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Grapevine berry shrivelling, water loss and cell death: an increasing challenge for growers in the context of climate change

>>> Late ripening berry dehydration is an important phenomenon that occurs through grape berry water loss due to the alteration of the fruit water budget when transpiration and potential water back flow to the plant exceed the import of water into the berry through the phloem and xylem. Berry shrivelling can have a significant economic impact, reducing yields by ≥25% with consequences on berry composition and the resulting wine. Its occurrence and consequences are expected to increase due to predicted climate change, shifting grape development and ripening into warmer periods (i.e., heat waves and drought events). <<<

Berry shrivel is a phenomenon of weight loss in grapevine berries which can occur during various developmental stages, either before veraison, as early as bloom (affecting the ovaries) or after veraison. Both red and white varieties (Cabernet Sauvignon, Zweigelt, Barbera, Grenache, Semillion, Sauvignon blanc, Shiraz, and other cultivars) were shown to be prone to berry shrivelling[1]. Four types of berry shrivelling are reported in the literature;
1/ Sun burn either before or after veraison, resulting in poor colour development in red varieties on severe occasions;
2/ Late season fruit dehydration (LSD), characterized by berry mesocarp cell death and water loss that leads to an increase in total soluble solids (TSS) concentration;
3/ Bunch stem necrosis characterized by necrotic rachis tissue affecting bunch tips, shoulders or even the entire clusters. Bunch necrosis can occur straight from bloom or later on after veraison, with different impacts on grape composition[2];
4/ Sugar accumulation disorder resulting in soft, irregular-shaped berries, with low fresh weight, reduced anthocyanins and sugar accumulation.

The most common type of shrivelling in warmer climates is LSD. Although LSD is variable between seasons, sites, and vineyards, it seems to be accelerated by higher temperatures, higher VPD, water constraints and/or stress and excessive bunch sun exposure. LSD can be attributed to dehydration and loss of berry cell vitality that results in losses of yield, quality and profitability[3]. Chou *et al.*[4] (2018) reported that LSD caused a 30-70 % lower fresh berry weight in Shiraz.
Most publications on berry development present results obtained on populations of berries, thus mixing various stages of berry development (Figure 1). Although time-consuming, measurements on single berries of parameters such as total soluble solids (TSS), fresh mass (g), organic acids, histological and cell death/berry internal oxygen is a pre-requisite to improve the understanding of berry metabolites accumulation and loss over the different phases of berry development. This article presents some original results related to LSD obtained by analysing single berries from various clusters of Shiraz.

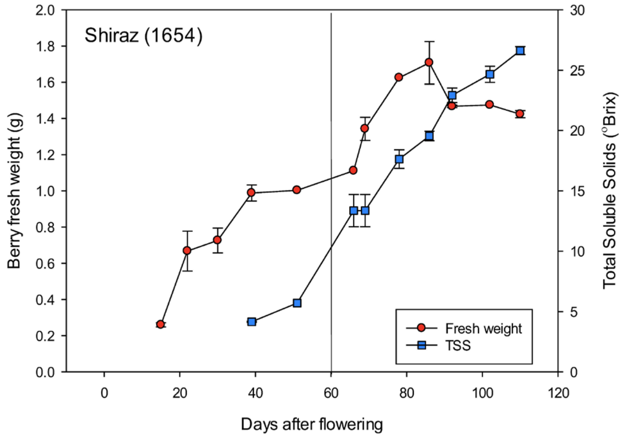

Figure 1. Changes in berry fresh weight and total soluble solids over time in Shiraz grown in a hot climate. Loss in fresh weight typically occurs at around 80-90 days after flowering. Due to the loss in berry water content, the existing sugars concentrate and further increase total soluble solids.

Single berries start loading sugar from the onset of veraison (berry softening) until sugar per berry reaches a plateau *ca.* 26 days later[5]. The plateau of berry sugar loading generally occurs at around 1-1,2 Molar (10-12% in probable alcohol; 18-20°Brix), irrespective of the cultivar. In parallel to sugar accumulation (but not necessarily in a linear relationship), the volume of the fruit increases through the loading of water.
From the plateau of berry sugar accumulation (second phase of berry ripening), the increase in sugar concentration (°Brix) is mainly due to berry water loss[6]. As the berry's water budget is no longer balanced between water loading and transpiration or water backflow to the vine, the berry may be prone to shrivelling in some cultivars such as Shiraz. Therefore, berry sugar concentration is an equation between the total amount of sugar that has been deposited into the berry (mg/berry) and berry volume. A recent study on individual normal vs shrivelled Shiraz berries, all sampled on the same clusters at the same date (Montpellier l'Institut Agro vineyard; vines trained in vertical shoot positioning, under fertigation), nicely illustrates the overall berry fresh mass loss while the °Brix increases in shrivelled berries, when compared to normal berries (Figure 2). The results reveal a significant but weak relationship between individual berry fresh mass and its sugar concentration, expressed in °Brix both for normal and shrivelled berries (Figure 3), confirming recent published results[7].
It was demonstrated that hypoxia (low oxygen) in the berry mesocarp (figure 4) may contribute to the onset of cell death[3]. Previous studies have shown that high temperature and deficit irrigation can exacerbate the extent of cell death and berry dehydration, which can be ameliorated with shading.
Berry shrivelling has a profound effect on Shiraz grape and wine composition, however modulations are shrivelling type dependent[4]. Wines made from grapes where 80% of the berries were affected by LSD resulted in significantly higher alcohol levels (more than 1% vol),

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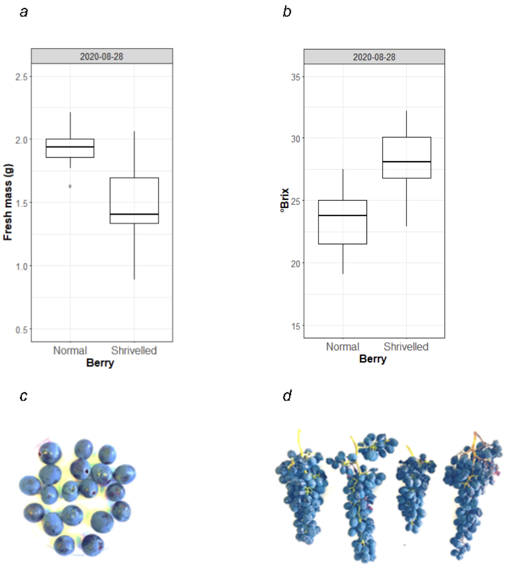

Figure 2. Boxplot representing the berry fresh mass (a) and °Brix value (sugar concentration) (b) of the same individual normal berries (c) and shrivelled berries (d). This is illustrating the overall berry weight loss and °Brix increment for shrivelled berries compared with normal berries.

increased wine hue and chemical age and decreased colour density. An increase in wine hue corresponds to a wine colour shift from purple to orange, while wine chemical age indicates the degree of polymerisation between anthocyanins and tannins. Thus, LSD accentuates colour development in red wines and in turn shortens the ageing potential of the wine. In addition, anthocyanins were lower in wines made from shrivelled grapes[4]. LSD also altered wine volatile composition, decreasing concentrations of some higher alcohol acetates and beta-damascenone (enhancer of fruity aroma) while increasing concentrations of γ-nonalactone and massoia lactone. Both compounds are known to contribute to cooked fruit, prune aromas in prematurely aged red wines. Finally, LSD affected wine sensory characteristics. Wines made out of grapes affected by LSD resulted in an increased perception of stewed fruit, and were more alcoholic and astringent[2]. More generally, compounds such as gamma-nonalactone, massoia lactone, furaneol, homofuraneol, 3-methyl-2,4-nonanedione and (Z)-1,5-octandien-3-one seem to contribute to the dry fruit character in wines made from dehydrated grapes[2]. It should be noted that late maturity is not always accompanied with berry shrivelling and high concentrations of chemical markers related to dry fruit aromas.

■ So, what do we have in the tool box to limit/avoid post-veraison berry water loss and ultimately shrivelling?

. Protect the bunch zone with leaves to limit berry transpiration and improve the bunch microclimate in terms of VPD (vapour pressure deficit). However it must also be considered that overly vigourous vines with large canopies may experience more water stress under severe heat if root uptake is insufficient to meet vine water demand.

. Apply a mild water constraint from berry set to veraison to force the vine and its bunches to adapt to a water constraint through the season (smaller berries are likely to undergo less total weight loss).

. Protect the vine with irrigation before a heat wave to limit berry water backflow, keeping in mind that post the plateau of berry sugar accumulation, irrigation might not curtail berry water loss (however, it has been shown that rain during the shrivelling phase may decelerate the rate of weight loss by direct water absorption through the skin).

. Protect vines by shading or sunscreen application (such as kaolin). ■

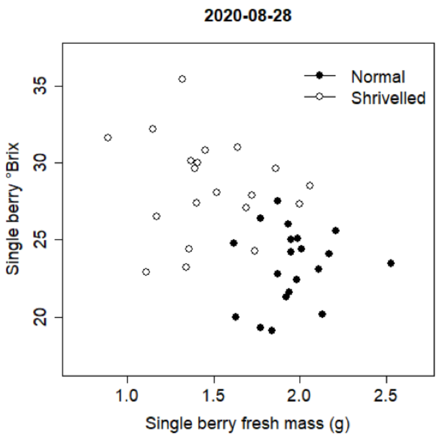

Figure 3. The relationship between single berry fresh mass and °Brix value (sugar concentration) of the same individual berry is significant, but not very tight, for normal berries and shrivelled berries. This is illustrating: i) the complex interaction between berry sugar content and berry volume; ii) for a specific sampling date, berries are not at the same developmental-ripening level for these parameters.

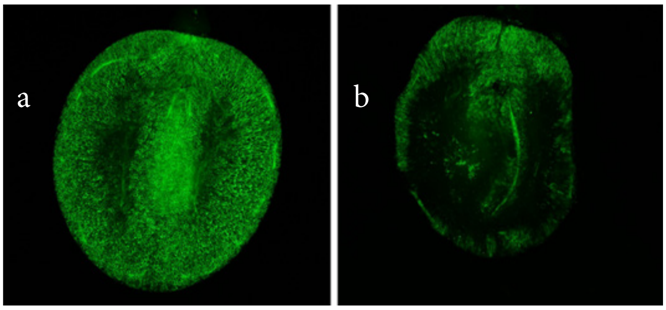

Figure 4. Fluorescent images of the berry cut surface (longitudinal cut through berry central axis) stained with fluorescein diacetate (FDA). Intact vital cells show fluorescent green. A turgid berry showing healthy/intact cells within the mesocarp in (a). A shrivelled berry showing large dark areas indicating cell death in (b). Scale bars are 2 mm.

Alain Deloire[1], Suzy Rogiers[2], Katja Šuklje[3], Guillaume Antalick[4], Xiao Zeyu[5], Anne Pellegrino[1],

1 Montpellier University, L'Institut Agro (SupAgro-IHEV), France

2 NWGIC, Department of Primary Industries-NSW, Australia

3 Agricultural Institute of Slovenia, Slovenia

4 Uiversity of Nova Gorica, Vipava, Slovenia

5 ARC Training Centre for Innovative Wine Production, National Wine and Grape Industry Centre, Charles Sturt University, Australia

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