Evaluation of Wine Grape Maturity for Harvesting

Premium wine production begins in the vineyard at harvest when all the combined factors that influence the fruit quantity and quality come together. The properties of the harvested fruit set limits on the potential quality of the wine. Certain winemaking practices can ameliorate deficiencies in grape quality but cannot fully offset inherent defects. Careful evaluation of berry maturity is one of the components in a successful vintage. Changes in fruit composition may happen quickly when high temperatures occur during the latter stages of ripening. Harvest decisions are usually based upon experience, intuition, and practical considerations. Luck is also needed in Missouri, as well as other places, particularly with respect to the weather during the ripening period.

Maturity could be described as the time when the analytical parameters such as sugar content, acidity, pH, and other compounds reach the proper balance, and the varietal characteristics, including aroma, flavor, and color, are fully developed for the style of wine to be produced. Attempts have been made to quantify maturity using analytical parameters as the sole means of predicting wine quality. Optimal maturity, however, does not necessarily coincide with specific levels of sugar, acidity, or pH. The evaluation of maturity for harvesting should consider the more subjective ripeness parameters such as flavor, aroma, and color for varietal characteristics, as well as the more standard °Brix for potential alcohol content, pH for chemical and microbial stability of wine, and TA for flavor balance and wine style.

The determination of harvest time is a complex compromise between availability of harvesting labor or a mechanical harvester, the weather, the likelihood of pest and disease damage, and the stage of ripeness of the grapes. Timing is most critical when all the fruit is harvested concurrently since only rarely is it economically feasible to selectively and repeatedly harvest for fruit of a particular quality for winemaking. The best harvest decisions are made by grape growers and winemakers who work closely together using a practical, integrated approach toward maturity assessment.
Changes of Chemical Composition During Ripening

Since wine quality depends on grape composition, and composition changes as grapes ripen, it is profitable to choose a harvest date which gives an optimum mix of compounds for winemaking. The specification of ripeness may be made for the grower by the purchaser. Whatever the circumstances, the more the grower understands about the course of ripening, the greater the chances that the prices paid for the grapes and the quality of wines will be maximized.

Berry development after veraison includes changes in appearance and the accumulation and metabolism of a range of compounds. The stems of the clusters turn from green to brown as do the seeds of the berries, and the basal leaves of the vines begin to turn yellow. Berries increase to a maximum size during ripening and begin to soften slowly. Sugars and aromatic compounds increase, and both total acid content and acid strength decrease. Berries of red varieties turn from green to a light red, to a deep red or black color, since the concentration of red pigments increases in the skin. Berries of white varieties turn from green to a light yellow or gold color and the skin becomes translucent, making the seeds more visible. Pronounced shriveling and berry shatter indicate overripeness.

Over 700 compounds are known to be present in ripe grape berries. Variations in the relative amounts of these compounds, that is, grape composition, directly determines wine quality. Many components increase in roughly the same manner as sugar. With others, the increase is influenced by different factors so that their relativity to sugar is not constant. Yet others, such as flavor volatiles and some amino acids, show most of their accumulation later in ripening when sugar increase is slowing.

Water content decreases. The major component in the berry is water, and the amount of water closely parallels berry volume. It decreases during ripening because of sugar accumulation. Water loss by continued transpiration from the berry can cause shriveling.

Sugar content increases. The majority of soluble solids in grape juice are fermentable sugars (90 to 95%). The balance consists of non-fermentable sugars (polysaccharides), tannins,pectins, pigments, organic acids, protein, potassium, and other components. About 90% of the fermentable sugars are glucose and fructose, with small amounts of sucrose, raffinose, and some others. Fructose has a much sweeter taste than glucose. These two sugars are present in grape juice in about equal proportions at harvest.

Sugar content increases steadily during ripening. The ratio of glucose to fructose shows characteristic changes as berries develop. At veraison, glucose considerably exceeds fructose, but as sugar accumulation proceeds, the ratio of glucose/fructose tends towards unity. Overripe berries may have more fructose than glucose. Sugar content ranges from 15 to 25% in grape juice.

Acid content decreases. The primary organic acids in grape juice are tartaric and malic acid, comprising over 90% of total acids, with citric acid and a number of others making up the balance. Tartaric acid has a stronger acid taste than malic acid. The ratio of the two acids will affect the flavor balance of the wine. Total acid content declines due to the decrease in malic acid respired during ripening. Tartaric acid is respired slowly, if at all. High temperature hastens malic acid respiration, and in some berries, malic acid decreases to very low levels. In addition, malic acid can be converted to sugar. Malic acid is metabolized to sugar more rapidly at warmer temperatures. Consequently, grapes from warmer sites or warmer seasons have less malic acid and lower titratable acidity than those from cooler sites or cooler seasons. Dilution by water due to berry growth and conversion of acids to weakly acidic salts also contribute to the decrease of acid content. Further, potassium forms potassium acid tartrate which precipitates readily from water as does calcium tartrate and calcium oxalate. The total acidity at harvest ranges from 0.4 to 1.4%.

Other compounds change. Compounds other than water, sugars, and acids make up a minor proportion of grape juice, but they are the source of most of the interest, pleasure, and value by which wine grapes and wines are judged. Phenolics, volatiles, vitamins, minerals, and nitrogen-containing compounds are significant in the harvesting of wine grapes. Phenolics embrace compounds that contribute color, astringency, and
flavor. Catechins, tannins, anthocyanins, and flavonols have complex sensory significance. Many of these compounds are more abundant in the skin and seeds. Phenolic compounds increase during ripening, but with differences between parts of the berry. Volatiles are the compounds of high vapor pressure that contribute to the aroma and flavor of grape juice in particular ways. Aroma becomes detectable quite suddenly during specific stages of berry ripening. Vitamins are not thought to be factors that influence time or method of harvesting even though the concentration of most vitamins increases with ripening. Potassium is by far the most abundant mineral in grape juice. With increasing potassium levels in grape juice, pH increases because of the formation and the solubility of potassium acid tartrate. In ripe berries, amino acids make up more than half of the total nitrogen-containing compounds.

**Acid strength weakens.** The strength of the acids in grape juice decreases about tenfold during ripening because hydrogen ions are lost to potassium and the total acid content also decreases. Every time a grape berry cell gets a needed potassium ion, it must give up an hydrogen ion, weakening its acid strength. The amount of potassium a grape berry takes in during ripening depends on the length of the maturation period and the crop; and it varies a great deal among varieties and growing seasons.

**Indices of Maturity**

Because of the importance of sugar and acid content to vinification, and their ease of measurement, these constituents have received major attention as indicators of grape maturity. The following are some harvest indices that have been suggested for monitoring maturity.

**Total soluble solids (TSS).** TSS is the most common guide to ripeness. The TSS level chosen varies with wine style as well as the known performance of a given vineyard. Sugar content is the basis for calculating the approximate alcohol yield. It takes about 2% TSS in grape juice to make one percent alcohol in the finished wine. The higher the TSS, the higher the potential alcohol or alcohol plus residual sugar of wine made from the juice. Overripe grapes with higher TSS values are used for sweet wines. TSS levels can be extrapolated with some accuracy from successive measurements as ripening progresses and, during the early phases, they provide a good basis for indexing the rate of change of other compounds.

**Titratable acid (TA).** TA has important effects on the course of the fermentation through their influence on oxidation-reduction potential, microbial metabolism, color, and flavor. Acidity makes an important contribution to wine palatability.

**pH.** More important for wine quality than the decrease in the total amount of acids in grapes is the weakening of acid strength. The strength of acids is measured in pH units. pH is the negative log of the concentration of free hydrogen ions (H⁺), the acidity strength, and generally correlates inversely with TA. A solution with a pH of 7 is a neutral solution having an equal number of acid and base ions. A change of one pH unit represents a tenfold change of H⁺ concentration. For example, a juice with a pH of 3.0 has 10 times the acid intensity compared to a juice with a pH of 4.0 (H⁺ concentrations 10,000 and 1,000 times greater, respectively, than water at a pH of 7). The lower the pH, the stronger the acid. Grape juices are moderately strong acids, with pH values in the range of 3.0 to 4.0. Grape juice samples from different vineyards or vintages can have the same total acid content but vary in their acid strength as reflected in different pH values. High levels of an alkali metal in a juice, especially potassium, reduce H⁺ concentration and elevate pH for a given level of TA. The optimum harvest pH depends on the grape variety and wine style, but pH values of 3.5 or less are preferred.

**Aroma, flavor, and color.** The foregoing indices provide guides to the basic composition of the grapes destined for wine, but they indicate little about actual quality. Experience is still clearly the best guide. Inadequacies of objective methods have led to organoleptic assessment of quality in juice samples—by smell and taste. A good correlation exists between wine quality and aroma and flavor score, far superior to that with TSS, TA, and pH. It is suggested that TSS, TA, and pH standards should only be used after aroma has developed. For most grape varieties there is a rough correlation between increasing amounts of sugar and higher concentrations of aroma components. Winemakers rely on that correlation and their experience with
each variety to estimate optimum ripeness. It is not practical to measure the aromatic compounds since they occur in tiny amounts that cannot be measured quickly on a routine basis with present technology. Because of the importance of anthocyanins and tannins to red wine quality, their presence is obviously an indicator of grape quality.

**Sampling**

A vineyard is sampled to gauge the collective composition of the fruit at that time. It is therefore important that the sample provides a good estimate of the composition of the total crop after it has been crushed. A sample may also serve to provide an estimate of berry size for calculating yield components to enable comparisons between vineyards and seasons.

Variation in maturity throughout the vineyard can arise from differences in the age and health of the vines, soil type and microclimate, protracted flowering and positioning of the cluster, as well as between berries and tissues. Vineyard sampling has to make allowances for variations in the berry population to be tested.

An optimal sampling scheme includes an assessment of the variation within each component of vine variability. The following factors influence the choice of sampling methods: the size of the samples for processing, the speed with which the sample can be collected, and the accuracy required from the sample. Comparing the sample analysis results to the crush analysis for several years will tell how good the samples were and what adjustment to sampling procedures needs to be done. The key to successful sampling is to standardize methods, apply it throughout the ripening period, and check the harvest sample with that of the crushed must.

Samples should be taken weekly beginning about three weeks before harvest. More frequent sampling should be done as the anticipated harvest date becomes closer or if there are changes in the weather which could affect maturation. There is merit in taking one sample for each fermentation lot, or several lots, after experience has shown the degree of variation between them. For best results, samples are taken at the same time of the day, preferably in the morning or the same part of the day when harvesting is done. Dew on the fruit may alter the results. The fruit should be stored in sealed polythene bags at 36 to 40°F (2 to 4°C) and processed within 24 hours.

Many methods of sampling have been investigated to determine the best combination of adequacy and ease. Sampling can be done on a whole vine, cluster, or berry basis. The procedure of whole vine sampling presents a problem in the ability to select vines representative of the block being sampled. Cluster and berry samplings help to reduce this problem as a wider range of vines may be covered within a reasonable sample size. Cluster sampling is faster than berry sampling and has the advantage of providing a larger and more representative sample, giving compositional data closer to that of the fruit at harvest. Another advantage of cluster sampling is that the average cluster weight can be obtained. With an approximate count of average number of clusters per vine, an anticipated yield at harvest can also be estimated. A minimum of 25 clusters should be sampled from a small vineyard block and a minimum of 50 from large blocks.

Berry sampling involving the collection of 200 or more berries from many clusters, selected randomly throughout the vineyard, appears both adequate and simple to perform. In a small, uniform vineyard, a 200 to 500 berry sample taken from vines evenly distributed throughout the vineyard (3 berries per vine and about 5% of vines sampled) is sufficient to provide an accuracy to within 1°Brix of the must after crushing. If greater accuracy is required, or the vineyard has significant range in vigor, a larger sample should be taken. In larger vineyards, a reduction in the number of vines sampled is possible with an increase in the number of berries taken per vine (5 berries per vine, 3% of vines sampled). In a very large vineyard with little variation in vine vigor across the vineyard, every tenth pair of rows may be traversed with every tenth vine sampled from alternate sides (1% of vines sampled).

Samples should be taken from exposed fruit and shaded fruit in the different parts of the canopy, on opposite sides of the row, and in a manner which closely represents the balance of the fruit in the vineyard. Distinct blocks within a vineyard should be sampled separately. Avoid sampling from vines at the end of the row and from odd vines which are
obviously physically different than the majority of vines in the vineyard block. There is a tendency to sample too few berries and to select riper, more mature ones with berry sampling. Exposed berries tend to be sampled more than shaded, less visible berries. This can result in sugar measurements as much as two percent higher in field berry samples compared to harvested, crushed fruit at the winery. Underdeveloped secondary clusters can lower overall fruit maturity and are best removed during veraison or selectively not harvested. However, secondary clusters must be included in the field sample if they will be picked at harvest.

Sample Preparation
The aim in preparing a sample for testing is to simulate the extraction operation of the winery crusher. Grape samples may contain berries in varying stages of development, ranging from hard and unripe to raisined and shriveled. Since the distribution of compounds within berries varies from compound to compound, as well as stage of development, it is necessary to check that the matching of method with the winery practice remains valid with all samples. Another useful precaution is to anticipate any post-harvest changes which may occur. Juice is obtained by pressing, blending, or crushing of the samples. After extraction and proper mixing, juice can be divided to subsamples for various measurements.

To prepare a juice sample for analysis, the cluster or berry sample should be thoroughly crushed without breaking the seeds. Berry samples can be crushed and pressed by hand, taking care to thoroughly crush each berry. Larger cluster samples are more easily crushed with a small crusher and pressed with a small bench scale press. The juice should be settled to reduce suspended solids and held in full containers to exclude air. Note that variation in titratable acidity levels may occur due to variation in the amount of pressure applied to the sample and the acidity variations in the berry and among the berries.

During crushing and processing, the juice extracts color from the skins. The ease with which pigments are extracted during processing is an indicator of the degree of maturity. Unripe fruit has green juice due to a high content of chlorophyll and a low content of colored pigments in the skins. Ripe fruit has a high content of characteristic pigments which are readily extracted during processing.

Natural enzymatic oxidation (browning) can occur after the fruit is crushed and has to be avoided for sensory evaluation samples. Refrigeration aids settling and delays enzymatic browning. Enzymatic browning is more rapid when the fruit is very ripe, when the fruit is warm or hot, and when mold and rot are present. To prevent browning and maintain sample freshness for sensory evaluation, add SO₂ (to give 25 to 30 mg per litter-free SO₂), erythorbate (50 mg/L), and pectic enzyme (as recommended by the manufacturer) to the juice receiving vessel. Initial observations of juice color should be noted before making these additions. The chilled grapes (<2.0°C) are crushed, sparged with N₂ to remove dissolved O₂, and SO₂ adjusted. The sample is then sieved into a CO₂-filled bottle, sealed, and allowed to settle for 24 hours. The clear juice is siphoned and decanted into another CO₂-filled bottle and sealed. Such samples are suitable for aroma assessment for several months when stored at 32°F (0°C).

Analysis
The tests made on juice samples include measurements of TSS, TA, pH, and, less frequently, color, aroma, and flavor.

TSS. TSS is the most common measure of maturity and is reported as °Brix that corresponds to the percentage of sugar by weight in the juice. TSS can be measured by a hydrometer or refractometer.

Hydrometers measure dissolved solids by comparing the density of the juice to that of water. Hydrometers are closed glass 'floats' weighted at one end. The depth of the hydrometer in solution is proportional to the solute concentration. A reading is taken by placing the eye at the level of the liquid surface and reading in the hydrometer stem at the bottom of the meniscus (the curved upper surface of the juice around the hydrometer stem) after the hydrometer has come to equilibrium in the juice. About 200 to 500 ml of juice are needed for most hydrometers. Accurate hydrometers are calibrated to a narrow range of 5 to 10 degrees and are subdivided to 0.1 degree units. The equipment must be clean, and the hydrometer should be floating freely. Hydrometers are calibrated to a specific temperature, usually 68°F (20°C). A cooler temperature...
increases the liquid density and gives a false high reading, while a warmer temperature gives a false lower reading due to the lower liquid density. The temperature of the juice is measured at the same time. If the temperature of the juice is not at the calibration temperature, a correction must be made (Table 1). Errors in reading may be caused by suspended solids in the solution or bubbles attached to the hydrometer, so use well-settled juice and gently slip the hydrometer into the juice.

Table 1. Temperature corrections for hydrometers and refractometer (calibrated to 68°F, 20°C).

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Refractometers measure soluble solids by the degree to which light is refracted (bent) when it passes through a solution. The higher the dissolved solids content, the more the light is refracted. Hand refractometers can be operated with as little as one drop of juice and are useful for spot checking in the vineyard as well as in the winery. A drop of juice is placed on the glass surface, making sure the whole surface is covered. The prism box is closed and the instrument held toward the light. A graduated scale in °Brix is read where the boundary of the dark and light field meet. Juice samples do not have to settle as they do for hydrometer measurements. Refractometers should be set to 0°Brix using distilled water at 68°F (20°C) by adjusting 0 position. Refractometers are usually calibrated to 68°F (20°C) and temperature corrections are often necessary. Some refractometers come with thermometers attached while others are self-correcting over a range of about ±10°F. Careful correction for temperature is attained by using a table of correction factors based on the temperature of the juice (Table 1). Common errors with refractometer measurements include failing to standardize with distilled water and not making the necessary temperature corrections, especially when samples are taken in the field.

TA. TA measures the sum of titratable organic and inorganic anions and is commonly expressed as percent tartaric acid. A 5 ml juice sample is added to 100 ml distilled water in a beaker or flask and titrated with 0.1 N NaOH, using a calibrated burette, until the juice solution is completely neutralized at a pH of 8.2 to 8.4. A calibrated pH meter can be used or a few drops of 1% phenolphthalein indicator solution can be added. In either case, it is important to neutralize the water until the pH reaches 8.2 to 8.4, or until the indicator turns a faint pink color before the sample is added and titrated with NaOH. Common sources of error in titratable acidity measurements are careless pipetting of the sample, failure to neutralize the acidity in the water before adding the juice sample, overtitration (past the first appearance of the pink color with the indicator, or to a pH greater than 8.4 using a pH meter), and failure to calibrate the pH meter.

pH. pH is measured by a meter with a pH sensitive electrode. A pH meter with an accuracy of no more than 0.05 pH units is required. The meter should be carefully calibrated prior to each use with standard buffer solutions, with a pH 4 and 7. A useful and inexpensive standardizing buffer for juice and wine can be prepared by adding 1 gram of cream of tartar (potassium acid tartrate) to 100 ml of water. This makes a standard solution with a pH of 3.56 at room temperature to check your pH meter. The temperature control of the pH meter should be set at the temperature of the standard buffer solutions and the juice samples should be at the same temperature when measured. Common errors in pH measurement include failure to standardize the pH meter properly, using chilled sample juice right out of the refrigerator, disregarding temperature correction, and use of worn or insensitive electrodes.
Sensory Evaluation

It is important to familiarize oneself with the changes that occur during ripening through sensory evaluation of the fruit and the juice. With experience, wine grape growers can learn to recognize varietal flavors as they develop. Most wine grapes have green, herbaceous flavors when underripe which are replaced by ripe, fruity flavors when fully ripe. Fruit can be tasted in the vineyard or during sample preparation. Detailed sensory evaluation can be done with the juice sample prepared with the procedure described above. The juice samples can be evaluated for both intensity and quality of aroma and flavor. For success with this method, it is essential that oxidation be minimized to reduce the alteration of aroma and flavor.

Record Keeping and Harvest Forecasting

Predicting grape harvest dates has not developed to the level of an exact science. Harvest date for optimal quality of the fruit varies from site to site, location to location, and year to year. There is no general guideline for harvesting grapes for optimal quality according to the calendar, even with the references of bloom and veraison dates. However, it is possible to make some early season judgments based on the historical data accumulated for the specific growing areas and more particularly for your own vineyards. It is best to refer to an established grower in your local area for his or her input until you accumulate your own historical data. A record should be kept each year of the maturity observations, analysis, and the condition of the fruit at harvest. Fruit maturity and quality are greatly influenced by the unique weather patterns of each harvest season and where possible, temperature and weather should be collected for each site. The development of a maturity and weather database will be invaluable in future years for determining the best time to harvest.

Wine grapes are harvested between late August and early October in Missouri, depending on the varieties, locations, and years. Intervals of harvest dates for selected wine grape varieties grown at the Fruit Experiment Station in Mountain Grove, Missouri between 1989 and 1994 are presented in Fig. 1. The harvest dates have varied by as much as one month for some varieties. Varieties ripen in an order which remains relatively consistent from year to year, though it may be altered slightly due to weather and cultural factors.

Pre- and Post-harvest Cultural Management

The harvest decision is not always based on fruit ripeness alone, but may be hastened if disease pressure is high. Be aware that rain during harvest can quickly ruin an otherwise beautiful crop if disease becomes established. Berry damage caused by birds, wasps, berry moths, fruit cracking, or powdery mildew can open avenues for infections and rot. Chemical control for Botrytis should include a pre-harvest spray, although this may not be necessary with resistant varieties. Rovral is the most effective material labeled for grapes with Benlate, copper and Captan somewhat less effective. Carefully watch the days-to-harvest intervals for all pesticides applied close to harvest. A word of caution about sulfur; although sulfur may legally be applied up to the day of harvest, most winemakers prefer that the last sulfur be applied to the vineyard several weeks prior to harvest. High residual sulfur in the must can retard yeast fermentation, and in some cases, cause off-flavor and hydrogen sulfide formation.

Excessive water stress impairing leaf function and ripening should be avoided. However, irrigation close to the time of harvest needs careful management to avoid interference with vineyard
Irrigation of every second row may be helpful with some irrigation methods. Drip irrigation is least complicating. Excessive water, whether from irrigation or rain, may lower sugar levels and cause splitting of berries, giving potential for rot development.

Completion of harvest does not mean that spraying in the vineyard should be stopped. Post-harvest sprays may be necessary to protect the fruiting potential of next year's production. Control of downy and powdery mildew is of special concern. Note that the number of chemicals available are limited for post-harvest sprays. Check your spray guide for details.

References


Understanding grape berry development

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In the world of winemaking, there is a universal truth about the quality of the vintage: It is directly correlated with optimal grape maturity. Site selection and grapegrowing practices have a tremendous influence on achieving optimal maturity. A considerable amount of viticultural research has identified strategies that can be used to optimize grape maturity at harvest including irrigation, canopy management, and cropping levels, among others. To fully appreciate how these strategies can be used to optimize grape maturity, grapegrowers and winemakers should have an understanding of berry development.

Fruit development

The grape berry is essentially an independent biochemical factory. Beyond the primary metabolites essential for plant survival (water, sugar, amino acids, minerals, and micronutrients), the berry has the ability to synthesize all other berry components (for example, flavor and aroma compounds) that define a particular wine.

There is a potential for tremendous variability in ripening between berries within a grape cluster, and therefore within the vineyard. Practically speaking, it is difficult to determine when a vineyard with a large variation in berry maturity is at its best possible ripeness. One of the major objectives of modern viticulture is to be able to produce a uniformly ripe crop.

If premium winemakers were to come up with what constituted the ideal, optimally ripe vineyard, it would be uniformly ripe clusters with small berries chock-a-block with flavor. An understanding of berry anatomy, when and where berry components are produced, is the first step in understanding the rationale behind managing wine style in the vineyard.

Berry structure

From a winemaking perspective, the grape berry has three major types of tissue (Figure I): flesh, skin, and seed, with the sheer bulk of wine being derived from the flesh. These tissues vary considerably in composition, and therefore by extension, they contribute differently to overall wine composition. Because of this, the composition of wine can be manipulated by simply changing berry size. As a general rule, wines made from smaller berries will have a higher proportion of skin and seed-derived compounds.

In addition to the effect of berry size on the proportion of skin and seed-derived components in wine, the actual number of seeds in the berry can influence the proportion of seed-derived components in wine. The normal or perfect number of seeds in the grape is four; in general, though, the actual number is much less.
Environmental and nutritional conditions at bloom time affect the success of fertilization, and the resulting number of seeds per berry, and therefore can be expected to influence the presence of seed-derived material in wine.

The berry is supplied through the berry stem or pedicel by a vascular system composed of xylem and phloem elements. The xylem is the vasculature responsible for transporting water, minerals, growth regulators, and nutrients from the root system to the rest of the vine. Current evidence indicates that xylem is functional in grape berries early in development (up to véraison), but afterward, its function is reduced or eliminated.

The berry is also supplied by the phloem, which is the vasculature involved in photosynthate (sucrose) transport from the canopy to the vine. It has reduced function early in berry development, but becomes the primary source of ingress after véraison. Increases in berry volume (primarily water) are associated with increases in sugar after véraison. However, in some grape varieties (most notably Syrah), sugar increases during the latter stages of fruit ripening are not accompanied by increases in berry volume, but are caused by berry shrinkage. This shrinkage appears to be due to the transpirational loss of water, suggesting that the inability of the berry to stay well-hydrated at this point is due to blockage of phloem elements into the berry. This indicates that, for some varieties, the vasculature between the vine and the berries has reduced function during late season fruit ripening.

**Development during first growth period**

Berry development consists of two successive sigmoidal growth periods separated by a lag phase (Figure 1). The first period of growth lasts from bloom to

![Figure 2: Diagram showing relative size and color of berries at 10-day intervals after flowering, passing through major developmental events (rounded boxes). Also shown are the periods when compounds accumulate, the levels of juice "brix, and an indication of the rate of inflow of xylem and phloem vascular saps into the berry. Illustration by Jordan Koutroumanidis, Winetitles.](image)
approximately 60 days afterward. During the first growth period, the berry is formed and the seed embryos are produced. Rapid cell division occurs through the first few weeks, and by the end of this period, the total number of cells within the berry has been established. The extent of cell division has some bearing on the eventual size of the berry.

Also during the first growth period, the berry expands in volume as solutes accumulate. There are several solutes that accumulate in the berry during the first growth period, all of which reach an apparent maximum around veraison. By far the most prevalent among these are tartaric and malic acid.

These acids are distributed in the berry somewhat differently, with tartaric acid being highest towards the outside of the developing berry, and malic acid being highest in the flesh. Tartaric acid appears to accumulate during the initial stages of berry development, and malic acid accumulates just prior to veraison. These acids provide wine with acidity and are therefore critical to wine quality.

Also accumulating during the initial period of growth are the hydroxycinnamic acids. Hydroxycinnamic acids are distributed in the flesh and skin of the berry and are important because of their involvement in browning reactions, and because they are precursors to volatile phenols.

Tannins including the monomeric catechins also accumulate during the first period of growth. Tannins are present in skin and seed tissues and nearly absent in the flesh, and are responsible for the bitter and astringent properties of red wine. These compounds are also believed to be important in red wine color stability.

There are other compounds that accumulate in the berry during the first phase of growth, and which have importance to wine quality. Minerals, amino acids, micronutrients, and aroma compounds (such as methoxypyrazines) have all been observed during the first period of berry growth.

Our understanding of berry formation and development during the first period of growth and of the production of compounds having sensory importance is still developing. Understanding berry formation and the factors that affect its formation is still limited because of the complex nature of this type of research.

Understanding berry development and its compositional changes during the first growth period is limited probably because the compounds produced are thought to be of less interest from a sensory standpoint. It should be remembered though, all compounds discussed above are critically important to wine quality.

Development during second growth period

The beginning of the second phase of berry growth or fruit ripening (veraison) is characterized by softening and coloring of the berry. Overall, the berry approximately doubles in size between the beginning of the second growth period and harvest. Many of the solutes that accumulated in the grape berry during the first period of development remain at harvest, yet due to the increase in berry volume, their concentration is reduced significantly.

Some compounds produced during the first period of growth are reduced on a per-berry basis (not simply diluted) during the second period of berry growth. Principal among these is malic acid. Its reduction varies considerably but can roughly be correlated with climate. That is, grapes grown in warmer regions tend to have less malic acid than those grown in cooler regions as a result of this reduction.

Tannins also decline considerably on a per-berry basis during the second period of growth. The reduction in seed tannin appears to be due to oxidation as the tannins become fixed to the seed coat. As a result of this, the composition of extracted seed tannins changes considerably, and is characterized by a proportional reduction in the most bitter tannin components.

Skin tannins decline or remain constant during the second period of growth, and also become modified. Significant modifications that take place for the skin tannins include an increase in size. Some compounds produced during the first period of growth decline (again, on a per-berry basis) during fruit ripening. These include several of the methoxypyrazine compounds that contribute vegetal characters to some wines (such as Cabernet Sauvignon and Sauvignon Blanc). The decline in pyrazines is thought to be linked to sunlight levels in the cluster. Therefore, if these compounds are deemed to be undesirable (the current prevailing opinion), then canopy management can be used to reduce them.

Notable aroma compounds that are produced during the first period of growth, decline (again, on a per-berry basis) during fruit ripening. These include several of the methoxypyrazine compounds that contribute vegetal characters to some wines (such as Cabernet Sauvignon and Sauvignon Blanc). The decline in pyrazines is thought to be linked to sunlight levels in the cluster. Therefore, if these compounds are deemed to be undesirable (the current prevailing opinion), then canopy management can be used to reduce them.

Despite these major changes in compounds produced during the first growth period, the big story during the second growth period is the tremendous increase in compounds (the major ones being glucose and fructose) that occurs as a result of a total biochemical shift into fruit ripening mode.
Beginning at véraison, sugar influx into the berry commences. Sucrose produced from photosynthesis is imported into the grape berry during fruit ripening. Once transported into the berries, the sucrose is hydrolyzed into its constituent sugars glucose and fructose. Their eventual concentration is dictated partly by the length of time the grape berry is allowed to stay on the vine. (Other factors include the crop load, canopy size, disease status, and as mentioned earlier, dehydration).

Beyond sugar accumulation, the major determinants of a wine’s quality are the secondary metabolites. In red grape varieties, anthocyanin production (restricted to skin tissue in most cultivars) is probably the most obvious compound of importance, but as with white varieties, most of the volatile flavor components are produced during fruit ripening. These would include such compound classes such as terpenoids, which are important to the pleasant aroma of many varieties, such as Riesling and Muscat, and fruity aroma precursors. Aroma compounds are distributed in the flesh and skin of the berry.

In addition, many other important aroma and flavor compounds are produced late in fruit ripening. Some of these components are produced as precursors, and are not actually volatile until after the wine has been produced and aged for some time. Nevertheless, their precursors are present in the grape as glycosides, and the period of time when many of them appear to be produced has recently been given the term "gustation."

In examining berry development, it helps to look at it from an ecological perspective. If the raison d’être for the berry is to reproduce, then its first priority is to develop a viable seed. During the first period of growth, the berry does just that: It develops a viable seed and produces compounds to protect it while doing so.

If you think about the compounds that are produced during the first period of growth (organic acids, tannins, pyrazines), they combine to make foraging by birds and mammals a downright unpleasant experience. By the end of the first period of growth, a viable seed has been produced, and therefore, the goal during the second period of berry growth is to make the berry as appealing as possible to birds and mammals so that seed dispersal can occur.

Conclusion
Many advances have been made in understanding of how the grape berry develops and of the components that are important in wine. No doubt the quality of our wines has improved as a direct result of being able to manipulate the grape berry through production practices.

Understanding when various components accumulate in the berry is critically important to understanding how grape-growing practices can be used to modify wine style. It is clear that this is an area of research that will continue in the future, yet it is already apparent that a wine-maker can influence wine style through grape-growing practices. The trick is understanding the what, when, and how of berry manipulation.

For Literature Cited, see original article in the NVC Library.
Our goal as winemakers and winegrowers is to produce and transform grapes into wine. Thus we need to consider what we want in the wine. We need to consider the needs and interests of our customers. For the vineyard, the winemaker is the customer — for the winery, the consumers are the customer, and they like well-flavored wines. Our work with Cabernet Sauvignon in our Alexander Valley Estate vineyard provides an example of how Simi Winery focuses on wine style and flavor.

SIMI WINERY’S APPROACH

Developing wine flavor in the vineyard

by Zelma Long, Simi Winery, Healdsburg, CA

(From a presentation at the International Cool Climate Conference, Rochester, NY, July 1996)

Achieving uniformity

After setting our flavor goals and characterizing the site, there are many ways to approach managing flavor. Among them are:
- The original planting decisions.
- Decisions in annual vineyard management including winter pruning and green (summer) pruning.
- Achieving flavor and tannin ripeness.
- Making the proper harvest-timing decisions.

However, I want to focus on a less frequently discussed aspect of achieving flavor and flavor concentration in the wine — achieving uniformity in the vineyards.

Two experiments, both done several years ago by Zelma Long, Simi Winery, Healdsburg, CA, were:

- A comparison of fruit-driven and tannin-driven styles.
- A comparison of different planting densities.

These experiments provided valuable insights into how to achieve uniformity in the vineyards.

Wine styles from the vineyard

<table>
<thead>
<tr>
<th>Location</th>
<th>Style</th>
<th>Days bloom to harvest</th>
<th>Characteristics</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowlands</td>
<td>Elegant</td>
<td>140 days</td>
<td>Fruit-driven; red-berry, blueberry flavors; lower tannins; more texture than structure; instant appeal; short length</td>
<td>Texture; front of mouth fruit; more fruit than tannin; finesse</td>
</tr>
<tr>
<td>Uplands</td>
<td>Powerful</td>
<td>130 days</td>
<td>Fruit/tannin balance; length; riper fruit flavors-blackberry; texture and structure</td>
<td>Fruit intensity; balance of tannin and fruit; gives mid-palate and finish; richness, flesh</td>
</tr>
<tr>
<td>Midlands</td>
<td>Dense</td>
<td>120 days</td>
<td>Ripe black currant; great length; structure; high tannin</td>
<td>Reserve foundation; provides length; very ripe fruit flavors; gives structure</td>
</tr>
</tbody>
</table>
years ago, illustrate the impact of uniformity on flavor. In each experiment, we took 400 berry samples from two blocks of Cabernet Sauvignon: one block was Rosé quality and the other was Cabernet Reserve quality. The average Brix of both samples was about 23.5°. However, when we plotted the Brix distribution of each sample, the Rosé berries ranged from 17° to 30° Brix, while the Reserve berries ranged from 21° to 26°. Clearly from these results, use of average Brix alone as a way of expressing ripeness and uniformity is inadequate in either block.

Other experiments where wines have been made from different maturity levels of grapes on the same vine, such as the Robert Mondavi Winery short-shoot work in the 1980s, have shown the dramatic wine differences that can occur where fruit uniformity is lacking. Uniformity is the foundation of flavor quality and is the result of good vineyard quality control. Four types of uniformity must be managed:

1. Berry uniformity — berries within a cluster are equally ripe.
2. Cluster uniformity — clusters within a vine are equally ripe.
3. Vine uniformity — vines within a block have a similar ripening curve.
4. Block uniformity — block definitions are based on soil changes, which enhance uniformity within a block.

The following chart shows some of the sources of poor uniformity and some of the actions that can be taken to address these problems.

At Simi, when we lack uniformity, particularly in our younger plantings, we perform annual vine vigor surveys to define the percentage of vines at full canopy or at four stages less than full canopy in a block. This information is used as a baseline for improving uniformity in that block and measuring the results.

Diane Kenworthy, until recently Simi’s viticulturist, developed vineyard standards for crop-load, canopy uniformity, pests and diseases, and fruit condition. The vineyards are assessed against the standards at post-pruning, fruit set, veraison, and harvest. Where problems are noted, responses are determined, and planning is done for next year.

Any discussion of uniformity must recognize the tradition of heterogeneity in a vineyard where different varieties or clones are inter-planted. It is the author’s belief that uniformity is an essential basis or foundation for fine winemaking. Once the thorough understanding of the site and the wine has been achieved, a finetuning of wines with some heterogeneity may be of benefit, but the basic quality control efforts should be focused toward achieving vine, cluster, and berry uniformity.

**Description of a ripe grape**

As grapes move from unripe to ripe, we see an evolution of flavor from green to herbal to red fruit to black fruit to jammy. We see a textural change from crisp to juicy to jammy with a pectin texture. We see an increase in the extractibility and thinness of the skins,
a change of color in the seeds from green to brown, and an evolution in the flavor characteristics in the skins, and tannins changing from "astringent" to "dusty" to "soft." Ideally, we want good red or black fruit flavors, a soft, easily extractable skin with ripe seeds, a juicy, jammy texture, and very soft tannins. The factors affecting our ability to achieve this are the weather, the balance and condition of the vine, and management of stress (disease, nutrients, water, weather) through this ripening period.

The following graph shows the difference in one block of close-planted Cabernet Sauvignon (clone 6, rootstock 110R) at Simi's Alexander Valley vineyard in three vintages. The 1994 and 1995 years provided much longer ripening seasons, slower sugar accumulation curves, and more time for the intersection of ripe tannins, good flavor development, and good balance. However, 1993—a much warmer year with a smaller crop—drove sugars up faster than the rate of ripening of the tannins and acid/pH evolution, creating less than ideal balance of the different grape components, and therefore requiring additional attention by the winemaking team to handle the unbalanced grapes in an appropriate way.

Simi's technique for monitoring vineyards requires some simple but important approaches.

We have a good field sample log which tracks Brix, TA, pH, berry weight, sugar per berry, sample timing, sample weather, and grape texture and color. These are analyzed, not so much for the achievement of ideal numbers, but for trends in the ripening of the vineyard, for example, evolution of pH versus TA versus Brix. We also watch weather, sugar per berry, and berry weight to assess sugar accumulation and to separate sugar accumulation from dehydration/rehydration conditions that cause Brix changes.

We keep a historical log which records the actual Brix, TA, pH, malate, and tonnage of each block at harvest. Many of our vineyards have records going back ten years. This consistent tracking of a vineyard helps us see when the vines tend to ripen in terms of their chemical and physical properties.

**VINEYARD STANDARDS AT FRUIT SET**

**Crop Load**
- Normal number of clusters for variety and clone.
- Even bloom for variety and clone.
- Crop evenly distributed along fruit zone.
- No crop on short shoots.
- No crop on non-count shoots.

**Canopy**
- Shoots still growing, will be possible to trim at desired number of leaves per shoot at one time.
- Medium green (for variety), functioning leaves.
- Action taken for good air movement in fruit zone.
- Moderate light exposure in fruit zone.
- Even growth along cane or cordon length.
- No lateral shoots in fruit zone.
- In vertical trellising, strong vertical orientation.
- No bull canes creating shade in canopy.
- No leaf symptom of mineral or water deficiency.

**Uniformity**
- Vines evenly vigorous throughout block.
- Crop evenly balanced to vigor throughout block.
- Irrigation in good working order, with no plugged or missing emitters, and no broken lines.

**Disease and pests**
- First brood leaf hoppers monitored and under control.
- No mildew on fruit or primary leaves.
- No weeds competing in vine row.
- No fruit on vines devigorated by phylloxera, armillaria, or Pierce's Disease.
- No gopher damage.
- Mites monitored and under control.
- No fanleaf virus symptoms.

**Fruit condition**
- No mildew.
- No botrytis.
istry and helps us define the personality of a particular site.

We all spend time in the vineyard, both pre-harvest and through the years. One of the best enhancers to achieving ripeness in a vineyard is an intimate knowledge of the site, of the variations within the vineyard, of the relative tonnages in each area, the best sampling methods, the best sample size, and the evolution of ripeness personality for that varietal, that rootstock, in that site.

Pre-harvest “feet in the vineyard” is crucial. Simi’s viticulturist visits each vineyard at least 20 times; the vineyards are sampled an average of six times; and our winemaker is in the vineyard at least five times before any one vineyard is harvested.

Achieving ripeness — The harvest decision

The science of developing and defining ripeness is still in its infancy. We know we can invest financial and human resources in our vineyards and reap the rewards of those investments either fully or less than fully depending on the quality of the harvest decisions we make. Deciding when to pick the grapes is just as important as deciding when to bottle the wine.

We recognize that a theoretical ripeness model is complex. It is the sum of what has happened throughout the year, that is the weather’s impacts on composition, quality, and quantity and the timing convergences of the different aspects on wine composition. A real computer model to determine harvest decisions would additionally take into account characteristics of the grapes themselves (color, texture, flavor composition), conditions of the vine, and undoubtedly weather projections as well.

We lack, among other things, quantitative means to assess the flavor and phenolic complexes that are important to our wines. Lacking that, much of what contributes to the ripeness decision about how ripe the grape is, and therefore its harvest timing, is observational and experiential.

Conclusion and questions for the future

There are many exciting challenges to answer in the future:

What is the chemistry of ripening?
How can we influence the intersection of ripening curves?

What is the chemistry of phenolics during the ripening process?
Can we measure “soft” tannins — quality and quantity?

We need a better understanding of vine stress responses and more specific tools to enhance flavor.

But until we have a better quantitative ripeness model — one that is linked directly to the wines and their flavors and balance — development and maintenance of systems for ripeness assessment are critical to “making the most” of our wine-growing efforts.