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Regulation of fruit and wine quality parameters of 'Cabernet Sauvignon' grapevines (*Vitis vinifera* L.) by rootstocks in semiarid regions of India

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Summary

Area under wine grape cultivation is increasing in semiarid tropical regions of India. There is lack of information on role of rootstocks influencing must composition and thereby wine quality under such climatic conditions. Majority of area under table grape cultivation is grafted on Dogridge rootstock, which is also been used for wine grapes. Grapes harvested from vines grafted on Dogridge were known to possess high potassium resulting in high pH which has adverse effect on wine quality. Hence, this study was initiated to understand fruit composition and wine quality of 'Cabernet Sauvignon' grapes grafted with each of the rootstocks 101-14Mgt, 1103P, 110R, 140Ru, Fercal, Gravesac and SO4. Rootstocks significantly influenced many of the must composition parameters such as sugars, organic acids, phenolic compounds, potassium and pH. Significant and positive correlation was observed between potassium content, juice pH and malic acid. Rootstocks 101-14 Mgt and Gravesac accumulated more potassium in fruits which also had higher malic acid and juice pH, while it was least on 110R, 1103P, Fercal and SO4 rootstocks. The potassium content in juice was directly related to wine pH, wherein wines made from 'Cabernet Sauvignon' grafted on 101-14 Mgt and Gravesac had highest pH. Content of most of the phenolic compounds in must and wine were significantly influenced by rootstocks. There was more than two fold increase in the total phenolic content from must to wines with highest phenols recorded in wines made from fruits harvested on 110R rootstock.

K e y w o r d s : Wine grapes; rootstocks; must composition; phenols; potassium; malic acid.

Introduction

Though factors such as soil characteristics, management practices, environmental factors determines the success of grape cultivation, understanding the capabilities and limitations of rootstocks helps in selection of appropriate rootstocks for a given location, variety and climatic conditions (Cousin 2009). In most of the grape growing regions of the world, rootstocks are used to overcome problems associated with biotic stresses such as phylloxera (Schmid *et al.* 1988, Reynolds and Wardle 2001), nematodes (Pearson and Goheen 1988, Mullins *et al.* 1992), crown gall (Gao *et al.* 1993, Sule 1999), viruses (Walker *et al.* 1989, Xue *et al.* 1999) etc. However, use of rootstocks is environmentally friendly and economically feasible alternative to overcome adverse effects of abiotic stresses such as soil and water salinity, drought, low soil pH, flooding stress etc. Apart from the use of rootstocks to overcome problems associated with biotic and abiotic stresses, several studies have also shown that rootstocks influence various physiological parameters of the scions such as photosynthesis, stomatal conductance, transpiration rate and hydraulic conductivity (Brown *et al.* 1985, Bavaresco and Lovisolo 2000); biochemical parameters such as total phenols, sugars, acid content, growth regulators (Düring *et al.* 1997, Fernandez *et al*. 1997, Iacono *et al.* 1998, Nikolaou *et al.* 2000); and morphological parameters (Satisha and Prakash 2006) after grafting. Nicholas (1993) reported the effect of rootstocks influencing the berry size which determines the concentration of secondary metabolites such as anthocyanins, flavor and aromas in wines. Fruit composition parameters that eventually affect quality include soluble solids, organic acids, pH, phenolic and anthocyanins, monoterpenes and other components (Jackson and Lombard 1993).

Kubota *et al.* (1993) grafted Fujimori grapes onto seven different rootstocks and observed higher concentrations of glucose and fructose content in berries grafted onto 3309 C, 3306C and other rootstocks. The highest level of skin anthocyanin was observed in berries from vines grafted onto 3306 C.

In India grape is cultivated in about 117,000 ha with annual production of 2,111,000 t. Of the total area under grape cultivation, only 1.5-2.0 % of the area is under wine grape cultivation and is increasing gradually. The necessity of using grape rootstocks in India is to have a profitable production against major abiotic stresses such as soil and water salinity, water scarcity etc. Though fruit composition is not a major issue in table grapes except for berry size, TSS, acidity etc. it is a major concern in wine grapes to produce good quality wines. Due to lack of knowledge about influence of rootstocks on fruit composition, most of the wine grapes under cultivation were grafted on Dogridge (*Vitis champinii*) rootstock, which is the rootstock of choice for table grapes in India (Chadha and Shikhamany 1999). Hale (1977) had concluded the non- suitability of Dogridge rootstock for wine grapes which tend to accumulate significantly higher concentrations of potassium in grape berries when it was grown in warm region. This opin-

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ion was again confirmed recently by Kodur *et al.* (2013), where they demonstrated the excess accumulation of potassium in 'Shiraz' grafted on Dogridge, which is not an acceptable parameter for wine grapes due to problems associated with high potassium concentration in deteriorating the wine quality in terms of high pH, poor color stability, high malic acid etc. (Somers *et al*. 1975, Rühl *et al.* 1992, 2000, Mpelasoka *et al.* 2003, Rankine 2004). Though potassium is an essential and important element in grapevine nutrition, its excess accumulation in fruits is not a desirable trait in wine grapes. Under K deficiency conditions, application of K fertilizers is known to hasten fruit maturity and accumulation of anthocyanins and hence, fruit quality (Morris *et al.* 1980, Morris and Cawthon 1982). However, excess K application under adequate or high soil K conditions can produce wines with high pH, lowers colour in red wines which reduces wine quality (Freeman and Kliewer 1983, Dundon *et al.* 1984). Avenant *et al* (1997) and Swanepoel and Southey (1989) attributed the variation in potassium accumulation rate in different rootstocks to their genetic origin and root distribution pattern. Vine potassium nutrition is usually checked by foliar or petiole analysis, according to Bavaresco *et al* (2010). Cirami *et al.* (1984) recorded higher juice pH in 'Shiraz' grafted onto Ramsey, Dogridge, Harmony, Schwartzman and 1613C than on own rooted Shiraz vines.Thus choosing rootstock is an important decision for cultivation of wine grapes.

Till recently many of the commercial wine grape cultivars were solely grafted on Dogridge rootstock. Due to more vigour inducing capacity of Dogridge and its tendency to accumulate more potassium, there was reduction in quality of wines produced in tropical regions. Systematic evaluation of rootstocks for important wine varieties has not been done so far for semiarid tropical climate of India. Hence, this study was initiated to understand the influence of rootstocks on must and wine composition of 'Cabernet Sauvignon' grapes.

Material and Methods

Location and plant material: This study was undertaken during 2012-13 and 2013-14 season in the experimental vineyards of National Research Centre for Grapes, Pune, India. Pune is located in Midwest Maharashtra state (India) at an altitude of 559 m above the mean sea level. It lies in 18.32° N latitude and 73.85° E longitude. The maximum and minimum temperature recorded during 2012-13 ranged from 99.75 °F (during May) and 52.43 °F (during January) respectively with annual rainfall of only 84.90 mm. Similarly the maximum and minimum temperature recorded were 98.96 °F (during May) and 51.8 °F (during December) respectively in the year 2013-14 with annual rainfall of 573.4 mm. The vines were grown on calcareous black cotton type soil (clay content was 44.5 %) exhibiting swelling and shrinkage properties. The soil pH ranged from 7.7 to 7.9 with average soil potassium concentration ranging from 800-1,000 ppm. The average bulk density of the root zone up to a depth of 30 cm was 1.25 g/cm^3. The average EC of the irrigation water during the experimentation was 1.98 dS/m with an average pH value of 7.78. The experiment block consisted of 4 years old 'Cabernet Sauvignon' vines grafted on seven different rootstocks. The list of rootstocks with their genetic parentage is given in Tab. 1. The vines were planted at a spacing of 2.4 m between rows and 1.2 m between vines thus accommodating about 3400 vines per hectare and were trained to mini Y system of trellises. Experimental vines were pruned twice in an annual growth cycle, which is a common practice in tropical viticulture. The first pruning was done immediately after fruit harvest during summer months popularly called as “back or foundation pruning” (first week of April) to develop fruitful canes and another pruning was done at about 5-6 months (second week of October) after back pruning on those canes to encourage cluster development which is popularly known as “forward or fruit pruning”. This system of grape cultivation is popularly known as “double pruning and single cropping system”. The average bud load retained per vine after forward pruning ranged from 85-90. After forward pruning, apical 2-3 buds on pruned canes were swabbed with bud breaking chemical, hydrogen cyanamide (25-30 $\mu L \cdot L^{-1}$) within 24-48 h after pruning to facilitate quick and uniform bud burst. Harvesting was done at about 145 d after forward pruning during the month of March in both years. The average yield per vine varied from 2.5 kg (on 101-14 Mt) to 8.0 kg (on 110R).

Harvesting and fruit sampling: At the time of harvesting representative berry samples of about 500 g were drawn from each stock/scion combination. Half portion of the samples was used immediately for estimation of basic fruit composition such as total soluble solids (TSS), acidity, pH, potassium etc. The other half portion was stored in -20 °C deep freezer for High Performance

Table 1

Rootstocks and their parentage selected for study

Rootstocks	Parentage
110 Richter (110R)	*Vitis berlandieri* × *Vitis rupestris*
140 Ruggeri (140Ru)	*Vitis berlandieri* × *Vitis rupestris*
1103 Paulsen (1103P)	*Vitis berlandieri* × *Vitis rupestris*
Selection Oppenheim 4 (SO4)	*Vitis berlandieri* × *Vitis riparia*
101-14 Millardet et de Grasset (101-14Mgt)	*Vitis riparia* × *Vitis rupestris*
Fercal	{*V. berlandieri* × Colombard 31) × EM333}
Gravesac	{161-49C (*Riparia* × *Berlandieri*) × 3309C (*Riparia* × *Rupestris*)}

Liquid Chromatography (HPLC) analysis of organic acids, sugars and phenolic compounds.

Analysis of fruit composition parameters: The fresh fruits were macerated in cheese cloth and the resultant must was centrifuged and the supernatant was analysed for TSS (hand held refractometer with temperature compensated to 20 °C); acidity (titration of juice against 0.1N NaOH using phenolphthalein as indicator); pH (pH meter, Model 420, Thermo Orion,) and potassium (Flame photometer, Model, PFP 7, Jenway Ltd, UK).

Wine preparation: After harvesting, grape clusters were cleaned to remove rotten and green berries and the de-stemming was done manually. The grape berries were passed through a stainless steel presser to prepare must. The must was inoculated with commercial yeast culture (*Saccharomyces cerevisiae*) with viable cell count, *i.e.* $1.06 \times 10^8 \cdot mL^{-1}$. Fermentation was carried out in 50 L capacity stainless steel tanks at 20-22 °C. During fermentation process, fermenting material was mixed twice every day. The fermentation was completed by 13 d. The material like skin, seed and yeast lees were separated from the finished wine. Later wines were filtered and stored in bottles. Sample of fresh wines were analysed for alcohol content, pH, acidity using the instrument Oeno FOSS, Model Type, 41 – 01. Phenolic compounds in wine were estimated using HPLC.

HPLC analysis of organic acids, sugars and phenolic compounds: The fruit samples stored at -20 °C were used for HPLC analysis. After removing samples from the freezer they were thawed overnight under refrigerated conditions. Later the fruits were macerated in cheese cloth and the resultant must was centrifuged and the supernatant was used for HPLC analysis.

Phenolic compounds: Chromatographic analysis of phenolic compounds was performed using the 1260 series Agilent Technologies HPLC, equipped with an inbuilt 4 channel degassing unit, standard auto-sampler, 1260 infinity quaternary pump, an Agilent 1260 infinity Diode array detector and an injector. The system was interfaced with a personal computer utilizing the Agilent EZ chrome elite software for control, data acquisition and further analysis. A Zorbax Eclipse plus C18 column (4.6 mm x 100 mm 1.8 µm particle size.) was used. The analytical column was preceded by a C18 guard column to prevent any non-soluble residues from samples from contaminating the column. The injection volume maintained was 10 µL with a flow rate of $0.80\ mL \cdot min^{-1}$. The mobile phase consisted of A (0.2 % acetic acid in 10 % acetonitrile) - 95 % and B (0.2 % acetic acid in acetonitrile) - 5 %. Prior to use, the solvent was filtered through vacuum filter and then sonicated for 5-10 min in an ultrasonic bath to remove air bubbles. The column temperature was maintained at 30 °C. Peaks were determined at 280 nm for all the phenolic compounds.

Organic acids: The analysis of organic acids (Tartaric acid and malic acid) was done with Agilent technologies 1260 series HPLC system with Diode array detector (DAD) at a wave length of 214 nm and band width of 4.0. The column used was Agilent Zorbax eclipse plus C 18 (4.6 ×100 mm 5 um). The separation was done with a mobile phase of A- 95 % Acidified water with orthophosphoric acid (pH 2.0) and B- 5 % absolute methanol with a flow rate of $0.8\ mL \cdot min^{-1}$. Column temperature was 25 °C. The injection volume was 10 µL and total run time was 7 min.

Sugars: The HPLC analysis of glucose and fructose was done with Agilent technologies 1260 series system with Evaporative Light Scattering Detector (ELSD) in isocratic mode. The amino column of 250 µ 4 or 4.6 mm, 5 µ particle size was used. The injection volume was 10 µL and total run time was 6 min.

Statistical analysis: The experiment was conducted as randomized block design with four replications and the two years average data was analysed using SAS Version 9.3. Least significant difference (LSD) was used for comparing treatment means.

Results

Influence of rootstocks on basic fruit composition, organic acids, sugars: Maximum total soluble solids and minimum titratable acidity; maximum juice pH and potassium content were recorded in must of 'Cabernet Sauvignon' grafted on Gravesac and 101-14 Mgt rootstocks. The lowest pH and potassium content was recorded on Fercal rootstock. Though must tartaric acid content did not differ significantly among rootstocks, the concentration of malic acid was significantly influenced by rootstocks. Highest malic acid was recorded on Gravesac, while least was on SO4 and 110R. The glucose and fructose content was lowest on 140 Ru, while it was highest on SO4 and Gravesac rootstocks (Tab. 2)

Influence of rootstocks on phenolic compounds in must: The concentration of phenolic compounds in must of 'Cabernet Sauvignon' grafted on different rootstocks is shown in Tab. 3. Among flavonoid compounds, the concentration of quercetin hydrate was highest in all the stock scion combinations which differed significantly. Highest quercetin was recorded on Fercal rootstock, while it was least on 110R. Concentration of Kaempferol did not differ significantly between different rootstocks. Rootstocks significantly influenced the concentration of most of the non-flavonoid compounds in must of 'Cabernet Sauvignon' grapes. Among those, gallic acid was the main constituent which differed significantly among rootstocks followed by that of cafteric acid.

Influence of rootstocks on wine composition: All the four parameters analyzed for fresh wines differed significantly between rootstocks (Tab. 4). Highest wine pH of 3.8 was recorded on Gravesac, while it was lowest on 140 Ru. Acidity was highest on 140 Ru and 101-14 Mgt and it was least on gravesac and 110R. The highest ethanol content was recorded on Gravesac, while it was least on 110R, 140 Ru and Fercal. Least volatile acidity was recorded on 110R while it was higher on Gravesac and SO4.

Influence of rootstocks on phenolic compounds in wine: Similar to concentration of phenolic compounds in fresh juice of 'Cabernet Sauvi-

Table 2

Influence of rootstocks on must composition of 'Cabernet Sauvignon' grapes

Rootstocks	TSS (°B)	Titratable acidity ($g \cdot L^{-1}$)	pH	Potassium (ppm)	Tartaric acid ($g \cdot L^{-1}$)	Malic acid ($g \cdot L^{-1}$)	Tart: malic ratio	Glucose ($g \cdot L^{-1}$)	Fructose ($g \cdot L^{-1}$)	Glu: fru ratio
101-14 Mgt	25.07 ab	5.87 d	3.95 a	1490 ab	6.09	3.17 ab	2.47 ab	89.56 a	87.01 a	1.029
1103 P	22.52 d	7.07 c	3.48 c	1430 c	6.58	2.23 c	2.05 b	82.01 ab	83.67 ab	0.980
110 R	22.67 cd	7.15 c	3.48 c	1425 c	6.49	2.47 bc	2.05 b	83.63 ab	81.14 ab	1.030
140 Ru	21.2 e	7.72 a	3.46 c	1460 b	6.20	3.16 ab	1.96 b	78.07 b	75.95 b	1.029
Fercal	23.97 bc	7.87 a	3.34 d	1410 c	6.34	2.61 abc	2.47 ab	81.12 ab	81.22 ab	1.000
Gravesac	26.05 a	5.60 d	3.85 b	1490 ab	6.04	3.25 a	2.05 b	88.71 a	86.10 ab	1.024
SO4	23.57 cd	7.47 b	3.46 c	1410 c	5.87	3.14 ab	2.65 a	87.18 a	89.94 a	1.002
LSD	1.32	1.83	0.0563	38.76	0.874	0.726	0.595	8.807	8.812	0.059
$P < 0.05$	*	*	*	*	NS	*	*	*	*	NS

[1)] Numbers followed by same letters are not significantly different *: Significantly differ at $P < 0.05$; NS: Non significant.

Table 3

Influence of rootstocks on must Phenolic compounds ($mg \cdot L^{-1}$) in 'Cabernet Sauvignon' grapes

Rootstocks	Flavonoids				Non-flavonoids			
	Flavan-3-ols		Flavonols and flavonl algycons		Hydroxy benzoic acids		Hydroxy cinnamates	
	Catechin	Epi-catechin	Quercetin hydrate	Kaempferol	Gallic acid	Vanillic acid	Caftaric acid	Chlorogenic acid
101-14 Mgt	1.59 b[1)]	0.0037 c	24.33 ab	2.32	36.78 ab	7.43 a	3.29 a	0.0037 bc
1103 P	0.49 cd	ND	23.41 ab	1.20	30.80 b	2.91 ab	3.62 a	0.0012 bc
110 R	1.03 bcd	0.0037 c	18.84 b	1.58	32.10 b	3.79 ab	4.61 a	ND
140 Ru	0.34 d	0.016 a	20.45 b	1.51	35.05 ab	5.30 a	3.28 a	0.0037 bc
Fercal	1.15 bc	0.230 a	28.36 a	1.69	22.36 c	3.98 ab	4.61 a	0.0212 a
Gravesac	2.41 a	0.0075 b	23.51 ab	2.18	40.30 a	6.99 a	4.54 a	0.010 b
SO4	1.811 ab	ND	22.50 ab	1.81	35.9 ab	ND	0.265 b	0.0012 bc
LSD	0.796	0.345	5.986	1.314	6.811	4.501	2.120	0.0089
$P < 0.05$	*	*	*	NS	*	*	*	*

[1)] Numbers followed by same letters are not significantly different *: Significantly differ at $P < 0.05$; ND: Not detected; NS: Non significant.

Table 4

Influence of rootstocks on basic composition of 'Cabernet Sauvignon' wines

Rootstocks	pH	Acidity ($g \cdot L^{-1}$)	Ethanol (%)	Volatile acidity ($g \cdot L^{-1}$)
101-14 Mgt	3.68 b	4.87 a	13.45 b	0.40b
1103 P	3.58 c	4.65 b	13.20 b	0.375b
110 R	3.63 bc	4.47 c	13.20 b	0.305c
140 Ru	3.68 b	4.87 a	12.85 c	0.38b
Fercal	3.65 bc	4.95 a	12.72 c	0.385b
Gravesac	3.80 a	4.45 c	13.77 a	0.411a
SO4	3.61 bc	5.05 a	12.85 c	0.410a
LSD	0.07	0.198	0.268	0.023
$P < 0.05$	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1)] Numbers followed by same letters are not significantly different.
* Significantly differ at $P < 0.05$.

gnon' grapes grafted on different rootstocks, phenolic compounds of wines also differed significantly between rootstocks (Tab. 5). In contrast to fresh juice, the concentration of flavonoid compounds accounted for the major portion of phenolic compounds. Catechin was highest among all the stock scion combinations followed bet that of epicatechin and quercetin hydrate. Kaempferol could not be detected in any of the wine samples. Among non flavonoid, highest gallic acid was recorded on 101-14 Mgt and Gravesac and lowest was on 140 Ru. Maximum vanillic acid was recorded on 101-14 Mgt and lowest was on Fercal. Both cafteric acid and chlorogenic acid were highest on 101-14 Mgt and Gravesac rootstocks, while they were lowest on 110R, 140Ru and Fercal rootstock. The total phenolic compounds were significantly highest on wines made from 'Cabernet Sauvignon' grapes grafted on 110R while they were lowest on 140 Ru and Fercal rootstocks (Figure).

Discussion

Rootstocks are known to influence yield and berry composition parameters such as berry size, glucose, fructose, malic and tartaric acids, phenolic composition of wine grapes as reported by several authors (KUBOTA *et al.* 1993, KASERER *et al.* 1997, REYNOLDS and WARDLE 2001, EZZA-HOUANI and WILLIAMS 2005). In the present study, significant variation was observed for most of the fruit composition parameters analyzed after harvest. Rootstocks 101-14 Mgt and Gravesac recorded highest total soluble solids and

Table 5

Influence of rootstocks on phenolic compounds (mg·L^{-1}) of 'Cabernet Sauvignon' wines

Rootstocks	Flavonoids				Non flavonoids				Total
	Flavan-3-ols		Flavonols and flavonl algycons		Hydroxy benzoic acids		Hydroxy cinnamates		
	Catechin	Epi-catechin	Quercetin hydrate	Kaempferol	Gallic acid	Vanillic acid	Cafteric acid	Chlorogenic acid	
101-14 Mgt	45.69 b	30.30 b	19.70	ND	43.50 a	12.01 a	17.57 a	0.95 a	168.17 b
1103 P	41.69 c	26.47 c	18.35	ND	39.41 b	10.62 b	9.56 d	0.709 c	146.83 d
110 R	66.37 a	32.74 a	14.16	ND	39.81 b	10.48 b	9.27 d	0.691 cd	175.07 a
140 Ru	33.55 e	22.12 f	14.16	ND	34.03 d	10.63 b	13.75 c	0.676 cd	132.85 e
Fercal	33.38 e	23.80 ef	19.95	ND	34.91 d	9.33 d	14.77 b	0.643 d	136.82 e
Gravesac	36.06 d	24.50 de	20.17	ND	43.14 a	10.12 bc	16.86 a	0.829 b	151.70 c
SO4	41.56 c	25.74 cd	18.34	ND	38.30 c	9.73 cd	9.36 d	0.524 e	143.58 d
LSD	1.851	1.813	3.188		1.012	0.686	0.817	0.060	4.622
P < 0.05	*	*	NS		*	*	*	*	*

[1)] Numbers followed by same letters are not significantly different *: Significantly differ at P < 0.05; ND: Not detected; NS: Non significant.

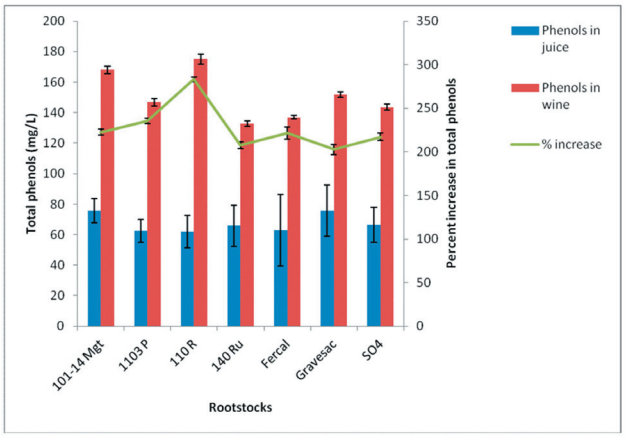

Figure: Effect of rootstocks on total phenols in grape juice, wine and percent increase of phenols in wines Vertical bars indicates standard error of mean (±) with n = 4.

lowest titratable acidity which also recorded lowest fruit yield (data not shown) as compared to 110R, which recorded lower TSS, highest acidity and maximum yield. Though vines of all the stock scion combinations were fruit pruned on the same day, the days taken to ripen differed between rootstocks which is evident from variation in sugar content at the time of harvest. Reduced glucose and fructose content on 110R and 140Ru rootstock may be due to slower rate of fruit ripening on those rootstocks (Satisha *et al.* 2010). The vegetative vigor measured in terms of pruned biomass was lowest on 101-14 Mgt, Fercal and Gravesac rootstocks, while it was highest on 110R, 1103P and 140Ru rootstocks (data not shown). The existence of an inverse relationship between grapevine vigor and the resulting composition of the must in terms of soluble solids, tannins and polyphenols (Cortell *et al.* 2005, 2007, 2008) has been clearly demonstrated. The present results are in accordance to findings of Pouget (1987), who has clearly established that large vine size conferred by rootstocks tend to prolong fruit maturation on grafted scions as compared to lower vigor inducing rootstocks which accelerate the fruit maturity and ripening. According to Alburquerque *et al.* (2007), increased TSS in 'Tempranillo' is correlated with lower production, while Merlot had the highest TSS and lowest vigor values, confirming the inverse relationship between quality and vigor.

The non-significant contribution of tartaric acid in influencing juice pH is in accordance to findings of Kodur *et al.* (2013). But, rootstocks significantly affected accumulation of malic acid in fruits of grafted scions as reported by several workers (Kodur *et al.* 2010, 2011). Maximum concentration of malic acid and highest juice pH was recorded in fruits grafted on 101-14Mgt and Gravesac rootstocks, which also accumulated higher potassium. The reduced accumulation of potassium in fruits harvested on 110R, 1103P, SO4 and Fercal rootstocks with *Vitis berlandieri* background (with exception of 140Ru) is confirming findings of Wolpert *et al.* (2005), who reported lower petiole potassium concentration in rootstocks with *Vitis berlandieri* genetic backgrounds. A significant positive correlation was observed (Tab. 6) for juice potas-

Table 6

Correlation coefficient (r) among some of the grape juice and wine parameters of 'Cabernet Sauvignon' grapes grafted on different rootstocks (n = 28)

Parameters	Correlation coefficient (r)
Juice pH vs Juice malic acid	0.471*
Juice pH v/s juice potassium	0.697*
Juice pH v/s acidity	-0.935*
Juice acidity v/s potassium	-0.656*
Juice acidity v/s TSS	-0.658*
Juice potassium v/s malic acid	0.513*
Juice tart: malic ratio v/ wine pH	0.478*
Juice Potassium v/s wine alcohol	0.483*
Juice TSS v/s wine alcohol	0.606*
Wine pH v/s wine malic acid	0.574*
Juice pH v/s wine acidity	-0.242
Juice potassium v/s wine pH	0.257
Juice acidity v/s wine acidity	0.481*

* Values above 0.471 are significant both positively and negatively at p ≤ 0.05.

sium and malic acid (r = 0.513) and juice potassium and juice pH (r = 0.697) which confirms the findings of earlier studies by Mpelasoka *et al.* 2003, Walker and Blackmore 2012, Kodur *et al.* 2013. The increased concentration of potassium on 101-14Mgt and Gravesac rootstock may be due to reduced yield as compared to those on 110R which recorded highest yield per vine owing to dilution effect. The concentration of potassium content in 'Cabernet Sauvignon' has been strongly linked to higher malic acid content and tartarate: malic acid ratio as they show significant positive correlation. As explained by Hale (1977), a higher concentration of potassium in juice may reduce the degradation of malic acid and hence may increase the final concentration of malic acid. Though we could get significant negative correlation between juice pH and acidity, a strong positive correlation was observed between tartarate:malate ratio and wine pH suggesting the importance of considering the ratio of taratarate:malate for making good wine than solely relying on total acidity (Kaserer *et al.* 1996).

Wine quality depends on must characteristics such as pH, total acidity, total soluble solids (TSS) etc. (De Andrés-de Prado *et al.* 2007, Walker and Blackmore 2012). In the present study, significantly higher pH was recorded in wines made from 'Cabernet Sauvignon' grafted on Gravesac, 140Ru, Fercal and 101-14Mgt rootstock, while least wine pH was recorded on 110R and 1103P rootstocks. Significant and positive correlation was recorded between wine pH and malic acid and tartarate: malic acid ratio in juice. Similarly significant positive correlation was recorded for juice acidity and wine acidity (r = 0.481) but no such significant relation was observed between juice potassium and juice pH. Hence, the observation from this study suggests the possible role of malic acid in juice which determines wine pH rather than concentration of potassium alone. Wines which were prepared from juice having higher concentration of total soluble solids also recorded higher concentration of alcohol which is evident by significant and positive correlation between TSS and alcohol (r = 0.606). Concentration of sugars in must is one of the good indicators, which provides an estimate of the probable alcohol yield and so helps in the selection of appropriate grape varieties to produce good quality wines (Alburquerque *et al.* 2004, 2007).

Rootstocks significantly influenced the concentration of several phenolic compounds in both must and finished young wines. Grape seeds and skin are the main source of phenolic compounds which determines wine color and structural properties. Koundouras *et al* (2009) reported increased accumulation of skin anthocyanins and flavan-3-ol monomers in 'Cabernet Sauvignon' grafted on 1103P than on SO4 rootstock. The variation in total phenolic compounds may be due to modification in cluster microclimate because of variation in vegetative vigor as suggested by Cortell *et al* (2007). Wallis *et al.* (2013) in their studies on the effect of rootstocks on scion sap phenolic levels affecting resistance to *Xylella fastidiosa*, observed significant variation in concentration of phenolic compounds in 'Cabernet Sauvignon' and 'Chardonnay' grafted on 13 rootstocks. 'Cabernet Sauvignon' grafted on 101-14Mgt, 1103P, 420A and Schwartzman had reduced disease incidence due to excess accumulation of phenolic compounds than on 110R, 5BB or SO4 rootstocks. In the present study also, the accumulation of different phenolic compounds was highest on 101-14Mgt and Gravesac rootstock while it was lowest on 110R and Fercal. The reduced phenolic compounds on 110R rootstock might be due to increased yield per vine which supports the studies of Cortell *et al.* (2007). Both hydroxy benzoic acids (gallic acid and vanillic acid) and hydroxy cinnamates (caftaric acid and chlorogenic acid) were known to increase as harvest times get delayed with increased TSS in the berries (Tian *et al.* 2009). This is in confirmation to the present study also where the grapes harvested on 101-14 Mgt and Gravesac rootstocks had higher TSS which also had higher concentration of hydroxy benzoic acids and hydroxy cinnamates. The phenolic profile in the wine largely depends on the total phenols present in fresh wine grapes, the extraction parameters, wine making technologies and other chemical reactions taking place during fermentation process (García-Falcón *et al.* 2007, Fang *et al.* 2007, 2008). Flavonols, some of which are in an aglycone form and others in a glycosidic form, constitute a small portion of the phenolic compounds in wine. The overall quantity is influenced by factors such as the variety, maceration process and climatic conditions (Gonzalez-San Jose *et al*. 1990, Sipiora and Gutíerrez Grande 1998). Despite their low concentration, they are important since they may participate in the co-pigmentation phenomenon with anthocyanins (Cheynierand Rigaud 1986), changing wine color and stabilizing pigments. The rate of extraction of flavonoid compound was lowest in the beginning of fermentation with gradual increase during later stages of fermentation (Gil-Muñoz *et al.* 1997). In the present study, the concentration of both catechin and epicatechin were several folds higher in wines than in fresh grapes. Flavan-3-ols are tannins which are mostly located in grape skins and seeds. Extraction of tannins from seed depends on type of yeast culture used, fermentation temperature, alcohol content etc. Ivanova *et al* (2012) could observe significant increase in the content of Flavan-3-ols after 10 d of fermentation which was very low on 3rd day of fermentation. Usually flavan-3-ols are located in seeds and are protected with a lipidic layer, which can be disrupted when concentration of alcohol increases allowing their extraction from seeds as reported by Ivanova *et al.* (2009).

The most abundant flavonol was quercetin in all the rootstock scion combinations, but there was a slight reduction in their content in wines after fermentation. Since the wine analysis was performed just on the 13th d after initiation of fermentation, their increased concentration could have been seen after completion of aging process as reported by several other workers (Gil-Muñoz *et al.* 1997, Burns *et al.* 2001, Budis-Leto and Lovri 2002, Gracia-Falcon *et al*. 2007). The concentration of hydroxy benzoic and hydroxyl cinnamates in wines made from grapes grown on 101-14Mgt and Gravesac was highest which is in relation to their concentration in fresh grapes on same rootstocks. Overall, there was 2.0 to 2.5 fold increase in total phenolic contents from fresh grapes to finished young wines (Figure). Though the total phenolic composition in must of grapes grafted on 110R rootstock was lowest, after

fermentation the total phenols increased by 2.3 fold compared to other rootstocks.

From the present study, it can be concluded that the grapes harvested from 'Cabernet Sauvignon' vines grafted on 110R and 1103P rootstocks could accumulate less potassium and malic acid and thus resulting in reduced juice pH. The same trend was also found in finished wines in terms of reduced pH on 110R and 1103P rootstocks. Similarly, wines prepared from grapes harvested on 110R and 1103P rootstocks also showed higher total phenolic content than on other rootstocks. Further monitoring of yield, fruit composition and wine quality on different rootstocks for longer duration will help us in identifying the particular rootstock for specific conditions. Similarly, studies on composition of phenolic compounds in different parts of fruits such as skin, pulp, seeds etc. and monitoring of wine quality during aging of wines for longer duration may help us in understanding the effect of rootstocks in assimilation of wine phenolics and other secondary metabolites in grapes and their release into wine during fermentation and post fermentation aging.

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