The Science of Red Wine

Flavor, Texture, and Tannins

By James Kennedy

> *Wine can of their wits the wise beguile,*
> *Make the sage frolic, and the serious smile.*
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> — Homer, *The Odyssey* (Alexander Pope translation)

Celebrated for centuries, red wine has extensive historical, cultural, and economic significance in the Western world. Wine connoisseurs become enamored with the "mystique" of a supple Burgundy or an explosive Australian Shiraz. They expound on the taste of black currants and leather coexisting in the same wine.The average wine drinker, by contrast, may be content to distinguish between "dry" and "fruity." Yet it is unlikely that either consumer fully grasps how dynamic the chemical system is that transforms a simple fruit juice into an ever-evolving synthesis of soil, sun, oxidation, winemaker influence, and age.

THE CHEMISTRY OF WINE

Wine is a complex liquid. Although water, ethanol, glycerol, and various organic acids comprise the major (nondescript) portion of wine, its distinct identity comes from the aroma compounds (such as terpenes, esters, and alcohols), polysaccharides and phenolics (such as anthocyanins and tannins). Some aroma compounds are present in the grapes from which the wine is made, and some are synthesized as by-products of fermentation by the yeast that turns the sugar in the grape must into ethanol. Still others are formed only after wine has been aged and are the result of oxidation and acid-catalyzed reactions. This constant evolution of the different kinds of aroma compounds is one of the many subtle aspects of wine appreciation.

Polysaccharides are polymeric unfermentable sugars that lend body and viscosity to a wine—without them, a wine might seem thin or watery. These compounds are formed during fruit ripening when the grape berry softens. The riper the grape, the more these components are found in the final wine. This explains why wines from warm growing areas (Australia, the Central Valley in California) often have more body than those from cooler climates.

Tannins contribute to the color stability, astringency, and bitterness of wine. This combination of factors is critically important to the age-worthiness and texture of wine, and possibly has health benefits. With regard to texture, tannins can be a positive or negative influence. This duality is a core aspect of red wine quality—the right amount of the right type of tannin yields a blockbuster wine, whereas too much of the wrong type of tannin results in a wine lacking character and suppleness. From a chemical and research standpoint, tannins are probably the most defining component of the quality of red wine.

WHAT ARE TANNINS?

Tannins (sometimes referred to as proanthocyanidins or condensed tannins) are a class of complex flavonoids that are localized in the grape skin and seed and are extracted into the wine during fermentation. Flavonoids are found in plants—and include several compound classes such as anthocyanins (responsible for the color in many fruits and flowers), catechins (the healthy component of green teas), and flavonoid-based tannins (found in blueberries, apples, cranberries, bananas, and quinces). Tannins encompass a large molecular weight range and interact strongly with most proteins. This interactive property is the functional role of tannins in nature. For example, many developing fruits contain large amounts of tannins, which interact strongly with salivary proteins. Any creature eating the fruit perceives it as astringent; therefore, tannins are effective feeding deterrents. This same property explains why tannins are the component of red wine that makes the taster's mouth pucker, a distinctive characteristic of red wine.

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Although scientists' understanding of the physiology of taste is incomplete, we do know that tannins can be perceived as "good" or "bad." Wines with "good" tannins we often describe as "ripe," "supple," "lush," "velvety," or "round," whereas a wine with bad tannins we find "unripe," "hard," "coarse," and "bitter." This is much like how we describe the taste of fruit (think of the experience of eating an underripe banana in contrast to one that is fully ripened). Eating an underripe fruit is not a pleasant experience for most people, yet with sufficient time and ripeness, the fruit emerges as a succulent and tasty morsel. Where did the tannin go? Through the complex biochemical process of fruit ripening, the tannins, while still in the fruit, have become "inactivated" by the production of sugars, oxidation, and the breakdown of cell-wall material. The fruit becomes a delectable treat. In the case of red wine, changes in the grape during fruit ripening yield wine with increasingly ripe tannins.

ASTRINGENCY AND TEXTURE

The molecular structure of the different tannins is strongly correlated with its sensory property in wine: the lowest-molecular-weight tannins can have a distinct bitterness associated with them, whereas the larger-molecular-weight tannins are regarded as purely astringent. Whether these sensory properties are considered individually or in combination, they are almost universally regarded as negative. Humans have evolved in such a way that we find bitterness and astringency to be repulsive. How can this repugnant taste become something we desire and prize in red wine?

Tannins become palatable in fruit because our ability to perceive tannins is influenced by many things. This combined perception of tannin in the presence of other components is described as texture or mouthfeel in the wine world. In many fruits, organic acids are produced at the same time as tannin and the combination of high organic acid and tannin concentrations yields a very astringent (and sour) experience. During fruit ripening, sugars are produced, and our ability to perceive astringency diminishes as the sweetness increases. Moreover, many fruits soften during fruit ripening, due to cell-wall breakdown. The breakdown of cell-wall material produces soluble polysaccharides which interact with tannins, once again reducing their astringent properties.

Built in the 14th century, destroyed in the 15th, then rebuilt in the 17th, the tower of Chateau Latour in the Bordeaux region of France is one of the world's most recognizable landmarks associated with the rich history and longevity of fine red wine. PHOTO BY THE AUTHOR

In a similar way, red wine contains many components that influence our ability to perceive tannins. The short list of compounds includes organic acids, simple sugars (generally too low in concentration to influence astringency), ethanol, polysaccharides, and anthocyanins. These all combine to modify astringency perception. As many winemakers describe the effect, it is much like flesh covering a skeleton. The tannins provide the structure and support of the red wine, and the other components provide the flesh and appeal.

TANNINS AND LONGEVITY

Essential as they are to red wine texture, tannins prove just as important to red wine longevity. Several chemical features of tannins give red wine its stability. First, under red wine's acidic conditions, tannins are continuously recombined through hydrolysis reactions. Through this recombination process the anthocyanins responsible for red wine color become incorporated into the tannin pool and become stabilized. Without tannins, the color of red wine would quickly fade and become orange. Once the anthocyanins join the tannin matrix, the color becomes stable. For age-worthy wines, color that would otherwise last for just a few years lasts for many decades in the presence of tannins.

During wine aging, tannins can also minimize the damaging effects of oxidation. Grape-based tannins possess the *ortho*-phenol (pyrocatechol) substitution pattern. These pyrocatechol groups are susceptible to oxidation and because of this, they are very effective antioxidants. In general, red wines that are built to age contain large amounts of tannin. The long-term effect of age on tannin structure is that it becomes increasingly pigmented (due to anthocyanins) and oxidized. These processes "soften" the tannin and make their texture more desirable. Wines that are built to age can often be quite astringent when young, and it is only with time that these wines reveal their innate wonder. Here lies the source of one of the fundamental schisms in the wine-producing world: When should a wine be drunk? On the one side, most wine is consumed within a couple of days of purchase and therefore it should be "ready to drink" when bought. From a winemaking perspective, these wines should contain lower concentrations of tannin. Theoretically, wines meant to be aged should contain lots of tannin.

Despite the worldwide movement towards the consumption of young wines, consumption of a well-aged wine offers complexity and a unique taste. There are very few people who can experience and appreciate this, due to the limited availability and costliness of aged red wines. This is unfortunate because wine of this caliber is a scientific, philosophic, and culinary wonder. More people should experience it. Wine writers do. While most wine is consumed when young, the most influential wine writers have a studied appreciation of age-worthy wines. These wines get media attention far beyond what their production volume or revenue justifies.

Is it possible to produce a wine that is ready to drink yet will age well? The answer depends on whom you ask. Based upon what we know, the ideal wine should have an abundance of structure (tannin) but with ample flesh to dress the tannins so that they aren't too astringent. How would this wine age? Must a wine that is made to be age-worthy be unpalatable in its youth? This question was put to the test in the famous Paris wine tasting of 1976 and again in 2006. In this tasting, first-growth Bordeaux wines were pitted against California Cabernet Sauvignon. These wines represent the stereotypical extremes detailed above: the aggressive and astringent-in-youth Bordelaise against the fat-and-happy, drink-me-when-I'm-young California Cabs. The winner in the 1976 tasting was a California Cabernet Sauvignon (1973 Stag's Leap Wine Cellars). Thirty years later in 2006, the tasting

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was repeated and again, the winner was a California Cabernet Sauvignon (1971 Ridge Vineyards Monte Bello). These results suggest that it is indeed possible to produce age-worthy wine in such a way that it can be consumed when young or after a considerable amount of time.

TIMING TANNINS

The process of optimizing tannin concentration and composition in red wines occurs at all stages of production and in a variety of ways. In the vineyard, research has shown that wines made from increasingly ripe fruit tend to have a more desirable texture. Yet, grapes that are left to ripen too long risk developing so much sugar content that the resulting wine is excessively alcoholic, and is therefore perceived as "hot" in the mouth. During the winemaking process, the fermentation temperature and the contact of the new wine with the skins and seeds influence the extraction of tannins and thus the balance of the wine. Skill in wine production is knowing when to separate the skins and seeds from the new wine. Premium wines are generally aged in small oak barrels. When they age in barrels the tannins oxidize (and thus soften) at a more rapid rate than they would in the bottle, so cellaring time is another critical factor. This is a significant cost to wineries because of the barrel and time investment. Recent advances in wine production practices have accelerated this process and reduced the cost by incorporating oak in wine stored in stainless steel tanks along with micro-oxygenation.

THE FUTURE OF WINE RESEARCH

The comparatively recent progress in our understanding of grape and wine tannins serves as a good example of how the wine industry is better served when scientists and craftsmen can work side by side to uncover the secrets of a centuries-old tradition. An example of how wine science has contributed immensely to the success of our global wine industry is seen in the emergence of commercial winemaking in parts of the world that have had little in the way of wine history. For example, in Oregon, the wine industry is based upon vineyards that were planted on sites without prior grape production experience. Moreover, the most significant varietal in Oregon is Pinot noir, a varietal notoriously difficult to produce well.

And Oregon isn't alone in its achievement. Other wine producers have done as well in Australia, Chile, New Mexico, South Africa, Texas, and many other new and emerging winemaking areas. What took centuries to achieve in well-established lands, new wine-producing regions have achieved in mere decades. Grape and wine scientists of the world: give yourselves a collective pat on the back. Job well done!

Where does wine tannin research go from here? Here are some examples of projects that are currently in progress and how they are designed to contribute to the progress of our fine wine industry.

- **Spatial Variation in Grape and Wine Tannins.** In many parts of the world, vineyards are planted in sites that are far from uniform (e.g., soil, aspect, elevation, nutrient availability). This makes the fruit as heterogeneous as the site. Transferring this heterogeneity into a fermentation tank is not desirable because it makes wine quality a guessing game. Using precision agriculture tools, this heterogeneity can be mapped out and the vineyard management practices can either be modified to try to minimize the heterogeneity or the winemaker can use this information to make harvesting decisions. Based upon our research findings, understanding how site variation influences tannin chemistry can have a large impact on the entire winemaking enterprise.
- **Influence of Grape Cluster Temperature on Composition.** The immediate climate around a grape cluster can profoundly affect its composition at harvest. Understanding how specific microclimate factors (e.g., light, temperature, relative humidity) influence grape composition could change grape management practices and our ability to predict effects due to climate change. Working with United States Department of Agriculture micrometeorologist **Julie Tarara**, the Food Science and Technology department at Oregon State University is investigating how cluster temperature influences grape tannin composition.
- **Relative Extraction of Skin and Seed Tannins.** When tannins are extracted from the grape into new red wine, they generally come from two sources, the skin and seed of the berry. Research has shown that these tannin pools have different compositions. Anecdotally, it is thought that seed and skin tannins have different sensory properties in wine. Winemakers have developed production methods to accentuate the presence of one or the other tannin based upon this anecdotal evidence. The problem: How do you differentiate skin tannin from seed tannin once extracted into wine? This problem was recently solved[1] and we are now studying how specific grape and wine production techniques influence the extraction and presence of these tannin pools in wine, and more importantly, their corresponding sensory properties.

SCIENCE AND CRAFTMANSHIP

Wine history predates western civilization itself, and it is not surprising that wine production today is steeped in tradition. Despite the many advances in wine science, from a traditionalist's perspective, it often seems that the product of wine science is dull and uninteresting. Yet I would argue that at no other time in the history of wine have so many fine age-worthy wines been readily available. Wine science has been instrumental in this progress. So pour yourself a fine wine and toast to the accomplishments of wine science! ■

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Note:

1. Peyrot des Gachons, C.; Kennedy, J.A. (2003) "Direct method for determining seed and skin proanthocyanidin extraction into red wine." *Journal of Agricultural and Food Chemistry* 51, 5877-5881.

on the web

Listen to a podcast of James Kennedy's talk, "A Toast to Tannins," at the December 15, 2006 Science of Wine event at the Academy, part of the "Science of Food" series, by going to www.nyas.org/podcast