extreme astringency. Few wineries currently use prolonged skin contact, preferring shorter, more efficient, gentle mixing to extract intense color and rich flavor, without the high tannin contents of old. By the judicious selection of skin contact time, mixing, and blending of the free-run with press-run fractions, the winemaker can significantly alter the style of the wine, from light and fruity to heavy and jammy.

Fermentation temperature is another factor winemakers use to adjust the style of their wines. It can be used in the production of both red and
white wines, but most commonly with white wines. With few exceptions, red wines begin their fermentation at above 20°C, rising up into the mid-to high-20s. Cooling is employed if fermentation is too rapid and the temperature approaches that which might kill the yeasts. The higher fermentation temperatures used for red wines favor the improved extraction of anthocyanins. For white wines, winemakers frequently select a temperature relating to the style they wish to produce. For more fruity, lighter wines, temperatures may be held at about 15°C. This is frequently the case for wines produced from grapes that are fairly neutral in aroma and are intended for early consumption. For wines meant to be stored for several years before opening, higher temperatures are preferred. These wines generally are more full flavored and produced from grapes with more distinctive aromas. Cool temperatures may also be specifically chosen to slow fermentation, inducing its premature cessation, leaving the wine with residual sugar.

Choice of spontaneous versus induced fermentation and the selection of yeast strain are other techniques of directing stylistic properties. This is clearly the case with neutral-flavored grapes, where most of the wine’s aromatic character comes from yeast metabolism. Thus, wines can be given a fruity aspect they would not otherwise possess. Inoculation with a particular yeast strain can also avoid the production of undesirable concentrations of hydrogen sulfide or acetic acid. Spontaneous fermentations allow a greater diversity of yeast species to influence the flavor profile of the wine. Whether this is beneficial or detrimental depends largely on personal preference and good luck.

Malolactic fermentation is another process that can subtly (or occasionally not so subtly) modify wine character. Originally, this bacterial fermentation was used to reduce wine acidity and the perceived astringency of red wines. Subsequently, malolactic fermentation came to be viewed as a tool in structuring a wine’s properties. Relative to flavor modification, malolactic fermentation is most well recognized for its donation of a buttery attribute. Moreover, different strains of *Oenococcus oeni*, the principal bacterium inducing malolactic fermentation, produce additional constituents that can variously influence a wine’s character. Examples are the production of acetic and succinic acids, as well as a variety of higher alcohols, acetaldehyde, and ethyl acetate. Malolactic fermentation can also modify perceived bitterness, fruitiness, and overall quality.

**After Fermentation**

Wines designed for early consumption are usually aged in stainless steel tanks. This is especially so for white and rosé wines, where maturation in oak cooperage may supply flavors that mask the wine’s delicate fragrance.
However, this tendency is largely dictated by habituation or tradition. For example, varieties such as Riesling and Sauvignon blanc are seldom aged in oak, whereas Chardonnay and Pinot grigio are typically matured in oak. The character transferred from oak cooperage varies depending on how the wood was seasoned, how it was heated during cooperage production, the size of the cooperage, the duration of maturation, and the number of times it has stored wines. The species of oak and the conditions of growth also influence the flavors donated. Thus, the oak aspect (regardless of intensity) may express features resembling wood to coconut fragrances, vanilla notes, a roasted or toasty character, caramel-like aspects, or smoky overtones. These features provide the winemaker with a veritable palate of flavors from which to choose. However, this variation can make the oak aspect of a wine difficult to recognize and characterize. In addition, oak flavors change as much during in-bottle aging as do the sensory attributes of the wine itself.

Another procedure that can be used by the winemaker to adjust the stylistic attributes of a wine is sur lies maturation. This old procedure is currently receiving much renewed attention worldwide. It typically involves delaying racking (removing wine from the yeast lees that settle during maturation). The storage cooperage of preference is small oak barrels (~225 liters). To limit the production of reduced sulfur off-odors originating from the lees, the wine and lees are manually stirred to permit the absorption of oxygen. The procedure is viewed as a means of enhancing the wine's flavor complexity.

**White Wine Styles**

White wines, in some ways, come in a wider diversity of styles than red wines. The major production options leading to these styles are outlined in Fig. 7.3.

Particularly popular are dry wines possessing a clean, refreshing taste and fruity bouquet. This is often derogatively termed 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 byproducts occur in excess of their equilibrium constants in young wine. As they hydrolyze back to their alcohol and acid constituents, 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 primarily by yeast metabolism, 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 often replaced by a pleasing aged bouquet. The chemical nature of this change is largely 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 flavors and 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 bracing acidity. It provides the balance they otherwise would lack. The lighter of these semi-sweet wines are often taken cold, and by themselves, as a “sipping” wine. In contrast, the 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 (Fig. 7.4, Plate 7.3). 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 *trockenbeerenausleses* of Germany and Austria, the Tokai aszus of Hungary, and the Sauternes.
Select infected cluster or portions, infected berries or dried infected berries (depending on style)

or

Press gently (no stemming or crushing) to minimize release of glucan polymers from pulp

Add nutrients and ferment at 20–22°C or 10–15°C (Depending on style)

Mature

Filter

Bottle

**FIGURE 7.4**  Flow diagram of botrytized wine production.
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 ice wines (eisweins) (Plates 7.4, 7.5, 7.6) and vino santo (partially oxidized, sweet wine). Figure 7.5 outlines the procedures leading to the major, sweet, white wine styles.

As noted, recognizing the varietal aroma of a wine is often difficult. Factors such as vintage, fermentation, and maturation conditions can minimize or modify the wine's varietal character. The most readily identifiable are varieties depending primarily on monoterpene alcohols (e.g., Muscat, Viognier, Torrontes, Gewürztraminer) or several labrusca cultivars (e.g., Niagara, Glenora). Table 7.2 provides a list of descriptors often thought to characterize particular white grape cultivars.

**FIGURE 7.5** Classification of sweet white wines based on production method.
Red Wine Styles

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. In addition, their subtly complex bouquet is more apparent in the absence of food flavors.

Most red wines that age well are matured in oak cooperage (Fig. 7.6). Storage in small oak cooperage (~225 liters) usually speeds wine maturation and adds complementary oaky, vanilla, or spicy/smoky flavors. Following maturation, the wines generally receive additional in-bottle aging, either at the winery or by the consumer. Where less oak character is desired, used barrels or large (1000 to 10,000 liter) oak tanks may be employed. Barrel aging appears to accentuate the varietal character of several major red cultivars, such as Cabernet Sauvignon, whereas tank maturation tends to moderate varietal distinctiveness. Alternatively, the wine may be matured in inert tanks to avoid oxidation or the uptake of accessory flavors.

Production procedures used in red wine making often depends on the consumer group for whom the wine is intended. Wines expected to be

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Table 7.2 Aroma Descriptive Terms for Several Varietal White Wines*

<table>
<thead>
<tr>
<th>Grape Variety</th>
<th>Country of Origin</th>
<th>Aroma Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chardonnay</td>
<td>France</td>
<td>apple, melon, peach, almond</td>
</tr>
<tr>
<td>Chenin blanc</td>
<td>France</td>
<td>camellia, guava, waxy</td>
</tr>
<tr>
<td>Garganega</td>
<td>Spain</td>
<td>fruity, almond</td>
</tr>
<tr>
<td>Gewürztraminer</td>
<td>Italy</td>
<td>litchi, citronella, spicy</td>
</tr>
<tr>
<td>Muscat</td>
<td>Greece</td>
<td>muscaty</td>
</tr>
<tr>
<td>Parellada</td>
<td>Spain</td>
<td>citrus, green apple, licorice</td>
</tr>
<tr>
<td>Pinot Gris</td>
<td>France</td>
<td>fruity, romano cheese</td>
</tr>
<tr>
<td>Riesling</td>
<td>Germany</td>
<td>rose, pine, fruity</td>
</tr>
<tr>
<td>Rousanne</td>
<td>France</td>
<td>peach</td>
</tr>
<tr>
<td>Sauvignon blanc</td>
<td>France</td>
<td>bell pepper, floral, herbaceous</td>
</tr>
<tr>
<td>Sémillon</td>
<td>France</td>
<td>fig, melon</td>
</tr>
<tr>
<td>Torbato</td>
<td>Italy</td>
<td>green apple</td>
</tr>
<tr>
<td>Viognier</td>
<td>France</td>
<td>peach, apricot</td>
</tr>
<tr>
<td>Viura</td>
<td>Spain</td>
<td>vanilla, butterscotch, banana</td>
</tr>
</tbody>
</table>

*Note that the varietal aroma frequently has but a faint resemblance to the fragrance of the descriptor. Descriptors often act as anchor terms verbally representing the memory for the varietal aroma.
consumed early tend to have mild flavors, whereas those requiring extended aging (to develop their full flavor potential) are unpleasantly tannic and bitter when young. 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 give 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 Fig. 7.7

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 (see Bourzeix et al., 1983). Retention of sufficient acidity and the judicious uptake of oxygen during maturation favor color retention. Distinctive aromatic constituents, such as the methoxypyrazines, eventually

![FIGURE 7.6 Oak maturation options.](image)
Classification of red wines based on basic production options.
oxidize, isomerize, hydrolyze, or polymerize to less aromatic compounds. They may be the origin of the cigar box, leather, mushroomy scents that characterize the aged bouquets of the best premium red wines.

Although most red wines owe much of their character to the cultivar(s) used in their production, some owe most of the character to their production technique. Notable examples were noted earlier. Carbonic maceration (Fig. 7.1) has several advantages. It generates a wine with a distinctive and very fruity fragrance rarely found elsewhere (except with Limberger wines). It also permits the wine to be released from the winery for consumption shortly after production. Its disadvantages include the extensive use of fermentor volume, special fermentation conditions, requirement for manual grape harvesting, and the wine’s relatively low price.

The advantage of recioto production (Fig. 7.2) comes from the concentration of flavors and the production of a distinctive, oxidized, phenolic odor. It donates a character that is unique and noticeably different from the same wine produced by standard procedures (e.g., Valpolicella della Amarone versus Valpolicella).

The emphasis often placed on a wine’s aging potential generates questions regarding when wines should be consumed. This, however, reflects a misconception that wines are best at some particular stage in maturation. In reality, wine progresses through a spectrum of aromatic changes, many of which are equally but distinctly pleasurable. The aging question also 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 richer, more complex attributes of mature wines; or the milder, subtle bouquet of a fully aged premium red. It is more appropriate to refer to a wine’s plateau than to its peak (Fig. 7.8). One of the major features that distinguish superior wines is the duration of the plateau. Wines with little aging potential have comparatively short plateaus, whereas premium wines ideally have plateaus that can span decades.

Because most grape varieties are still cultivated locally, close to their presumed origin, limited information is available on their winemaking potential. New World experience has been largely restricted to a few cultivars from France and Germany—reflecting the biases of those who started vineyards in former 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 untapped. How many varietal diamonds 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 wines. Sadly, the self-perpetuating cycle of
consumer, critic, and producer conservatism limits the more extensive investigation of other varieties. Nonetheless, more adventuresome wine-makers are investigating both largely forgotten indigenous cultivars, as well as newly developed varieties. Thus, there is increasing hope that consumers may soon not depend so much on variations-on-a-theme, but sample new and pleasurable sensory experiences.

As noted relative to white wines, aroma expression is often indistinct. Clear demonstration of a 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.
Except for sparkling rosés, which are made by blending a small amount of red wine into the base white wine, still rosés are usually produced from red grapes given short maceration. This limits anthocyanin uptake, generating a slight pinkish coloration. Frequently, this process involves a gentle crushing of the grapes, followed by contact between the juice and pomace for between 12 and 24 h under cool conditions (to delay the onset of fermentation). The juice is run off and fermented similarly to a white wine. Alternatively, the grapes may be pressed whole to limit color extraction. Where fruit coloration is low, the grapes may be crushed and fermented with the skins until sufficient pigment has been extracted. Alternatively, pectinase enzymes may be added to the crush to enhance color extraction as well as encourage flavor liberation from the skins. Subsequently, the juice is fermented without further skin contact. Occasionally, rosé production can be a byproduct of red wine production. This typically occurs in poorer years, when there is insufficient color to generate a typical red wine. The technique, called saignée, involves drawing off a portion of the fermenting juice, which is used to produce a rosé. The remaining juice continues its fermentation with the seed and skins, achieving a more intense color than would have been possible otherwise.
Although short maceration limits anthocyanin uptake (achieving the desired color), it even more markedly restricts tannin extraction. Thus, rosés tend to show poor color stability (much of the color being derived from unstable free anthocyanins, not the more stable tannin-anthocyanin polymers typical of red wines). Despite their relatively low anthocyanin concentration, these phenolics still appear to act as important antioxidants (Murat et al., 2003). For example, they protect 3-mercaptohexan-1-ol from oxidation (and rapid loss of this essential ingredient to the fruity fragrance of several rosé wines). Phenethyl acetate and isoamyl acetate are also significant contributors to the fruity flavor of many rosés (Murat, 2005).

Rosés have the stigma of lacking aging potential. Correspondingly, they have never been taken seriously by connoisseurs. Furthermore, rosés are often denigrated for possessing some of the bitterness, but not the flavor of red wines, while not exhibiting the fresh crispness or fruitiness typical of white wines. To mask the bitterness, many rosés are processed semi-sweet, and mildly carbonated to increase their appeal as a cool refreshing drink. Both features augment their negative connotation among wine aficionados. To counter the unfavorable image frequently associated with the name rossé, some ostensibly rosé wines are now termed “blush” wines. Despite the negative connotations, there has been a recent and marked upsurge in rosé popularity.

Most red grape varieties can be used in producing rosé wines. However, except for saignée versions, it is not economically sound to use premium cultivars in the production of rosés. Of all cultivars, Grenache is probably the favorite. In California, Zinfandel is also 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 derive much of their distinctive character from their high carbon dioxide content (often 600 kPa—six times atmospheric). Its prickling, tactile sensation is central to the style. The cold serving temperature further accentuates the pleasing pain sensation generated by the dissolved gas. In addition, the bubbles generate a textural feel. Flat sparkling wine (like decarbonated soft drinks or soda water) loses its appeal. For most sparkling wines, the base wines are chosen to be nearly colorless, relatively low in alcohol content (to avoid the final alcohol content exceeding 12%), minimal varietal aroma (favoring expression of a sur lies-derived, toasty aspect), and relatively acidic (to heighten the flavor, as citric acid does to fish).
Typically, sparkling wines are classified by production procedure (Fig. 7.9) and flavor characteristics (Table 7.4). Most derive their effervescence from trapping carbon dioxide, generated during a second, yeast fermentation. Although definitive, this classification system seldom denotes clear sensory differences. For example, both standard and transfer methods can produce dry to semi-dry versions. Differences arise primarily from the duration of the sur-lies-like maturation following the second fermentation. Yeast contact releases compounds that are critical to the development of the distinctive fragrance, described as toasty. Prolonged yeast contact (typically 1 year, but occasionally 3 or more years) also favors the release of mannanproteins. These yeast cell-wall degradation products not only entrap flavorants (releasing them when the wine is in the glass), but also favor the production of a delicate but abundant effervescence. This involves the production of multiple chains of minute bubbles, as well as the mousse that forms in the center of the glass and around the meniscus. Additional differences in character arise from the cultivars and conditions used in preparing the base wine. This is particularly marked in the production of some Charmat-produced wines, for example, Asti Spumante. The use of Muscato d’Asti donates the characteristic, marked, muscat aroma of Asti Spumante, while premature termination of fermentation gives it its sweet finish. The Charmat process is also extensively used in the production of many other Italian wines, many of which may be produced in dry, sweet (amabile), or slightly sparkling (frizzante) versions. The most well known outside Italy are Prosecco (white) and Lambrusco (red). Occasionally, these are produced by adding grape must to finished wine and inducing a second, in-bottle fermentation. With red versions, the second fermentation is often incomplete, producing a pétillant wine with mild sweetness. Many sparkling wines in Germany (Sekt) are (or were) produced using the Charmat method.

The predominant use of the traditional (champagne) method largely reflects consumer image. All three standard procedures employ a second, yeast fermentation to produce the carbon dioxide. Assuming similar quality base wines, the resultant wines should be very similar to identical. The traditional and transfer processes are identical up until disgorging (Fig. 7.9). In the traditional process, the wine remains in the bottle in which the second fermentation took place. In the transfer process, the wine is discharged into a pressurized tank. The wine is filtered (to remove the lees), transferred into new bottles, and restoppered. Other than avoiding the expense of riddling and minimizing any bottle-to-bottle variation, there are no published data indicating any sensory difference accruing from the choice of procedure. The basic disadvantage of the transfer process is the expense of purchasing the pressurized tanks into which the wine is discharged, prior to eliminating
FIGURE 7.9  Flow diagram of the three principal methods of sparkling wine production.
the yeast sediment. Automation of the riddling step, required in the traditional method, has largely eliminated the financial savings that formerly favored the transfer method. Riddling transfers the lees to the bottle neck, prior to ejection during disgorging. The Charmat process uses a specially designed fermentation tank that can withstand more than the six atmospheres of pressure that develops during the second fermentation. At the end of the maturation period, the wine is filtered (as in the transfer method) before bottling and corking. Its expense involves both the pressurized tanks and the controls needed to avoid the development of a highly reduced environment in the accumulated yeast sediment. The latter could generate reduced sulfur odors. Properties considered appropriate for the majority of dry sparkling wines are outlined in Table 7.5.

Carbonation (incorporating carbon dioxide under pressure) is the least expensive method of producing sparkling wine. However, its primary use in the soft drink industry and in the production of flavored pétillant wines has given the process a negative connotation with connoisseurs. Although carbonation obviates the presence of a toasty aspect, it can accentuate the varietal aroma of the wine (or any faults the wine may possess). Absence of yeast contact also minimizes the extraction of mannoproteins. This tends to limit the production of the fine effervescence so desired in sparkling wines. Although this aspect is critical to aficionados, most consumers probably would not notice the difference—attention is usually directed toward celebration, not the attributes of the wine.

Sparkling wines are predominantly white, due to difficulties posed by the presence of phenolics in red wine. Phenolics not only suppress yeast action, as the pressure builds up during the second fermentation (and, therefore, limiting CO₂ production), but also favor gushing when the bottle is opened. To partially circumvent these problems, most rosé sparkling wines are

<table>
<thead>
<tr>
<th>With Added Flavors</th>
<th>Without Added Flavors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fruit Flavored</strong></td>
<td><strong>Highly Aromatic</strong></td>
</tr>
<tr>
<td>Carbonated</td>
<td>Muscat Based, Sweet</td>
</tr>
<tr>
<td>Coolers</td>
<td>Asti</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
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</tbody>
</table>
produced by blending a small amount of red wine into the cuvée. Sparkling red wines are usually carbonated and possess a reduced carbon dioxide content (to minimize gushing).

Extensive blending is used in the production of sparkling wines. This process usually involves combining wines from many vineyards, as well as several vintages and cultivars. Only in superior years do all the base wines come from a single vintage. Blending not only minimizes sensory deficiencies in the base wines, but also tends to accentuate their individual qualities. Examples of cultivars used are Parellada, Xarel-lo, and Macabeo in the production of cava from Catalonia; and Chardonnay, Pinot noir, and Pinot Meunier in Champagne. In other regions, single varieties may be used, for example, Riesling in Germany, Chenin blanc in the Loire, and Muscat in Asti, Italy.

Carbonated sparkling wines show a wide diversity of styles. These include dry white wines, such as Vinho Verde, most crackling rosés; and fruit-flavored coolers. In the case of Vinho Verde, the wine originally obtained its slight sparkle from the late onset of malolactic fermentation in wine stored in barrels. This occurred during the spring following fermentation. The wine was originally served directly out of the barrels. However, when the makers started to bottle the wine, filtering provoked the release of most of the carbon dioxide. To reestablish the sparkle, the wine was carbonated just prior to bottling. Because the pressure is relatively low, there is no need to use the strengthened bottles required for most sparkling wines.

### Table 7.5 Desired Attributes for Most Sparkling Wines

<table>
<thead>
<tr>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brilliantly clear.</td>
</tr>
<tr>
<td>2. Pale straw-yellow to bright gold.</td>
</tr>
<tr>
<td>3. Slow prolonged release of carbon dioxide that produces many, long, continuous chains of minute bubbles.</td>
</tr>
<tr>
<td>4. Bubbles mound on the surface in the center of the glass (mousse) and collect around the edges of the glass (chordon de mousse).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fragrance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Presence of a complex subtle bouquet that shows a hint of toastiness.</td>
</tr>
<tr>
<td>2. Subdued varietal character (to avoid masking the subtle bouquet).</td>
</tr>
<tr>
<td>3. Possess a long finish.</td>
</tr>
<tr>
<td>4. Absence of atypical or grape-like aspects.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bubbles that explode in the mouth, producing a tingling, prickling sensation on the tongue.</td>
</tr>
<tr>
<td>2. Possess a zestful acidity without tartness.</td>
</tr>
<tr>
<td>3. Presence of a clean, lingering, after-taste.</td>
</tr>
<tr>
<td>5. Absence of a noticeable astringency or bitterness.</td>
</tr>
</tbody>
</table>
Regardless of the source, it is the nature and content of mannoproteins that largely affect bubble size. When the bottle is opened, the dissolved carbon dioxide becomes unstable, relative to atmospheric pressure. Without agitation, there is insufficient free-energy to result in a rapid gas escape. Inherently, the excess dissolved carbon dioxide would slowly dissipate by diffusion over several hours. When wine is poured, however, the free-energy generated permits the well-known, rapid, but short-lived formation of bubbles. Once this ends, the formation of the characteristic chains of bubbles depends on the presence of minute particles on the glass or that are suspended in the wine. Dust particles are the most well studied of these nucleation sites (Liger-Belair et al., 2002). When the wine is poured, microscopic air bubbles are trapped in crevices of these particles. Carbon dioxide can easily diffuse (with little energy) into these nucleation sites. As their volume increases, bubbles of carbon dioxide bud off and initiate the effervescent chains so typical of sparkling wine. As they rise, additional carbon dioxide uptake enlarges the bubbles, and the distance between each increases. On reaching the surface, most bubbles burst. Some, however, begin to accumulate, forming a mound in the center of the glass (mousse). Others collect around the edge of the glass (cordon de mousse). Because of the small amount of protein in wine, the bubbles quickly coalesce, forming larger but increasing unstable bubbles. Thus, sparkling wine does not produce a head of foam as does beer.

Glass cleaning is of particular importance to the wine’s effervescence characteristics. Even small traces of detergent can hinder bubble generation. This results as detergent covers the nucleation sites with a thin layer of hydrophobic molecules. The diffusion of carbon dioxide into nucleation sites is retarded or prevented, limiting the formation of a continuous chain of bubbles. This can be easily demonstrated by washing wine glasses with detergent and improperly rinsing or drying them. Using soft drinks in lieu of sparkling wine is equally demonstrative but avoids the loss of good wine.

The use of flutes is always recommended. Otherwise, it is difficult to fully appreciate the beauty and elegance of the effervescence.

**FORTIFIED WINES (DESSERT AND APPETIZER WINES)**

All terms applied to the category of fortified wines are somewhat misleading. For example, the sherry-like wines from Montilla, Spain, achieve their elevated alcohol content naturally (without fortification). The alternative designations of “aperitifs” and “dessert wines” are also somewhat erroneous. Sparkling wines are often viewed as the ultimate aperitifs, and botrytized
wines are often considered the preeminent dessert wines. Table 7.6 provides a categorization of some of the more common fortified wines.

Regardless of designation, fortified wines are generally consumed in small amounts. Thus, individual bottles are rarely consumed completely upon 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 upon 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 enzymes, they promote digestion (Teyssen et al., 1999). 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, possibly in lieu of dessert.

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 wines may have been made as far back as late 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, within a limited alcohol range, favors the development of a yeast pellicle on the wine’s surface. The addition of distilled spirits has 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 10th century A.D., the Arabs developed efficient stills for alcohol purification. Alcohol distillation in Europe developed in earnest only in the 1500s. Fortification of wine with distilled spirits was apparently first used in preparing the herb-flavored medicinal called *treacle*. This later evolved into modern vermouth. Subsequently, it was used in the production of many fortified wines, liqueurs, brandies, and the range of fortified spirits common today. Despite this, credit for the production of the first distilled alcoholic beverage appears to go to the Chinese, some 2000 years ago.

The use of wine spirits in sherry production was occasionally practiced by the middle 1600s. Its use in port stabilization began about 1720. By 1750, the practice shifted from fortifying the finished wine to fermenting must. The resultant disruption of fermentation retained up to 50% of the original grape sugar content. Extensive treading (grape crushing and mixing by foot in shallow stone fermentors) throughout the short fermentation period achieved sufficient pigment extraction to produce a dark red wine. The tannin, 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 from the original onion shape (Fig. 7.10) led to the rediscovery of the benefits of wine aging. These advantages were clearly recognized by the early 1800s.

### Sherry

Sherry is produced in two basic styles: *fino* and *oloroso* (Fig. 7.11). 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
FIGURE 7.11 Flow diagram of sherry production. Shading indicates whether the butts are kept full or partially (~20%) empty. (Reprinted from Wine Science: Principles and Application, 3rd ed. R. S. Jackson (2008), with permission from Elsevier).
to their forming a pellicle (flor) that covers the wine. At 18%, all microbial activity in the wine is typically inhibited.

The flor covering protects the wine, stored in partially filled barrels (termed butts), 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 fractional blending, where fractions of wine from older series of barrels (criaderas) are removed and replaced by wine from younger criaderas (Fig. 7.11). After about 5 years, the wine has reached an average alcohol content of 16 to 17%. Unlike most other categories, fino sherries are typically left unsweetened, even for export. They are pale to very light gold in color, and characterized by a mild walnut-like bouquet. Manzanilla is the palest and lightest of all fino sherry styles. Amontillado sherries begin their development as a fino, but partway through their development, the alcohol content is raised. They subsequently complete their maturation similar to an oloroso. This style is darker in color and often 1 to 3% stronger in alcohol content than a typical fino. Amontillados are also more full-flavored, with a clean, nutty bouquet. For export, they are usually slightly sweetened.

Oloroso sherries are the most oxidized of sherry styles. These sherries receive no flor protection and undergo minimal fractional blending. Thus, 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 melanoid pigments produced during the heat concentration of the sweetening juice. Cream sherries are amaroso sherries initially developed for the English market. Palo cortado and raya sherries are special oloroso sherries. They are more subtle and rougher versions, respectively.

Sherry-like wines are produced elsewhere, but 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 are likely to be similar. Most non-European sherries used to be baked, producing a caramelized character more typical of inexpensive madeiras. They were 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 nonrectified wine spirits (aguardente), retaining about half of the original grape
sugars. This produces a sweet wine with an alcohol content of about 18%. The addition of *aguardente* also contributes significantly to the wine’s fragrance. For example, the majority of the fusel alcohols, esters, benzaldehyde, and some terpenes come principally from *aguardente* (Rogerson and de Freitas, 2002). These constituents give *porto* much of its distinctive fragrance. Subsequent maturation defines the various port styles (Fig. 7.12). The blending of wines from various cultivars and locations produces the consistency required for the production of “house” brands. Although there are distinctive port styles, proprietary blends tend to typify port as much as they do sherries or sparkling wines.

Vintage-style ports are blended from wines produced during a single vintage and aged in inert or oak 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 2 years, the wine is bottled unfined. Consequently, the wine “throws” considerable sediment. It takes from 10 to 20 years before its famously complex aroma and bouquet are considered to have reached maturity. It can subsequently continue to age well for an indefinite period. Late-bottled Vintage Port (L.B.V.P.) is treated similarly but receives about 5 years’ maturation before bottling. By this time, most of the sediment has settled, eliminating the need for decanting that is required with Vintage Port. 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 (termed 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 the uptake of an oaky 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, which has lost most of its 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, or sweet styles, and 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 (*porto*). Most ports produced in North America are baked. Thus, they typically possess a madeira-like (caramelized) odor.
FIGURE 7.12 Flow diagram of port wine production.
Madeira

Fortification of madeira wine developed as a means of microbi ally stabilizing 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 (more than 40°C for up to 3 months). Maturation occurs in wooden cooperage for several years. To avoid giving the wine an oak 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 extensively blended and carry only a brand name. Despite these variations, the predominant factor that distinguishes madeira is their 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, wine has been used as a carrier for various medicinal herbs and spices. This presumably is the origin of vermouth. Fortification aided both its preservation and facilitated flavorant extraction.

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 proprietary secrets. After flavorant extraction, 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.

BRANDY

By definition, brandy is distilled wine. Brandies are produced in almost every wine-producing region, but the most well recognized come from two regions in southwestern France, Armagnac and Cognac. They are differentiated by geography, cultivar use, and the type of still used (Jackson, 2008). All brandies are aged in oak barrels, and wines from different lots
are blended to make the proprietary blends that typify the industry. The major brandy designations are based on a combination of the minimum age of the youngest distillate used and the minimum average age of the blend. Respectively, these are Three Stars (2/2 years); VO, VSOP (4/5 years); XO, Extra, Napoleon, Vieille Réserve, Hors d’Age (5/6 years).

Related distilled beverages, variously called marc (France), grappa (Italy), aguardiente or orujo (Spain), bagaceira (Portugal), and tsipouro (Greece) are derived from pomace-based wine. They can be more grapy or neutral flavored than brandies, depending on the degree for rectification during distillation. They tend to be rougher in character due to their shorter maturation period.

By tradition, brandies possess moderate levels of higher alcohols, generally in the range of 65–100 mg/liter (donating pungency), aldehydes and acetalts (supplying sharpness), oak lactones (furnishing a coconut fragrance), phenolic aldehyde derivatives from lignin degradation (providing vanilla and sweet fragrances), and ethyl esters of C8 to C12 fatty acids (appending fruity/floral notes). The oxidation and transformation of fatty acids into ketones and heat-derived furans and pyrazines generate caramel and roasted notes. Excessive amounts of low volatile constituents, such as ethyl lactate and 2-phenylethanol, tend to produce an atypical heavy flavor, whereas highly volatile constituents create sharp, irritating notes. Terpenes typically add their particular character only when Muscat cultivars are used as the base wine.

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acid and succinic acid in fermented alcoholic beverages are the stimulants of gas-
Inherent in all wine tastings is an exploration of quality. Reeves and Bednar (1994) consider that quality entails several factors. They are categorized as excellence, conformity with historical percepts, exceeding expectation, and relative monetary value. Thus, quality can be viewed as possessing both intrinsic (physicochemical) and extrinsic (price, prestige, context) aspects. Only the intrinsic factors have direct relevance to wine tasting. Nonetheless, extrinsic factors may be the more important to many consumers’ concept of quality (Hersleth et al., 2003; Verdú Jover et al., 2004) and purchase decisions (see Jaeger, 2006).

Understanding the chemical underpinning of quality is one of the principal purposes of sensory wine analysis. The major problem is the absence
of a clear concept of what constitutes wine quality. The perception of quality (like beauty) is highly subjective. Other than a few innate tendencies at birth (dislike of bitter and a liking for sweetness), human sensory responses are primarily dependent on experience, not instinctive reflex mechanisms. As a consequence, flavor preferences are potentially malleable and primarily culturally based. Thus, there are few absolutes relative to wine acceptability. Acquaintance and experience appear to be the predominant factors. For example, familiarity abets odor discrimination and often enhances perceived intensity and pleasantness [Distel and Hudson, 2001; Mingo and Stevenson, 2007]. Furthermore, repeat exposure often modifies consumer preferences, promoting acceptance [Köster et al., 2003]—thus, the oft expressed view that experience induces people to appreciate more complex wines. Although valid in some instances, it clearly is not a consistent sequel.

The various and changeable nature of what constitutes wine quality makes defining this enigma doubly difficult. For example, it is common to read wine critics complaining about overoaked Chardonnay. In addition, Hersleth et al. [2003] found that the consumers they assayed in California preferred unoaked Chardonnay. Nonetheless, two of the most popular brands of Chardonnay in the United States and Canada (Lindeman’s Bin 65 and Casella’s Yellow Tail) are distinctly oaked. There are probably as many concepts of wine quality as there are people. Stability in viewpoint is one of the principal advantages of trained versus consumer panels. Nonetheless, consistent response does not necessarily confirm validity or truth, any more than strong correlation assures causation.

For many consumers, quality is a reflection of their level of satisfaction, this often being associated with quality/price ratio. This influence has been observed at the neuronal level [Plassmann et al., 2008]. The more marked the perceived price differential, the greater was the difference in perceived pleasure. Surprise also appears to be a major element in enhancing pleasure [Berns et al., 2001]. Sampling a wine of quality, when it is not expected, can elevate enjoyment to ecstasy.

Effective marketing clearly affects how the brain responds to stimuli, even in the absence of clearly detectable sensory differences [McClure et al., 2004]. Cultural influences and the degree of sophistication may also override inherent sensory aspects, affecting both how a person views quality and its appropriateness. For many connoisseurs, quality becomes a reflection of their desires, such as affiliation with the wine’s historic and/or romantic heritage (e.g., a geographic region), a life style (e.g., food and wine combination), social status (e.g., prestigious estate), a sense of cultural identity (e.g., French, Italian), individuality and uniqueness of origin.
(e.g., *terroir*, estate bottling), refined living (e.g., port), physical and social warmth (e.g., Provence, Tuscany), relaxed elegance (e.g., Rheingau auslese), celebration (e.g., champagne), a social statement (e.g., association with the cognoscenti), or intellectual stimulation (e.g., incredible palette of flavors, complexities of geographic appellations). Wine can also provide exclusivity and pride of ownership. For such individuals, wine is not just a beverage, but a means of fulfilling a symbolic and/or psychological need (see Bhat and Reddy, 1998). That the wine may not live up to its expectation upon opening is often less important than the feeling derived during and after purchase. It may provide a form of “virtual reality.” These extraneous associations are not necessarily bad. They often amplify the appreciation and joy derived from a wine. I suspect these are the primary reasons why most people purchase and consume wine.

Appreciation is often highly influenced by context. For example, wine in the morning rarely seems appropriate, with the possible exception of champagne with breakfast. The latter is considered most civilized. Expectation also significantly influences how quality is perceived, as well as how people view its combination with food (Wansink *et al.*, 2007). At its most venerable, wine is an aesthetic experience (Charters and Pettigrew, 2005). As such, it is both sensual and ennobling.

Typically, objects considered to possess high quality are considered to be difficult to produce, obtain, or find. This often means that they are rare and expensive (possessing the attribute of exclusivity). For rarity to possess desirability, it must give the purchaser pride of ownership—being a recognized icon. Why else would wines from reputed estates command prices frequently out of all proportion to their absolute sensory quality? The desire for ownership can also develop into a compulsion: collection masquerading as economic investment (Burton and Jacobsen, 2001).

Objects of any sort, considered of high quality, normally possess attributes such as complexity, harmony, dynamism, development, duration, elegance, uniqueness, memorability, and most definitely pleasure. With wines, these elements are also associated with flavors that donate distinctive stylistic, varietal, and possibly regional attributes. These are the aspects that appeal most to true aficionados. Sensory quality is (or should be) independent of context and is most appealing when nothing is known about the wine. Even sampling in black wine glasses has its charm. It forces the connoisseur to focus solely on the wine’s sensory qualities.

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

In the popular press, most wine critics appear to agree on what constitutes wine quality. This has been interpreted as support for its reality (Goldwyn and Lawless, 1991). Alternately, the appearance of consensus may reflect no more than similar training, habituation to, and adoption of accepted norms. In contrast, Brochet and Dubourdieu (2001) found no evidence for a consistent view of wine quality, or at least how qualitative attributes were described. There is far too often genuflection to a few prominent “paragons” of prestige and tradition, and far too little to their actual sensory quality. In what other field would the ranking of products, developed more than one hundred years ago, be considered of any relevance today? The real damage of such condescension is that it hinders little-known but superior wines and winemakers from receiving the respect and just financial return they deserve.

**SOURCES OF QUALITY**

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. Human olfactory skills are rarely up to the task of recognizing the styles of individual winemakers. If the enologic equivalents of a Michelangelo or Mozart exist, their finesse largely goes unnoticed. Unfortunately, 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 are even more difficult to consistently recognize.
Grape cultivar use and production style are next in importance to wine quality (conformity to accepted paradigms). 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. It is not without reason that Pinot noir has been called the “heartbreak grape.” Production style more distinctly stamps its particular flavor profile on a wine. For example, red grapes can generate red, rosé, or white wines, 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 impacts 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, where any one is likely to reflect the influences of others. For example, wine produced from older vines of Cabernet Sauvignon are often considered to be more berrylike and possess less of a vegetal character (Heymann and Noble, 1987). However, this might simply be a consequence of the vine’s lower vigor and associated improved fruit light exposure. Because of their perceived greater quality, the grapes may also be given preferential treatment during fermentation and maturation.

In addition, caution must be taken not to overextend the relevance of existing scientific 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 previously was based on an analysis of twenty-one wines. Their results are consistent, though, with commonly held beliefs in the wine community.

VINEYARD INFLUENCES

Before the microbial nature of fermentation was discovered, wine quality was attributed to the soil and grape production procedures. Subsequently, the significance of winery technology dominated explanations of wine quality, at least in the New World. More recently, winemakers have returned to ascribing quality to what occurs in the field, possibly as a response to growing public distrust of technology, and a desire to distinguish their wines from the competition. In reality, both viticultural and enologic practice are of importance. In most instances, one would be hard pressed to say any
one factor was really more important than the other. Although the adage “one cannot make a silk purse out of a sow's ear” applies to wine, without skilled guidance, the finest grapes 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 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 stable, dry, table wines. However, modern viticultural and enologic procedures can offset many of the climatic conditions that once regulated regional wine production. Thus, no region or country can legitimately claim that it is preeminent in producing wine. Hopefully, we have outgrown this form of nationalistic narcissism. 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—what I have termed the soil-atmosphere microclimate (SAM). In the popular wine vernacular, this is termed “terroir.” Unfortunately, the term has been misappropriated and frequently imbued with elitist connotations that verge on the ludicrous or mystic—the terror of terroir. SAM is a more precise and an emotionally neutral term.

There is no doubt that the SAM of an individual vineyard or region will influence grape and wine chemistry. What is in doubt is whether the observed, minute, detectable changes in the concentration of trace elements (such as barium, lithium, and strontium) or the relative proportions of isotopes of carbon, oxygen, and hydrogen have a humanly detectable sensory significance.

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. Clayey soils, due to their huge surface area to volume ratio ($2$ to $5 \times 10^6 \text{ cm}^2/\text{cm}^3$), have an incredible water-holding capacity.
This means that the soil warms slowly in the spring (retarding vine activation), but provides extra warmth to the vine during the autumn (reducing the likelihood of damaging early frosts). However, the small average pore size of clayey soils can induce poor drainage. The result can be water logging during rainy spells, and the associated potential for berry splitting and subsequent rotting. Vineyard practices that augment humus content can increase soil drainage and aeration by promoting the development of a fine soil aggregate. Humus is also a major reserve of mineral nutrients. These are held loosely in a form 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. Thus, famous wine regions are as likely to be situated on geologically uniform (e.g., Champagne, Jerez, Mosel) as on geologically heterogeneous soils (e.g., Bordeaux, Rheingau). 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.

Studying variation in a vineyard plot is one of the central goals of what is termed precision viticulture. It offers the hope that vineyard uniformity may be increased by selective treatment or modification of particular plots. In addition, it presents the opportunity to selectively harvest parcels of the vineyard so that the grapes going to the winery are of more uniform maturity.

Viticultural practices, such as vine density and training system modification, affect light penetration and wind flow within and among vines. These influences can markedly affect fruit ripening, disease susceptibility, and flavor development. Each significantly adjusts 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 fruit. Sloped sites become increasingly significant the higher the latitude of the vineyard (providing 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 sunlight exposure 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 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 previously, 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 year has not been established. Vintage (or vine 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 differences when the wines are sampled individually. Nevertheless, there is considerable financial advantage to the implication that

**FIGURE 8.3**
sensory differences are detectable. It justifies the creation and promotion of appellations as indicators of uniqueness, if not quality. In reality, they are simply indicators of geographic origin, as are home addresses.

**Species, Variety, and Clone**

Conventional wisdom implies that only cultivars of *Vitis vinifera* produce wines of quality. Other species and interspecies hybrids, even possessing *vinifera* heritage, are viewed as unworthy of consideration. This prejudice provoked laws restricting the cultivation of interspecific hybrids in western Europe. This misguided decision partially arose from unfamiliarity with the “foreign” flavors occasionally associated with some interspecies hybrids. More significantly, it arose due to concerns about higher yield. Interspecific hybrids were contributing to the growing problem of excess wine production. The ill-considered nature of this insularity is evident when considering the quality of the *Chambourcin* wines from Australia, and the fine *Maréchal Foch, Vidal blanc, Cayuga White,* and *Traminette* wines produced in North America. They are an example of the heights attainable 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 they could produce. Their non-*vinifera* aromas also conflicted with the sensibilities of those habituated to *vinifera* wines. Thus, habituation has been a major hindrance. The aroma intensity of cultivars such as *Concord, Catawba,* and *Niagara* has also been claimed to be a negative attribute. However, if this were so, then *vinifera* cultivars such as *Gewürztraminer* and *Muscat* should be equally 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 originated from favorable climatic and socioeconomic 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 finer wines. With expansion of the
British Empire, 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 fare equally well, either climatically or socioeconomically. Thus, their equivalents of Cabernet Sauvignon, Riesling, and Chardonnay are largely unknown, except locally. In addition, how many distinctive variations can be produced from the major, so-called premium cultivars? Other cultivars could provide added interest to stimulate what is a relatively stagnant sales situation worldwide, at least at the upper end of the market. Increased cultivar variety may, however, be counterproductive at the lower end of the market. It would add further to consumer confusion. The current bewildering array of wines, so similar as to be essentially identical, is already bad enough. Increased consumer confusion would undoubtedly depress wine sales, not augment it (Drummond and Rule, 2005). The mental paralysis many consumers experience in wine stores is an example of what has been termed “Gruen transfer”—named after Victor Gruen, the architect who created the concept of the shopping center.

Most cultivars exist as a collection of clones, forms genetically identical in all but a few mutations or epigenetic factors. Occasionally, these differences significantly influence winemaking potential by directly or indirectly affecting fruit flavor. For example, certain clones of Chardonnay possess a distinct muscaty character, whereas particular clones of Pinot noir are better for champagne than red wine production. Clones can also differ significantly in yield. Until recently, growers typically planted a single clone. This is beginning to change as winemakers search for new ways to increase aromatic complexity. This feature could potentially add 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 (except for an unexplained slight decline between the 1950s and 1980s).

**Rootstock**

Rootstocks produce the root system of grafted vines. Although vital to the growth of the fruit-bearing portion of the vine (scion) in many viticultural regions, rootstocks seldom receive the public acknowledgment of the importance they deserve—a case of “out of sight, out of mind.” Nonetheless, they
affect vine vigor (and thereby, the vine's potential to ripen its fruit), as well as influence 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 effective means of combating the ravage being caused by the phylloxera infestation. 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.

**FIGURE 8.4**
Time series of (A) grape yield and (B) must quality of Riesling at Johannisberg (Rheingau, Germany) from 1893 to 1993 (from Hoppmann and Hüster, 1993, reproduced by permission).
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 the tendency for grape sugar (noted as potential alcohol content) to decline as yield increases. Although enhanced flavor is inherently beneficial to wine quality, the benefits of increased aroma may eventually be offset by an 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 the 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, vines excessively pruned (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. These
observations 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 (vigor).

Central to most new training systems has
been the division of large vine canopies into sev-
eral, smaller, separate canopies (canopy manage-
ment). The resultant increase in water demand
limits mid-season shoot growth. Judicious use of
shoot topping and devigorating rootstocks further
helps to restrict mid- to late-season vegetative growth. The division of the
canopy into several smaller, thinner canopies opens the fruit to increased
sun and wind exposure, both tending to favor early and complete fruit ripen-
ing. Figure 8.7 illustrates how improved sun exposure can reduce excess
fruit acidity. This means that increased fruit yield need not be associated
with reduced fruit quality. Although improved light exposure may enhance
fruit coloration in red grapes, this is often variety dependent and may not
necessarily be reflected in a more intensely colored wine. Fruit shading,
however, appears to lessen the flavor potential of the resultant wine.

High-density planting (common in Europe) is an older alternative, tend-
ing to achieve the same results as modern, canopy-management, training
systems. Table 8.1 illustrates the value of high-density planting on color


**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).

<table>
<thead>
<tr>
<th>Plant Spacing (m)</th>
<th>Vine Density (vine/ha)</th>
<th>Leaf Area (m²/vine)</th>
<th>Leaf Area (cm²/g grape)</th>
<th>Yield (kg/vine)</th>
<th>Yield (kg/ha)</th>
<th>Wine Color (520 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 × 0.5</td>
<td>20,000</td>
<td>1.3</td>
<td>22.03</td>
<td>0.58</td>
<td>11.64</td>
<td>0.875</td>
</tr>
<tr>
<td>1.0 × 1.0</td>
<td>10,000</td>
<td>2.7</td>
<td>26.27</td>
<td>1.03</td>
<td>10.33</td>
<td>0.677</td>
</tr>
<tr>
<td>2.0 × 1.0</td>
<td>5000</td>
<td>4.0</td>
<td>28.25</td>
<td>1.43</td>
<td>7.15</td>
<td>0.555</td>
</tr>
<tr>
<td>2.0 × 2.0</td>
<td>2000</td>
<td>4.0</td>
<td>15.41</td>
<td>2.60</td>
<td>6.54</td>
<td>0.472</td>
</tr>
<tr>
<td>3.0 × 1.5</td>
<td>2222</td>
<td>4.5</td>
<td>18.01</td>
<td>2.50</td>
<td>5.51</td>
<td>0.419</td>
</tr>
<tr>
<td>3.0 × 3.0</td>
<td>1111</td>
<td>6.3</td>
<td>15.36</td>
<td>4.12</td>
<td>4.57</td>
<td>0.438</td>
</tr>
</tbody>
</table>

aData from Archer and Strauss, 1985; Archer, 1987; and Archer et al., 1988.
density. However, these benefits come at considerable development and maintenance costs. Canopy management is a more economic means of 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 pruning need. Partial rootzone drying is a 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 an adequate water supply. The consequence is the production of an abundant fruit crop that ripens fully.

A new and apparently better relationship 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 an LA/F of about 10 cm²/g. 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 ultimate 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,
improved fruit health (reduced incidence of infection) and cluster location facilitates economic mechanical harvesting. These features both enhance quality and decrease production costs.

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 year’s 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 do so well. These systems not only achieve a desirable LA/F ratio, but also provide improved grape exposure to light and air. These features promote ideal berry coloration, flavor development, fruit health, flower-cluster initiation, as well as long-term vine health.

**Nutrition and Irrigation**

In the popular literature, stressing the vines is often viewed as promoting fine wine production. This view probably arose from the reduced-vigor, improved-grape-quality association found in some renowned European vineyards. However, as noted previously, balancing vegetative and fruit-bearing functions is the ideal goal. Exposing the vine to extended periods of water or nutrient stress is 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 yearly nutrient demands of grapevines are surprisingly small (partially due to the nutrient reserves of the vine’s woody parts), deficiency symptoms may not express for several years. In addition, establishing soil nutrient availability (versus simple presence) is still an inexact science.

Irrigation, as noted earlier (partial rootzone drying), can be used to regulate vine growth and promote optimal fruit ripening. Irrigation water can also supply nutrients and disease control chemicals directly to the roots, in precisely regulated amounts, and at specific times. These possibilities
are most applicable in arid and semi-arid conditions, where most of the water comes from irrigation.

Disease

It is not glamorous to contemplate disease as a component of wine quality, but its absence is certainly a necessity. With most diseases, however, exactly how it depresses fruit quality is little known. An exception is in the case of powdery mildew. It donates a bitterish attribute and other flavor modifications (Stummer et al., 2005). These effects were enhanced with increased maceration prior to or during fermentation. Some of these changes may result from the conversion of several ketones to 3-octanone and (Z)-5-octen-3-one (Darriet et al., 2002).

Only in one instance can a grape disease occasionally be considered a quality feature. This occurs under conditions of cyclical alternating sunny days and humid cloudy evenings in the autumn. Under these climatic conditions, Botrytis cinerea, a normally destructive pathogen, concentrates grape constituents and synthesizes its own special aromatics. This is termed “noble rot.” Grapes so affected produce some of the most expensive, luscious, white wines available. Examples are German ausleses, beerenausleses, and trockenbeerenausleses, and French sauternes (Fig. 7.4).

Although not a direct consequence of pathogenesis, the application of protective chemicals may indirectly affect wine quality. For example, the copper used in Bordeaux mixture can compromise the quality of Sauvignon blanc and related cultivars. It can reduce the concentration of important varietal thiol aroma compounds, such as 4-mercapto-4-methylpentan-2-one. This effect can be reduced by prolonged skin contact (Hatzidimitriou et al., 1996), or by limiting the application of Bordeaux mixture (Darriet et al., 2001). Even the chemicals used in organic viticulture are not devoid of detrimental effects. Various soaps and oils can contaminate wine with off-tastes or off-odors, and sulfur can seriously damage leaves and increase the incidence of some insect pests.

Maturity

Most vineyard activity is designed to promote optimal fruit maturity. Once this maturity is achieved, the grapes are normally harvested and processed into wine. Measuring optimum maturity is, however, far from simple. Maturity can be estimated by grape sugar or acid contents, their ratio, color intensity, or flavor characteristics. 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 cannot be
directly augmented. The only accepted methods of their adjustment relate to procedural or enzymatic techniques that enhance pigment extraction or the volatility of existing flavorants. Thus, there would be considerable interest if color or flavor intensity could be used as measures of grape maturity. However, fermentation and maturation conditions so affect color development and stability that no direct relationship exists between fruit and wine coloration. For Muscat and related grape varieties, the presence of monoterpenes 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 juice glycosyl-glucose content. 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 made, 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. 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 practical and aesthetic skills. As such, no two winemakers produce identical wines. Each person brings to the process the culmination of his or her experience and concepts of quality. How well these are transformed into wine defines the difference between the skilled technician and the creative artisan.
Increasingly, the winemaker is in frequent contact with the grape grower. The interaction helps supply the raw materials the winemaker needs, as far as nature permits. Depending on the characteristics of the grapes reaching the winery, the winemaker must make decisions on how to transform the grapes into wine. Figure 8.10 illustrates the basic sequence of events involved in this metamorphosis. None of the stages are without choices, the selection 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 in the following sections.

Prefermentation Processes

Typically, grapes are crushed immediately upon reaching the winery. This allows the juice to escape and disrupts the integrity of the grape cells. This is essential for the release of flavorants into the juice. It also liberates hydrolytic and 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 subsequent oxidation, by activating the expeditious oxidation and precipitation of readily oxidized phenolics. Thus, most winemakers allow air access during crushing or aerate the juice after crushing. This enhances the shelf-life of white wines, as well as encourages 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 (pomace) 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. An example of the close correlation between wine pigmentation and quality is illustrated in Figure 8.11. Skin contact also favors a quick onset and completion to fermentation, but also alters the synthesis of yeast-produced aromatics. Thus, the fundamental character of a wine is partially determined by the timing and duration of maceration, as well as the temperature at which maceration occurs (Fig. 8.12).

The next major process affecting wine quality is pressing—separation of the juice from the seeds and skins. Ideally, this should occur with minimal incorporation of particulate matter (cellular debris and macromolecular complexes). This is achieved by applying pressure over as large a surface area as is practical. Most modern presses are elongated, horizontally positioned, cylindrical chambers. Pressure is applied either via air pumped into a membranous bladder against the must (juice, seeds, and skins) or by plates that move in from one or both ends. The older, basket-type presses were positioned vertically and had pressure applied by a plate from the top only. The gentler pressure applied by the new presses liberates juice that is less bitter and astringent, but proportionally richer in varietal flavors. In contrast, the older presses produced rougher tasting wines with less fruit flavor. Frequently, grape stalks were left to produce drainage channels that facilitated the drainage of the juice.

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 with quality concerns. Most clarification procedures have little effect on wine quality, if not used to excess. Because pressing in red wine production occurs at or near the end of fermentation, rapid clarification is rarely a critical issue. Correspondingly, clarification of red wines is initially by gravity-induced sedimentation.

If the sugar and acid composition of the juice is unavoidably inferior, the winemaker usually attempts to make adjustment. The addition of sugar and/or the addition of acidity (or its neutralization) can improve the basic attributes of the wine. It cannot compensate for a lack of color or flavor, though. As noted earlier, these desirable qualities frequently develop concomitantly with desirable 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 (economies of scale). However, small producers may choose fermentation in small (~250 liter) oak barrels, especially for lots of high-quality juice. Those who favor this option justify the expense by the “cleaner” (less fruity) expression of the wine’s varietal aroma. In addition, in-barrel fermentation can modify the aromatics produced by the fermenting yeasts, as well as those extracted from the oak. These differences alone can donate features that distinguish wines from adjacent properties.

For the majority of white wines, fermentation occurs in structurally simple tanks. These are preferentially made from inert materials, notably stainless steel. This permits transformation of the juice into wine without compromising the grape’s natural flavors. Red wines are also frequently fermented in inert tanks. However, they vary considerably more in design that 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 this 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 fermentors commonly possess several blades attached to a central cylinder that slowly rotate, gently mixing the seeds, skins, and juice. This process 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."

**Yeast**
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 yeast strains (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 concentrations 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 strain choice can be more than just subtle (Figs. 8.13 and 8.14).

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.

**Lactic Acid Bacteria**
Most wines undergo two fermentations. The first, yeast-induced fermentation, generates the alcohol and vinous bouquet that characterize wines. The second, bacteria-induced fermentation, converts malic into lactic acid, reducing wine acidity. This alone can modify the wine's perception. However, byproducts released by bacterial metabolism further modify the wine's flavor (Fig. 8.15).
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, 2b, VL-1; 4a, 4b, K1; 5a, 5b, CEG (from Dumont and Dulau, 1996, reproduced by permission).

Malolactic fermentation 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 wines low in pH, winemakers frequently inoculate their wines with one or more desirable strains (typically of *Oenococcus oeni*). As with yeast strains in alcoholic fermentation, bacterial strains differ considerably in aromatic impact. Figure 8.16 illustrates the sensory effects potentially induced by

**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).
different strains of *Oenococcus oeni*. From the divergence of opinion shown in Fig. 8.16, it should be no surprise that there are strong and diverse opinions concerning the relative merits of malolactic fermentation.

**Postfermentation Influences**

**Adjustments**

Ideally, a wine should require only minimal clarification, such as spontaneous settling and gentle fining before bottling. However, if the wine is bottled early, is imbalanced, or possesses some fault, additional treatment(s) will be necessary. Nevertheless, such treatments should be kept to a strict minimum. Most forms of adjustments 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 every wine. It can vary from the simple mixing of wine from different tanks to the complexities of combining wines produced from different cultivars, vineyards, or vintages. For several wines, notably sparkling, sherry, and port, complex blending is central to their quality and brand distinctiveness. In other regions, blending wines made from several grape varieties supplies their traditional character (e.g., Chianti and Bordeaux). Blending tends to enhance the best qualities of each wine, while diminishing their individual defects. Figure 8.17 illustrates the general benefits of blending. It shows that blends between wines of roughly similar character and quality were considered as good or better than their components.

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 quality. Whether this is valid depends more on the skill of the producer and grape maturity than its 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. Thus, marketing explains most of the appeal of estate-bottled wines.

**Processing**

An old processing technique receiving renewed attention is *sur lies* maturation. The process involves leaving white wine in contact with the lees (dead and dying yeast cells) for an extended period. Usually, lees contact occurs in the same container (usually a barrel) as did fermentation. *Sur lies* maturation can enhance wine stability and increase flavor complexity. 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. They include the species of oak used [Fig. 8.20], the conditions under which the trees grew [Chatonnet, 1991], the method of wood seasoning [Chatonnet *et al.*, 1994], the degree of “toasting” [heat applied

![FIGURE 8.18](image-url) 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 permission).

FIGURE 8.20 Polar coordinate graph of mean intensity ratings and least significant differences (LSD) for descriptors by oak origin ($n = 14$ judges $\times$ 3 reps $\times$ 6 samples) (from Francis et al., 1992, reproduced by permission).
during barrel construction, and number of times the barrel has been used (Fig. 8.21). Each aspect modifies the attributes contributed by the oak. The intensity of these aspects can be partially regulated by the duration of 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.

**Bottle Closure**

For several centuries, cork has been the exclusive closure for wine matured in barrel or in bottle. In this role, cork has several distinctly desirable properties. They include compressibility (with little lateral expansion for ease of insertion), elasticity (rapid return to its original shape after compression), resilience (prolonged exertion of pressure after insertion), chemical inertness (notably to wine acids and alcohol), imperviousness to most liquids and slow diffusion of gases, and a high coefficient of friction (adheres well to surfaces). Thus, it normally provides a long-lasting, tight seal that limits contamination and the loss of aromatics. Most cork stoppers possess a permeation barrier of about 300 to 500 cells/cm along their length. Because of the direction in which stoppers are removed from the bark, the principal porous regions of the cork (lenticels and crevices) are positioned at right angles to the stoppers’ length (Fig. 8.22).

Nevertheless, the dominance of natural cork is being challenged by alternatives. This has arisen due to variations in cork quality (difficult to assess visually) that can affect its protective function. Seemingly random examples
of premature wine oxidation in bottled wine may result from cork faults that permit excessive ingress of oxygen. In addition, cork bark may become contaminated in the forest, during stopper manufacture, or shipping and storage with compounds that donate off-odors. The most well known of these is 2,4,6-trichloroanisole (TCA). In addition to being a potential source of off-odors, cork can also scalp (absorb) aromatics from the wine. Alternatives to natural cork for bottle closure include agglomerate cork, synthetic cork, and roll-on (screw) caps.

Premium quality cork possesses sealing qualities equivalent to screw caps but progressively loses its elasticity. Thus, its sealing properties eventually fail. The deterioration progresses outward, from the end in contact with the wine. Thus, the length of the cork is an indicator of how long it is likely to effectively seal the wine.

A factor little recognized for its importance to sealing quality is the rate at which the cork tissue grew. Cork from trees that grow slowly contain a higher proportion of resilient spring-grown cork (and correspondingly show more annual growth rings—Fig. 8.23). Thus, cork derived 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 a few months to several years, before considered to show progressive and irreversible deterioration (Fig. 8.24). Thus, unless one prefers these largely oxidative changes, most wines are appreciated more with limited aging.

During the initial stages, loss of yeasty odors, excess dissolved carbon dioxide, and the precipitation
of particulate material lead to sensory improvements. Additional 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 subsequently become lighter and take on a ruby and then brickish hues. 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 (Fig. 8.25), respectively. Without polymerization, anthocyanins fairly rapidly oxidize, and the wine permanently loses 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 or other conditions during maturation, have been suggested to enhance anthocyanin-tannin polymerization. Age-related color changes in red wines are often measured by changes in optical density 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 probably involves a combination of phenolic oxidation, metal ion-induced structural changes in

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1Compare the slow change observed in Fig. 8.25 (anoxic reducing conditions) to the more rapid changes seen in Fig. 2.1 (mild oxidizing conditions in large oak cooperage).
galacturonic acid, Maillard reactions between sugars and amino acids, and 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 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 8.26 illustrates the decline in fruit esters (e.g., isoamyl acetate) and the increase in poorly volatile carboxylic acid esters (e.g., diethyl succinate). Oxidation of 3-mercaptohexan-1-ol is one of the principal reasons for the short shelf-life of most rosé wines (the loss of its fruity fragrance) (Murat, 2005). Wines are considered to age well when the varietal character develops (e.g., Riesling), or when it is replaced by a subtle, complex bouquet. In red wines, the aged bouquet (if it develops) often has a similar character, regardless of cultivar origin.

The exact origin of an aged bouquet is unknown. However, it likely involves the 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 an aged bouquet. Table 8.2 illustrates a few age-related chemical changes that

![FIGURE 8.26](image.png)

Examples of the influence of wine age on the concentration of esters, notably acetate esters (isoamyl acetate) and ethanol esters (diethyl succinate) (from Jackson, 2008, data from Rapp and Güntert, 1986, reproduced by permission).
can occur in Riesling wines. The table also demonstrates the importance of temperature to the aging process, as does Fig. 8.27.

Carbohydrate degradation products, notably brown Maillard products, develop 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

<table>
<thead>
<tr>
<th>Substance from Carbohydrate Degradation</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Furfural</td>
<td>4.1</td>
</tr>
<tr>
<td>2-Acetylfuran</td>
<td>–</td>
</tr>
<tr>
<td>Furan-2-carbonic acid ethyl ester</td>
<td>0.4</td>
</tr>
<tr>
<td>2-Formylpyrrole</td>
<td>–</td>
</tr>
<tr>
<td>5-Hydroxymethylfurfural (HMF)</td>
<td>–</td>
</tr>
</tbody>
</table>

aData from Rapp and Güntert (1986).

bRelative peak height on gas chromatogram (mm).

FIGURE 8.27 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).
etherification of Maillard-generated alcohols may play a role in the development of aged bouquets.

The concentration and nature of reduced-sulfur compounds often change during aging. Of these, only dimethyl sulfide has been correlated with development of a desirable aged aspect (Fig. 8.27D). Its addition to wine (20 mg/liter) can enhance its flavor score (Spedding and Raut, 1982). Higher concentrations (~40 mg/liter) were considered detrimental. By itself, dimethyl sulfide has a shrimp-like odor. Occasionally, the production of dimethyl sulfide is so marked at warm temperatures that it can mask 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, though, these polymers become so large that they lose their ability to effectively bind to proteins. This produces the well-known smoothing of the taste of red wines after moderate to prolonged aging. A summary of potential chemical modifications in wine during aging is illustrated in Fig. 8.28.

Other than the initial benefits of aging noted earlier, older wines do not necessarily show greater quality than their younger versions. Younger versions demonstrate more fruitiness and a truer expression of their varietal character. As the wine ages, the fragrance tends to become more subtle, less intense, less varietal, and develops more of an aged aspect. Descriptors for the aged character of wines occasionally include such expressions as “hay,” “honey,” “truffle,” and “leather.” It depends on personal preference whether the young aroma, mature character, or aged bouquet is more esteemed. They are certainly different but can be equally enjoyable. The principal feature that gives old wines their major appeal is not superior quality but rarity. Thus, unless consumers do the aging themselves, only a few individuals (usually the wealthy) have access to aged wines. Very old wines tend to be of greater historic than sensory 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 encourage longer aging. The personal relevancy of the advice can be established only by experimentation.

Aging Potential
Currently, the sources of a wine’s aging potential remain speculative. It is usually considered that such potential is a partial function of alcohol, sugar,
and tannin contents. Increases in any of these constituents are thought to augment aging potential. As a consequence, the maturity and health of the grapes are as important as the conditions during and after fermentation. Varietal origin is also considered important. This is especially so with varieties that depend on terpenes or yeast-generated ethyl and acetate esters. As noted, both tend to degrade comparatively rapidly during bottle aging. Thus, most white wines with little distinctive aroma do not age well, nor do Muscat varieties, Viognier and Gewürztraminer (all depending primarily on monoterpenes for their fragrance). Riesling is a clear exception to this generality. In contrast, most red wines can age considerably longer. Nouveau-style wines such as Beaujolais are the major exception. Surprisingly, there have been almost no studies on the chemical changes in the fragrance of red wines during aging.

Although variety is certainly important to aging potential, how the wines have been made and stored is equally important. Cool storage temperatures dramatically slow the effects of aging (Fig. 8.27). Although aging is considered optimal at about 10°C, this may simply reflect habituation to the events that occur at temperatures typical of underground cellars in Europe.

Unfortunately, consumers rarely have the opportunity to investigate these factors personally. For them, they must depend on extrinsic factors. These typically involve the wine’s price, as well as the repute of the vintage, winery, region, and producer. For additional “precision,” there is the plethora of books, magazines, and newspaper articles extolling the virtues of wines and their aging potential. Another indicator, suggesting the views of the winemaker, is the length and quality of the cork used to seal the wine (or now the use of screw caps). It is the common view, but with little direct experimental support, that the better the wine is sealed (minimal oxygen ingress), the better the aging potential.

Whether aging can be effectively accelerated is a moot point. Heating promotes some aging reactions, but it also activates others that are generally viewed as detrimental (Singleton, 1962). Several commercial products supposedly produce the effects of aging within minutes. Except for magnets, they appear not to have been subjected to scientific scrutiny. It the case of magnets, the results did not verify the claims of the producer (Rubin et al., 2005). Patience and time are the only known effective procedures.

**CHEMISTRY**

Ultimately, the quality of wine is dependent on its chemistry. With more than 800 organic constituents known to be present in wine, that chemistry
is obviously complex. Nonetheless, 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 fifty in any particular wine. Of these, only a few groups, notably sugars, alcohols, carboxylic acids, and phenolics, affect the sensory attributes of essentially all wines.

Ritchey and Waterhouse (1999) conducted a fascinating analysis of the chemical differences between high-volume and ultra premium Cabernet Sauvignon California wines. The most marked differences were in phenolic content. Ultra premium versions showed about three times the concentration of flavonols, with cinnamates and gallates being about 60% to 70% higher. Ultra premium wines were also more alcoholic (14.1 versus 12.3), but lower in residual sugar and malic acid contents.

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. Thus, 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, the chemical origin of phenomena termed “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.
SUGGESTED READINGS


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Wine and Food Combination

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INTRODUCTION

Food and wine pairing is primarily the prerogative of the sommelier and wine aficionado. Nonetheless, it behooves the wine professional to understand this association. Winemakers need no reminder that their wines should be compatible and preferably be ideally suited to consumption with food. The view that wine is primarily a food beverage is traditional in many European cultures. More recently, this view has become widespread, being adopted by much of the developed world. The profusion of books on the subject confirms the degree of interest in the subject. The intensity of this
interest may be similar to the attention given wine pundits in the popular press. The presence of hundreds of essentially identical wines and variation from vintage to vintage cause confusion. Consumers are searching for direction as what to buy and with what to pair it. The mental paralysis elicited from the overwhelming selection of wines is well known. Consternation and risk aversion are recognized as major impediments to restaurant wine sales (see Wansink et al., 2006).

The interest in food and wine pairing probably also relates to how wine can donate a sense of elegance to even a simple meal. However, it seems that many consumers are unaware that most wines combine surprisingly well with food. It is rare that any combination is a “failure.” The relation between food and wine is equivalent to

“When I’m not near the girl I love, I love the girl I’m near.”

from Finian’s Rainbow

This should not be too surprising. Most people make food (and presumably wine) decisions based on a few, personally significant criteria (Scheibehenne et al., 2007).

The simplest guide to selection is to choose a wine equivalent to the quality and flavor intensity of the meal, the importance of the affair, and your mood. This usually equates to the more significant or celebratory the occasion, the more expensive the wine. Wines of higher price are usually of finer quality, possessing more marked and distinctive flavors. Unfortunately, there is no direct relationship between price and quality.

For the wine aficionado, the goal is more than just compatibility: it is achieving a seraphic duet. The perfect marriage of food and wine is often viewed as the quintessential vinous experience. Wine becomes a liquid salve for the soul. This view is, however, in conflict with the frequent observation that the best wines express their finest qualities when sampled alone. Science cannot help in selecting wine based on context, but it can begin to provide an explanation of some food and wine pairings.

However, in the search for that paradigm of synergies, the basic rationale for wine and food combination is often forgotten. This is reducing the inebriating influence of wine’s alcohol content. The consumption of wine with food slows the uptake of alcohol in the intestinal tract. Thus, the liver is better able to limit blood alcohol content by its metabolizing of ethanol (blood from the intestinal tract first passes through the liver before circulating to the rest of the body). Although timing of the peak blood alcohol content is unaffected (about 30 min after consumption), it is only about 40% of what it would have
been had the wine been taken on an empty stomach. In addition, the cumulative blood alcohol content is limited to about a third (Fig. 9.1).

Most comments concerning food and wine pairing revolve around generalities such as white wines with fish or poultry, and red wines with red meats. The lighter, floral/fruit fragrances and acidic nature of most white wines seem to agree more with the milder flavored attributes of fish and poultry. In contrast, the fuller jammy flavors and tannic features of most red wines seem more suited to the more intense flavors of red meats. However, in reality, it is often the intensity and characteristics of the food preparation and seasoning that are more critical to matching flavor intensities. Fish boiled versus broiled are markedly different in flavor. Adding pepper or curry to a meal has an equivalent effect. More detailed suggestions often consist simply of personal recommendations. Rationales for these opinions are rarely if ever given. Although useful in a “paint-by-number” approach, such rationales provide little understanding on which to base future pairings. Suggestions by Harrington (2007) are a start, but make the issue unduly complex. Few people have, or need, the detailed knowledge of the wine or food flavor characteristics he expects. In addition, these features frequently vary from producer to producer, from year to year, and with aging. Thus, without personal experience with the options available, it is often
impossible to predict how well any of the wines might pair with a particular meal. Furthermore, when rationalizations are noted, the terms used are often too personal, nebulous, and variable to be of value. If the situation were not already complex enough, the sensory characteristics of food and wine change in the mouth. A clear example of the evolution of food flavor during consumption is found in Grab and Gfeller (2000).

Although consumers are generally ill-equipped to understand sensory terminology, it would be useful if food and wine writers abetted the educational process by adopting terms with precise and definable meanings. In addition, there has been regrettably little attempt to offer evidence for claims such as: wine acidity and tannins “cutting” through fats (presumably reducing perception); that fatty foods “smooth” (presumably reduce) the perception of tannins; or that the saltiness of cheese “contrasts” with the sweetness of dessert wines. Furthermore, statements that tannins “cut” through animal fats more than wine acids, and that wine acids “cut” better through vegetable-based fats need more than just anecdotal comment. Without serious investigation, it is impossible to differentiate between these views as sensory illusions or reality. Doubts about the applicability of these claims also arise when mildly tannic Pinot noir wines can be suggested to pair particularly well with the fattiness of Pacific salmon (Harrington, 2007, p. 85). One also has to wonder about the validity of comments that food and wine flavors combine well when they either complement or contrast (Harrington, 2007, p. 188). This leaves only neutrality as incompatible. This seems far too simplistic to be of practical use.

Nevertheless, food chemistry can start to formulate reasonable hypotheses for some of the views expressed in the popular press. For example, acid stimulation of trigeminal receptors in the mouth may suppress the perception of fats. Conversely, a thin coating of fatty acids would likely limit the access of hydrogen ions to taste receptors on the tongue, and the access of astringent tannins to trigeminal receptors in the mouth.

More disappointing than unsupported rationales are suggestions based on an implied hierarchy of wines. Suggestions such as the pairing of simple foods with humble Beaujolais smacks of elitism. Are popular or fruity wines inherently humble, whereas expensive wines automatically exquisite? This type of pejorative attitude has far too long given wine connoisseurship the perception of snobbism that is as deplorable as it is inappropriate. Many of the popular expressed opinions clearly reflect habituation. Responses to oronasal stimuli are largely experience based. What is considered palatable starts to evolve in the womb (based on what the mother eats), develops primarily during early childhood, and is adjusted (refined?) later in life. The strength of such entrainments is indicated by the correlation
between the “loss” in mint flavor of chewing gum and declining sugar content (the menthol content remains almost unchanged) (Davidson et al., 1999). The flavor “returns” when the sugar content is augmented. In addition, the intensity of garlic (diallyl disulfide) and mushroom (1-octen-3-ol) flavors are more dependent on perceived saltiness than their release from test solutions (Cook et al., 2003b).

Culture is the primary director of food preferences (Chrea et al., 2004). Although unconfirmed, the same is likely to be equally true for wine. Humans evolved as omnivores, capable of living on anything that is nourishing and nontoxic. We have few inherent likes or dislikes (Rozin and Vollmecke, 1986). Examples are the universal appreciation of sweetness and the smooth texture of creams, and the initial aversion to bitter and acidic tastes and oral irritants. Most of these responses undoubtedly have evolutionary justification. For example, the appreciation of the mouth-feel of creams and oils probably relates to their high caloric value. In contrast, the typical aversion to bitter and irritant compounds involve a protective adaptation. 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. Phytotoxin destruction was also one of the principal early advantages of fire production and cooking. It expanded the paleolithic human food supply. The heat-induced hydrolysis of proteins and starches not only made meat and tough grains more palatable, but also increased the sweetness of vegetables, by releasing sugars from starch molecules. The negative response to sourness is also likely an ancient, evolved, protective reflex. However, humans are highly adaptive and can develop a passion for sensations initially disliked and inherently unpleasant (see Moskowitz et al., 1975; Rozin and Schiller, 1999). Even people hypersensitive to certain irritants can come to appreciate and seek out painful sensations, for example, the burning aspect of capsicum peppers. Cultural norms can also change with surprising speed—for example, the rapid adoption of hot spices in North American cuisine over the past twenty-five years. Thus, 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 pairing, availability and personal upbringing are the primary defining factors. Subsequently, peer pressure may modify these preferences in an attempt to achieve social respectability.

Despite these major influences, genetic factors clearly influence individual preferences. For example, tasters of the bitter compounds phenylthiocarbamide (PTC) and 6-n-propylthiouracil (PROP) are more likely than nontasters to reject bitter foods and beverages (Drewnowski et al., 2001), experience a heightened oral burn with capsaicin (Karrer and Bartoshuk,
1995], and are more sensitive to the irritation of high concentrations of ethanol. Other genetic factors affecting flavor sensitivity (and presumable food preferences) include the relative number of fungiform papillae on the tongue (hypo-, average, and hypertasters), and specific anosmias. Genetic sensitivity to aromatic compounds is another important factor in food and beverage selection. Figure 9.2 illustrates an example of differences in individual sensitivity to the most important aromatic compound in black pepper (rotundone). In the figure, the threshold concentration was assessed in red wine, in relation to a study on the importance of rotundone to the peppery aroma of Shiraz wines. Rotundone occurs in black pepper at concentrations in the range of 1200 ng/L.

After initially attempting to eat almost everything, children usually develop neophobia—a distrust of new foods. Its inactivation can take decades. Acceptance often depends on familial example and/or peer pressure. For example, people usually find wines sour, bitter, and astringent on first exposure. In the absence of negative consequences, social factors can mollify food and beverage preferences. It is this experience-based learning, and availability, that generates cultural norms.

Despite wine’s long association with food, there seems little inherent logic to this association. It is undoubtedly as culturally based as the acceptance of sweet and sour combinations in Chinese cuisine, chili peppers in Mexican cooking, and a preference for sour and bitter tastes in the Karnataka region of India (Moskowitz et al., 1975). Certainly, the appreciation of innately unpalatable food items, such as chili pepper, horseradish, mustard, bitter chocolate, black coffee, burnt and acidic foods are cultural based.
Likes are also highly context sensitive (Hersleth et al., 2003). For example, one may like both table and dessert wines, but certainly not with the same foods, or even time of day.

Most discussions of food and wine pairing concentrate on some ideal marriage of flavors. In reality, this is only one aspect of the topic. At one end of the spectrum are incompatible associations—in which either (or both) the food or the wine accentuates unpleasant aspects of the other. For example, highly alcoholic wines may undesirably enhance the spiciness of a dish, whereas the sweetness of a dessert augments the sourness of a wine. Such combinations are the only true food and wine mismatches. Other associations can range from being neutral, to refreshing, harmonious, or rapturous.

It is likely that the majority of food and wine combinations are of the neutral type. This is not necessarily because there is no interaction, but because people do not take the time to think about the association. This certainly seems to be the frequent case in cultures where wine is the standard food beverage. Wine is given little thought, being simply the traditional fluid that rinses and refreshes the mouth between food samples. Where a diversity of foods is being served at the same time, such as a buffet or potluck, choice of a neutral to mild-flavored wine is probably preferable. Most restaurant house wines are of this genre. They are unlikely to offend the sensibilities of those unfamiliar with wine, are relatively inexpensive, and always available. The pairing of local wines with regional cuisines has more to do with habituation, ready availability, and low price than any conscious attempt of chefs and winemakers to match their respective products. Even for connoisseurs, most wine consumption is probably sampled more-or-less unconsciously. It is not often in our rushed life that we have time to actually savor our food and wine. It is a reality of modern life. Even in a restaurant, most people are more interested in the conversation than the food or wine (as long as they are acceptable and unoffensive).

When the pairing is harmonious, but not exceptionally inspiring, the combination can be highly refreshing and enjoyable, without being distracting. This is not negative. It is actually an advantage. It does not demand (or merit) extended attention. Here, the wine acts to diminish any of the less desirable attributes of the food. It also cleanses the palate, reestablishing its sensitivity, so that the next morsel can be savored afresh. Ideally, the wine will also supply an additional sensory element to enhance the food’s appreciation. In such instances, the wine acts as a foil for the food, or as food condiment. It may be in these roles that wine initially came to be viewed as pairing with food. It may also explain why most wines, which are usually “unbalanced” when sampled alone, appear more harmonious with food. Many white wines are too acidic and red wines overly tannic to
be fully enjoyed alone. In the case of white wine, the reaction between wine acids and food proteins probably mellows the perception of the wine. In addition, the coolness of white wines can dampen the “heat” of spicy foods. With red wines, balance may develop when tannins react with proteins, preventing or reducing their ability to activate receptors that elicit bitter and/or astringent sensations.

Occasionally, compatibility is viewed as arising from both wine and food having similar elements. Examples might include the buttery character of a Chardonnay matching that of crab; the peppery aroma of Shiraz pairing with pepper steak; the fruity flavor of a Riesling spätlese affiliating with a sweet, fruit-based sauce; or the nutty aspect of dry sherries blending with a hazelnut cream soup. Conversely, similar attributes may unfavorably heighten their influences. For example, the herbaceous aspect of most Sauvignon blanc and poorer Cabernet Sauvignon wines accentuate similar flavors in capsicum peppers or the vegetative aspect of green beans. However, in most instances, the basic characteristics of table wines (acidity, bitterness, astringency, plus fruity to floral fragrances) are not found in food. Conversely, the fatty and meaty flavors of food and adjoining vegetal, spice, and condiment elements find few equivalents in wines. A few wines (notably Gewürztraminer and Shiraz] possess spicy attributes. Nevertheless, these are mild in comparison to what occurs in many recipes. The marked disparity between the sensory features of most wines and foods strains the logic of many published food and wine combinations.

The compatibility between wine and foods seems to stem more from their complementary differences than their similarities. For example, the reaction between wine acids and tannins with food proteins diminishes the perception of the former, creating a smoothness the wine would not otherwise possess. Diminished flavor intensity has been noted in several white (Nygren et al., 2003a) and red (Madrigal-Galan and Heymann, 2006) wine-and-cheese combinations. Studies on multiple taste and odor mixtures suggest that people have limited abilities to identify more than two or three items (Marshall et al., 2006). Thus, much of the perception of enhanced pleasure from food and wine pairing may be an illusion, though a pleasant one. It probably has the same origin as taste/odor/color interactions noted in Chapters 3 and 4. Admittedly, most people would prefer to think of flavor enhancement, not a mirage generated in the brain based on past experiences. Such an interpretation lacks “romance.”

Frequently, whatever attributes wine possesses should be less pronounced in the meal and vice versa. This view may explain the frequent association of low-alcohol German Riesling wines with hot or spicy foods.
This presumably is associated with the coolness of the wine, and the low alcohol and phenolic contents not accentuating any in-mouth irritation. Occasionally, wine acts as a beverage condiment, acidity adding a zesty tang (like lemon juice) and its phenolic constituents supplying some complementary bitterness. Wine also provides an appealing change in flavor from those found in the food.

At its ultimate, the association between food and wine augments the appreciation of both components. Occasionally, however, it is the wine that takes center stage. For example, the delicateness of chicken acts as a foil for the qualities of the wine. Usually, this demands a comparatively simple preparation, with minimal seasoning to avoid masking or competing with the wine’s attributes. In such a situation, the wine receives considerable attention—in fact, scrutiny. This is especially valuable when the wine is old and has a delicate but subtle flavor. Where the quality of the wine is less exquisite or more intensely flavored, a more savory meal may be selected. In this situation, equal importance is given to both the food and the wine, with concentration directed to how they complement and/or enhance each other. What is preferred depends as much on the individuals participating as on the actual food and wine. Is a dynamic contrast of flavors desired, enhanced flavor expression preferred, or the evolution of flavor harmony coveted?

In organizing such specific food and wine pairing, much of the enjoyment comes from its planning and anticipation. However, it is often very difficult for reality to match expectation. Truly memorable associations are usually unplanned and unforeseen—therein lies their appeal. It is the unexpected transcendental experience that is so embracing and memorable. Once experienced, the elation is hard to reproduce, even with the same wine, meal, and surroundings. Personally, these unanticipated explosions of gustatory and olfactory pleasures are at the heart of the “holy grail” of wine appreciation—forever remembered but un reproducible.

**WINE SELECTION**

As is evident from Chapters 7 and 8, many factors affect wine style and quality. Nonetheless, in selecting wine, personal preference should be the primary concern. Principal in this regard is the relative importance of varietal character, regional origin, and production style to choice. It is often mentioned that European wines are more subtle and suited to pairing with food, whereas New World versions show too much fruit character to be food compatible. Is sensory nuance, so refined as to occasionally require
imagination to detect, a central criterion of food pairing, or is a wine that makes its own clear sensory statement more likely to refreshen the palate and intrigue the mind? Again, personal preference should be the deciding gauge.

Another important factor relates to wine age. Young wines typically are more flavorful as well as varietally and stylistically distinctive. In addition, red wines tend to be more bitter and astringent when young. As wines mature, they tend to lose these attributes, becoming more subtle, smoother tasting, and developing a partially oxidized fragrance (bouquet). It is for these reasons that old wines are usually reserved for sampling after the meal, where their milder character can be more effectively appreciated.

The presence of an oak aspect can also significantly influence choice. With wines of little varietal flavor, oak character tends to mask (as well as the wood to absorb) the mild fragrance of the wine; with those of more pronounced flavor, oak can add complexity. Whether this is appreciated depends on personal predilection.

Regional differences in character tend to be very subtle and often somewhat nebulous. Typically, only years of extensive experience permit confident differentiation, if at all. Thus, unless one has some individual or cultural bias for particular countries or regions, this factor should be the least significant in determining wine selection.

Ultimately, price is the most defining factor in most people's choice. However, unlike most commercial products, price is neither a good indicator of quality, nor of flavor or style. Within a country or region, price often can have some value as a relative indicator, but between regions and countries, direct comparisons are unjustified. For wine, prestige or reputation of the producer and, therefore, demand are often the prime drivers of perceived monetary value. For most individuals, the only valid method of assessing whether a wine is worth its purchase price is to sample it blind and unknowingly, either with friends or in a tasting society.

HISTORICAL ORIGINS OF FOOD AND WINE COMBINATION

Cooking has been a major factor in human evolution (Wrangham et al., 1999). However, the adoption of wine as a food beverage may be as little as 3000 years old. Prior to this, limited availability restricted its use to ceremonial occasions, often involving only priests and the ruling elite. Beer was the beverage of the masses. It was simpler and more rapid to prepare, and could be produced year round (barley is easily stored). Wine production became a staple only in regions where grapes grew indigenously, such as
southern Europe and southwestern Eurasia, and along river valleys leading into central Europe. Although made from a perishable crop, available only in the fall, wine’s higher alcohol and phenolic content gave it the potential for long-term storage. The alcohol and phenolic content of wine also provided it with antimicrobial activities, very useful where water supplies were often sources of food- and water-borne infections. Wine’s high acidity also added to its microbial stability and the safety of the beverage.

Upon the development of nonporous containers (amphoras and oak cooperage) that could be sealed with cork, wine could be retained for at least a year under cool conditions. The stage was set for wine to become the standard food beverage in the ancient Greek and Roman worlds. That grape-vines required little in the way of cultivation abetted their selection. They could grow up trees, adjacent to food crops, or, with pruning, cultivated on poor soils and up slopes unfavorable for grain production or animal grazing. Thus, grape culture did not compete with food production. What is unclear is whether southern European cuisines adapted to the phenolic and/or acidic content of the predominant beverage, or the populace simply became accustomed to the taste of wine. The answer may be a bit of both, but I suspect it is more the latter.

From the historical record, wine’s association with food was well established by ancient Greek and Roman times. Even then, it took on a degree of sophistication among the wealthy, wines from particular regions and vintages being preferred to others. However, striving for the perfect amalgam between wine and food appears to be of recent origin. It seems to have begun in Italy during the Renaissance. The Industrial Revolution subsequently encouraged the rise of a middle class, provided increased leisure time, and generated the disposable income required for the development of an urbane clientele (Unwin, 1991). In addition, improved transport provided the means of supplying the diversity of wines requisite for connoisseurship.

The limited mention of specific food and wine pairing in ancient Greek and Roman writing may stem from the still relatively primitive methods of wine preservation. Thus, marginal quality may not have invited specific food and wine associations. Most of the famous wines of antiquity seem to have been sweet, concentrated wines. To modern taste, such wines would not combine well with food.

During the medieval period, winemaking skill was relatively crude. The use of sulfur dioxide (acting as an antioxidant and antimicrobial) began only in the late 1400s. The first clear reference to its use is found in a report published in Rotenburg, Germany, 1487 (reproduced in Anonymous, 1986). Nonetheless, its use did not become common until the latter part of the
nineteenth century. Wine storage was also primitive. Wines, stored primarily in barrels, often spoiled within the first year of production. To fill the void, makeshift wine (verjus) was produced from immature fruit during the summer. Because most wine did not travel well, especially under the barbaric 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.

Coinciding with the improving economy of Western Europe in the mid-1600s was the disappearance of the morass of medieval cooking. Grand medieval meals often included a chaotic medley of simultaneously presented soup, meat, fish, poultry, and sweet dishes (Tannahill, 1973). This situation is incompatible with matching wines with food. However, as the old pattern of disparate dishes was replaced by an orderly sequence we would recognize (Tannahill, 1973; Flandrin and Montanari, 1999), rational pairing of food with particular wines became feasible.

In addition, culinary practice based on the theories of Hippocrates and Aristotle were supplanted by those derived from thinkers such as Paracelsus, an early sixteenth century Swiss 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 view that proper nutrition involved three essential principles. 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 final principle (“sulfur”) bound the first two 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 wealthy families for their restorative, culinary advice. With a change in nutritional theory, heavily spiced dishes disappeared, sweetening 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 initial 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 in some southern European regions prevented their spoilage during transport 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 elegant associations with wine.
Thus, the refined pairing of food and wine is little more than three centuries old. It evolved with the development of French-modified Tuscan cuisine, itself derived and adopted initially by the Venetians from the Middle East.

**CONCEPT OF FLAVOR PRINCIPLES**

In a study of world cuisines, Rozin (1982) grouped culinary styles according to their primary ingredients, cooking techniques, and unique flavorants—flavor principles. Of these, the most distinctive was the use of flavorants. For example, East Asian, East Indian, Mexican, and Italian cuisines could be characterized by their use of soy sauce, curry, tomatoes and chili peppers, and a sauce combining olive oil, tomato, garlic, and herbs, respectively. Condiments often give regional culinary styles their distinctive character.

The intensity of some regional seasoning may seem to give the cuisine a monotonous character. However, the incredible variation in chili peppers, curry preparations, and soy sauces can provide a rich diversity of sensory nuances, to those habituated to their basic attributes. This is probably equivalent to the apparent similarity of wines to those unaccustomed to their consumption.

Especially intriguing is the appreciation of the burning sensation of chilies, the bitterness of coffee, or the sourness of pickled foods. The rapid and widespread acceptance of intense flavors, initially perceived as painful or harsh, is in stark contrast to the slow spread of neutral-flavored foods, such as corn, zucchini, and casava. Intriguingly, Northern Europe and other northern climatic regions have, until recently, largely resisted the spread of chili pepper use in their cuisine (Andrews, 1985).

The active ingredients in some condiments have a numbing, desensitizing influence on trigeminal nerve receptors. This is clearly the case for capsaicin found in chili peppers. Habitual use probably leads to the degeneration of TRPV1 receptors in the mouth and throat, as it does in the skin (Nolano et al., 1999). The rate of recovery appears to be concentration and duration dependent (Karrer and Bartoshuk, 1991). How desensitization by capsaicin and other pungent flavorants (piperine in black pepper, eugenol in cloves, isothiocyanate in mustard and horseradish, and menthol in peppermint) influences wine perception appears not to have been studied. Laboratory studies suggest that the immediate effect of capsaicin is a moderate reduction in the sensitivity to sweet, bitter, and umami tastants (Simons et al., 2002; Green and Hayes, 2003), and possible salty and acidic tastes (Gilmore and Green, 1993). These effects appear to be more marked in those unhabituated to capsaicin. However, this has not been consistently found (Lawless et al., 1985). The oft noted suppression of taste and flavor
may be due more to a sensory disruption caused by the burning sensation than an actual reduction in flavor detection. Thus, the problem of pairing hot spicy foods with wine may occur only with those unaccustomed (desensitized) to their presence on a daily basis. Traditional solutions have been to choose a simple white wine. It acts as a palate cleanser, while the cool temperature diminishes the burning sensation. Cold directly suppresses the reaction involved in trigeminal nerve activation (Babes et al., 2002). Occasionally, intensely flavored wines, such as those made from Gewürztraminer or Muscat varieties, have been suggested. Their more marked aromas may be sufficient to partially offset the sensory disruption caused by hot spices in neophytes.

Because food preferences are so culturally linked, value judgments must be viewed in relation to the norms on which they are based. For example, sweet-sour combinations are common in some Chinese cuisines and accepted in desserts. However, a lemon juice syrup with fish would seem uncouth, and acidic wines with dessert are a non sequitur.

FOOD AND WINE PAIRING

There are fundamental problems in suggesting any food and wine pairing. Personal preferences are so diverse. In addition, variation in oronasal sensitivity is much more marked than with other sensory perceptions. Furthermore, upbringing and personal experience markedly influence both cultural and individual norms. Finally, other than professional chefs, sommeliers, and food/wine critics, few people seriously contemplate food and wine pairing. Nonetheless, discussion of the issue probably promotes more wine sales than any other topic and helps to broaden wine’s consumer base.

Despite extensive advertising, the majority of consumers select the house wine in restaurants and generally purchase wines with which they are already familiar and comfortable. However, the impression remains in the media that there is considerable demand for wine and food information. How else can one interpret the steady stream of books and magazine/newspaper articles on these topics? If one can assume that these truly reflect the desires of the reader, then most consumers want specific recommendations. Explaining underlying principles is rarely noted. Certainly, it takes more concentration and effort to analyze potential combinations than the “point and shoot” approach. My feeling is that, like travel articles, reading the article provides most of the enjoyment—there being little intention or likelihood of following any of the suggestions. Under special circumstances, though, wine consumers do genuinely desire good council. This may be
for a celebratory meal, the presence of someone important for dinner, or going out to a fine restaurant with a client. If one of the guests is known to be a wine aficionado, then the host may be eager to honor his or her presence with an especially fine wine. Regrettably, the choice may occasionally be used to make a social statement, demonstrating the host’s ability to present expensive and prestigious wines.

Although detailed suggestions have their place, under most conditions wine is simply a beverage. Its selection is given little more thought than spent on the choice of vegetables. This is certainly not what wine producers want to hear, but it is probably the attitude of the majority of wine purchasers. For all its prominence in the literature, prestigious wine is beyond the purchasing power of most people. The majority of consumers also tend to concentrate on taste attributes, largely disregarding aroma (Bastian et al., 2005).

For wine lovers, though, food and wine pairing is not only important, but also one of the central features of a meal. Because it is beyond the financial or time constraints of most people to investigate extensively, there is practical value to understanding the fundamentals of food and wine pairing. It is also important for chefs, sommeliers, and others in the hospitality industry to understand the real needs and desires of their clients.

The central theme in most concepts of food and wine pairing is harmony between comparable flavor intensities. At least, this is how it is normally presented in Western thought. However, it may simply be another example of customary habit being rationalized and the apparent appropriateness of drinking acidic and tannic wines with food being a historic reflection of availability, nutritional value, and microbial safety. The role of habituation in directing food preferences has been repeatedly shown (see Rozin, 1977; Blake, 2004).

Viewed traditionally, the concept of harmony is crystallized in this adage: “red with red, white with white.” White wines are typically lighter in flavor and more acidic than red wines. What red wines may lack in acidity is more than compensated by its polyphenolic content. Another element of food and wine harmony relates to color. White wines simply look better when matched with pale-colored foods and sauces, just as red wines are visually more appealing with dark meats and sauces—or is this just another example of custom dictating preference?

An alternative explanation for the general pairing of “red with red” has been proposed by Ronca et al. (2003). It is based on the relative health benefits of consuming red wines with red meats. Red wines, with their higher phenolic content, have a greater propensity to bind metal ions, such as iron and copper. Because these metals tend to occur in higher concentrations in
red than white meat, metal chelation by red wines could reduce the production of toxic free oxygen radicals during digestion. Red wine phenolics have been shown to reduce the production of toxic lipid oxidation products in the stomach, and their levels detected in blood after a meal (Gorelik et al., 2008). The higher protein content of red meats may also bind more wine tannins, limiting their antinutritional effect, caused by their complexing with and inactivation of digestive enzymes. Generally, tannins inhibit enzyme activity. In the mouth, this could slow starch degradation. Because starch viscosity delays the release of aromatics, it could affect food (and wine) flavor. Nevertheless, some red wine phenolics have been shown to enhance enzyme action in the stomach, notably pepsin (Tagliazucchi et al., 2005).

In theory, the concept of flavor compatibility is easy to comprehend. However, in practice, its application is far from simple. There is no easy way of determining flavor intensity. Rietz (1961) attempted to quantify the relative flavor intensities of different foods. When items are selected from various food columns, menus could be developed to combine foods of compatible flavor intensity, or to show a predetermined change in flavor intensity throughout the meal. Although interesting, factors such as preparation technique (e.g., poaching, baking, broiling, grilling) strikingly affect food flavors (by both modifying and generating new flavorants). Condiments and spice addition also considerably enhance food flavor. As a consequence, flavor characteristics, complexity, and intensity can vary markedly, as well as in texture. Serving temperature also significantly modifies flavor intensity. Each of these factors can independently influence the choice of wine.

Establishing an estimate of wine flavor intensity is equally or even more complex. Figure 9.3 illustrates the relative flavor intensities of several wines. It indicates that considerable variation in flavor intensity is often found. For example, Gewürztraminer can vary from mildly flavored and slightly sweet, to bone dry and intensely perfumed. 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 can give a meal dynamic tension. This is most often provided by spice. Alternatively, condiments such as a roux or salsa can generate the concentrated flavors desired. Occasionally, though, wine supplies the flavor intensity required. The wine acts as a condiment—for example,
### WHITE WINES

<table>
<thead>
<tr>
<th></th>
<th>Light</th>
<th>Medium Light</th>
<th>Medium</th>
<th>Medium Full</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
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<td>California</td>
<td>Australia</td>
<td></td>
</tr>
<tr>
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<td>Loire</td>
<td>New World</td>
<td>Alsace</td>
<td></td>
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<tr>
<td>Gevürztraminer</td>
<td></td>
<td>Rheinpfalz</td>
<td>Rheinhessen</td>
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<tr>
<td>Müller-Thurgau</td>
<td>Veneto</td>
<td>Alsace</td>
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<td>Catalonia</td>
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<td>Parellada</td>
<td></td>
<td>Mosel</td>
<td>New World</td>
<td>Rheingau</td>
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<tr>
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<td>Loire</td>
<td>Bordeaux</td>
<td>New World</td>
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<tr>
<td>Sauvignon Blanc</td>
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<tr>
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<td>Bordeaux</td>
<td>New World</td>
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<tr>
<td>Sylvaner</td>
<td>Franconia</td>
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<td>Trebbiano</td>
<td>Soave</td>
<td>Orvieto</td>
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<tr>
<td>Viura</td>
<td></td>
<td>Rioja (new style)</td>
<td>Rioja (old style)</td>
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</table>

### RED WINES

<table>
<thead>
<tr>
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<th>Medium</th>
<th>Medium Full</th>
<th>Full</th>
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<tbody>
<tr>
<td>Barbera</td>
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<td>Piedmont</td>
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<tr>
<td>Cabernet Sauvignon</td>
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<td>Bordeaux</td>
<td>New World</td>
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<td>Cannonau</td>
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<td>Sicily</td>
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<td>Amarone</td>
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<td>Beaujolais</td>
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<tr>
<td>Maréchal Foch</td>
<td>Eastern N. A.</td>
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<tr>
<td>Merlot</td>
<td>Bordeaux/New World</td>
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<tr>
<td>Nebbiolo</td>
<td>Barbaresco</td>
<td>Barolo</td>
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<tr>
<td>Pinot Noir</td>
<td>Burgundy</td>
<td>Oregon</td>
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<tr>
<td>Sangiovese</td>
<td>Chianti</td>
<td>Brunello</td>
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<tr>
<td>Shiraz (Syrah)</td>
<td>Rhône</td>
<td>Châteauneuf-du-Pape</td>
<td>Australia</td>
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<tr>
<td>Tempranillo</td>
<td>Rioja</td>
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<tr>
<td>Zinfandel</td>
<td>‘White’ Zinfandel</td>
<td>Red Zinfandel</td>
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### SPARKLING

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<th>Medium Full</th>
<th>Full</th>
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</thead>
<tbody>
<tr>
<td>Vinho Verde</td>
<td>Cava</td>
<td>Champagne</td>
<td>Vintage Champagne</td>
<td>Asti Spumante</td>
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### SHERRIES

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<tbody>
<tr>
<td>Manzanilla</td>
<td>Fino</td>
<td>Pale Cream</td>
<td>Amontillado</td>
<td>Dark Cream</td>
<td></td>
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</tbody>
</table>

### PORTS

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<thead>
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<tbody>
<tr>
<td>White</td>
<td>Tauny</td>
<td>Ruby</td>
<td>Vintage</td>
<td></td>
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</table>
a red wine served with poultry. Conversely, a light wine may soften the intense flavors of the dish. The combinations and permutations of food and wine pairings are almost endless, as are the associations of various ingredients in a recipe. The real limitations are the imagination and desires of the creator.

Infrequently, famous associations occur when seemingly opposed tastes or flavors combine in a dynamic, seemingly unstable equilibrium. The rationale for the combination of sweet, richly flavored wines (e.g., ports and Sauternes) with salty, creamy, blue cheeses (e.g., Stilton and Roquefort) may relate to their similar richness and the blend of salt and sweetness. The complexities of their flavors are interpreted as integrating and enhancing mutual enjoyment. In Germany, the gamey character of well-aged venison is supposedly counterbalanced by the sweet, rich flavors of a mature Riesling auslese. In the Loire, the aggressive dry acidity of Sancerre is viewed as counterpoised when taken with the raciness of goat cheese. Finally, the sourness of Chablis is deemed to be offset by the sweet flavors of crab. The ingenuity of some combinations may, in itself, be enough to engender the perception of new and unexpected gastronomic delights. Novelty has an appeal to the adventuresome.

Of the five principal taste sensations, wine usually possesses only three: sweet, sour, and bitter. As noted, most corporal food ingredients exhibit neither sour nor bitter tastes, and except for dessert, food rarely shows obvious sweetness. Therefore, there is little obvious logic to wine’s association with food. However, food does suppress the sour, bitter, and astringent aspects found in many table wines. Proteins in food have already been mentioned as minimizing the sensory impact of tannins and acids, resulting in the wine appearing smoother, less sour, and more balanced. Thus, in many cases, it is the food that enhances the perception of wine, rather than the reverse. Nevertheless, the acidity of wine tends to freshen the mouth, whereas moderate bitterness and astringency can enliven bland foods. Only rarely are there common elements. Examples are the nutty aspect of cream sherries pairing with a walnut dessert; the oaky character of a wine combining with the smoky flavors of meat roasted over charcoal; or more specifically, the joint presence of ethyl 3-mercaptopropionate. This compound is important to the flavor of both Munster and Camembert cheeses (Sourabié et al., 2008). It has also been proposed as being associated with the foxy character of some labrusca grapes and the toasty aspect of sparkling wines. Might this explain why some wines go better (or worse) with particular cheeses?

Although most food flavors are not inimical to wine, several are—at least to the sensibilities of wine connoisseurs. For example, vinegar and
vinegar-based condiments create an unpleasant harshness, and may mask
the wine’s fragrance. Thus, salads are rarely combined with wine. Taste
buds are also numbed by the burning sensation of chilies and most curries.

Most commentators suggest that wine enhances food appreciation,
and vice versa. However, this view (illusion) probably arises from the unrecog-
nized reduction in the less pleasant attributes of one or both. Under lab-

FIGURE 9.4 Identification of mixture components by individual subjects. Number of trials (y-axis) represents the number of presentations of a particular type of mixture, for example, the four-component mixture, with each presentation involving a different composition. The x-axis shows the number of components present in a stimulus. Numbers within the matrix indicate the number of subjects who correctly identified all the components present in a mixture, while the number of shaded boxes indicates the number of trials at which these particular subjects were successful. (Reproduced from Marshall, K., Laing, D. G., Jinks, A. J., and Hutchinson, I. (2006). The capacity of humans to identify components in complex odor-taste mixtures. Chem. Senses 31, 539–545, by permission of Oxford University Press.)
reverse. Those more limited effects may involve dilution, such as the bitter-tasting peptides derived from casein (Roudot-Algaron et al., 1993).

Madrigal-Galan and Heymann (2006) have confirmed and extended the findings of Nygren to red wines, where cheese reduced the perception of bell pepper and oak flavors. In contrast, the buttery aspect of wine was enhanced by combination with Hollandaise sauce and cheese. These effects appear to be largely independent of the type of cheese. These findings lend support to the maxim: “sell wine over cheese, but buy it over water.” In another study, white wines were perceived to be more balanced in flavor with a range of cheeses than were red or specialty wines (King and Cliff, 2005). Marked variation in judge opinion was observed.

**FIGURE 9.5** Influence of wine and cheese on flavor. Mean intensity of apple flavor of white wines (A) before and after tasting blue cheeses; (B) before and after mixed tasting with the cheeses—black bars represent wine before cheese tasting, white and gray bars represent wine after or with Bredsjö Blå and Roquefort cheeses; (C) and the mean saltiness of the cheeses before and after sampling the same white wines—black represents Bredsjö Blå, light gray represents Roquefort, before sampling is represented by (0) and after wine sampling (see bar explanations). Level of significance: *P < 0.05; **P < 0.01; ***P < 0.001; ns (not significant). (from Nygren et al., 2002, 2003a & b, respectively, reproduced by permission).
Although interesting, whether these studies have direct relevance to tasting under nonlaboratory situations is unclear. Frequently, contextual factors and knowledge are the predominant regulating factors in sensory perception.

Another example of flavor interaction may be found in the combination of champagne with caviar. The wine’s effervescence appears to suppress the saltiness of the caviar, either by its masking due to stimulation of trigeminal (pain) receptors or by removing sodium ions (the scouring action of carbon dioxide).

Both suppression and activation probably play mutual roles in some combinations, such as port with Stilton cheese. The presence of salt and soluble fats in the cheese probably suppresses the perception of bitterness (Keast et al., 2001) and astringency (Yan and Luo, 1999), whereas the wine’s sweetness could mollify the pronounced bite and strong flavors of the cheese.

Certain aspects of food texture can also directly affect flavor perception. A prominent example is the suppression of odor intensity by thickening agents (Hollowood et al., 2002; Cook et al., 2003a; Ferry et al., 2006). This explains the need for strong or concentrated seasonings in sauces. Another example of the complex interactions between food and wine relates to the heightened perception of certain textural sensations in the presence of aromatic compounds (Bult et al., 2007).

Perception is a function not only of the stimulus received, but also its physical location and temporal sequence. The contrast between the nearly overpowering smell of Limberger cheese and its pleasing in-mouth flavor is classic. Not surprisingly, wine sampled in the glass can be very different than when sampled in the mouth or taken with food. This may be associated with orthonasal olfaction being correlated with the “anticipatory” phase of food/beverage intake, whereas retronasal olfaction is more directly associated with food’s “reward” circuitry (Negoias et al., 2008). Each of these responses involves distinct neurotransmitter systems, dopamine versus opioid and GABA/benzodiazepine, respectively (Berridge, 1996).

These complex interactions of taste, touch, and odor are clearly largely based on processing in the higher centers of the brain (Small et al., 2005, Fig. 3.10). The increasing understanding of their interrelated nature further helps explain why predicting how a wine will pair with food is so difficult.

However explained, the most memorable food and wine combinations relate to their aesthetically pleasing flavor combination. Regrettably, scientific understanding of these interactions is still rudimentary. Although indicating what direction future research should follow, consumers must still largely rely on their own sensory skills, or accept the recommendations of
“experts.” Every culture has had its arbiters of good taste. If personal sensory acuity and preferences are similar to those of the author, then their suggestions probably have predictive value.

One of the more intriguing developments in Western cuisine is the recent and extensive use of hot spices. This seems to have led 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 certain Chinese dishes, may herald a renewed appreciation of semi-sweet wines with food.

**USES IN FOOD PREPARATION**

**Basic Roles**

At its simplest, wine acts as a palate cleanser throughout the meal. By rinsing food particles and substituting its own flavors, wine minimizes sensory fatigue. Thus, the wine maintains the freshness and appeal of the food unabated throughout the meal. In its turn, food helps freshen the palate for the wine. In red wines, the phenolics also stimulate saliva production [Hyde and Pangborn, 1978]. Ethanol is also an activator of saliva production [Martin and Pangborn, 1971].

Wine is often considered a foil for the meal, accentuating the central flavors of the food. However, as noted previously, food more frequently enhances the appreciation of the wine. It modulates the typical imbalance of the majority of wines, which are commonly too acidic, bitter, or astringent to be fully appreciated alone. This appears to be changing, though, as winemakers modify their wine production in response to the increasing use of table wines as an aperitif. Thus, wines are being produced more balanced [less acidic, bitter, and astringent] at bottling.

As a food beverage, though, adequate acidity has the benefit of freshening the mouth, as well as appearing to diminish the oiliness in some foods. In addition, the moderate bitterness and astringency of red wines are often stated to enhance the flavor of red meats. Prolonged maceration and oak maturation are also considered to give white wines the flavor and bitterness sufficient to complement more tangy foods.

Wine has significant solubilizing action. Its acid and alcohol content may help solubilize or volatilize food flavorants. In so doing, wine could accentuate food appreciation. Conversely, the dilution of alcohol by food constituents can promote the liberation of wine aromatics [Fischer et al., 1996; Fig. 3.16]. This is most likely to affect the wine’s finish.

Wine also has several direct and indirect effects on food digestion. As noted, its phenolic and alcohol contents activate saliva production.
In addition, wine promotes the release of gastrin as well as gastric juices in the stomach. The release of gastric juices seems most likely to be activated by the succinic acid component of wine (Teyssen et al., 1999). Wine also significantly delays gastric emptying (Franke et al., 2004; Benini et al., 2003). This favors digestion, by extending acid hydrolysis, as well as facilitating the inactivation of potentially pathogenic food contaminants. Delayed gastric emptying also retards the uptake of alcohol, giving the liver more time to metabolize ethanol and minimize alcohol accumulation in the blood.

Despite these benefits, the probable reason most people take wine with their meals is simply that they enjoy the combination. It slows eating, permitting each morsel to be savored. Wine also tends to encourage conversation and the social aspect of dining. The presence of a fine wine raises a biologic need to one of life’s most civilized delights.

**Involvement in Food Preparation**

Wine has long been extolled for its capacity to complement food. Wine has an equally long tradition in food preparation. Probably the oldest example is as a marinade. Wine acids can hydrolyze proteins, tenderizing meat. The acids also temporarily preserve the meat. 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 adds to the food’s flavor, since it is usually discarded after use (except when marinading fruit).

Another culinary use of wine is as a base for poaching, stewing, or braising. Fine wines are seldom used because cooking dramatically changes their flavor. Nevertheless, the quality should be adequate to not adversely affect the food’s flavor. Shorter cooking times, or lower temperatures, result in more of the original attributes of the wine being retained. Thus, whether the wine is red or white has significance depending on whether the cooking time is short and/or its temperature low. Normally, prolonged cooking turns any wine brown via the generation of Maillard and Strecker degradation products.

When one is poaching or braising, the wine is often 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, may be incorporated into a sherbet, or may function as a blending medium for creamy custards. Otherwise, only sweet wines are
compatible with dessert, notably fresh, fully mature, low-acid fruits such as strawberries, peaches, and apricots.

Carbon dioxide escapes from wine even more rapidly than does alcohol. Thus, there is little value in using sparkling wine in lieu of still wine. Cooking promotes the evaporation of ethanol, but its loss is often much slower than generally realized (Table 9.1).

### TYPES OF OCCASIONS

Different situations invite different qualities or styles of wines. This is self-evident in the choice of fine wines to complement special meals. Exquisite tastes demand exceptional wines as much as honored guests deserve the best one can offer. Equally, the light, semi-sweet wines that are a delight in summer may seem inappropriate by the fireplace in winter. Port seems much more appropriate in front of a roaring fire. However, the choices people make often seem to reflect more habit than appropriateness. For example, the balance of a dry table wine is more evident in combination with food than alone. Nevertheless, such wines are frequently served in place of the more traditional sherry or port as an aperitif. Consumer preferences (fads?) seem to change almost as fast as computer technology.

### WINE PRESENTATION

**Presentation Sequence**

Grand meals, served with a multitude of wines, are now largely viewed as an anachronism. There is much greater awareness of the dangers of excessive food and wine consumption, both in terms of personal health as well as in one’s ability to drive. In addition, the accumulation of alcohol, due to

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**Table 9.1** Comparison of Various Methods of Food Preparation on the Loss of Alcohol\(^a\) (from Jackson, 2000, reproduced by permission)

<table>
<thead>
<tr>
<th>Preparation Method</th>
<th>Alcohol Remaining (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flambee</td>
<td>75</td>
</tr>
<tr>
<td>Marinade (overnight)</td>
<td>70</td>
</tr>
<tr>
<td>Simmered (15 min)</td>
<td>45</td>
</tr>
<tr>
<td>Simmered (30 min)</td>
<td>35</td>
</tr>
<tr>
<td>Simmered (1 h)</td>
<td>25</td>
</tr>
<tr>
<td>Simmered (2 h)</td>
<td>10</td>
</tr>
</tbody>
</table>

\(^a\)Data from Augustin et al. (1992).
sampling multiple wines, progressively dulls the senses. If one cannot clearly remember the vinous pairings of the previous evening, what was their value? Nevertheless, a brief discussion of traditional views on presentation sequence is provided here.

Because sensory acuity tends to decline during a meal, the flavor intensity of a series of wines should increase throughout the meal. An exception to this rule is the choice of dry sherry as an aperitif. This is ostensively chosen to stimulate the appetite and activate the secretion of digestive juices. More in keeping with increasing flavor intensity is the choice of a light dry white or sparkling wine before dinner. They equally activate the release of digestive juices, and their subtle flavors do not blunt the appetite. They also tend to combine well with many hors d’oeuvres. 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. With grand meals, several table wines may be served consecutively. In this case, the youngest wine is served first, reserving the finer, older vintage[s] for later. At the end of the meal, a full-flavored fortified wine, such as a port, Palo Cortado, or Setubal may be served before or after dessert. Alternatively, a botrytized dessert wine, such as an Auslese or Sauternes, may be presented.

Several serving traditions have developed over the years. One recommends that the finest wines should be presented last. The rationale is that they will appear better by the comparison. This custom does run the risk that satiety may numb the senses, reducing appreciation. Another custom advises that the better the wine, the simpler should be the accompanying meal. The avoidance of strong food flavors allows the subtleties of the wine to express themselves more fully. Finally, convention states that guests should be informed of the vinous pleasures to come. This not only enhances anticipation, but also increases expectation. If this is the outcome, fine. Otherwise, it may produce expressed accolade, but internal disappointment: the greater the expectation, the greater must be the manifestation. This can be avoided by presenting the wine without acknowledgment. If the guests recognize the wine’s quality, your pleasure is all the greater. For me, my most memorable vinous experiences have occurred when a seraphic wine was offered without the expectation that heavenly delights were to follow.

My personal suggestion would be to reserve your best wines for both you and your spouse, or a select few, unbiased, open-minded friends. This will avoid the public embarrassment and some of the disappointment of presenting a fine (or expensive) wine that fails to meet expectations. Conversely, if your anticipation is fulfilled, you will have ample opportunity to enjoy the wine slowly and savor every nuance to the full. The finest and certainly the oldest wines express their attributes optimally when taken by themselves.
Cellaring

For the majority of wine consumers, cellaring in the traditional sense is impossible. A wine rack in an apartment cannot be considered cellaring. In addition, most wines are consumed with hours or days of purchase. Occasionally, this is countenanced on the assumption that without elaborate precautions most wines will deteriorate within a year or so. If aging is considered to be fifty or more years, this is certainly valid. Only some reds and very sweet wines are likely to retain much sensory appeal after this period, even under optimal conditions. More relevant is whether the purchaser prefers the fresh fruity, varietal fragrance of young wines, to the more subtle, delicate, aged bouquet of older wines. Most modern wines are produced to be consumed with pleasure shortly after bottling. Premium red wines are still produced to possess a higher tannic content, on the belief (probably true) that it enhances aging potential. It does protect important flavorants against early oxidation. Correspondingly, premium wines require extended maturation to develop their potential. Coincident with a “softening” of the tannins is the replacement of the fruity and varietal flavors of the young wine with an equally enjoyable, but distinctly different, subtle, aged bouquet.

The only wines that definitely should not be stored for an extended period are nouveau wines. These often show obvious deterioration within several months to one year. Most wines sealed with artificial corks should also not be stored for more than one or at most a few years. This situation may change as manufacturers solve problems associated with the oxygen permeability of artificial corks.

In the absence of a below-ground cellar or a large refrigerated wine cabinet, a dark, cool location is about as good as can commonly be expected. Temperatures below 20°C are preferable, with 10°C generally viewed as ideal for prolonged aging. Regrettably, such cool temperatures decidedly slow aging. Premium wines may take decades to reach maturity. Temperatures in the 15 to 20°C range are a convenient compromise between the desire to age and the impulse to sample. Another, complementary solution is to purchase several bottles and sample them periodically over an extended period. Prolonged exposure to temperatures above 25°C is definitely not recommended.

The duration of maturation is a very contentious issue. Probably as good an indicator as any may be the price or prestige of the wine. Relatively inexpensive wines probably need little aging, though this does not necessarily imply that further maturation is inappropriate or not beneficial. Certainly, the least expensive “jug” wines will unlikely benefit from aging. They are
produced to have minimal character (to avoid offending the clientele of this genre of wine) and are not sealed in a manner to avoid significant oxidation for more than a few months to years. For many wines, the primary limiting factor for aging potential is how the bottle is sealed and the antioxidant content of the wine (primarily tannins and sulfur dioxide). If the wine is adequately protected against oxidation, the wine should age well for several years.

For cork-closed bottles, cellaring bottles in a horizontal position is standard. This is thought to retard the loss of moisture from the stopper, retaining its resilience and maintaining its tight adherence to the bottle neck. Despite this general recommendation, some studies have shown that upright storage does not necessarily result in detectable wine oxidation for two (Lopes et al., 2006) or more years (Skouroumounis et al., 2005). Storage position is of little or no importance for bottles closed with screw caps.

The humidity level of most storage areas is rarely an issue, except in earthen cellars where the humidity may be excessively high. In such situations, mold growth can damage the appearance of the label and eventually make it illegible. The old bottles seen in photos covered with cobwebs in dark cellars are stored without paper labels.

An incredible diversity of holding racks and construction materials have been used to store wine: brick, stone, clay tiles, metal, plastic, and wood. Each has its benefits and drawbacks. Wood is possibly the most common construction material. It possesses high strength/weight; is easily worked, joined, and repaired; and provides an aesthetically warm ambience to the cellar. The example shown in Plate 9.1 was designed to minimize the appearance of the rack structure, to accentuate the visual impact of the bottles. The openness also facilitates identification of the wine. Designing each section to contain twelve bottles is standard practice, accommodating the location of a case of wine. The 8 cm × 8 cm individual slots will accept most standard 750 ml bottles.

**Glasses**

Glass use was discussed in both Chapters 5 and 6. In the home and restaurant, the desires and needs are usually different from those in the sensory lab or in training/tasting sessions. Nonetheless, the ISO wine tasting glass is appropriate in all these situations. The one major drawback of thin crystal versions is their fragility. This limits their use to special occasions. Thicker, more sturdy, regular glass versions are more practical for everyday use (Plate 5.11). Some of these also exist in larger versions, more appropriate for the dinner table. Unfortunately, these are not readily available in
most retail stores. Restaurant supply stores are usually the best local sources. Certainly, the more common bulbous-shaped glasses will do but lack finesse for the same or higher price.

At the upper end of the market are crystal glass firms such as Reidel, Bohemia, and Waterford. They produce a wide range of wine glasses. While glass shape and size clearly affect wine perception, there is no convincing evidence that particular shapes uniquely enhance the appreciation of specific wines. Nonetheless, this does not negate the psychological impact of different glasses during a meal.

**Serving Temperature**

The range of temperatures typically recommended for various types of wine were noted earlier (Chapters 5 and 6). These preferences probably reflect the effects of temperature on gustatory sensations in the mouth and the volatilization of wine aromatics. However, habituation cannot also be ruled out as a major factor (see Zellner et al., 1988). The wine’s temperature also has direct effects on wine appreciation in its traditional association with food. The standard cool temperature of white wines adds to its fresh cleansing influence in the mouth. This is especially appreciated with hot spicy foods. Even red wines at “room” temperature will often provide some refreshing contrast with the food’s temperature.

**Breathing**

Breathing was discussed in Chapter 6. Little further needs to be mentioned here, other than to indicate that it is both unnecessary and a regrettable exercise—unnecessary, because whatever reactions occur following opening occur far more rapidly in the glass when the wine is swirled; regrettable, because it can result in missing one of the more fascinating and evanescent experiences a wine can present, its opening. While unromantic, “opening” refers to the progressive release of aromatic compounds from the wine. Not only does this often result in an increase in the overall intensity of the wine’s fragrance, but it is also associated with a transformation in its character. This metamorphosis (“development”) is a quality feature of the finest wines that should not be missed.

**Wine Preservation after Opening**

Usually, no preservation is required. Opened bottles are usually fully consumed during the meal. Where it is not, preservation is a proverbial problem. The common but inadequate solution is to reseal the bottle and
store it in the refrigerator. While the cool temperature does delay deterioration, it also increases oxygen uptake by the wine (oxygen solubility increases as the temperature falls). Usually, there is noticeable character loss within a day, and the wine may be unrecognizable within a few days.

An inexpensive means of reducing the degree of oxidation is to use one of the commercially available vacuum pumps. Although partially effective, it really is inadequate. During the interval between opening and resealing, the wine can absorb oxygen. This initiates the oxidation of aromatics, notably fruit esters and terpenoids. In addition, hand pumps do not fully evacuate the air, leaving oxygen that can be absorbed by the wine. Finally, the partial vacuum encourages the escape of aromatic compounds into the headspace (frequently more than half the bottle’s volume). When the wine is subsequently poured, these aromatics remain in the bottle and eventually escape into the air. The result is a loss of character due to oxidation and volatilization.

A nonelegant but effective solution is to pour the portion of the bottle one expects not to consume into a clean, small, screwcap bottle of sufficient volume. This should be done immediately upon opening to minimize oxygen uptake. In addition, the wine should be filled to the rim (essentially no headspace). Ideally, and before pouring, the air in the bottle should be flushed out with carbon dioxide, nitrogen, or argon. These gases are often available in conveniently small gas cylinders appropriate for home use.

For commercial establishments or the serious connoisseur, the former techniques are clearly unacceptable. This has led to the development of a variety of devices. The simplest may be the Pek system (Plate 9.2). It preserves wine by displacing air that enters the bottle after opening and pouring. Argon gas is injected from a cylinder in the cap of the device. Because argon is heavier than air, it effectively displaces air (and its associated oxygen). The internal light and transparent front panel permit the bottle label to remain in prominent display. Refrigerated units can also maintain the wine at an appropriate serving temperature. Although applicable for home use, they are ill designed for restaurant application.

Several producers (e.g., Cruvinet, Eurocave, WineKeeper) produce a variety of refrigerated units that can dispense wine by the glass (Plate 5.7). Units dispensing four bottles (two white, two red) are ideal for home use. Larger units are typically used in restaurants. Some, such as Enomatic, can be supplied with a card system that allows customers to serve themselves. Samples are dispensed through individual spigots in refrigerated units or may be attached to individual bottles where appearance is unimportant (Plate 5.9). Compressed nitrogen or argon gas is typically used to both dispense the wine and replace the voided volume.
It is essential to periodically cleanse and disinfect the units. Even traces of oxygen left in the headspace after inserting the replacement stopper can permit the growth of spoilage bacteria, notably acetic acid bacteria. Bacterial multiplication in the spigot is even more of a problem. Any residual wine in the spigot can rapidly absorb oxygen, favoring bacterial growth and the conversion of ethanol to acetic acid. Without frequent wine dispensing (essentially daily), vinegarization of the residual wine can taint the first sample poured. These problems are avoided in the dispenser produced by Fresh-Tech (Plates 9.3 and 9.4). It has a system where the cork is removed and replaced with a dispensing stopper in a nitrogen-filled environment. The shooter is also flushed with nitrogen after dispensing a wine sample. The system is gravity fed, with nitrogen (produced by its own generator) replacing the dispensed wine at atmospheric pressure.

Many of these wine dispenser systems come in a range of sizes or can be designed to suit the specifications of the client. As a result, upward of several hundred bottles can be made available by the glass.

All dispenser systems are designed to minimize or avoid wine oxidation prior to dispensing into a glass. However, to date, there have been few studies on what actually occurs to wine shortly after bottle opening. Left in the bottle, wine begins to show signs of oxidation within about 8 to 12 h. Poulton (1970) found that oxygen consumption showed a first-order reaction rate, becoming complete within 10 to 12 days in white wine. If half a bottle were poured, the headspace in the bottle would contain about 90 mg oxygen—more than sufficient to initiate noticeable oxidation. Aromatic deterioration has been correlated with a decline in the presence of fruit esters and terpenoids aromatics (Roussis et al., 2005). Because the decline was reduced in the presence of various phenolics and other antioxidants (Roussis et al., 2007), it was concluded that the aromatic deterioration was at least partially due to oxidation. It may also result from the progressive volatilization of aromatics from the wine. This results in an irreversible loss in aromatics. Surprisingly, and contrary to common belief, short-term deterioration has not been associated with the accumulation of acetaldehyde (Escudero et al., 2002; Silva Ferreira et al., 2003). This may result from the rapid bonding of acetaldehyde, indirectly produced as a result of phenol oxidation, in nonvolatile complexes with wine phenolics and sulfur dioxide. This would effectively prevent the development of an oxidized (aldehyde) odor in the wine. Extensive contact with oxygen is required for the development of an oxidized, sherry-like, acetaldehyde taint.

The studies noted here have involved exposure periods longer than usually occurring during a tasting. However, Russell et al. (2005) did investigate exposure periods lasting 0, 5, 15, and 30 min. The tasters could not detect
any difference in the Merlot wine over the test period, although there were measurable changes in the concentration of some phenolics. The only wine aromatic known to degrade quickly on air exposure is hydrogen sulfide, an infrequent off-odor compound. Nonetheless, there is ample anecdotal evidence that wine fragrance changes qualitatively after pouring. In the glass, finer wines often show development, an interesting aromatic transformation over the duration of a tasting. Like the opening of a flower, these changes are highly appreciated [until the fragrance begins to fade]. It is interpreted as a sign of quality. Part of this phenomenon undoubtedly involves modifications to the dynamic equilibrium between dissolved and weakly bound aromatic in the wine and their presence in the headspace gases above the wine. This process is greatly facilitated by swirling. Swirling also increases the rate at which oxygen dissolves in the wine. However, what, if any, effect this has on a wine’s aroma, within the time frame of a tasting, remains unknown.

Label Removal

The human brain is remarkably skilled at retaining information, but few of us are endowed with the ability to retain even a fraction of the impressions of the thousands of wines we may taste over our life span. One solution is to record impressions in a book dedicated to the purpose, a wine log. Although writing the name, producer, and vintage is sufficient to denote the wine’s origin, most people prefer to add the label.

For labels attached with water-based glues, soaking in warm water for an hour is sufficient for the label to easily slip off. When the label has a waxy, plastic, or aluminum foil coating, several days may be required for water to seep in along the edges and the label to soak off. For other glues, use of hot water, strong detergent, or the addition of ammonia may be beneficial. Occasionally, rubbing alcohol can be effective. Once the label is removed, gently rub off the remaining glue into the soak solution. However, for recalcitrant labels, attached with heat-activated or other non-water-soluble glues, these treatments are inadequate. The only method found effective is a short soak in hot water, followed by the use of a single-sided razor blade [e.g., GEM® or PAL® blades]. Through a slow, meticulous slicing action, the label can usually be extricated without significant harm. The alternative is to print a copy of the label from the producer’s website.

For all labels, except those removed by slicing, place the label between two sheets of heavy felt paper or several pieces of newsprint. Once it is damp dry, place the label between dry sheets of felt paper or newsprint. The sandwich is subsequently placed between sheets of corrugated
cardboard, in between sheets of plywood (8” × 11” is typical). Heavy weights are applied (or the whole is tied tight with straps as in a plant press—this will be familiar to anyone having taken a course in plant taxonomy). Within several hours the label will be dry and perfectly flat. If there are wrinkles or creases, these can usually be easily removed with pressure applied by a cold iron. For labels removed by slicing, place the label first on an equivalently sized piece of cling wrap. This will prevent the label from sticking to the newsprint or felt paper. Otherwise, the procedure of drying and pressing is identical to other labels. So prepared, the labels make an accurate and attractive record of the wine’s origin.

**FINAL NOTE**

Rarely is choosing the “right” wine of critical importance, if such an entity exists. As Andrea Immer [2002] points out, the right wine is often a matter of convenience, what is available, or what you happen to want to try at the time. Nonetheless, half the joy of preparing a special meal may come from selecting the wines that will grace the table. For the guests, too, much pleasure can be derived from contemplating the vinous treasures to be offered. When one is appreciating wine outside the lab, psychological factors that enhance enjoyment can definitely have their place. Even using wine to impress some business associate can occasionally be justified, although it seems a shame if one needs label prestige rather than sensory quality to impress.

“For wine to taste like wine, it should be drunk with a friend.”

Spanish Proverb

**SUGGESTED READINGS**


REFERENCES


Glossary

Acidity—The concentration of nonvolatile organic acids in must or wine, or the perception of acids in the mouth.

After-smell—The fragrance that lingers in the mouth after swallowing wine.

After-taste—The lingering taste perception in the mouth after wine has been swallowed.

Aging—Changes in wine chemistry that occur after bottling; occasionally used to include maturation.

Anthocyanin—Flavonoid pigments that generate the red to purple color of red grapes and wine (see Table 2.1).

Aroma—The fragrant perception that is derived from aromatic grape constituents.

Aromatic—A relatively lipid-soluble compound sufficiently volatile to stimulate the olfactory receptors in the nose.

Baking—The heating used in processing wines such as Madeira to obtain their distinctive bouquet.

Bouquet—The fragrant sensation in wine derived from aromatics produced during fermentation, maturation or aging.

Breathing—A term that refers to either the exposure of wine to air shortly following the opening or the decanting of bottled wine.

Browning—An undesired increase in the yellow-brownish cast of a wine; primarily considered to be due to the oxidation of phenolic compounds.

Carbonic Maceration—The intracellular fermentation of grape cells that may precede yeast fermentation; used in the production of beaujolais-like wines.

Caudalie—The unit (seconds) of flavor duration (finish) in the mouth after swallowing or expectorating a wine.

Color Density—The sum of the absorbency of a wine, typically measured at 420 and 520 nm ($E_{420} + E_{520}$).
Color Stability—The long-term retention of a wine’s young color; favored by low pH, oxygen exclusion, and (for red wines) anthocyanin polymerization with tannins.

Congener—Compounds that influence the sensory quality of related substances; usually refers to alcohols other than ethanol in wines or distilled beverages.

Dry—Having no perceived sweetness, in wine.

Fatty Acid—A long, straight hydrocarbon possessing a carbonyl (acid) group at one end.

Flavor—The integrated percept of taste, touch, and odor of food and beverages; often influenced by color and occasionally sound.

Fortification—The addition of wine spirits to arrest fermentation, increase alcohol content, or influence the course of wine development.

Fragrance—The aromatic aspect of wine; includes both aroma and bouquet aspects.

Fusel Alcohol—A short-chain (3- to 5-carbon) alcohol possessing a pronounced fusel or petroleum odor.

Headspace—The volume of gas left in a container after filling and attaching/inserting a closure.

Herbaceous—Describing an odor induced by the presence of above-threshold levels of several hexanols and hexanals, or certain pyrazines.

Lees—Sediment that forms during and after fermentation; it includes material such as dead and dying yeasts and bacteria, grape cell remains, seeds, tartrate salts, and precipitated tannins.

Maillard Product—The product of nonenzymatic reactions between reducing sugars and amine compounds (i.e., amino acids and proteins), which produce polymeric brown pigments and caramel-like aromatics.

Malolactic Fermentation—The decarboxylation of malic to lactic acid by several lactic acid bacteria and some yeast strains; a biologic form of wine deacidification.

Maturation—The cumulative name for those processes involved in wine making that occur between the termination of fermentation and bottling.

Micelle—Aggregation of molecules in a solution, usually water, that typically form microspheres; the more water soluble portion facing out into the water, whereas the less water soluble portion is positioned inward; micelles may contain higher concentrations of additional compounds inside the sphere than is found in the suspending solution.
**Mouth-feel**—The sensation produced by compounds dissolved or suspended in the saliva that activate trigeminal receptors in the mouth; produce the various perceptions of astringency, burning, pain, prickling, temperature, touch, viscosity, etc.

**Mouthspace**—The gaseous (air) phase above food and liquid in the mouth (analogous to headspace).

**Oak Lactones**—A pair of optical isomers found in oak that contribute to the characteristic flavor of wine matured in oak cooperage.

**Off-odor**—A fragrant or pungent compound that is generally considered undesirable.

**Off-taste**—An atypical or imbalance in taste sensations considered undesirable.

**Olfaction**—The sensation produced by volatile compounds carried by inspiration or expiration to the olfactory patches in the nose and able to reach and stimulate receptive neurons in the olfactory epithelium.

**Olfactory Bulb**—The region of the brain just above the olfactory receptor regions of the nose; the site in which sensations are collected before being sent to the piriform cortex.

**Orbito-Frontal Complex**—The region of the brain where various sensory inputs (olfaction, taste, mouth-feel, vision, sound) are integrated into the percept termed *flavor*.

**Oxidation**—A reaction in which a compound loses an electron (or hydrogen atom) and becomes oxidized; although molecular oxygen is the principal initiator of most oxidation-reduction reactions in wine, it is probably its more reactive radicals, such as peroxide, that directly oxidize most wine constituents; in a more restricted sense, oxidation may be used to refer to the browning of white and red wines, the development of a pungent, cooked vegetable off-odor in bottled wines, the development of a distinct aldehyde odor in sheries, the development of bottle sickness, or the fragrance loss after bottle opening.

**Partition Coefficient**—An indicator of the relative solubility of a compound in a solution of immiscible solvents (such as oil and water) or between a liquid and the gaseous (air) phase above it.

**Pétillance**—Oral sensation generated by a slight amount of carbon dioxide (about 200 kPa–2 atm).

**Phenolic Compounds**—Compounds containing one or more benzene-ring structures and at least one hydroxyl (OH⁻) group.

**Piriform Cortex**—The region of the brain to which most impulses from the olfactory bulb go; the site in which odor quality is interpreted and odor memories appear to be stored.
Quality—The property of wine showing marked aromatic and flavor complexity, subtlety, harmony, and development, associated with a distinct aroma and aged bouquet; in aromatic compounds, quality signifies the subjective similarity to a known flavor or aroma, for example, apple-like (in contrast to the intensity of the sensation).

Residual Sugar—The sugar content that remains in wine after fermentation is complete; in a dry wine this primarily involves the nonfermentable sugars arabinose and rhamnose.

Taste—The sensation produced by substances dissolved or mixed in the saliva that activate receptors in the mouth (mostly tongue); includes bitter, salty, sour, sweet, and umami perceptions.

Tannins—Polymeric phenolic compounds that can tan (precipitate proteins); in wine they contribute to bitter and astringent sensations, promote color stability, and are potent antioxidants.

Tears—The droplets that slide down the sides of a swirled glass of wine; they form as alcohol evaporates and the increased surface tension of the film pulls the fluid on the glass together.

Terroir—The combined influences of vineyard atmospheric, soil, and cultural conditions on vine growth and fruit ripening; the term is often misused in an attempt to justify the supposedly unique quality of wines from certain vineyard sites.

Trigeminal Nerve—The fifth cranial nerve, three branches of which carry impulses from the nose and mouth; it gives rise to the sensations of astringency, heat, body, prickling, and pain in wine.

Viscosity—The perception of the resistance of wine to flow; a smooth, velvety mouth-feel.

Volatile—In wine, it refers to the escape of aromatic compound from the wine into the air; it is affected by the partition coefficient of the compound, and how it is affected by other wine constituents, the surface area/volume contact, the formation of micelles, and the formation of reversible complexes with other wine constituents.

Volatile Acids—Organic acids that can be readily removed by steam distillation; almost exclusively acetic acid in wine.

Wine Spirit—Distilled wine used to fortify wines such as sherry and port; it may be highly rectified to produce a neutral-flavored source of high-strength alcohol.
Tasting Term 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.

Spritz—Formation of a few bubbles on the sides or bottom of a glass; may generate a just perceptible prickling on the tongue.

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.

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.

Fragrance—Olfactory perceptions that may come from sniffing the wine (ortho-nasal) or vapors reaching the nasal passages via the mouth (retronasal).

Aroma—The fragrance derived from grapes; typically resembling some complex of fruity, floral, spicy, herbaceous, or other aromatic attributes; see Fig. 1.3

Bouquet—The fragrance derived either from alcoholic fermentation (e.g., fruity, yeasty), processing (e.g., buttery, nutty, oaky, madeirized), or aging (e.g., 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 quality during the period 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 Fig. 1.4 for specific examples.
**Quality**—For specific odors, this term refers to a descriptive term applied to the odor; for wine, it refers to the ranking of wine relative to some standard (personal, varietal, regional, stylistic, etc.).

**Artistic**—Features such as complexity, subtlety, dynamism, development, duration, harmony (balance), uniqueness, memorableness that distinguish the flavor of the wine.

**Regional**—The flavor attributes that are thought to characterize the wines from a particular region.

**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 a 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 small 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.

**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 term of imprecise meaning, generally referring to the summary perception of weight or richness in the mouth; a tactile sensation induced primarily by the presence of alcohol, but clearly influenced 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 content.

Heat—A perception of warmth generated by the presence of ethanol.

Pain—A sharp sensation occasionally induced by excessive tannin content or high carbon dioxide content under cold conditions.

Prickling—The pleasant sensation of pain induced by the bursting of bubbles of carbon dioxide on the tongue.

Finish—The perceptions that linger in the mouth after the wine has been swallowed or expectorated; when measured (in seconds), each unit is termed a caudalie.

After-smell—The flavor aspect of finish; usually a highly regarded attribute.

After-taste—The taste-mouth feel aspects of finish.
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PLATE 5.1 Sensory cubicle showing monitor with tasting form on which responses can be entered; note lids on wine glasses and slot for passing samples. (Photo courtesy of Dr. Gary Pickering, CCOVI, Brock University, St. Catharines, Ontario.)

PLATE 5.2 Sensory lab showing arrangement of cubicles. (Photo courtesy of Dr. Gary Pickering, CCOVI, Brock University, St. Catharines, Ontario.)

PLATE 5.3 Sensory lab showing back of cubicles and prep area. (Photo courtesy of Dr. Gary Pickering, CCOVI, Brock University, St. Catharines, Ontario.)

PLATE 5.4 Sensory lab showing ceiling red lights. The flash used in taking the photo negates the actual impression of the use of only red light. (Photo courtesy of Dr. Gary Pickering, CCOVI, Brock University, St. Catharines, Ontario.)
PLATE 5.6  Double action cork screws, lever model of the Screwpull™. (Photo courtesy of Le Creuset, New York, NY.)

PLATE 5.5  Double action cork screw, original model of the Screwpull™ and foil cutter. (Photo courtesy of Le Creuset, New York, NY.)

PLATE 5.7  Eight-bottle wine dispenser with refrigerated compartment for white wines. (Photo courtesy of WineKeeper, Santa Barbara, CA.)

PLATE 5.8  Spigot of wine dispenser. (Photo courtesy of WineKeeper, Santa Barbara, CA.)
PLATE 5.9  Individual dispensing unit and nitrogen tanks. (Photo courtesy of WineKeeper, Santa Barbara, CA.)

PLATE 5.10  Black ISO wine tasting glasses. (Photo courtesy of Midnightsun Designs, Norrköping, Sweden.)

PLATE 5.11  Wine tasting glasses: left, Royal Leerdam Wine Taster #9309RL – 229 ml, 7 oz (ISO model), and right, Citation All Purpose Wine #8470 – 229 ml, 7 oz. (Photo courtesy Libbey Inc., Toledo, OH.)

PLATE 5.12  Setup for assessing the effect of glass shape on the sensory attributes of wine. (Photo courtesy of Drs. M. L. Pelchat and J. Delwicke, Ohio State University.)
PLATE 5.13  Sparkling wine flutes: left, Royal Leerdam Allure Flute #9100RL, 214 ml, 7 3 oz; right, Citation Flute #8495, 185 ml, 6 3 oz. (Photo courtesy Libbey Inc., Toledo, OH.)

PLATE 5.14  The Cyranose 320 electronic nose. (Photo courtesy of Cyrano Sciences, Inc., Pasadena, CA.)

PLATE 5.15  z-Nose sampling machine. (Photo courtesy of Electronic Sensor Technology, Newbury Park, CA.)

PLATE 7.1  Grapes exposed to progressive drying in the recioto process: upper row healthy grapes; lower row of grapes infected with Botrytis cinerea. (Photo courtesy Dr. Usseglio-Tomasset, Instituto Sperimentale per l’Enologia, Asti, Italy.)
PLATE 7.2  Storage location for the progressive slow grape drying for the production of recioto wines. (Photo courtesy of Masi Agricola S.p.a., Italy.)

PLATE 7.3  Cluster of botrytised grapes showing berries in different states of noble rot. (Photo courtesy of D. Lorenz, Staatliche Lehr-und Forschungsanstalt für Landwirtschaft, Weinbau und Gartenbau, Neustadt, Germany.)

PLATE 7.4  Grapes protected with netting prior to harvesting for icewine. (Photo courtesy of CCOVI, Brock University, St. Catharines, Ontario, Canada.)
PLATE 7.5  Harvesting grapes for the production of icewine. (Photo courtesy of E. Brian Grant, CCOVI, Brock University, St. Catharines, Ontario, Canada.)

PLATE 7.6  Dumping frozen grapes into press in preparation for juice extraction. (Photo courtesy of E. Brian Grant, CCOVI, Brock University, St. Catharines, Ontario, Canada.)

PLATE 9.1  Small wine cellar designed with sections containing twelve bottles. (Photo courtesy of R. Jackson.)
PLATE 9.2 Pek Supremo wine preservation system. (Photo courtesy of Pek Preservation Systems, Windsor, CA.)

PLATE 9.3 Basic WHYNOT wine preservation system. (Photo courtesy of Fresh Tech Inc., Tokyo, Japan.)
PLATE 9.4  On design installed WHYNOT unit. (Photo courtesy of Fresh Tech Inc., Tokyo, Japan.)