WATER balance of grape berries

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Growers are constantly struggling to balance yield and quality in wine grapes. They are often asked to shut down irrigation sometime during ripening to achieve better quality. Moreover, a fear of dilution has led to the custom of not irrigating immediately pre-harvest.

Surprisingly, there is little scientific evidence to support this practice. For every economy-minded vineyard manager, the goal should be achieving the highest potential yield without compromising quality.

At ripeness, 70% to 80% of grape berry fresh weight is water.[1] Also, water as a solvent determines the concentrations of all important compounds (sugars, acids, phenolics, etc.) that are essential to fruit quality. Therefore, it would be difficult to overestimate the importance of berry water balance to the commercial yield and quality of grape berries.

Four components in water balance of grape berries

Grape berries are storage organs whose growth and ripening are almost entirely supported by the water and sugar flows from the mother vine. Imagine grape berries as a checking account—there are two streams of "direct deposit" in terms of water: xylem and phloem.

Xylem is the main pipeline transporting water and minerals into berries. Water flow in the xylem follows the hydrostatic pressure gradient, the same mechanism as in a garden hose; water always flows "downhill." On the other hand, **phloem** transports sugar solution, and it is virtually the only source of sugar supply to the berries.

The grape "checking account" does not just receive deposits; water is also withdrawn as a normal physiological process. Grapes are not the only organs on a vine that require water supply. The berries are always competing with other vine components (mainly leaves) for water. As leaves are transpiring rapidly during a warm or hot day, the pressure gradient points toward the leaves. Thus xylem flow can be reversed, going from fruit to the leaves. This is called "**xylem backflow.**"

Meanwhile, water also evaporates (transpires) from the berry surface. Although the rate of **berry transpiration** is much lower than that of the leaves (100 times or so), it is still not negligible, especially late in the season when the "deposits" from the xylem and phloem stop. The four components of berry water balance are summarized in Figure 1.

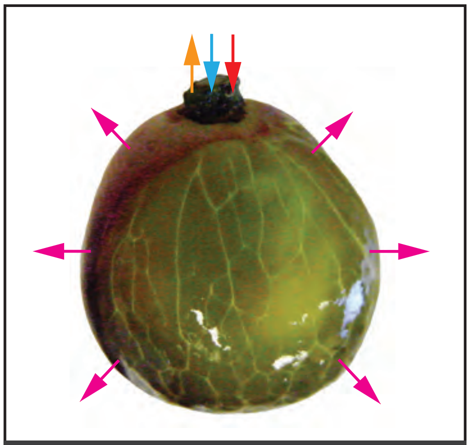

Figure 1. Image of a peeled grape berry with pedicel showing the four components of berry water. Red (phloem) and blue (xylem) arrows indicate water inflows. Orange (xylem backflow) and pink (berry transpiration) arrows indicate water loss. Note that transpiration occurs at any surface while phloem and xylem are bundles embedded within the berry and pedicel.

Keeping a balance in the water "account" is important

In order to mature normally, grape berries need to balance their water checking account. Unlike a bank checking account, grape berries have a "ceiling" (the skin), which limits the amount of water they can take in. The expandability of the skin is not boundless, and it declines during ripening.[2] If there is too much water coming in but not enough water going out, the pressure exerted on the skin could crack or split the berries (Figure 2a).

If water "deposits" do not equal "withdrawals" in grape berries, shrinkage will occur (Figure 2b). For example, pre-*véraison* berries may shrink during the daytime, when competition from transpiring leaves is high, especially during water stress that limits water supplies from both the xylem and phloem.

Shrinkage may also occur late in the season with extended hang-time (later harvest). Please note that this kind of shrinkage is dehydration, but not a physiological disorder (sour shrivel); the berries shrink because they lose water due to xylem backflow and transpiration. Late-season shrinkage (dehydration) may cause substantial yield loss, because when the shrinkage becomes visible, berries have already lost about 10% weight.

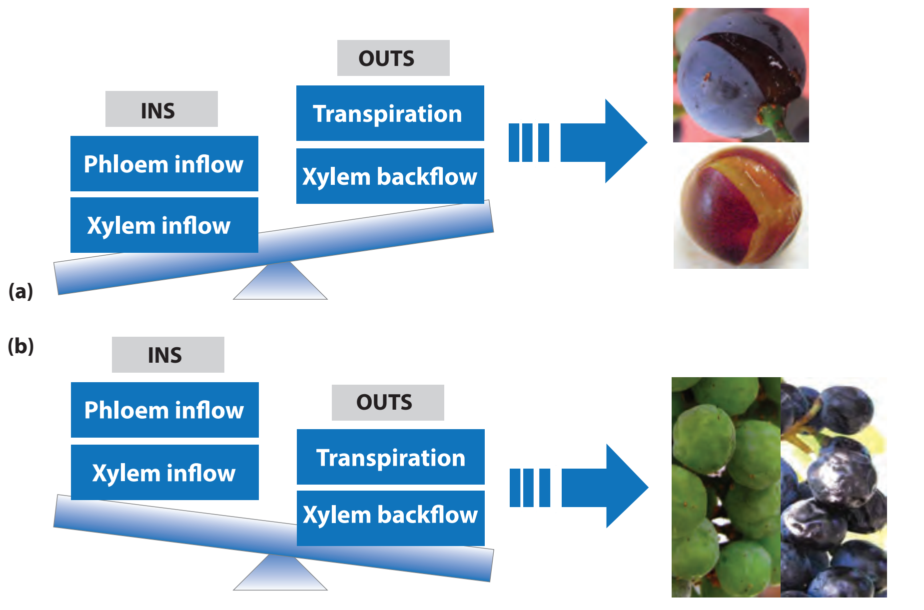

Figure 2. When the berry water "account" is unbalanced, berries may (a) crack when water inflows exceed water outflows, or (b) shrink when water inflows are inadequate to balance water loss.

Depending on the variety, once a berry reaches 22°–25° Brix, it stops accepting sugar delivered by the phloem.[1] Therefore, any increase in Brix during hang-time is due only to dehydration; there is no net gain of sugar content. From one of our experiments, we estimated that Merlot and Syrah berries gained 2.2° and 2.8° Brix per 10% weight loss, or had 4.7% and 3.9% weight loss to gain 1° Brix at ripeness. Therefore, it is important to evaluate the cost in yield to reach a certain Brix level if hang-time is required.

Berry transpiration and xylem backflow enhance ripening

There is no doubt that getting stable supplies of water and sugar through the xylem and phloem is essential to the normal ripening of grape berries. However, what roles do berry transpiration and xylem backflow play during berry development? Should we stop berries from losing water to prevent any yield loss?

In order to answer these questions, we conducted several experiments with three varieties (Concord, Merlot and Syrah) to learn what would happen if we artificially restricted one or both of these pathways. In a field experiment, commercial anti-transpirant was used to restrict berry transpiration. To stop xylem backflow, we carefully drilled through the peduncles of clusters to destroy only xylem tissue without damaging the phloem.

It is important to evaluate the cost in yield to reach a certain Brix level if hang-time is required.

Treatments were applied just before *véraison*. Both treatments slowed color change and delayed ripening (Figure 3). By harvest, berries with either restricted transpiration or restricted xylem backflow had accumulated 33% less sugar compared with untreated berries, and the combination of these two treatments almost doubled the effect (65% less sugar). Besides less sugar accumulation, treated clusters also had much higher cracking incidence than untreated ones (seven-fold higher with restricted transpiration).

In a separate experiment with potted vines, a custom-designed root-pressure chamber (Figure 4) was used to stop xylem backflow. Again, berry sugar accumulation decreased when xylem backflow was stopped.

The science behind our findings is that grape berries cannot get unlimited sugar solution supply through the phloem. This long-distance transport from leaves (sugar factory) to berries is sophisticated, and the "language" of their communication is hydrostatic pressure. Similar to the mechanism in the xylem, yet actively regulated, phloem sap from the leaves to the berries also follows a pressure gradient.

When phloem delivers sugar solution into berries, incompressible water flows into the berries along with unloaded sugars, and the pressure is also transmitted into the berries. If the pressure could not be released, as was the case of treated clusters in our experiments, increased pressure in the berries would become a signal telling the leaves to stop sending more sugar solution. This is why decreased sugar accumulation and delayed ripening in treated clusters was observed. Additionally, if the pressure exerted on the skin exceeds its extensibility, berries will crack as found in the experiment.

Grape berries have more than one pathway that ensures the important sugar-delivery process will not be disturbed easily. By measuring berry transpiration, we have found that it varies markedly with changes in environmental conditions. Any decrease in air temperature or increase in humidity reduces berry transpiration. Therefore, berry transpiration is evidently not a reliable pathway to dispose of excess phloem water. But grape berries have another pathway, xylem backflow, to ensure the continued delivery of sugar solution through the phloem and avoid cracking.

Figure 3. Clusters with restricted transpiration (right) ripened more slowly than untreated clusters (left).

To conclude, berry transpiration and xylem backflow are both necessary during berry development. When one or both pathways are restricted, the unbalanced berry water "account" causes delayed ripening, reduced sugar accumulation and increased cracking.

Irrigation and rainfall

Irrigation and rainfall are events in a vineyard that most directly influence berry water balance. It is important to note that supplying water directly to the soil by drip irrigation has different effects than supplying water to the canopy (overhead sprinkler irrigation or rainfall). When roots take up water from the soil, how much water will be delivered into the berries is controlled by pressure gradients, as explained above.

However, with overhead irrigation or rainfall, water is intercepted by the canopy. This increases canopy and cluster zone humidity, and thus decreases berry transpiration.

Figure 4. A root pressure chamber was used to stop xylem backflow by pressurizing the roots of potted grapevines.

What is worse is that water can move into a berry through the skin.[3,4] Thus, the berry water balance is tilted toward increased cracking incidence. Berry cracking was observed when we artificially increased the humidity around the clusters by bagging them. Also, individual berries took up water (up to 9% of berry weight) when they were immersed in water even with sealed pedicels.[4]

As ripening progresses, berries naturally receive less water from the xylem. This means that water derived from the soil will not "dilute" berry quality late in the season. However, overhead irrigation and rainfall may cause more water to be retained in the berries and even more water to be taken up directly through the skin or stem surface, causing berries to crack.

Cracked berries may lose a tremendous amount of sugars with continuous rainfall. We have found that berry total soluble solids dropped as much as 15° Brix due to sugar leaching after cracking.[4] Therefore, when using drip irrigation, there should be no fear of applying irrigation late in the season so long as it does not stimulate renewed shoot growth. However, overhead irrigation must be used with caution, as it can cause and exacerbate *Botrytis* bunch rot and/or berry cracking. PWV

Bibliography

1. Keller, M. *The science of grapevines: anatomy and physiology.* 2010 Burlington, Elsevier Academic Press.
2. Matthews, M.A., G. Cheng, S.A. Weinbaum. 1987 "Changes in water potential and dermal extensibility during grape berry development." *J. of Am. Society of Horticulture Science* 112: 314-319.
3. Becker, T. and M. Knoche. 2011 "Water movement through the surfaces of the grape berry and its stem." *Am. J. of Enol. & Vit.* 62: 340-350.
4. Biondi, M. Dynamics of grape berry volume change during ripening. 2007 M.S. Thesis. Washington State University.

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