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Regulation of berry quality parameters in 'Shiraz' grapevines through rootstocks (*Vitis*)

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Summary

The concentration of potassium (K) and pH in juice of grapevines is influenced by rootstocks (*Vitis*). However, the performance of rootstocks with respect to berry quality parameters and inter-relationships among berry quality parameters are not well understood. The current study addresses these issues. Berry and leaf samples at harvest maturity were collected from mature field-grown 'Shiraz' grapevines grafted with each of the rootstocks Dogridge, Freedom, Ramsey, 1103 Paulsen and 140 Ruggeri. Concentrations of K in juice and petiole and pH in juice were each highest for Dogridge and Freedom, but lowest for 140 Ruggeri and 1103 Paulsen. High concentration of K in juice was related to high concentrations of malic acid and TSS but low tartaric acid/malic acid ratio. In this study, lower concentrations of K in juice and in turn pH in juice of 'Shiraz' grapevines were maintained through rootstocks such as 140 Ruggeri and 1103 Paulsen that also show lower concentrations of K in petiole and TSS in juice, and higher tartaric/malic acid concentration ratio in juice at maturity. Selective use of these rootstocks in turn helps to produce quality grape juice and wine.

K e y w o r d s : potassium, pH, scion, malic acid, tartaric acid, solids.

Introduction

Juice pH is one of the most important factors that affects the quality of grape juice and in turn wine (Iland 1987), and is related to the concentrations of potassium (K) in grape juice (Somers 1975, Rühl *et al.* 1989). Over 60 % of Australian wine grapes are grown in warm irrigated regions (e.g. Sunraysia, Riverland, Riverina), where the concentration of K in the grape juice is often high (e.g. > 50 mM), depending on the scion, rootstock and location. A high concentration of K in the grape juice leads to a high juice pH (> 3.8), and in turn the production of wines of reduced quality (e.g. reduced colour and flavor, Rühl *et al.* 1992). Grape juice with a high concentration of K, and in turn, a high juice pH, requires acid adjustment during winemaking which increases the cost of processing (Mpelasoka *et al.* 2003).

The concentration of K in grape juice and in the whole grapevine can be regulated through grapevine rootstocks (Rühl 1989, Kodur *et al.* 2010 a, b, Walker and Blackmore 2012). However, the field performance of rootstocks in maintaining acceptable concentration of K and pH in the juice of the scion, and of the inter-relationships among berry quality parameters such as K, pH, organic acids and total soluble solids (TSS) in juice are not clearly understood, especially in mature grapevines. Given these knowledge gaps, and the predominance of K primarily responsible for affecting juice pH, the current study aims to i) evaluate the field performance of rootstocks with respect to berry quality parameters of 'Shiraz' grapevines, and ii) determine the inter-relationships among berry quality parameters as affected by five rootstocks. This study in turn helps to i) enhance our understanding of the mechanisms and factors that regulate K in the grapevine, and ii) maintain acceptable quality of juice and wine through selective use of rootstocks.

Material and Methods

S i t e a n d e x p e r i m e n t a l c o n d i t i o n s : The study site was Koorlong (34°.26' S, 142°.09' E), Sunraysia region in the north-west of Victoria, Australia. Rootstocks studied were Dogridge, Freedom, Ramsey, 1103 Paulsen (1103 P) and 140 Ruggeri (140 R), each grafted with 'Shiraz' as a common scion. Each rootstock grafted with 'Shiraz' constituted a treatment. There were 6 replicates for each rootstock treatment in a completely randomized design. The rows were 3 m apart and vines within rows were 1.8 m apart. The experimental site was irrigated by overhead sprinklers, and the soil was classified as a mixture of Dareton sand and Tiltao loamy sand (Northcote 1988); with a depth of surface soil to 1.8 m. All the treatments had an average rooting depth of 1.2 m. The vines were spur pruned with cordons developed on a 2 wire vertical trellis with wires at 1.05 m and 1.35 m. The growing season was 2005-2006, with mean rainfall of 276 mm·year^{-1}, mean pan evaporation of 2117 mm·year^{-1}, and mean maximum and minimum temperatures of 23.9 °C·d^{-1} and 10.3 °C·d^{-1} respectively, between July 2005 and June 2006.

S a m p l e c o l l e c t i o n a n d p r e p a r a t i o n : Samples of 100 mature berries and of 20 leaves were collected from each grapevine in March 2006 when maturity

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was around 24 °Brix (coinciding with harvest) and transported to the laboratory. Leaf samples were each separated into the lamina and petiole. Petiole samples were then oven-dried (65 °C for 3 to 5 d). Berries were peeled and then squeezed by a hand crusher and the juice was collected. The juice in each treatment was frozen and stored at -20 °C. Frozen samples of juice were later thawed in a water bath at 34 °C for 10 min, centrifuged and clear juice collected.

Analysis of K: Petiole samples were digested with a 3:1 volume mixture of nitric acid and perchloric acid. Juice samples were diluted (1:100) with de-ionized water. The concentration of K in each sample was measured with a flame photometer (Corning, England). Concentration of K in petioles was expressed as $mg \cdot g^{-1}$ (dry weight) and in juice as mM.

Analysis of pH, TSS, titratable acidity, tartaric acid and malic acid: Juice samples were analysed for pH with a CDM210 conductivity meter (Radiometer Analytical S.A., Lyon, France), and TSS (°Brix) with a digital refractometer (PR-1, Atago Co Ltd, Japan). Titratable acidity was determined by titration with 0.1 M NaOH, with an end point of pH 8.2. The concentration of tartaric acid in each treatment was determined according to the procedure described by Iland *et al.* (2000), whereas the concentration of malic acid was determined by a malic acid kit (Megazyme, Bray, Ireland).

Statistical analysis: One-way analysis of variance and Spearman rank order correlations were conducted with SPSS V.12.0.1 for Windows. Treatment means were separated by least significant differences (P = 0.05).

Results

Juice pH and K: Juice pH and concentrations of K in both juice and petiole were highest for Dogridge and Freedom, whereas 140 R and 1103 P had the lowest (Tab. 1). Thus, the order of rootstocks based on the juice pH and concentration of juice K were similar (Dogridge = Freedom ≥ Ramsey > 1103 P = 140 R). There were significant correlations between pH, concentrations of K in juice and in petiole (Figure, Tab. 3).

Table 1

Juice pH and concentrations of K in juice and petiole at maturity of 'Shiraz' grapevines grafted with five rootstocks

Rootstock	pH	Juice K (mM)	Petiole ($mg \cdot g^{-1}$)
Dogridge	4.27	79.5	44.9
Freedom	4.25	76.4	46.6
Ramsey	4.02	58.1	36.4
1103 P	3.80	51.9	31.9
140 R	3.76	46.6	25.4
LSD	0.17	6.22	9.70

LSD = least significant difference (P = 0.05).

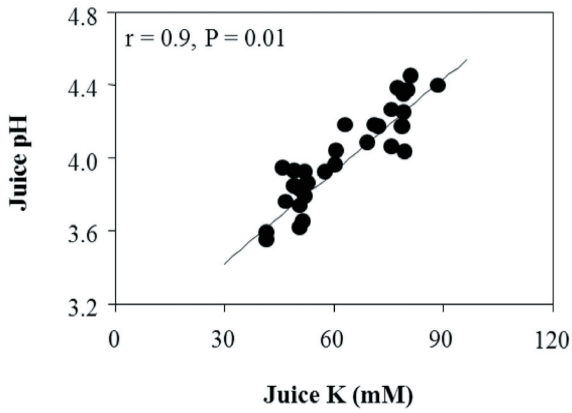

Figure: Correlation between pH in juice and concentration of K in juice at maturity of 'Shiraz' grapevines grafted with five rootstocks (n = 30).

Berry weight, TSS and titratable acidity: The berry weight of Dogridge was significantly higher than that of Freedom, Ramsey and 140 R (Tab. 2), whereas the concentration of TSS in Freedom was significantly higher than that in 1103 P, Ramsey and 140 R (Tab. 2). However, differences among rootstocks in the titratable acidity of juice were not significant (Tab. 2). Significant positive correlation existed between the concentration of K and concentration of TSS (Tab. 3).

Table 2

Berry weight (BW), concentrations of total soluble solids (TSS), titratable acidity (TA), tartaric acid (Tar) and malic acid (Mal), and tartaric acid/malic acid concentration ratio (Tar/Mal), in juice at maturity of 'Shiraz' grapevines grafted with five rootstocks

Rootstock	BW ($g \cdot berry^{-1}$)[a]	TSS (°Brix)	TA ($g \cdot L^{-1}$)	Tar ($g \cdot L^{-1}$)	Mal ($g \cdot L^{-1}$)	Tar/Mal
Dogridge	1.65	23.6	3.77	1.53	3.79	0.40
Freedom	1.40	25.0	2.88	1.56	3.30	0.48
Ramsey	1.48	22.4	3.32	1.99	3.34	0.60
1103 P	1.51	21.9	3.63	1.75	3.34	0.54
140 R	1.34	23.1	3.00	1.74	2.13	0.86
LSD	0.14	1.83	–	0.13	0.50	0.14

[a]Fresh weight; LSD = least significant difference (P = 0.05); – = not significant.

Table 3

Correlation coefficients (r) among selective berry and/or plant parameters at maturity of 'Shiraz' grapevines grafted with five rootstocks

Parameter	Juice pH	Juice K	Berry weight
Petiole K	0.52**	0.64**	–
Juice TSS	–	0.5*	–
Juice TA	–	–	–
Juice Tar	–	-0.46**	–
Juice Mal	0.62**	0.62**	0.52**
Tar/Mal	-0.65**	-0.64**	–

TSS = total soluble solids; TA = Titratable acidity; Tar = tartaric acid; Mal = malic acid; – = not significant; *, ** = significant at P = 0.05 and 0.01, respectively.

J u i c e a c i d s : In the juice, the concentrations of tartaric acid and malic acid, and tartaric acid/malic acid concentration ratio were each significantly different among rootstocks (Tab. 2). Dogridge and Freedom had the lowest concentration of tartaric acid, but higher concentration of malic acid than 140 R, resulting in lower tartaric acid/malic acid concentration ratio than 140 R and/or Ramsey. Significant positive correlations were apparent between the concentration of malic acid in juice and each of pH, concentration of K in juice and berry weight (Tab. 3), whereas the concentration of tartaric acid in juice had a significant negative correlation with that of K in juice (Tab. 3). This in turn led to a negative correlation between tartaric acid/malic acid concentration ratio and each of pH and concentration of K in juice (Tab. 3).

Discussion

J u i c e p H a n d K : The rootstocks 140 R and 1103 P maintained lower juice pH and concentration of K in juice than the other rootstocks (Tab. 1), as Rühl (1989) also showed with 140 R. This suggests that these rootstocks can be selectively used in conditions where high concentration of K and in turn high pH in juice are important issues. High concentration of K (≥ 69 mM) and high pH (≥ 4.1) in juice of Dogridge and Freedom suggest that these rootstocks are not suitable for the production of wine of high quality unless pH is adjusted during wine making. The strong relationship between concentration of K in juice and pH in juice as shown in this study and elsewhere (Iland 1987, Mpelasoka *et al.* 2003, Walker and Blackmore 2012) suggests the need to explore the role of various factors that affects concentration of K in the juice of grapevines.

Concentration of K and pH in juice of rootstocks were each closely related to the concentration of K in petiole when sampled at harvest (Tabs 1, 3). A similar observation from other studies (e.g. Rühl and Walker 1990) suggests that a lower concentration of K in juice and in turn a lower pH in juice of the scion can be controlled through rootstocks that maintain lower concentrations of K in petiole, although site factors are also likely to be involved (Dundon *et al.* 1984, Walker and Blackmore 2012). Differences between rootstocks in concentration or content of K in various shoot parts of grapevine, including petioles are related to differences in K uptake from soil and K transport from roots to shoot (Rühl 1989, Kodur *et al.* 2010 a, b), but not to water use or transpiration (Kodur *et al*. 2010 a, b).

B e r r y w e i g h t : Berry weight can affect juice pH. Rootstocks Dogridge and 140 R which respectively had the highest and the lowest juice pH and concentration of K in juice, also had the highest and the lowest berry weight (Tab. 2). A positive effect of berry weight on juice pH however appears as an indirect effect, for example, *via* increased malic acid concentration or decreased tartaric acid/malic acid concentration ratio (Tab. 3). Although not evident in this study, berry weight may also affect concentration of K (Clingeleffer 1996). Thus, the influence of berry weight on juice pH is through altering the balance between concentrations of malic acid and K in juice. This has been linked to relationships between vine vigour and berry weight or to differences in the fruit per canopy and fruit shading across rootstocks (Clingeleffer 1996).

T S S a n d t i t r a t a b l e a c i d i t y : Total soluble solids (but not titratable acidity) and the concentration of K in juice were linked, as also shown by Walker and Blackmore (2012). Concentration of sugar in the berry generally increases as the berry ripens, due to transport of sugars from leaves. Similarly, concentration of K is expected to change as the berry ripens (Hale 1977). Both sugars and K are transported in the phloem to developing berries (Lang and Thorpe 1989). These observations and the current results (Tabs 1, 2, 3) reveal an association in the transport and accumulation of TSS and K in 'Shiraz' grapevines grafted with various rootstocks. Potassium is the most abundant cation in grape berries, and may affect solute translocation via phloem loading and unloading (Lang 1983). Hence, a relationship between K and sugar transport *via* phloem to the grape berries as they ripen is expected. Evidence in caster bean (*Vicia faba*) suggested that there is a specific K channel in sugar unloading (Ache *et al.* 2001). In contrast to TSS, a poor relationship between titratable acidity and other berry quality parameters with various rootstocks (Tabs 2, 3) suggests the limited role of titratable acidity in the regulation of pH and K in juice.

J u i c e a c i d s : Concentration K in juice of 'Shiraz' grapevines grafted with rootstocks is linked to concentrations of juice organic acids. High concentration of K in juice (e.g. > 60 mM) and high juice pH (e.g. > 3.8) were associated with high concentration of malic acid (> 3.3-3.8 $g \cdot L^{-1}$) but low tartaric acid/malic acid concentration ratio (e.g. < 0.5). A high concentration of K in juice may reduce the degradation rate of malic acid (Hale 1977), and hence may increase the concentration of malic acid in juice. Tartaric acid/malic acid concentration ratio was somewhat more directly related to that of juice pH, than was the concentration of malic acid alone (Tab. 2). Tartaric acid and malic acid are the two major anions that regulate pH balance (Boulton 1980), and a high tartaric acid/malic acid concentration ratio is desirable for wines of high quality (KASERER *et al.* 1996). The ratio between these acids therefore can act as a good indicator in the selection of low K accumulating rootstocks for maintaining acceptable juice quality.

Conclusions

Lower concentration of K in juice and in turn pH in juice of 'Shiraz' grapevines was observed through rootstocks such as 140 R and 1103 P that show lower concentrations of K in petiole and TSS in juice, and higher tartaric/malic acid concentration ratio in juice. Selective use of these rootstocks in turn helps to produce quality grape juice and wine and reduce processing costs.

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