Evaluation of Grape Maturity and the Factors Impacting Maturity

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Definition of grape quality

Science provides the knowledge to produce fruit that can result in consistent, flawless wines, but lacks signposts pointing the way to greatness. Minimalists correctly argue that fine wines have been successfully made long before our understanding of the science of grape growing and winemaking, and modern technology in general. This has added to the debate between the use of technology and non-interventionism. It also has highlighted the role of *terroir.*

Some suggest that a superior wine conveys a sense of place, originality and the natural telos of the site, a mantra echoed by virtually all premium wineries. This has spurred the interest in the concept of *terroir* in the New World. However, attempts to separate the kaleidoscope of variables associated with this term, including geology, geomorphology, soil, climate, the biology of the vine, microbiology and human interventions have proven difficult due to the complexity of interactions (van Leeuwen *et al*., 2013). Matthews (2015) suggests that today, *terroir* is primarily a marketing term that mixes extrinsic and intrinsic wine properties. Regardless, it is widely accepted that wine quality begins in the vineyard.

High quality wines, regardless of how defined, are the result, in part, of the confluence of important fruit attributes. Grape quality is impacted by 1) maturity, purity, and condition, 2) aroma/flavour and phenolic characteristics, and 3) harvesting methods, transportation and processing protocols. Grape quality must be defined in terms of attributes suitable for a particular wine type and style.

Physiological maturity is a term that is representational of the perceived temporal disconnect between aroma/flavour “ripeness” and sugar accumulation in the fruit. Ideally, desirable fruit components such as aroma/flavour and phenol components coincide with primary metabolites such as optimum soluble solids concentration. In reality, grape maturity indices seldom align; if they did, maturity evaluations would be an easy task.

Berry Development

There are three stages of berry development following flowering: green berry; arrest of green berry development, and the pause before the onset of ripening; and fruit ripening or *véraison* (Jackson and Lombard, 1993) (Fig. 4.1). *Véraison* can be divided into stages based upon berry metabolism and transport of substances to the vine (Fig. 4.1) (Bisson, 2001).

Overall, the berry approximately doubles in size between *véraison* and harvest (Conde *et al*., 2007). As a result, many of the solutes accumulated in the fruit during the first period of development have their concentration substantially reduced. However, some compounds are reduced on a per-berry basis, not simply due to dilution. For example, malic acid, which is metabolized and used as an energy source during the ripening phase, is substantially decreased relative to tartaric acid, whose concentration usually remains almost constant after *véraison*. Tannins also decline significantly on a per-berry basis after *véraison*. Some aromatic compounds, including several of the methoxypyrazine compounds, decline after *véraison.* Both changes in phloem transport and the onset of berry dehydration influence fruit composition (Matthews *et al*., 1990).

Vineyard factors impacting fruit maturation

A significant volume of research has advanced our understanding of how various viticultural variables and practices, including fruit maturity, crop level, crop exposure (Bergqvist *et al*., 2001; Zoecklein *et al*., 1998,1992), leaf area to crop ratio (Kliewer and Dokoozlian, 2005), shoot density and training systems (Reynolds *et al*., 1996) affect grape composition and maturation. Important features impacting fruit maturation beyond the general climate of the region and season include the following:

- Fruit temperature
- Humidity
- Soil characteristics
- Soil moisture
- Variety/clone
- Training and trellising systems
- Row orientation
- Canopy management
- Rootstock
- Yield components: fruit weight/vine, clusters per vine, clusters per shoot, berries per cluster, berry weight

Climate

It is well established that optimum wine quality requires the selection of the proper cultivar and clone on a desirable site. A clone is a population of plants, all of which are descendants by vegetative propagation from a single parent vine. Both cultivar and clonal selection can affect yield, fruit set, growth rate, clusters per vine, berry size, fruit rot susceptibility, and berry aroma/ flavour components. Field vine selection can be either by mass selection, where many vines are selected to provide bud wood, or by clonal selection, in which a single mother vine is selected to provide clones.

Meteorological parameters have a crucial influence on fruit composition. The primary climate vectors impacting viticulture include temperature, moisture stress and radiation (Jones *et al.*, 2012). It is well established that the phenology of bud break, flowering, and *véraison* are temperature dependent. Temperature affects the rate of fruit ripening. Sugar concentration increases with temperature, although secondary metabolites such as aroma/ flavour and phenol compounds are generally negatively affected by high temperatures (Kliewer and Torres, 1972).

Climatologists recognize three levels of climate: macroclimate or regional climate, meso- or site climate, and micro- or grapevine canopy climate. Grapevine leaves are the major cause of microclimate variations; the presence of fruit, shoots, stems, and permanent vine parts are less significant (Smart, 1985). In the sense that grapevine canopy influences microclimate, it is under the control of the viticulturist.

Canopy microclimate components include radiation, temperature, humidity and evaporation, each of which can impact fruit components. Berries maturing in densely shaded canopy interiors are generally associated with the following fruit attributes, when compared with berries in open or exposed canopies (Smart, 1985):

- low total soluble solids
- high titratable acidity
- high malate concentrations
- elevated pH
- high potassium
- low proline
- high arginine
- qualitative difference in tannin phenols
- low anthocyanin concentration in reds, and high chlorophyll versus flavonoid pigments in whites

The above points to the importance of proper fruit sampling based upon the degree of cluster solar exposure (see below).

The Huglin Index is similar to Winkler's macroclimate degree days, with the additional parameter of latitude on day length. However, Matese *et al.* (2012) have suggested commonly used climatic indices are not appropriate to represent vineyard meteorological variability, particularly the daily dynamics that are important in grape maturation. Molitor *et al.* (2014)

noted that the common cumulative degree day models used to forecast grape growth stages are often restricted to a limited number of phenological stages, or do not take into consideration the effects of higher temperatures.

Jackson and Lombard (1993) divided grape-growing regions into two temperate zones: alpha zones, with mean temperatures of 9-15°C (48-59°F) during stage III, the final ripening period; and beta zones, with mean temperatures greater than 16°C (61°F). The best variety for any region is one that matches the length of the growing season, so that maturation occurs during the coolest portion of the season, allowing fruit maturity to occur just before the mean monthly temperature drops to 10°C/50°F. As such, studies have been conducted to adjust harvest dates within a region. For example, minimal pruning can delay berry ripening (Zheng *et al.*, 2017). Palliotti *et al*. (2017) also demonstrated that double pruning can reduce berry sugar accumulation and its potential to delay harvest date or increase crop hang time under specific vineyard conditions. Palliotti *et al.* (2013) delayed sugar accumulation in Sangiovese by removing 30–35% of vine leaf area at 16-17°Brix. By contrast, Zoecklein *et al*. (2011), using an ethanol spray, increased the ripening rate of Cabernet franc and Merlot.

As suggested by Happ (1999), if the movement of temperature between the daily maximum and minimum exhibited the properties of a straight line, the mean would provide the average temperature experience. The true average lies away from the mean. The rise in a temperature curve is asymmetrical, and it changes with cloud cover, wind, etc. The optimum temperature for enzymatic reactions, which govern maturity, including aroma/flavour development and retention, is about 22°C. Therefore, it has been suggested that the periodic difference between the temperature experienced throughout the day (for example, every twenty minutes) and 22°C, is the true measure of site climate. As such, Happ (1999) calculated a heat load index, which takes into account the observation that a temperature rise does not necessarily have a linear effect on fruit components such as aroma/flavour. Table 4.1 illustrates how some viticultural and environmental factors can affect grape composition.

Light

Sunlight can affect grape maturation through photosynthetic and thermal responses. The amount of diffuse solar radiation reaching the interior canopy leaves and fruit decreases as the number of leaf layers increases (Smart, 1985), resulting in a reduction in photosynthetic rates. Varying shoot numbers, reducing vine vigor, or adopting training and trellising systems that divide canopies into separate, thin curtains of foliage can influence grapevine microclimate and impact grape and resultant wine quality (Reynolds *et al*., 1996). Canopy microclimate can influence fruit maturation and quality via the following:

- heat
- light
- fruit rot incidence
- spray penetration
- relative humidity
- desiccation and reduction of evaporation potential

Sunlight interception also depends on cloudiness and, to a much lesser degree, latitude (Gladstone, 2011). The sun is at a different angle on June 22 (longest day of the year) versus Fall equinox (September 23). At noon, when the sun is highest, row direction is less important. At 35 degrees latitude, in midsummer, north-south rows give about 17% more solar interception than east-west rows. In the northern hemisphere, the sun is in the southern part of the sky for most of the day during the summer. Fruit on the southern side of east-west rows will receive more light. North-south rows may have a disadvantage in warm climates where fruit on west sides goes from morning shade to direct sun exposure at mid-day (Gladstones, 1992). As such, differences in row orientation and canopy side can impact fruit maturation rate and fruit volatiles (Zoecklein *et al*., 2011; Devarajan *et al*., 2011), suggesting the importance of differential harvest dates.

Soil

Soil is a complex medium and its role involves the multiple influences of texture, mineral composition, water supply, and root zone temperature, among other variables (van Leeuwen, 2013). Jackson and Lombard (1993) reported that soil is known to have several direct influences on plant growth by affecting moisture retention, nutrient availability, heat and light reflecting capacity, and root and vegetative growth. Duteau *et al.* (1981) found that soil and its geological composition, not microclimate, was the major factor influencing grape maturation in St. Emillion. According to Barbeau *et al*. (1998), early grape maturing sites are characterized by sandy, sandy-clayey, or gravelly soils with good drainage. Late maturing sites often have clayey or silty soils. Soil Information Systems are available to evaluate detailed soil properties for each block, such as compaction, root zone depth, moisture retention and fertility.

Integrated pest management (IPM) is now the common practice of promoting the natural ecological balance of flora and fauna in the vineyard. Such practices are now frequently used as alternatives to heavy tillage, pesticides and herbicides to create what is referred to as living soils, that is, with a healthy earthworm population. Such soils are reportedly associated with wines that provide enhanced reductive strength (Smith, 2013).

The term microbial *terroir* has been adopted to relate to soil ecology, specifically the microbiology of the soil. Although a good soil should have adequate microbiological flora to aid in mineralization, little scientific evidence is available to suggest the link between soil microbes and wine quality or *terroir* (van Leeuwen *et al*., 2013). It is interesting to note the level of copper (in the form of Bordeaux mix) used in some French vineyard sprays (up to 3 kg/ha/year). Such sprays over many years may have had a detrimental impact on soil microorganisms (Courde *et al*., 1998).

Yeasts and bacteria are part of a complex series of interactions where competition, equilibrium and collaboration form a dynamic ecosystem. Even with the addition of sulfur dioxide and cultured yeasts to a red must, a portion of a fermentation can be conducted by other, native un-inoculated organisms (Bokulich *et al.,* 2012). There can be a substantial difference in microbial populations among different vineyards and that microbial ecology can be a source of wine variation. Some winemakers report that certain vineyards produce wines that are more prone to *Brettanomyces* spp. growth than others. The implication is that this spoilage yeast is coming from the vineyard. Mansfield *et al*. (2002) and Fugelsang and Zoecklein (2003) demonstrated the significance of regionality among *Brettanomyces* spp. strains, which may help explain this observation.

Water management and grape maturity

Some winemakers believe that dry farming (the absence of irrigation) produces fruit and wines that more fully express the nature of the vineyard site, at least in arid regions. Some European *vignerons* equate limited soil moisture with their *terroir* expression and remain reluctant to irrigate, even when legally permitted. Catena (2016) suggests that many of these vineyards are on abundant underground aquifers. In many other regions of the world, aquifers are very deep, and thus the water is unavailable to vines.

Vine water status depends on soil texture, percentage of stones, rooting depth, rainfall, evapotranspiration and leaf area (van Leeuwen and Darriet, 2016). Basile *et al*. (2011) noted that berry composition significantly correlated with the vine water status, but the nature of the relationship depended on the phenological stage and the parameter measured. Water deficiency affects photosynthesis and shoot growth, and can increase both tannin and anthocyanin content (Duteau *et al*., 1981), while excess stress can lead to leaf damage and severally impair fruit ripening. Chapman *et al*. (2005) found that vine water deficits lead to wines with more fruity and less vegetal aromas and flavours than vines with high vine water status. It has also been reported that irrigation practices such as regulated deficit irrigation (RDI) positively impact the fruity aromas (Casassa *et al*., 2013; Gamero *et al*., 2014). Keller *et al*. (2016) demonstrated that the potential effects of water deficit on fruit composition may be related to altered canopy size and microclimate, in addition to decreased berry size. Roby *et al*. (2004) demonstrated that there are effects of vine water status on fruit composition that arise independently of the resultant differences in fruit size. In their study, the effect of vine water status on the concentration of skin tannin and anthocyanin was greater than the effect of fruit size on those same variables. Pre-véraison water deficit can accelerate fruit pigmentation and colour change earlier than non-water deficit fruit (Herrera *et al*., 2016).

The proper cover crop may help assure ground shading and contribute to humus formation while helping to buffer the very dry and very wet periods. As such, vineyard floor management has multiple goals that encompass improving weed management and soil conservation, reducing soil resource availability to control vine vigor, and influencing fruit and wine quality. In one study, Guerra and Steenwerth (2012) reported that cover crops increased juice soluble solids, anthocyanins, and other phenolic components, and decreased pH.

Fruit ripening is influenced by plant hormones. Optimum hormone balance is dependent on a continuous and moderate moisture stress and favorable soil temperatures (Gladstone, 2011). Water stress, through the stimulation of stress hormones such as abscisic acid and the suppression of growth hormones such as gibberellins, cytokyinins and auxins, stimulate the production of enzymes, promoting flavour ripening in the fruit. The majority of these changes occur just prior to and during *véraison.* As such, managing mild water stress at this time may allow for optimum aroma/flavour peaks, possibly prior to excess sugar production (Greenspan, 2018).

Vine balance, yield and fruit maturity

Fruit ripening is dependent upon source leaves, a reason for the general interest in the concept of vine balance and an understanding that high yield does not necessarily mean low quality (Matthews, 2015). For fruit at similar maturity, factors other than yield, such as water availability, may determine fruit composition (Matthews, 2015). The many components contributing to grapevine yield include the following (May, 1972):

- Vines per acre/vines per hectare
- Shoots per vine/shoots per meter
- Clusters per shoot
- Clusters per vine
- Cluster weight
- Berries per cluster
- Berry weight
- Fruit weight per vine

Yield can impact the rate of fruit maturation (Winkler, 1965). An over-cropped vine is one that has a large crop with insufficient, healthy active leaves; it cannot produce enough sugar to maintain all clusters for desirable ripening, and it fails to produce grapes with sufficient aroma/flavour and/or desirable phenol compounds.

Variation in components of yield can contribute to yield variation at harvest, although the grapevine itself is capable of self-regulation (Clingeleffer, 1983) and yield compensation (Freeman *et al*., 1979; Smart *et al*., 1982). While many yield components cannot be controlled directly, vineyard managers do have the capacity to manipulate some variables in the vineyard. For example, pruning regulates node number per vine and budburst.

Vine balance is known to impact plant hormone concentrations. Higher levels of the growth hormone cytokinin are stimulated by high nutrient and water availability. This excess of cytokinin may dominate the mainly leaf-borne ripening hormone abscisic acid and, thus, delay ripening and aroma formation. A vine under nutrient and/or water stress has a dominance of abscisic acid over cytokinin, resulting in a hastened ripening rate (Gladstones, 2011).

Berry weights can be used to estimate crop load. There is a relationship between berry weight at *véraison* and berry weight at maturity. For Syrah, McCarthy (1997) determined that relationship to be the following: $y = 1.35x + 0.53$, where y = the berry weight at 23°Brix, and x = the berry weight at about 5°Brix. This relationship will differ by cultivar and site, but can be determined by collecting *véraison* and harvest samples for several seasons. Accurate estimations of yield from precision viticulture techniques, with mapping using GPS systems, optical remote sensing and other tools, are available.

Asynchronous ripening and measuring vineyard variation

Variation in the vineyard occurs among berries, bunches, and vines and can have a negative impact on crop level, fruit composition, and wine quality. Two components of berry-to-berry variation are size and berry composition. In extreme cases, this is referred to as ‘hen and chicken’ or *millerandage* (Winkler, 1965). Variation in berry size affects vineyard yield and may impact wine quality. However, Matthews (2015) reported that smaller berries obtained by water deficits had an increased colour and tannin concentration. Smaller berries resulting from canopy shade had the opposite effect.

High levels of variation in the early post-flowering period suggest that that variation originated prior to berry set, likely as a result of asynchronous cell division in the floral primordium at budburst. Decreasing levels of variation may indicate points of re-synchronization in the berry growth cycle. A crop with asynchronous clusters or berries has a mixture of developmental stages, resulting in berries with optimal qualities diluted by berries which may be inferior. The practical significance of this dilution depends upon the degree and stylistic goals. There are those who believe some asynchrony aids in complexity. Figure 4.2 demonstrates a frequency distribution, with berry numbers plotted against °Brix. Even before differences arise from processing, it is generally not true that two vineyards or vineyard blocks with the same °Brix values will give similar wines. A juice with Brix of 22° might be composed of a narrow distribution of a few berries at 20° and a few at 24°Brix, with the majority nearer to 22°. However, there may be a much wider distribution, with berries below 18° and greater than 24°. Because °Brix is a distribution average, juices with similar °Brix values can produce quite different wines, due to variations in aroma/flavour and phenol compounds. Relative maturity dates of the various important components of a red berry (skin, pulp, seeds, and cap stem) are generally different. Given that all parts enter the fermenter in red wine production, the control of stylistic winemaking may be negatively influenced if component parts of the fruit are not at the optimal maturity at harvest. The variables that contribute to variation among berries include berry size, berry composition, seed number, seed size, degree of lignification etc.

Vine to vine variation

Many variables can be measured at the vine level, including soil characteristics, carbohydrate reserves, bud fruitfulness, percent budburst, inflorescence primordia number, node number, shoot number and cluster number. Vine-to-vine variability of visually uniform vines, expressed as percentage of the coefficient of variation, was reported by Gray (2006), highlighting the inherent nature of vineyard variability. While soluble solids concentrations may be fairly uniform, with a coefficient of variation usually less than ten per cent, the variance can be much greater if the fruit is not uniform across clusters or if the cluster microenvironment is variable among vines:

- Brix 4 to 5%
- pH 3 to 4%
- Titratable acidity 10 to 12%
- Berry weight 6 to 20%
- Colour 13 to 18%

The inherent variation among individual vines can have a greater impact on yield than external influences such as soil variability, or drainage and fertility irregularities. Variation in soluble solids concentrations, titratable acidity, and cluster weight between vines can be much greater than within vines (Rankine *et al.*, 1962). Spatial analysis techniques and global positioning systems (GPS) have aided our understanding of vineyard variability. Aerial vineyard images, using satellite or aircraft, can be used to calculate a normalized difference vegetation index (NDVI) for each vine. These maps can be used to visualize differences in vine vigour or relative biomass on a vineyard scale (Hall *et al.*, 2002), which may allow for differential harvests.

Differences in cluster size are commonplace in most vineyards. Since yield forecasting and maturity testing procedures may rely on cluster sampling, differences in cluster size can be a major source of error. Stratified cluster and berry sampling programs have been devised to overcome some of these problems, but seasonal, varietal and site-specific considerations confound general sampling protocols (Wolpert and Howell, 1984; Kasimatis and Vilas, 1985). The variables that contribute to variation among bunches include inflourescence primordia size, flower number, fruit set, berry number, cluster weight, and cluster position.

Measuring vineyard variation

A number of studies have reviewed the factors impacting vineyard variation (Rankine *et al*, 1962; Smart and Robinson, 1991; Trought, 1996; Trought and Tannock, 1996). Prior to fruit sampling, one needs to gain some appreciation of the variation within each vineyard block that can be influenced by microclimate effects, which can result in differences in heat, light and soil moisture. Several techniques can be used to quantify the level of dispersion around a population mean, including range, mean deviation, sum of squares, variance, standard deviation, and coefficient of variation. Expressed as a percentage, the coefficient of variation (CV) is a unitless measure of the sample variability, relative to the sample mean:

$$\text{coefficient of variation (CV)} = \frac{\text{standard deviation (s)}}{\text{mean (x)}} \times 100$$

A sequential comparison of CVs can reveal both the source of variation and the points of re-synchronization in the berry's developmental cycle (Gray, 2006).

Vineyard variation management

Zonal management and zonal harvest are appropriate techniques where the grape grower has ready access to the necessary technology. Perhaps the best approach to help minimize vine variation is site selection. Variation may be minimized by choosing a site with limited variation in soil, topography, aspect, and extreme weather events, optimally suited for the variety.

Cluster variation may be managed by applying viticultural best practices or a viticultural Hazard Analysis and Critical Control Point (HACCP) plan to promote uniform bud burst, shoot growth, flowering, cluster exposure and berry development (Coombe and Iland, 2004). Factors that may contribute to variations include cluster architecture, the role of vascular function in berry growth and development, the relationships between seed development and berry development, and the relative importance of cell division and cell expansion throughout the entire developmental cycle (Gray, 2006).

Fruit Sorting

Manual sorting in the field is generally supplemented by additional sorting practices in the winery. Optical sorters performing selection based on size, colour, and level of berry shrivel are available which aid in stylistic winemaking. Being able to sort high Brix and high-coloured red fruit, for example, from average colour and Brix, and being able to separate additional material other than grapes (MOG) and fungal degraded berries also adds additional quality and stylistic freedom. Ward *et al*. (2015) highlighted the importance of sorting by demonstrating that the concentrations of the predominant methoxypyrazine in the wines, 3-isobutyl-2-methoxypyrazine, increased with increasing additions of unripe berries to the must. Research into hyperspectral sorting based on compounds visible in the UV range, such as organic compounds, will likely increase and may result in significant increases in wine quality and vintage uniformity.

Fruit sampling methods

Regardless of maturity gauges utilized, an important concern is accurate vineyard sampling. Fruit sampling methodologies have been extensively reviewed (Rankine *et al*., 1962; Roessler and Amerine, 1963; Jordan and Crosser, 1983; Kasimatis and Vilas, 1985; Wolpert and Howell, 1984; Gray, 2006). There are two basic choices in fruit sampling: cluster sampling or berry sampling. With cluster sampling, a further choice can be made by gathering clusters from throughout the vineyard, or using one or more targeted vines.

If berry sampling is to be employed, two samples of 100 berries each can give accuracy to 1.0°Brix, and five samples of 100 berries each can give accuracy to 0.5°Brix. Using cluster sampling, ten clusters can be accurate to 1.0°Brix (Jordan and Croser, 1983; Kasimatis and Vilas, 1985). The three factors which have a major role in maturation dynamics are heat, light and soil moisture. Therefore, variation of these within a vineyard block can result in significant sample variation. It should be noted that there is a general tendency, when examining a cluster prior to berry sampling, to select the most mature berries. Therefore, berry sampling should involve locating the fruit zone, and sampling without examining the clusters or berries. Samples should be collected from the top, middle and bottom of the cluster while randomizing the side of the cluster sampled. If this does not occur, berry samples will frequently be about 2°Brix higher than the true value.

About 90% of the variation in berry sampling is believed to come from variation in the position of the cluster on the vine and the degree of sun exposure (Jordan and Croser, 1983). Therefore, vineyards must be sampled based on the degree of fruit exposure using the following protocol: Avoid edge rows and the first two vines in a row, and collect samples from both sides of the vine. For each row, estimate the proportion of shaded bunches and sample accordingly. Maximum sample area should be less than 2 hectares.

Applying traditional statistical models to vineyards with known field variability can lead to inefficient sampling. Meyers and Vanden Heuvel (2014) used aerial normalized difference vegetation index (NDVI) images for the purposes of quantifying vineyard spatial structure and computing optimal vineyard sampling protocols. Bramley (2005) suggested that in the absence of zonal management, a winemaker's ability to maximize benefits from differential vineyard management, such as selective harvesting, is unlikely to be satisfied.

Fruit maturity gauges

Maturity evaluation must be viewed in the context of stylistic goals. Maturity evaluations usually involve a review ofseveral to many of the following (Zoecklein *et al*., 1999):

- Aroma/flavour, and intensity of aroma/flavour
- Grape skin tannins and tannin extractability
- Red fruit colour/anthocyanins
- Stem lignification or 'ripeness'
- Seed numbers per berry
- Seed 'ripeness', 'maturity' or tannin extractability
- Sugar per berry
- °Brix
- Acidity
- pH
- Berry softness
- Berry size/weight
- Berry shrivel
- Potential for further ripening, general fruit condition

It is not completely understood how each of the above relate to one another, or the importance of their individual or collective values as predictors of ultimate wine quality. The time to harvest is prior to deterioration of desirable fruit characters or components. While desirable attributes do change over time, grapes change physiologically rather slowly at the end of the season, less the impact of fungal outbreaks and detrimental weather (Matthews, 2015). However, the factors that control the loss of berry aroma/flavour compounds, for example, and when degradation may be initiated, is not well understood. As such, a chemical marker of the onset of fruit aroma/flavour deterioration would be ideal as a maturity gauge, as suggested by Bisson (2001).

Berry size/weight

Many winemakers determine berry size via weight. Many believe that smaller berries may yield richer must, in terms of colour intensity and tannin composition. However, Matthews and Kriedemann (2006) reported that the cause of berry size is more important in determining must composition and wine sensory properties than berry size *per se*. They suggested that how the change in size came about is important, making a distinction between environmental factors versus biological processes that underlie variation in reproductive development. For example, smaller berry size in red varieties, such as Cabernet franc, commonly yields a richer must if berry size is reduced by environmental factors such as deficient irrigation. By contrast, Shiraz berries that are smaller for developmental reasons, and have fewer seeds, do not necessarily produce musts that are richer (Walker *et al.*, 2005).

High total yield reduces the weight of individual fruit, but generally causes lower, rather than higher, concentrations of solutes (Bravdo *et al.*, 1985). Increased light exposure increases both berry size and solute concentration (Dokoozlian and Kliewer, 1996). Additionally, the timing of water deficits prior to *véraison* often, but not always, increases Brix. The question remains whether that is solely the consequence of a reduction in berry size. Knowledge of berry size may allow for adjustments in wine processing methodologies such as cap management and *saignée* to reach stylistic goals.

Sugar evaluation

Sugar is usually expressed as °Brix or total soluble solids concentration (TSS), °Baumé or potential alcohol, or by specific gravity. °Brix is defined as grams of soluble solids per 100 g of solution. It is a measure of all soluble solids, including pigments, acids, glycerol, and sugar. Generally, the fermentable sugar concentration of grape must accounts for 90 to 95% of the total soluble solids. Therefore, determination of °Brix provides only an approximate measurement of sugar concentration. The vast majority of grape sugar consists of the two monosaccharides glucose and fructose. The ratio of these two is dependent upon the variety and the extent of fruit maturity, with glucose dominating during early berry development. Overripe fruit generally has a low glucose-to-fructose ratio, which can have implications with regard to fermentation completion (Zoecklein *et al*., 1999).

Baumé, often used in Europe and Australia, is an estimation of the potential alcohol, a measure of the sugar concentration of fruit and the potential alcohol that can be achieved by complete fermentation. Thus, °Brix and °Baumé naturally relate to each other: 1.0 °Baumé is equivalent to 1.8 °Brix. Grapes with a 13 °Baumé, if fermented completely, would produce a wine with about 13% (v/v) alcohol.

Sugar concentration and aroma/flavour

A number of studies have shown a correlation between sugar accumulation and grape berry aroma/flavour compounds, however, the strength of the association depends on a number of variables (Robinson and Davies, 2000). The synthesis of many grape aroma/flavour compounds requires energy, but the factors leading to cessation of synthesis have not been well defined. In cold to cool heat summation regions, °Brix is generally more strongly correlated to aroma/flavour than in warmer regions (Jackson and Lombard, 1993). Strauss *et al.* (1987) demonstrated that one group of aroma/flavour compounds, norisoprenoids, are strongly correlated to grape sugar. Norisoprenoids, 13-carbon terpenoids, are derived from the degradation of carotenoids, and are associated with descriptors such as grassy, tobacco, smoky, kerosene, tea and honey (Strauss *et al.*, 1987). The norisoprenoids appear to be more stable than the compounds associated with fruity aroma notes.

Boss *et al*. (2014) demonstrated the complex relationships among sugar content, harvest date, and wine volatile composition. They reported that monoterpenes generally increased in abundance in relation to increasing Brix, with less of an effect due to harvest date. Compounds that decreased in abundance in relation to Brix were also influenced by harvest date. Many of these compounds were acetate esters of higher alcohols, as well as ketones and acetals. The positive impact volatiles accumulate is closely related to increasing Brix. However, the loss of compounds that may impart negative attributes may be a passive process and require a certain amount of time on the vine. The main compounds responsible for green aromas in grapes and wines are 3-isobutyl-2-methoxypyrazine and C_6 compounds. Mendez-Costabel *et al*. (2013) found that seasonal variation was more important than regional variation, and similar trends among regions were found within each season. Temperature during the spring, a period of active growth, was found to be a significant driver of fruit green aroma compounds at harvest, likely due to its interactions with vine vigor and fruit shading. Thus, while sugar can indicate general maturity level, it is not a clear estimation of aroma/flavour.

‘Hang time’ - Potential for further ripening

The limited correlation between changes in Brix and aroma/flavour and phenol compounds has resulted in the concept of physiological maturity and the expression ‘hang time’. A typical sugar profile during ripening shows an initial rapid accumulation, but at some point during development, the vine ceases transport of sugar to the fruit. Sugar accumulation occurs only to a certain point, usually around 24°Brix; further increases in sugar concentration are due to dehydration. °Brix, berry aroma/flavour, and phenol maturity are not always strongly correlated. This has resulted in extended fruit hang time to allow for desirable changes in secondary metabolites. The results may include the loss of fruit weight, increases in °Brix (often as a result of dehydration) and the elevated level of potential wine alcohol. Luna *et al*. (2017) reported that delayed harvest date had a greater effect than crop reduction on fruit composition.

Figure 4.3 illustrates the relationship between berry weight and °Brix at several sampling dates. As maturation continues, berry weight increases, then declines. This decline frequently occurs prior to harvest. °Brix can increase in late stages of maturity, either due to the production of sugar by the plant, or to dehydration of the berry. Mathews (2015) suggests that the so-called Old World style is associated with a lower Brix with wines categorized as having finesse. This is contrasted by New World wines, notably in warm climates, frequently harvested at higher Brix levels and sometimes called ‘fruit bombs’. Both New World and Old World wines have merit, which suggests the limits of the association of quality to concentration.

Berry shrivel and firmness

Grape maturation can be evaluated by assessing physical properties of the berry, such as firmness and deformability. Berry softening is due to changes in composition of cell walls of the fruit, particularly due to pectin and xyloglucan depolymerization, which accompanies arrest of xylem flow to the fruit (Rogiers *et al.*, 2006). This softening can result in increased skin tannin extraction at crush, resulting in a form of fining caused by precipitation of the larger molecular weight astringent tannins with cellular components (Keller 2011). Thus, changes in the tannin distribution in the juice and subsequent wine can occur.

Berry shrivel is an important attribute impacting yield and, frequently, wine style. Shrivel is particularly notable in some varieties such as Shiraz, where shrinkage begins in warm regions at about 80 to 90 days post-flowering (McCarthy and Coombe, 2001). The decline in berry weight is more closely related to the time from flowering than to °Brix. Symptoms include loss of berry turgidity and wrinkling of the skin. The rate of berry shrinkage varies as a result of region, season and/or climatic conditions, and among vines within blocks (Rogiers *et al.*, 2006).

Between the maximum berry weight and time of harvest, there can be substantial decline in weight. In one study, McCarthy and Coombe (2001) determined optimum harvest weight for maximum secondary metabolite concentration in an Australian Syrah to be 1.2 g per berry. The incidence of berry shrivel and degree of shrivel is used as a maturity gauge for some varieties.

Sugar per berry and sugar loading

The °Brix of grape must accounts for 90 to 95% of the fermentable sugars. However, this measurement is a ratio (wt/wt) of sugar to water and may change due to physiological conditions in the fruit. A potential problem encountered in °Brix, °Baumé, or any soluble solids measures used as a fruit maturity index, occurs with changes in fruit weight. Over time, soluble solids readings may show no change but, in fact, there may be substantial changes in the fruit weight, either increases or decreases (Table 4.2).

Sugar accumulation may cease due to unfavourable environmental conditions, such as very high or low vineyard temperatures, but resume once conditions have changed. It is important to be able to distinguish transient effects from the permanent cessation of transport of photosynthates. Once phloem transport has ended, any further increases in °Brix will be due to loss of water, not continued synthesis and translocation of sugar. Assessing changes in berry weight, and noting the point at which average berry weight starts to decrease while °Brix increases, can indicate the onset of dehydration. However, this can be difficult to monitor where fruit maturity is not uniform across clusters or berries.

The concept of sugar per berry utilizes a soluble solids evaluation such as °Brix, and takes into account the weight of a berry sample. For example, if data were taken from the same vineyard at 5-day intervals and the soluble solids (°Brix) of both sample dates measured 22°Brix, it might be concluded that there had been no change in fruit maturity. However, sugar per berry calculations could lead to a different conclusion if there were changes in berry weight (Table

4.2). Sugar per berry calculations yield considerably more information than that available by evaluation of °Brix measurements alone. Research indicates that the maximum rate of production of aroma/flavour compounds occurs at about the time the berry stops importing water from the phloem, or shortly thereafter. Therefore, maximum aroma/flavour occurs sometime after the berry reaches maximum weight in most instances, suggesting the importance of this as a stylistic winemaking tool.

Some industry practitioners use sugar loading peaks (increase of less than 3 mg/berry/day) as a method of maturity evaluation. By measuring when the vine has stopped exporting sugar into the fruit, harvest can be conducted at intervals thereafter. Time spans of 5-7 days post sugar maximum can result in qualitative differences in both the aromatic and mouth-feel features highlighted in the resultant wines.

Brix-to-alcohol ratio

Producing balanced harmonious wines is an important industry goal. Balance refers to the relative concentrations of volatile and structural/textural components (Zoecklein, 2013). Making wine in a warm growing region or vineyard site may pose a challenge with regard to avoiding excessive alcohol concentration, where increased hang time can result in alcohol levels that are relatively high and negatively impact wine balance.

Theoretically, a given weight of fermentable sugar will yield 51.1% alcohol by weight. The actual alcohol yield is generally different from the theoretical. In the past, winemakers used the conversion factor of 0.55 multiplied by the °Brix to estimate the potential alcohol produced in a dry wine. However, the actual conversion rate can vary from 0.54 to 0.62, or higher. These differences are the result of several factors listed below. For example, softening of grapes occurs from *véraison* to harvest as a result of changes in pectin polysaccharides. Increases in deformability occur with increases in the water-soluble polysaccharide concentration, which can increase the non-sugar soluble solids concentration. The soluble solids to alcohol ratio can be influenced by the following:

- Variety
- Season
- Maturity level/soluble solids
- Fermentation temperature

- Open vs. 'closed' fermenters (alcohol loss due to entrainment with carbon dioxide)

In many regions the alcohol levels of the resultant wines are higher than desired for optimum balance. As such, where legally permissible, some choose to 'water down', that is add water to the juice per-fermentation to reduce the alcohol potential.

pH, acidity and potassium

Assessments of acidity and pH are used to help define the optimal time of harvest for a particular wine style. Both are known to have significant impacts on wine (Zoecklein *et al*., 1999). The pH values for white wines may be 3.5 or less. Higher values are usually observed for red wines, largely because of contact of juice and skins before and during fermentation. Changes in fruit pH are complex and the result of a number of environmental and viticulture management factors. Grapes are rich in potassium, an essential macronutrient for growth and development. Potassium ion (K^+) is the main cation in must and wine (Blouin and Cruège, 2003) and is absorbed by the roots and distributed to all parts of the vine. Early in the season, when the growth rate is high, much of the K^+ accumulates in the leaves. After *véraison*, a sharp increase in berry K^+ is observed as a result of K^+ redistribution from leaves to berries (Ollat and Gaudillère, 1996; Blouin and Cruège, 2003).

Excessive K^+ concentration in the fruit at harvest may result in increases in pH and thus negatively impact potential wine quality, particularly in red wines (Davies *et al*., 2006). The stoichiometric exchange of tartaric acid protons with K^+ cations results in the formation of largely-insoluble potassium bitartrate, leading to a decrease in free acid and tartrate-to-malate ratio (Gawel *et al*., 2000). The overall result is an increase in pH. High K^+ levels in the berry may decrease the rate of malate degradation by impairing malate transport from the storage pools in the vacuole to the cytoplasm. Grape skin contains from three to 15 times more K^+ than is present in the pulp. Therefore, berry K^+ levels are often more important to red than to white wines, due to skin contact in red wine production (Mpelasoka *et al*., 2003). The levels of K^+ in grape berries may be affected by numerous factors, including K^+ level in the soil, antagonistic elements in the soil such as magnesium and calcium, grape variety, soil moisture and viticultural practices (Mpelasoka *et al*., 2003; Davies *et al*., 2006). Several vineyard management considerations impact K^+ uptake and pH evolution. Severe stress late in the season can increase K^+ uptake. Potassium concentrations have a significant impact on juice and wine buffering capacity (see below). Crop and overall vine balance are also important in helping to manage pH evolution. Over-cropping may delay the rate of fruit maturity, which can result in increases in pH.

Titratable acidity

The acid concentration of fruit and resultant wine is important to structural/textural balance. Titratable acidity (TA) in grapes normally ranges between 5.0 and 16.0 g/L expressed as tartaric acid; these values are influenced by variety, climatic conditions, cultural practices, and maturity of the fruit. The reduction in TA during fruit ripening is partly related to the respiration of malic acid in the berry and is, therefore, related to temperature. Grapes grown in warmer regions (more heat summation units) mature earlier and have a lower TA at the same soluble solids concentration, when compared to fruit grown in a cooler climate (Gladstones, 1992). A characteristic of cooler growing regions is lower daily temperature fluctuations during the late stages of fruit ripening, an important contributor to acid retention (Gladstones, 1992).

Organic acids

Malate is consumed as an energy source in the berry during *véraison*, and the concentrations decrease relative to tartrate (Jackson and Lombard, 1993). Tartrate concentrations generally remain constant during *véraison*, but may rise slightly during grape dehydration. Malate concentrations decrease with maturity, and may plateau at a low level, roughly 2 to 3 g/L (Jackson and Lombard, 1993). Grapes may catabolise sugar if malate concentrations decline too much, depending upon the variety (Conde *et al*., 2007).

Generally, the malate-to-tartrate ratio does not appear to correlate well with aroma/flavour production in the fruit. Generally, the warmer the season, the lower the malic acid content. There is a strong correlation between the malic acid concentration and the concentration of an important group of grape-derived aroma compounds, the methoxypyrazines. Methoxypyrazines such as IBMP (2-methoxy-3-isobutylpyrazine), a nitrogen-containing plant metabolite, can impart a vegetal aroma to some varieties including Cabernet Sauvignon, Cabernet Franc, and Sauvignon Blanc. Described as bell- or green pepper-like, excessive concentrations of IBMP can negatively impact the aromatic quality of wines. Decreases in pyrazines are the result of fruit maturation and temperature (Allen, 2006). The decrease in IBMP is directly correlated to malic acid decline (Roujou de Boubee, *et al*., 2000).

Buffering capacity

The buffering capacity of juice or wine is a measure of its resistance to pH changes. Buffering capacity is particularly important in regions and seasons where fruit pH at harvest may be elevated and the winemaker desires to acidulate to lower it. Essentially, buffering capacity is a measure of the organic acid pool (malic and tartaric) at winemaking pH. A system with a high buffering capacity requires more hydroxide (OH^-) ions or hydrogen ions (H^+) to change the pH than one of lower buffering capacity. Thus, buffering capacity can be defined in practical terms as the quantity of hydroxide or hydrogen ions needed to obtain a change of one pH unit (e.g., from pH 3.4 to 4.4). The net result of buffering action is to create, within the system, resistance to changes in pH that otherwise would occur with addition of either acid or base. In the case of base addition, excess OH^- ions are consumed by H^+ ions of the buffer's acid component to form water, whereas excess protons are consumed by the anion component. Generally, the higher the fruit K^+ level, the greater is the buffering capacity. Buffering capacity explains why each year is unique in the relationship between acidulation and pH changes, since the buffering capacity of fruit changes as a function of growing conditions and subsequent fruit chemistry. A method for determination of buffering capacity is described by Zoecklein *et al*. (1999).

Phenolic compounds

The quantitative and qualitative evaluation of fruit phenolic compounds is used as important maturity gauges. In general, higher phenolics are associated with higher sunlight exposure, lower nitrogen levels, lower soil moisture, moderate canopy size, moderate crop load, lower soil fertility and smaller berry size (Kennedy 2018). Classes of compounds of particular importance to winemakers include: hydroxycinnamates, tannins, and the flavonoid phenols anthocyanins, and flavonols.

Hydroxycinnamates are found mainly in the pulp and can be converted to unpleasant aroma compounds by spoilage yeasts, including *Brettanomyces* sp. Over exposure of fruit to sunlight elevates their production.

The term tannin defines a heterogeneous group that are identified based on certain properties:

- astringency
- bitterness
- reaction with ferric chloride
- ability to bind with proteins,

It was their characteristic interaction with proteins (e.g., ability to tannin leather – hence, the term tannins) that traditionally differentiated tannins from other phenols. However, not all phenols that bind with proteins elicit an astringent response, and tannins are not the only wine components that cause astringency. Flavan-3-ols are the building blocks of tannins.

Some practical tannin considerations include the following (Kennedy *et al*., 2001):

- Tannins are mainly in the skin, seeds and stems.
- Grape seeds, skins and stems contain different types of tannin with different sensory properties.
- In skins, tannin accumulation starts around flowering and is completed before *véraison*.
- In seeds, tannin accumulation starts around flowering and is completed one to two weeks post-*véraison*.
- Skin tannin maturation occurs during ripening and results in progressively increased extractability of tannins, coinciding with perceived softening and so-called ‘ripening’ of tannins.
- Skin and seed tannin extraction can be manipulated during processing as a stylistic tool.
- Methods of increasing tannin extraction include enzymes, heat, and extended maceration.

Grape tannins are evaluated both chemically and sensorially by winemakers to help determine harvest dates. Tannin perception in wine is a function of tannin activity, which is impacted by compositional parameters including the following (Kennedy, 2013):

- Skin to seed tannin ratio
- Tannin-pigment polymerization
- Oxidized tannins
- Tannin molecular weight

Some phenols, including tannins, have the ability to polymerize or associate, with themselves and other compounds, including anthocyanin pigments. As polymerization occurs, the molecule becomes larger. The number of subunits bound together is referred to as the DP number, or degree of polymerization. So-called tannin “quality” relates to the following:

- degree of polymerization
- association of tannins with other molecules

- stereospecific nature of the molecule

Skin tannins contribute to astringency, palate weight, and overall mouthfeel, while seed tannins can enhance the perception of bitterness. Basic components of seed tannins such as catechin and epicatechin are often esterified with gallic acid. This galloylation increases the perception of astringency, although the seed coat limits the extraction of tannins during processing.

Generally, as fruit maturity increases, so does the formation of polymeric pigments (tannin-pigment polymers), likely the result of breakdown of cellular vacuoles which compartmentalize tannins and anthocyanins. Fruit maturity also results in increased skin tannin extraction as a result of changes in the cell wall components. This can result in a form of fining during berry breakage, causing precipitation of the larger molecular weight astringent tannins changing the tannin distribution in the juice and subsequent wine (Kennedy, 2013).

Factors Impacting Red Wine Colour

Humans are visually oriented. As such, colour is an important wine attribute. Red wine colour is a function of three elements derived primarily from the fruit:

- anthocyanins
- cofactors, or certain non-coloured compounds which bind with anthocyanins
- polymeric pigments

Red wine hyperchromicity, also known as co-pigmentation, is a phenomenon that allows more visible red colour than would be expected due to the anthocyanin concentration alone. The concentration and type of spectral colour enhancers or cofactor compounds vary greatly from variety to variety, season to season, and by vineyard management practices. These compounds include some non-flavonoid phenols, flavonols, and the amino acid arginine. Levengood (1996) reported total phenols correlated more strongly to red wine colour than total anthocyanin concentration.

Polymeric pigment concentration is mainly a function of the anthocyanin concentration, rather than the ratio of anthocyanins to tannins. Anthocyanin concentration increases with maturity, a reason why many use the anthocyanin plateau (highest concentration level) as a means of determining optimum red wine grape maturity.

Flavonol phenols and are in lower concentration than both tannins and anthocyanins, but can also impact wine sensory features. These compounds are produced exclusively in the skins and are in greater concentration in sun-exposed fruit. Flavonol glycosides contribute to astringency. During processing limited hydrolysis occurs liberating the aglycone which can remain as a color cofactor. Flavonols, catechins, cinnamic acids and other cofactors increase stability can account for as much as 30-50% of wine colour (Keller, 2010). Indeed, colour in young red wines may be limited more by cofactor than by anthocyanin concentration. This is important considering, for example, that at pH of 3.0 less than 30% of the anthocyanins present are in the flavylium or coloured form.

Vineyard Management and Grape Phenols

Vignerons routinely use vineyard management techniques to help influence fruit phenol composition. Excessive berry exposure and excessive canopy shade can impact the rate of maturity. For example, canopy shade often results in lower concentration of fruit phenol compounds, however, different classes are impacted differently. Anthocyanin and flavonol phenols are generally increased as a result of sunlight exposure. Indeed, flavonol phenols increase proportionally to solar exposure. As such, the concentration can be used as an exposure barometer.

Grape skin anthocyanin concentrations plateau at a photon flux of approximately 100 µmoles m^{-2} $/s^{-1}$ of solar exposure with direct sunlight resulting in about 2000 µmoles m^{-2} $/s^{-1}$ (Keller, 2010). As such, saturation occurs at only about 5% of direct sunlight. Leafs transmit about 10% light, therefore a single leaf layer above the fruit will provide enough visual light for anthocyanin production. There are significant differences in cultivar response to canopy shade. Varieties such as Cabernet Sauvignon, Pinot noir, Malbec and Merlot generally have lower anthocyanin concentrations as a result of shade while Syrah is often unaffected (Kelle,r 2010).

There is not a strong correlation between fruit temperature and wine quality, except perhaps in the extremes. It is understood that berries in different locations within the canopy can vary widely with regard to temperature, regardless of row orientation. Anthocyanins, as a group, have an optimum temperature range of about 17 to 26°C with inhibition occurring around 35 degrees °C. Day-time temperature vs. light appears to be the main determinant regarding anthocyanin development (Spayd et al., 2002). Tannins also generally increase with increased temperature while flavonols are unaffected. Shade nets are used in some regions to reduce the incidence of sunburn, cluster damage and berry shriveling. A black net on with 40% shading factor on the southwest side of the canopy can reduce the temperature by 3.7 C° (Martinez-Luscher 2018). It appears the diurnal temperature variation is not a significant feature with regard to fruit phenols.

One study reported that forty percent of the variation in red wine colour could be explained by vineyard variables (Levengood, 1996). Excessive irrigation, too much nitrogen, calcium deficiency and *Botrytis* or other mould growth can negatively impact grape phenols, including anthocyanins. Additional variables impacting phenols and phenol extraction include the uniformity of ripening, skin-to-pulp ratio, berry pectin concentration or softness and the kaleidoscope of processing variations. Between 25 and 75% of the fruit tannins may be extracted during processing, including 50-80% from the skins (Keller 2010).

During processing anthocyanins bind with tannins. As such, by in large, the greater the must anthocyanin concentration, the greater the concentration of polymeric pigments. Polymeric pigments increase color stability, enhance mouth-feel and aromatic integration. Large anthocyanin -tannin polymers provide a relatively large number of binding sites to interact with proteins, including salivary proteins. Smaller polymers, on the other hand, have fewer protein binding sites. As such, they produce less astringency, and provide a greater degree of soft tannins and more palate depth. Smaller polymers also lead to smaller colloids which have a softer mouthfeel. Additionally, pigment polymers may be important in helping to provide reductive strength (see below). Methods of increasing the production of fruit anthocyanins include vineyard management strategies discussed above and treatment with abscisic acid (ABA) and ethanol sprays (Martin *et al.,* 2008, Zoecklein *et al.*, 2011).

There is a poor correlation between fruit phenols and wine phenols. Anthocyanin extraction is variable with usually 50 to 65% extracted. Many winemakers use the anthocyanin plateau as a harvest gauge, similar to the idea of sugar loading (point at which the sugar input to berry stops or is slowed significantly). Because fully mature fruit has a greater anthocyanin extraction, such fruit produces wines with a higher concentration of anthocyanin-tannin polymers.

An increasing number of practitioners either measure fruit phenols in-house or employ contract laboratory services. Analytical procedures include spectrophotometric estimations, direct assays and precipitation tests (Zoecklein *et al*., 1999; Harbertson and

Spayd, 2006). The following is a typical analysis of a California Cabernet Sauvignon wine in mg/L:

Total anthocyanin	1212
Free anthocyanin	734
Bound anthocyanin	420
Protein precipitable tannins	1692
Total Iron reactive phenols	3326

During processing there is a reduction of free and an increase in bound anthocyanins as a function of polymerization. Winemakers use the change in free vs. bound anthocyanin to evaluated variations in processing techniques such as when to dejuice. Generally, dejuicing cannot easily be determined by taste. As such, it is not uncommon to use a ratio of tannin to total phenols of less than 50% to aid in determining the relationships between timing of dejuicing and wine style. Depending upon style, a tannin levels less than 50% of the total phenols may optimize mouthfeel. The evaluation of seed catechins and the ratio of polymeric pigments to tannins is also a common stylistic gauge.

Reductive strength

Longevity, or the ability to age, is considered to be an important wine quality attribute. The reductive strength or antioxidative power of a wine is a measure of the uptake of oxygen without resulting in a build-up of dissolved oxygen. This is largely influenced by the phenol composition, particularly in red wines and by lees and the mineral content of white wines. Some phenolics, including tannins, have the ability to react with oxygen, bind with other compounds, and recreate the original structure, thus allowing it to react over and over again, binding oxygen (Smith, 2013). Young wines have a capacity to adsorb oxygen and that can actually increase their resistance to later oxidation, thus allowing desirable aging potential. Smith (2010) reviewed the impacts of fruit maturity on reductive strength. The problems with over-ripe fruit include the following:

- Loss of colour
- High alcohol capacity, which can destabilize colour
- Significant loss of reductive strength in the resultant wine

Storage of phenolic compounds such as anthocyanins inside acidic vacuoles protects them from oxidation (Keller 2010). With increases in maturity those vacuoles begin to break down. Changes in the phenolic content of red grapes as a function of excessive fruit maturity can lower the reductive strength by a factor of 10, significantly impacting longevity (Smith, 2013).

Grape aroma/flavour and maturity evaluation

Major aroma/flavour components in fruit are present in low concentrations, in the order of 10 to 6000 µg/kg fresh weight (Winter, 2004). For example, the concentration of a methoxypyrazine is generally in the range of 8 to 20 ng/L (Allen *et al.*, 1995). Such small concentrations have profound implications with respect to both analytical measurement, and sensory evaluation as a maturity gauge.

Most varieties have a spectrum of five to 20 aroma/flavour volatiles that may be sufficient to characterize them (Winter, 2004). The pool of free aroma components and their precursors increases rapidly in the advanced stages of fruit maturity, a process referred to as ‘engustment’ (Coombe and McCarthy, 1997). Many, but not all, varietal aroma/flavour compounds are chemically bound, odourless precursors which can be influenced by vineyard management practices such as leaf removal (Zoecklein *et al*, 1998). Hydrolysis, as a result of heat, acidity, UV or fungal enzyme activity, can convert a percentage of aroma/flavour precursors to their odour-active forms (Francis *et al.*, 1992; Sefton *et al.*, 1993; Günata *et al.*, 1988). For this reason, many berry sensory analyses (BSA) of grape aroma involve an enzyme addition prior to review to allow for conjugate hydrolysis and release of additional odour-active compounds. Analysis of the total and/or non-phenolic precursor concentration, by assessment of the glycoconjugates (glycosyl-glucose or GG analysis), has been used to evaluate fruit aroma/flavour potential (Williams and Francis, 2000; Zoecklein *et al*., 2000).

As with many primary metabolites, aroma/flavour components may be dramatically affected by growing conditions and viticulture practices (Zoecklein *et al*., 1992, 1996). As such, any aroma/flavour index of ripeness must be customized to site-specific factors and cultural practices. For example, cluster microclimate may exert more of an influence than the vine environment (Bureau *et al.*, 2000). Cluster and vine shading decrease the concentration of norisoprenoid glycoside conjugates.

Methoxypyrazines are sensorially potent volatile compounds responsible for herbaceous/vegetal attributes in wines made from certain grape varieties. The biosynthesis of these compounds in grape berries is known to occur via a pathway that involves the methylation of hydroxypyrazine intermediates. Certain viticultural management regimes can be used to alter methoxypyrazine concentrations in fruit of those varieties that have the genetic capability of producing them. Light exposure increases the levels of compounds such as 2-methoxy-3-isopropyl and 2-methoxy-3-isobutyl pyrazines in unripe grapes. Light also catalyzes photodecomposition of these compounds in mature grapes (Hashizume and Samuta, 1999). Dunlevy et al. (2013) reported that reducing the crop level of Cabernet Sauvignon vines to less than half of that of controls significantly increased the 3-isobutyl-2-methoxypyrazine (IBMP) concentration. IBMP appears to be synthesized in the flesh of the berry which suggests differences in berry size may explain the crop level effect on IBMP concentrations.

Additional evaluations at harvest

Nitrogen

Nitrogen and water availability exert a strong impact on grape flavourant composition (Keller *et al.*, 1998; Sipiora and Granda, 1998). Wines made from fruit with adequate nitrogen generally have superior aroma and overall quality (Sinton *et al*., 1978). Nitrogen availability can be considered a *terroir* factor, being correlated to both red and white wine quality, particularly where soil moisture is not limiting (van Leeuwen, 2013). Both YAN (yeast assimilable nitrogen) and micronutrients are essential for fermentation.

While it is standard practice in the New World to add supplemental nitrogen to the fermentor, some evidence suggests additions fail to enhance the fermentation the same way as natural, grape-produced nitrogen (Sinton *et al*., 1978; Treeby *et al*., 1996). Even in soils with adequate nitrogen concentrations, there can be large differences in the amount taken up by the vine due to soil type and composition, depth, moisture, microbial content, etc. Shallow soils are often reported to be superior in wine potential than deeper soils, due to lower water-holding capacity and possibly lower nitrogen, both contributing to a reduction in vigor. Nitrogen availability increases with the organic content and organic turnover (van Leeuwen, 2013).

Red grape potential for quality wines has been correlated to vine nitrogen status, particularly when water is not limiting (van Leeuwen, 2013). Low vine nitrogen reduces vine vigor in general, and increases tannins and anthocyanins (Chone *et al*., 2001). Thus, it has been suggested that red grape quality is increased by limiting vine nitrogen status (van Leeuwen *et al*., 2013), a practice referred to as regulated deficit nutrition RDN (Keller, 2012). Excessive plant nitrogen is believed to suppress the gene associated with phenol production. Vegetative, vigorous varieties may need less nitrogen and more moisture stress to attain balance (Gladstone, 2011). In white grape production, the desirable plant N status of the vine may be quite different than for reds. In whites, low nitrogen reduces the concentration of important aroma/flavour precursors. It has been suggested that the analysis of YAN at the end of the season may be a good barometer to the status of plant N.

The amino acid arginine has been reported as a maturity gauge (Jackson and Lombard, 1993). A decline in arginine may signal maturation. However, arginine concentrations are variable and influenced by varietal and seasonal differences. There is interest in measuring another amino acid, proline, as a gauge to monitor vine water stress. There appears to be a positive correlation between vine stress and proline production (Dubourdieu, 2006).

Glutathione

Glutathione (GSH) is a naturally occurring tripeptide found in grapes and a strong antioxidant. The management of glutathione may be important in aiding white wine longevity by helping to preserve aroma/flavour. The enzymatic oxidation of a simple, but important, juice phenol (caftaric acid) forms an oxidation product that can react with glutathione. This binding forms what is termed the grape reaction product (GRP). The grape reaction product terminates the oxidation process and subsequently limits oxidation (Cheynier, 2008). The effect of this reaction product can be significant. For example, one molecule of a simple phenol can consume 3.4 atoms of oxygen. When this phenol is combined with glutathione to form the grape reaction product, consumption increases to 8.5 molecules (du Toit *et al*., 2007). GSH increases with fruit maturation (Adam and Liyanage, 1993; Okuda and Yokotsuka, 1999) and the concentration is positively correlated to fruit YAN (yeast assimilable nitrogen) concentration (Dubourdieu and Lavigne-Cruege, 2004). GSH can slow the decrease of some wine volatiles during aging (Doubourdieu *et al*., 2000, Roussis *et al*., 2007; Papadopoulou and Roussis, 2008).

Berry sensory analysis

In the wine industry, monitoring frequently involves sensory evaluations. From testing grapes for assessment of maturity and quality in the vineyard, to evaluations of wines post-bottling, critical decisions are made based on sensory evaluation. Often, evaluators lack formal sensory training experience. There are several problems in relying on a single evaluator:

- Variation among evaluators
- Assessments based upon personal standards and experiences
- Possible bias due to preconceptions about the product or treatment

Berry sensory analysis (BSA) follows a standardized set of 20 descriptors, assessing the ripeness of wine grapes by judging fruit stems, skin, pulp, and seeds separately (Winter *et al.*, 2004). It uses a four-point scoring system to determine relative ripeness and the change in ripeness over time. As with any maturity analysis, this system is most advantageously used in conjunction with other assays. Additionally, aroma evaluation of the fruit is important in assessing relative maturity and stylistic goals. A typical progression of aroma descriptors for Cabernet Sauvignon grapes includes the following:

- Green, under-ripe
- Lightly herbaceous
- Herbaceous
- Minty/black currant
- Blackberry
- Jam/prune-like

Aroma/flavour masking, the subjectivity of sensory evaluations and the fact that many compounds are present as conjugated bound precursors, makes fruit aroma/flavour evaluation only a rough approximation of the aroma/flavour potential of the wine. The following should be noted:

- Most aroma/flavour compounds are likely synthesized independently of each other in the berry.
- High concentration of one aroma volatile is not necessarily correlated with high concentration of another.
- Synthesis of most aroma/flavour molecules varies dramatically with the season and vineyard management practices.
- Grape aroma/flavour compounds have different rates of loss in the fruit.

Many juice aroma evaluation methods recommend addition of pectolytic enzymes to aid in the conversion of a portion of the bound glycosidic precursors to their odour-active forms.

Additionally, salivary enzymes, which contain lyase, may be an important reason for tasting fruit such as Sauvignon blanc, versus simple evaluation of processed juice aroma. It has been reported that cysteine-bound conjugates may be hydrolyzed by lyases, thus releasing volatile thiols that contribute to varietal aroma/flavour (Dubourdieu *et al.*, 2000).

Because of differences in detection thresholds among evaluators, it is important to have as many evaluators as possible. It is also important to use contrasts when evaluating fruit. The best approach is to freeze a sub-sample of the fruit or juice collected. At the next sensory evaluation, the frozen sub-sample from the previous review is thawed, and the sensory features are compared with the current sample. Contrasting allows for the detection of changes occurring with time, and the presence or absence of undesirable aroma/flavour, textural, and visual characteristics. Optimal sensory evaluation involves an understanding of the following:

- Standardized and controlled environment
- Representative sample
- Optimal sample temperature
- Elimination of bias
- Importance of sample contrasts
- Use of skilled evaluators
- Number of evaluators and evaluations required to gain a true picture
- Minimize presentation effects (adaptation)
- Minimize physiological effects (time of day, not tasting for a period after eating or drinking)
- Using the proper testing method

The goal of BSA is to improve wine quality by enhancing our ability to understand the limits and potential of sensory evaluations. Even under the best of circumstances, significant variation in sensory response can occur due to genetic, biological, physiochemical and psychological factors.

In addition to aroma/flavour, cluster stems can also be evaluated to aid in the assessment of berry ripeness. Stems undergo a change from green unripe, to brown or ripe stems, to overripe or brittle. These changes are seasonal and varietal-specific. Green or un-lignified stems, including cap stems, which enter the fermentor can negatively influence the tannin profile of the resultant wine.

During fruit maturation, seeds may mature at a different rate than Brix changes. As seeds mature, they change colour from green to brown to dark brown. This colour change represents oxidative reactions and corresponds to the degree of extractable tannins (Fig. 4.4). Tannin extractability decreases during phases II and III of berry development.

Some winemakers taste seeds in order to assess grape maturity. However, seed bitterness may be overwhelming, and many are not able to distinguish levels of seed bitterness. The physical characteristics of the seeds, including colour, uniformity of colour, brittleness, and texture, are important indicators of fruit maturity. Because of the quantitative and qualitative role of seed tannins in red wines, seed evaluation is highly important. Fredes *et al*. (2017) developed a way to quantify seed colour ripening stages along with the chemical and colourimetric data. They differentiated under-ripe seed (brown with green traces), ripe seed (dark brown with green traces) and overripe seed (dark brown without any green traces). Additionally, some winemakers place seeds in a water/ethanol mixture of 12-14% alcohol (v/v) and evaluate by taste 24 to 48 hours later as a means of gauging seed tannin maturity/extractability.

Non-conventional maturity evaluation tools

Because of the difficulties associated with sensory evaluation, there is a need for additional simple, reliable, and objective techniques for evaluation of fruit maturity. A major challenge for the grape and wine industry is to replace time-consuming laboratory analyses, used in process and control quality monitoring, with new application techniques that are fast, precise and accurate. For example, red grape colour measurements represent the need for rapid analytical methods that may be used as objective indicators of grape ripeness and/or uniformity of ripeness. Substantial progress has been made in this area of component analysis. Many of the technologies are spectroscopic techniques that operate in the visible (Vis), near-infrared (NIR) and mid-infrared (MIR) wavelength regions of the electromagnetic spectrum (Zoecklein *et al.*, 2011). Giovenzana *et al*. (2014) evaluated a nondestructive hand-held spectral analysis for ripeness assessment in the field, while Bramley *et al*. (2011) reported the use of a fluorescence-based non-contact hand-held optical sensor for determining grape anthocyanins.

Some non-invasive testing using fluorescence or photoluminescence, T-rays (terahertz radiation, or the far-infrared region of the spectrum just before microwaves), X-ray and gamma rays for some grape and wine components have proven successful.

Conventional analyses of volatiles are mostly conducted using gas chromatographic (GC), GC mass spectrometry (GC-MS), and GC olfactory (GCO) methods, and involve very expensive equipment, time- and labour-intensive steps, methods development, sample preparation, separation of specific volatile compounds using appropriate chromatographic columns, and chromatogram interpretation. Electronic nose (Enose) technology represents a possible alternative to volatile measurement, at least in some applications. Electronic nose systems are so-named because their methods of operation are analogous to the way the human sense of smell operates. These are multi-sensor arrays designed to measure headspace volatiles. Each sensor type has a greater or lesser affinity for a particular chemical class or group of compounds. The adsorption of volatiles on the sensor surface causes a physical or chemical change in the sensor, allowing a specific reading for that sample in a unique pattern or 'fingerprint' of the volatiles (Mallikarjunan, 2005). Using chemometric techniques and multivariate statistical analysis, it is possible to distinguish among groups of samples and possibly identify individual sample components. Several studies used this technology to evaluate grape maturity and vineyard management practices on grape and wine volatiles (Athamneh *et al*., 2008; Martin *et al*., 2008; Devarajan *et al*., 2011; Zoecklein *et al*., 2011).

Grape sample processing

There are three distinctive juice zones in the fruit (Fig. 4.5). Due to compartmentalization within the fruit, it is essential that growers and winemakers standardize fruit sample processing. Without such standardization, it is impossible to compare results.

Sample processing should be performed to duplicate what is expected to occur in the cellar. Therefore, the use of a laboratory hand press would duplicate whole cluster pressing, while a blender may provide a level of extraction similar to red fruit fermented on the skins to dryness. Common systems used to process fruit samples include the following:

- Stomacher bag
- Blender
- Press

Diseases and fruit rots

Moulds are saprophytic filamentous fungi. When conditions permit, their growth may lead to fruit deterioration, as well as exposing fruit to secondary activity of spoilage yeast and bacteria. Common moulds involved in vineyard spoilage include *Penicillium*, *Aspergillus*, *Mucor*, *Rhizopus*, and *Botrytis*. The nature and concentration of microbial metabolites differ as a function of biotic and abiotic factors. Quantification of mould, yeast, and bacterial metabolites in juice samples is the best procedure for evaluation of potential impact on wine quality factors. Key indicators of fruit rot, such as the presence and concentration of ethanol, glycerol, gluconic acid, galacturonic acid, citric acid, laccase, acetic acid, ethyl acetate and ochratoxin A (OA) can be determined.

Many grape growers attempt to quantify rot based on visual assessment of the incidence. This is frequently done as a percentage of clusters impacted, or a percentage of incidence per cluster. Regardless, most premium wineries, in regions where fruit rot potential is great, conduct fruit sorting. This is generally a combination of field culling and winery sorting.

Mould growth on grapes is considered undesirable, except for the association of *Botrytis cinerea* in the production of certain sweet wines. *Botrytis cinerea* is unique in its parasitology. In rainy weather, the infected grapes do not lose water and the percentage of sugar remains nearly the same, or it may decrease. *Botrytis* infection followed by warm, sunny, windy weather causes berries to lose moisture by evaporation. With dehydration, shriveling occurs and the sugar concentration increases; this is called *pourriture noble,* or noble rot. Growth of the mold and associated bacteria consumes a portion of the grape sugar. However, the utilization of sugar may be countered by increases in sugar due to dehydration. Although noble rot develops regularly and uniformly, *pourriture grise*, or grey rot, is normally heterogeneous, when secondary infection by other microbes follows.

Under cool and wet conditions, *Penicillium, Mucor*, *and Aspergillus* spp., as well as other fungi and yeast, may overgrow *Botrytis*; this is referred to in France as vulgar rot (*pourriture vulgaire*). Breakdown of the grape skin provides a substrate for the growth of yeasts and acetic acid bacteria, and may produce a condition called *pourriture acide,* or sour rot.

Although sour rot is sometimes used in the US as a catch-all term to refer to unidentified late-season bunch rots that develop in tight cluster or thin-skin varieties, it is more precisely defined as a condition involving decayed berries with brown (oxidized) skins, whose pulp smells of acetic acid (Hall *et al*., 2017). Sour rot results from the interaction of yeasts (which ferment grape pulp to ethanol), specific bacteria (which oxidize ethanol to acetic acid), and *Drosophila* fruit flies which catalyze this process through an unknown mechanism. Hall *et al*. (2017) found that the use of vineyard antimicrobial sprays targeting the causal yeast and bacteria alone achieved modest reductions in sour rot severity. They reported that insecticides targeting *Drosophila* fruit flies significantly reduced sour rot severity, and combining antimicrobial sprays with the insecticide improved it even further. Management of sour rot involves controlling both the microbes and the *Drosophila* fruit flies, and is aided by viticultural practices that enhance ventilation and exposure of the fruit.

Agrochemical residues

The use of agricultural chemicals has received a great deal of attention. Biodynamic (BD) agriculture stems from the suggestions of Rudolf Steiner (1861–1925). The principles and practices of biodynamics are based on a philosophy called anthroposophy, which includes understanding the ecological, the energetic, and the spiritual in nature. For a wine to be labeled 'biodynamic', it has to meet the standards laid down by the Demeter Association, an internationally recognized certifying body. It is interesting that BD would be so widely undertaken in the absence of scientific justification, particularly with high valued vineyards. This interest is the result of concern for the impact of agricultural chemicals.

Pesticides can influence fermentation by producing stress metabolites such as reductive compounds, as well as by inhibiting and/or preventing fermentation. Not all yeasts and bacteria are affected the same way by pesticides. There is a significant difference between systemic and contact fungicides with regard to residues. Vinification style influences pesticide residue concentrations. For example, contact pesticide residues are influenced by pre-clarification of white wines and by the addition of enzymes which increase clarification.

To help prevent the problem of pesticide residues, records must be kept to help assure compliance with regard to maximum residue limits, and help provide the winemaker with the knowledge that fermentations will not be compromised by spray residues. Such records should be part of the viticultural HACCP plan. For example, late season copper sulfate sprays (Bordeaux mix) can significantly increase the production of volatile sulfur-like off odors and decrease wine longevity.

Climate Change and Fruit Maturity

The Intergovernmental Panel on Climate Change (IPCC, 2014) estimates that temperatures will increase from 2.0 to 2.5°C by the end of the century, with the worst case being an increase of 3-

3.5°C (Catena, 2016). Petrie and Sadras (2008) found that maturity advancement in Australia between 1993 and 2006 occurred at rates between one-half and 3 days per year. On a temperature basis, these rates are comparable to long-term rates reported for the northern hemisphere.

According to Miguel Torres (2016), “Climate change is the greatest threat for the wine business in general and for wine growers in particular.” Each of the main wine producing regions of the world can be characterized by mean climatic conditions that are drivers of wine typicity for that region. Those drivers are changing. Gladstones (2011) and Roehrdanz and Hannah (2016) summarized some of the overall effects of a changing climate, many of which impact fruit maturation:

- Increase in temperature during the growing season
- Increase in growing degree days
- Increase in mean temperature during fruit maturation
- Increase in mean temperature of the warmest month of the growing season
- Increase in mean temperature of the coldest month of the growing season
- Increase in length of growing season (frost-free days)
- Occurrence of extreme winter minimum temperatures
- Increase in precipitation for July through October
- Increase in precipitation seasonality (coefficient of variation)
- Change in the Aridity Index (annual precipitation/potential evapotranspiration)

It is well established that the phenology of bud break, flowering, and *véraison* are temperature dependent. In some regions, the intervals between these events has decreased (Bock *et al*., 2011; Lageder, 2016) as a result of climate change. Ripening is dependent on a constant supply of hormones. Optimum hormone balance is dependent on a continuous and moderate moisture stress and favorable soil temperatures. Therefore, irregular patterns of moisture stress and increased rainfall will certainly have a viticultural impact (Gladstones, 2011).

An additional effect of climate change is that of diurnal temperature range (difference between day and night). Temperatures during both the day and night are known to influence grape berry metabolism and resulting composition. Cohen *et al*. (2013) reported that compressing the diurnal temperature range of grape berries had a consistent effect on berry development and partitioning of flavonoid metabolites. Diurnal temperature range is expected to decrease as carbon dioxide levels increase (Bindi *et al*., 2010; Gladstones, 2011). Such changes can influence fruit secondary metabolites, such as aroma, flavour and phenolic compounds. According to Gladstones (2011), large differences in clouds, humidity and diurnal range, particularly in mid latitudes and continental interiors, will continue to occur with a changing climate.

Climate change may result in minimal impact on *terroir* expression, due to the multitude of influences of geography, topography, soil, and underlying geology (Catena, 2016). However, some grape varieties are more impacted than others regarding warmer temperatures and seasonal variations. Tight-clustered grapes are much more prone to fungal diseases, as are varieties with thin versus thick skins.

Vintage to vintage variations are likely to become much greater throughout the world, impacting typicity. It may not be climate change, per se, that will cause the effects, but the erratic nature of the unpredictable weather that may be a greater problem. Increased seasonal variations may influence fruit set and will affect maturity, crop uniformity and maturity evaluations. Champy (2016) reported that harvest dates for Pinot noir at Louis Latour, Beaune, France, have moved from mid-October to approximately September 20th. Frank (2016) reported that a New York vineyard has experienced an increase in GDD (growing degree days) of 10% in the last 10 years. Many regions have experienced sugar concentration increases, resulting in potential alcohol elevations of 1-2%. Such increases can have a significant impact on wine balance (Zoecklein, 2013). Research continues on methods for abating this problem, including regional reviews of new cultivars and clones, and changes in vineyard management practices. Caccavello *et al*. (2017) determined that post-*véraison* defoliation and trimming of moderate intensity was a suitable strategy for decreasing berry sugar at harvest and wine alcohol concentration. They suggest that selection of the correct intensity of leaf removal appears to be one of the critical factors in correctly designing a suitable strategy of post-*véraison* summer pruning that aims to decrease sugar accumulation in the berries. Filippetti *et al*. (2015) also showed that post-*véraison* trimming to lower the rate of sugar accumulation in berries had no impact on the concentration of anthocyanins and seed tannins

Others, however, have noted that the average sugar levels at harvest have not significantly changed over the years, suggesting that grape sugar levels are dependent not only upon weather, but are influenced by a multitude of other factors including yield. Research on additional methods for controlling sugar production and alcohol reduction will certainly continue. One contribution of global climate change is the tendency in some regions to pick grapes at a slightly earlier ripeness.

Insects, plants and animals have moved to higher elevations and more northerly climates to adjust to warmer temperatures. It is likely that viticulture will need to follow a similar pattern in the future (Catena, 2016). Some have chosen to plant fruit at higher altitudes to find cooler ripening climates. This can impact heat and, likely, UV interception. Tóth and Végvári (2016) predicted that the European range stability until 2050 is dynamic, implying adaptations such as changing of grape cultivar, and selection or modification of grapevine management, could be necessary even in those regions that remain suitable in the future.

Conclusion

The knowledge of grape quality parameters is of cardinal importance, since wine quality is directly and strongly correlated to the quality of the vintage. This review outlined fruit components that may influence wine, particularly in regard to fruit maturity. While it is understood that grape maturity can have a profound impact on wine, other factors impacting fruit composition, including cultivar, climate, soil, and notably vine water status, vineyard management and winemaking protocols are also important.

The challenges for the grape and wine industry include prediction of optimal fruit maturity for the types and styles of wines desired, and understanding the relationships between fruit composition and consumer wine preferences. Additional challenges include replacing time-consuming grape sampling and evaluation methods with new techniques that are fast, precise, and accurate. Technologies, including remote sensing, may provide objective, non-destructive measures of grape composition, grape ripeness, and/or uniformity of ripeness.

Table 1 Grape variables impacted by viticulture and the environment

Quality variable	Soil nutrition	Canopy	Irrigation	Pests and disease
Sugar	Nitrogen excess Potassium	Leaf & fruit exposure Crop load Pruning Summer pruning Crop removal Plant growth regulators	Irrigation RDI[a] PRD[b]	Powdery mildew Viruses
Colour	Nitrogen excess Potassium	Shading Crop removal	RDI Irrigation	*Botrytis* Viruses
Berry size	Nitrogen excess	Pruning Crop removal Plant growth regulators	Irrigation RDI	
pH	Nitrogen excess Potassium	Shading Crop load	Irrigation	
Titratable acidity	Nitrogen excess	Shading Crop load	Irrigation	
Contaminants (including MOG, and pests and diseases)	Nitrogen excess Excess chloride	Canopy ventilation Bunch exposure Shading Pruning Crop removal	Saline water	Pests & diseases Chemical residues *Botrytis* Powdery mildew Downy mildew Pests Harvest

Source: Krstic *et al*. (2003). Legend: [a]RDI = Regulated deficit irrigation; [b]PRD = Partial rootzone drying.

Table 2. Determination of sugar per berry

Changes in Sugar/berry	Changes in berry weight		
	Decreases	No Change	Increases
Increases	Maturation & dehydration	Maturation	(a) Major increase: maturation & dilution (b) Minor increase: maturation
No change	Dehydration	No change	Dilution
Decreases	Dehydration & sugar export	Sugar export	Sugar export & dilution

Source: Long (1984)

Fig.1. Stages of Grape Maturation.

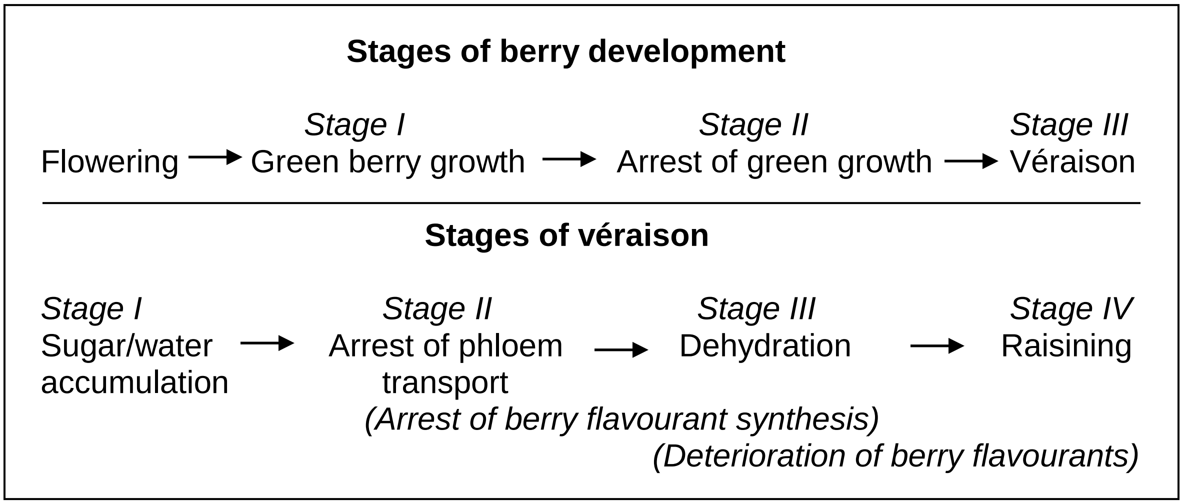
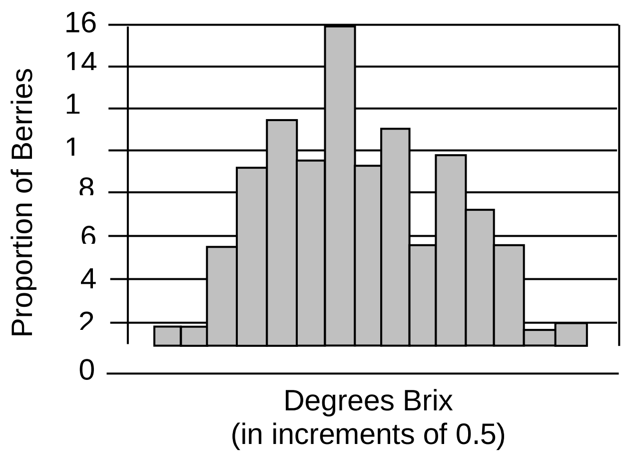


Fig. 2. Proportion of Berries at Different °Brix at Harvest



Source: Long (1986)

Fig. 3. Relationship Between ^{O}Brix and Berry Weight at Different Sampling Dates.

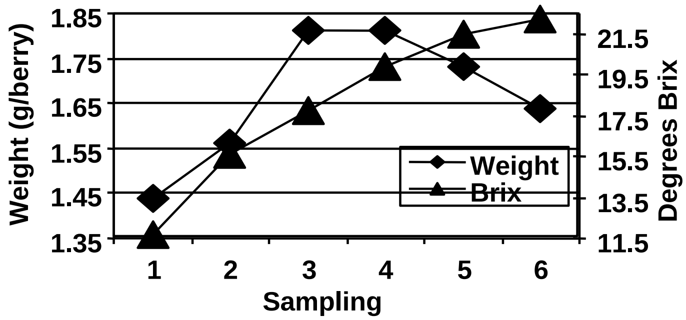
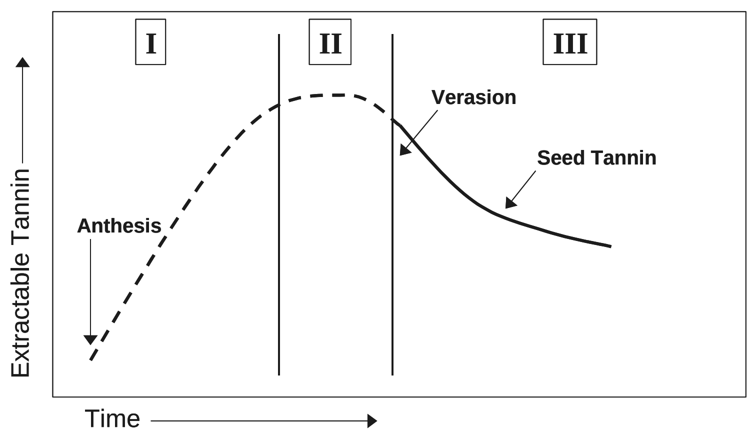
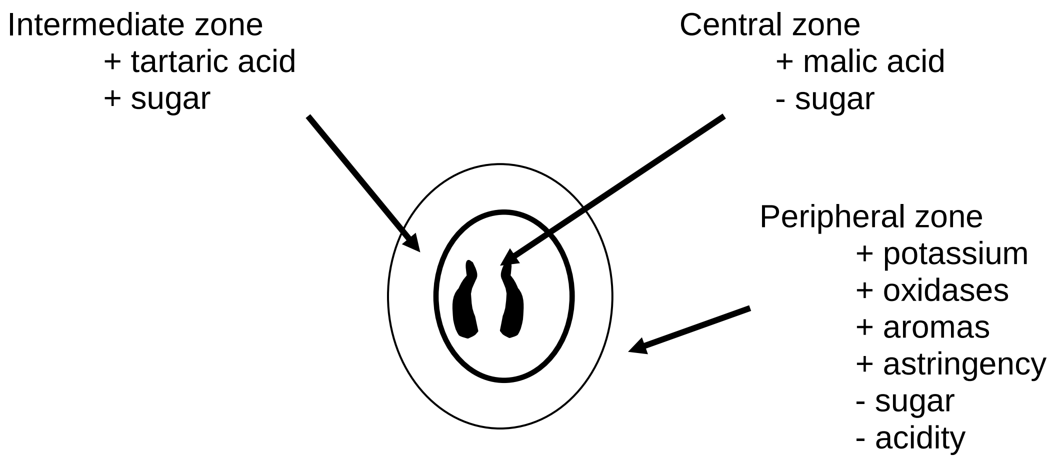


Fig. 4. Changes in Seed Tannin Extractability.



Source: J. Kennedy (2000)

Fig. 5. The Three Zones of a Grape Berry, Showing the Relative Concentration of Berry Components (Adapted from Dunsford & Sneyd, 1989).



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