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Potassium application to table grape clusters after veraison increases soluble solids by enhancing berry water loss☆

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ABSTRACT

Application of aqueous potassium solutions to grapevine (*Vitis vinifera* L.) canopies and clusters was reported to increase soluble solids concentration (SSC) in grape berries, although detailed study of the effect was lacking. The objective of this study was to evaluate its repeatability across genotype and year, further optimize its means of application, and provide information on its likely mode of action. Grape clusters were treated in the field with glycine-complexed potassium or water at veraison and then 3 weeks later in 2 separate years to 'Autumn Royal', 'Scarlet Royal', and 'Sweet Scarlet' or in a single year to 'Summer Royal'. At harvest the mean SSC of the untreated berries was 17.3%, while those treated with potassium was 19.8%. Dates of commercial maturity were advanced in these varieties from 4 to 11 d by potassium treatment. Berry weight tended to be slightly reduced by potassium treatment and the grapes often became darker in color, while the effect on firmness was inconsistent. Field treatment of 'Flame Seedless' grape clusters with potassium sorbate at veraison or both at veraison and prior to harvest indicated that a dual potassium application enhanced soluble solids more than a single application. Dipping 'Flame Seedless' grape clusters in potassium sorbate while attached to the vine increased the subsequent concentration of SSC to the same degree as spraying both clusters and the leaf canopy, while application to the canopy alone had no significant effect. Analysis of the elemental composition of the grape juice indicated that potassium was significantly enhanced in concentration by cluster application of potassium as was phosphorus, magnesium, boron and copper. Potassium sorbate, potassium bicarbonate and glycine-complexed potassium were effective at increasing SSC, while potassium phosphate and potassium phosphite had no significant effect. The increase in SSC among detached berries treated with potassium salt solutions was positively correlated with the rate of weight loss. Those salts that caused the most rapid loss in berry weight were those that caused the largest increase in SSC. Those that did not increase weight loss did not increase SSC. Potassium salts with basic pH were most effective in inducing weight loss. Potassium application consistently enhanced soluble solids concentration in grapes and most likely acts by increasing water loss from the grape berries.

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1. Introduction

High sugar concentration in grapes is particularly desirable and is a critical component of eating quality that defines maturity and time of harvest (Winkler, 1932). There are two main reasons to enhance the sugar concentration in grapes: (1) to advance maturity in the beginning of the season, thus prolonging the market window; (2) to overcome problems of reduced sugar accumulation, such as what occurs when yield is high or environmental factors occur which interfere with sugar accumulation (Miller and Howell, 1998), or there are treatments that enhance berry size at the expense of sugar levels (Zoffoli et al., 2009).

There are only a few means to enhance sugar level in table grapes. Girdling at veraison is considered one of the important tools (Nikolaou et al., 2003), but it can risk the vine health and increase

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astringency (Lurie, 2006). Deficit irrigation also can act to enhance sugars in grapes (Chaves et al., 2010), although it can reduce berry firmness and inhibit shoot growth in the following season if not carefully applied. Another approach is to alter crop load, by reducing cluster or berry numbers (Dokoozlian and Hirschfelt, 1995), but this may directly impact a grower's profitability.

A number of prior research reports have indicated that application of canopy or cluster-applied potassium can enhance soluble solids concentration (SSC) in table grapes. Abeer (2011) reported that two canopy potassium applications at fruit set and at the onset of veraison significantly increased SSC of 'Crimson Seedless' grapes. Furthermore, the highest concentration of potassium improved berry weight, firmness, SSC, acidity, and contents of anthocyanins. Canopy potassium application was also reported to increase SSC in 'Thompson Seedless' (Feliziani et al., 2013) and 'Flame Seedless' (Kelany et al., 2011) grapes. In an overview of Indian research performed on this topic, Bhargava (2001) described research indicating that application of potassium both prior to anthesis or during the period of berry growth acted to enhance SSC. Finally, research by Strydom and Loubser (2008) found that three late-season grape cluster applications of a glycine-complexed potassium increased SSC to 20.3% as compared to 17.1% in the untreated controls.

The effects of potassium on solute accumulation in grapes have been primarily considered in terms of its role within the grape berry. Since it is mainly present in its ionic form, it is one of the major osmotic solutes within the cells (Keller, 2010). During grape berry growth, cells need to accumulate solutes to maintain a water potential gradient so that the cell expansion process can be maintained. Although sugar is the major solute during the second rapid growth period after veraison, potassium can significantly contribute as an osmotic component, especially under low sugar accumulation conditions at pre-veraison (Mpelasoka et al., 2003). The role of potassium in cell expansion can explain the large potassium cation fluxes in the growing tissues during rapid plant growth and development (Keller, 2010). After veraison, grape berries continue to enlarge, but presumably the cell expansion during this phase of development is driven by the increase in sugar in the cell vacuole and potassium may play a secondary role in the accumulation of sugars (Davies et al., 2006). Potassium may also be involved in the translocation of solutes into the berry through its roles in phloem loading and unloading (Lang, 1983; Mpelasoka et al., 2003). Both potassium content and soluble solids content in grape berries greatly increase after veraison (Ollat and Gaudillère, 1995; Coombe, 2001; Zhenming et al., 2008). In a recent work, Keller and Shrestha (2014) observed that vacuolar potassium concentration was positively correlated with total vacuolar sugar concentration in both 'Merlot' and 'Concord' berries, indicating that potassium influx was coupled to sugar influx via the phloem.

While prior research has clearly demonstrated that potassium applied to the entire canopy or to clusters can be used to enhance grape berry soluble solids there has been relatively little work done to understand why it works and to optimize its effects. Part of the reason for this is due to the negative effects on wine grape quality that can occur due to high levels of potassium in the juice. Under such conditions, formation of insoluble potassium bitartarate crystals can occur in the finished wine and cause an unfavorable lowering in acidity (Mpelasoka et al., 2003).

The reluctance of wine grape growers, a major portion of the grape industry, to purposefully enhance grape berry potassium, resulted in the topic receiving only minimal research attention. These concerns are of little consequence to table grape growers, who can potentially utilize potassium to enhance the profitability of their operations.

Preliminary work in our laboratories had indicated that the effect of potassium on grape quality differs depending on a number of factors, including the type of potassium salt used, variety and year of application. This research had the goal of performing a systematic examination of a number of the important variables that can govern the effectiveness of potassium as well as examining water loss as a possible mode of action.

2. Material and methods

2.1. Fruit

Israel: 'Flame Seedless' grapes (planted in 2004) were grown in a commercial vineyard in Moshav Lachish, Israel. The planting system was of Y-shaped trellis in planting distances of 3 m × 1 m. Irrigation was by drippers every 50 cm with a total of 5500 m^3/ha during the entire season. 'Thompson Seedless' grapes from Moshav Arugot, planted in 1995, were used for the experiments on the effect of pH on berry dehydration. United States: One portion of the study utilized two red cultivars ('Scarlet Royal', planted in 2007, and 'Sweet Scarlet', planted in 2001) and two blue-black cultivars ('Autumn Royal', planted in 1998, and 'Summer Royal', planted in 2004), all grown in a vineyard located at California State University, Fresno. The vines were drip-irrigated, on a "Y" trellis, spaced 2.4 m apart, and the rows were separated by 3.5 m. Clusters were trimmed to approximately 600 g in size 2 weeks before the first treatment began. Experimentation examining dehydration of grape berries following application of various potassium salts also utilized 'Scarlet Royal' and 'Sweet Scarlet', but these grapes were located at the San Joaquin Valley Agricultural Research Center in Parlier, CA. 'Scarlet Royal' was planted in 1997 and 'Sweet Scarlet' in 1996 and both were drip irrigated with 2.4 m vine spacing and 3.7 m between the rows on a triple cross arm "T" trellis.

2.2. Effects of K^+ on multiple grape varieties

This test was conducted in the United States in 2010 and repeated in the same vineyard (California State University, Fresno) in 2013, although 'Summer Royal' was used only in 2010. In both seasons, two cluster-directed sprays were applied at 0.5% (1.3 g L^{-1} potassium) using a glycine-complexed potassium (Metalosate® Potassium, Albion Plant Nutrition, Clearfield, UT) or water (control) to five replicate plots of five vines, each arranged in a randomized complete block design. This product was applied because the sprayed clusters were later harvested and sold, and this product is approved for use while approval of several other potassium salts has not been addressed. To improve wetting and the distribution of potassium on the surface of the berries, a surfactant (Latron B-1956, BFR Products, Five Points, CA) was added at a rate of 0.035% to the potassium solutions and controls. The solutions were applied into the clusters to run-off from a handgun sprayer operating at 2.8 bar. In each season, the clusters were treated at the beginning of veraison, when between 5% and 20% of the berries were either soft or beginning to color, and again 3 weeks later. In 2010, however, 'Scarlet Royal' grapes only received the first application.

Samples of 50 berries were collected from each plot weekly beginning 1 week after the first potassium application until harvest at commercial maturity. Commercial maturity is defined, for most cultivars, by a berry sugar concentration of not less than 16.5% SSC (USDA, 1999) and a uniform berry color. Berries were collected at the end of the second lateral from the top of the rachis of each cluster. If the second lateral was difficult to locate, terminal berries of the first or third lateral were collected instead. This sampling method was employed because of differences in soluble solids among berries within the same cluster as those at the bottom half of the cluster were typically much lower in soluble solids than those at the top. At harvest, observations included berry firmness, determined by the force required in g to cause one mm deflection