Understanding grape berry development

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In the world of winemaking, there is a universal truth about the quality of the vintage: It is directly correlated with optimal grape maturity. Site selection and grapegrowing practices have a tremendous influence on achieving optimal maturity.

A considerable amount of viticultural research has identified strategies that can be used to optimize grape maturity at harvest including irrigation,[1,2,3] canopy management,[4–9] and cropping levels,[10,11,12] among others.[13–16] To fully appreciate how these strategies can be used to optimize grape maturity, grapegrowers and winemakers should have an understanding of berry development.

Fruit development

The grape berry is essentially an independent biochemical factory.[17] Beyond the primary metabolites essential for plant survival (water, sugar, amino acids, minerals, and micronutrients), the berry has the ability to synthesize all other berry components (for example, flavor and aroma compounds) that define a particular wine.

There is a potential for tremendous variability in ripening between berries within a grape cluster, and therefore within the vineyard.[18,19,20] Practically speaking, it is difficult to determine when a vineyard with a large variation in berry maturity is at its best possible ripeness. One of the major objectives of modern viticulture is to be able to produce a uniformly ripe crop.

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

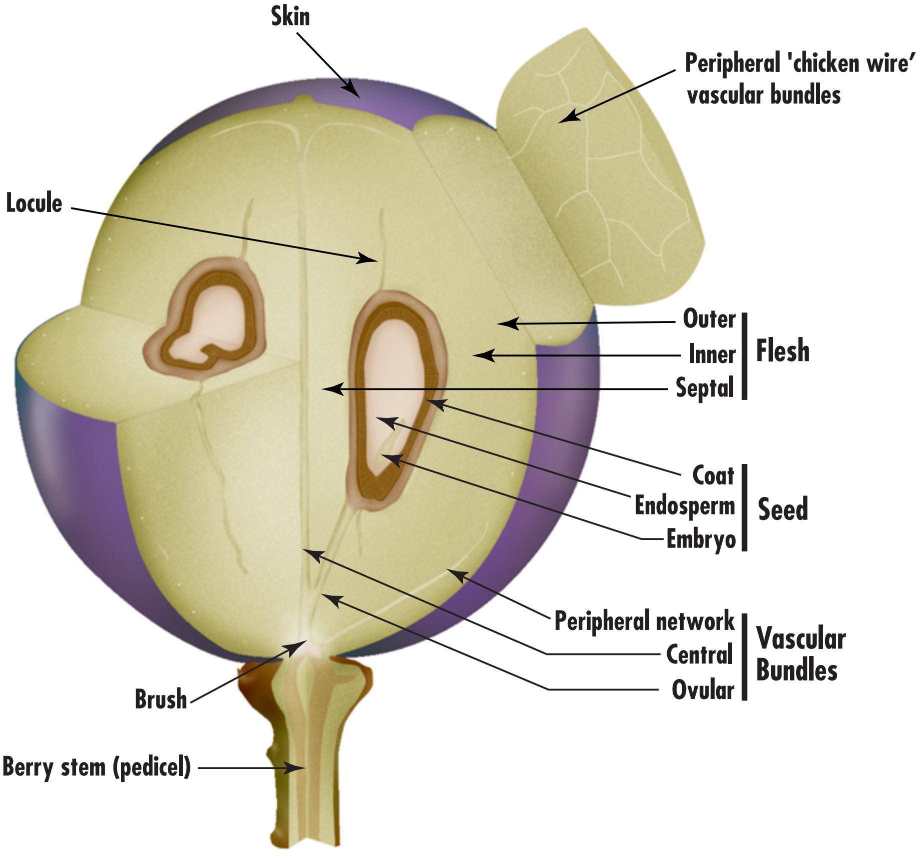

Figure I: Structure of a ripe grape berry partially sectioned on the long and central axis to show internal parts. Illustration by Jordan Koutroumanidis, Winetitles.

Berry structure

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

In addition to the effect of berry size on the proportion of skin and seed-derived components in wine, the actual number of seeds in the berry can influence the proportion of seed-derived components in wine. The normal or perfect number of seeds in the grape is four;[21]

in general though, the actual number is much less.

Environmental and nutritional conditions at bloom time affect the success of fertilization, and the resulting number of seeds per berry,[20,22,23,24] and therefore can be expected to influence the presence of seed-derived material in wine.

The berry is supplied through the berry stem or pedicel by a vascular system composed of xylem and phloem elements. The xylem is the vasculature responsible for transporting water, minerals, growth regulators, and nutrients from the root system to the rest of the vine. Current evidence indicates that xylem is functional in grape berries early in development (up to véraison), but afterward, its function is reduced or eliminated.[25]

The berry is also supplied by the phloem, which is the vasculature involved in photosynthate (sucrose) transport from the canopy to the vine. It has reduced function early in berry development, but becomes the primary source of ingress after véraison.[25]

Increases in berry volume (primarily water) are associated with increases in sugar after véraison. However, in some grape varieties (most notably Syrah), sugar increases during the latter stages of fruit ripening are not accompanied by increases in berry volume, but are caused by berry shrinkage. This shrinkage appears to be due to the transpirational loss of water,[26,27,28] suggesting that the inability of the berry to stay well-hydrated at this point is due to blockage of phloem elements into the berry. This indicates that, for some varieties, the vasulature between the vine and the berries has reduced function during late season fruit ripening.

Development during first growth period

Berry development consists of two successive sigmoidal growth periods sep-

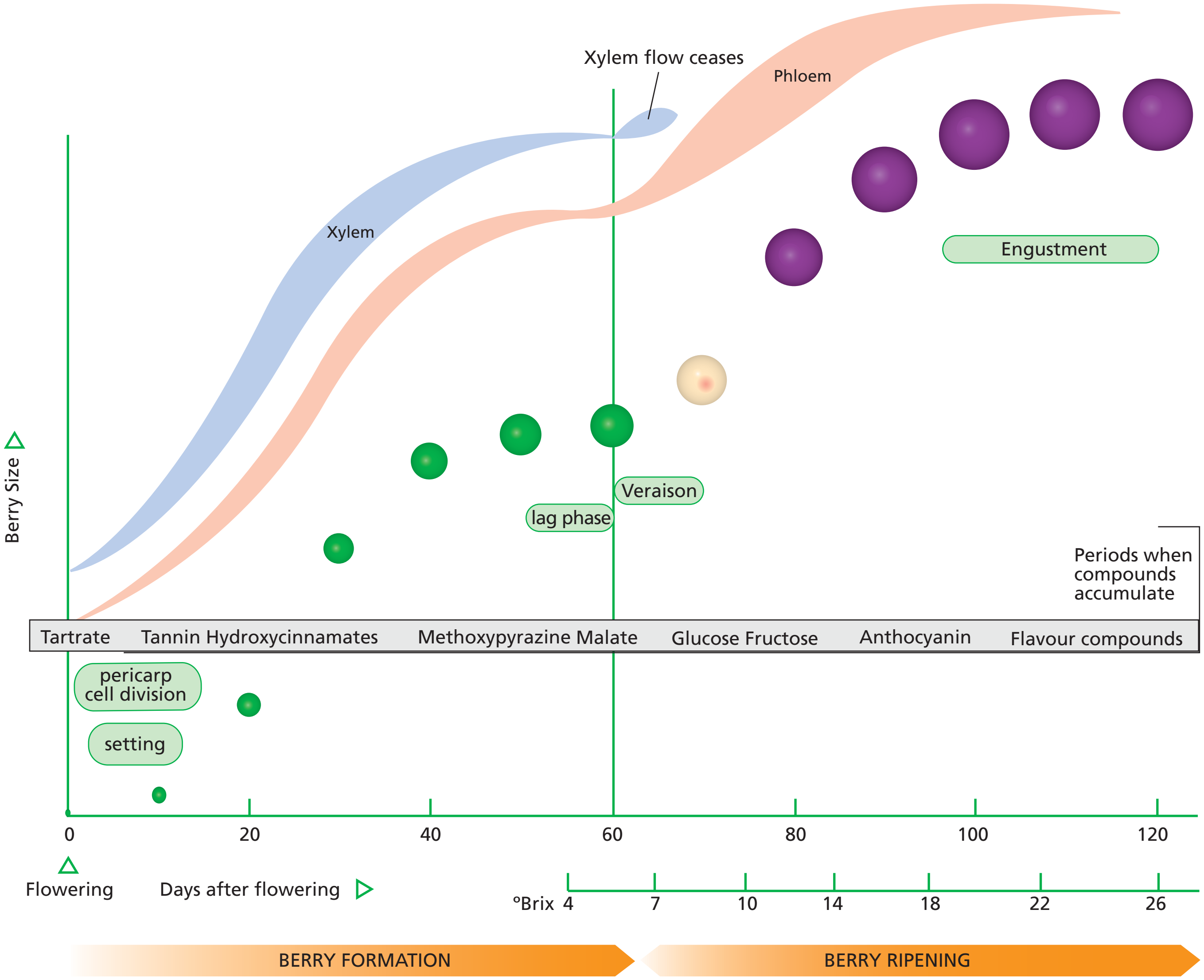

Figure 2: Diagram showing relative size and color of berries at 10-day intervals after flowering, passing through major developmental events (rounded boxes). Also shown are the periods when compounds accumulate, the levels of juice °brix, and an indication of the rate of inflow of xylem and phloem vascular saps into the berry. Illustration by Jordan Koutroumanidis, Winetitles.

arated by a lag phase (Figure II).[18] The first period of growth lasts from bloom to approximately 60 days afterward. During the first growth period, the berry is formed and the seed embryos are produced. Rapid cell division occurs through the first few weeks, and by the end of this period, the total number of cells within the berry has been established.[29] The extent of cell division has some bearing on the eventual size of the berry.

Also during the first growth period, the berry expands in volume as solutes accumulate. There are several solutes that accumulate in the berry during the first growth period, all of which reach an apparent maximum around véraison.[30] By far the most prevalent among these are tartaric and malic acid.

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

Also accumulating during the initial period of growth are the hydroxycinnamic acids.[31] Hydroxycinnamic acids are distributed in the flesh and skin of the berry and are important because of their involvement in browning reactions, and because they are precursors to volatile phenols.[32]

Tannins including the monomeric catechins also accumulate during the first period of growth.[33,34] Tannins are present in skin and seed tissues and nearly absent in the flesh, and are responsible for the bitter and astringent properties of red wine. These compounds are also believed to be important in red wine color stability.

There are other compounds that accumulate in the berry during the first phase of growth, and which have importance to wine quality. Minerals,[30] amino acids,[35] micronutrients, and aroma compounds (such as methoxypyrazines[36,37]) have all been observed during the first period of berry growth.

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

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

Development during second growth period

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

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

Tannins also decline considerably on a per-berry basis during the second period of growth. The reduction in seed tannin appears to be due to oxidation as the tannins become fixed to the seed coat.[38] As a result of this, the composition of extracted seed tannins changes considerably, and is characterized by a proportional reduction in the most bitter tannin components.

Skin tannins decline or remain constant during the second period of growth, and also become modified. Significant modifications that take place for the skin tannins include an increase in their size. Also of potential significance from a wine quality standpoint is evidence that extracted skin tannins are modified with pectins and anthocyanins.[33] This could make berry development an important consideration in the areas of wine texture and color stability.

Notable aroma compounds that are produced during the first period of growth, decline (again, on a per-berry basis) during fruit ripening. These include several of the methoxypyrazine compounds that contribute vegetal characters to some wines (such as Cabernet Sauvignon and Sauvignon Blanc).[39] The decline in pyrazines is thought to be linked to sunlight levels in the cluster. Therefore, if these compounds are deemed to be undesirable (the current prevailing opinion), then canopy management can be used to reduce them.

Despite these major changes in compounds produced during the first growth period, the big story during the second growth period is the tremendous increase in compounds (the major ones being glucose and fructose) that occurs as a result of a total biochemical shift into fruit ripening mode.

Beginning at véraison, sugar influx into the berry commences. Sucrose produced from photosynthesis is imported into the grape berry during fruit ripening. Once transported into the berries, the sucrose is hydrolyzed into its constituent sugars glucose and fructose.[40] Their eventual concentration is dictated partly by the length of time the grape berry is allowed to stay on the vine. (Other factors include the crop load, canopy size, disease status, and as mentioned earlier, dehydration).

Beyond sugar accumulation, the major determinants of a wine's quality are the secondary metabolites. In red grape varieties, anthocyanin production (restricted to skin tissue in most cultivars) is probably the most obvious compound of importance, but as with white varieties, most of the volatile flavor components are produced during fruit ripening.[41–45] These would include such compound classes such as terpeneoids, which are important to the pleasant aroma of many varieties, such as Riesling and Muscat, and fruity aroma precursors. Aroma compounds are distributed in the flesh and skin of the berry.

In addition, many other important aroma and flavor compounds are produced late in fruit ripening. Some of these components are produced as precursors, and are not actually volatile until after the wine has been produced and aged for some time.[46] Nevertheless, their precursors are present in the grape as glycosides, and the period of time where many of them appear to be produced has recently been given the term "gustation."[47]

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

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

Conclusion

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

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

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