Stionic Influence of Grape Cultivar Syrah (*Vitis vinifera* L.) on Inter-specific Hybrid Rootstocks

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Rootstocks play a crucial role in commercial viticulture by mitigating abiotic and biotic stresses and enhancing scion characteristics. Although Dogridge (Vitis champinii) is widely used for wine grapes, it is generally unsuitable due to its tendency to accumulate higher potassium, phenols, and tannins, along with lower acidity in berries. In this study, wine grape cultivar Syrah was evaluated on seven interspecific Vitis rootstocks, namely SO4, 110R, P1103, 140Ru, Fercal, 3309 C and 41B, to assess their influence on the vegetative, physiological, biochemical and quality traits. The experiment was conducted in a randomised block design and the data obtained were analysed using SAS software. The experiment revealed significant variations among rootstocks. Rootstock P1103 showed the earliest berry ripening, longer bunches (14.17 cm), highest total phenols (158.43 mg 100 ml-1 GAE), total flavonoids (83.5 mg 100 ml-1 QE), and yield (9.26 kg vine-1). Rootstock 110R induced the earliest budburst and produced longest internodes (10.08 cm), highest berry TSS (22.26°Brix), total monomeric anthocyanins (406 mg 100 g-1 FW) and lowest juice acidity (0.40%) along with dense trichomes- indicators of stress resistance. Rootstock 41B showed superior juice recovery (72.45%), reducing sugars (14.91%) and leaf iron content (408.93 µg g-1). Rootstock SO4 induced maximum cane length (131.89 cm), bunch weight (170.53 g), berry weight (1.487 g) and length (12.61 mm), highest leaf chlorophyll 'a', total chlorophyll, and P (0.235%) and Zn content (96.67 µg g-1), along with the highest peroxidase activity. These findings highlight the significant impact of rootstocks selection on Syrah performance, emphasizing the need for long-term evaluation to determine their commercial suitability.

INTRODUCTION

Grapes (*Vitis vinifera* L.) occupy an eminent position in the fruit industry of the world, owing to their versatile utilisation for table, raisin, wine, juice and canning purposes. Grapes belong to the family Vitaceae and have two major types, viz., *Muscadinia* and *Vitis*. They are known for their delicious taste and refreshing juice, and are a rich source of sugars and acids. They are also rich in vitamins like B_1 and B_2, and minerals, namely calcium, phosphorus, potassium and magnesium (Pushpavathi *et al*., 2021). Although the grape is a crop of temperate origin, it is also being cultivated successfully in the tropics, where it shows an evergreen nature. Globally, grapes are cultivated on an area of 6.73 million ha, with 74.94 MT of annual production and 11.13 t/ha productivity (FAO, 2022). In India, the grape is the fourth most important fruit crop, both in terms of area and production, and is grown on 0.140 million ha (National Horticultural Board [NHB], 2021).

According to Liu *et al*. (2006), 80% of global grape production is utilised for winemaking, while in India only about 2% to 3% is utilised (Chadha & Shikhamany, 1999; Ausari *et al*., 2024). Thus, there is huge scope for wine grape cultivation in India, as it can help strengthen the country in the global processing sector. The successful cultivation of grapes in the tropics is possible due to certain modifications in cultural practices, including pruning, and also with the adoption of technologies like grafting (Satisha *et al*., 2007). Numerous studies have shown that rootstocks can affect tree growth, flower development, yield and fruit quality in apples (Hirst & Ferree, 1995), grapes (Ollat *et al*., 2003) and pistachio (Turker & Ak, 2010). Differences in flowering have been reported by El-Shammaa *et al*. (2011) in cv. Anna apple grafted onto different rootstocks.

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Rootstocks play a vital role in viticulture as they help in modifying the vine vigour and productivity. Rootstocks influence growth and physicochemical characteristics, viz. fruit quality, uniformity, early bud burst and increased fruitfulness, etc., thus improving the overall productivity and quality of the grapes (Li *et al*., 2019). Iannini *et al.* (1980) reported that shoot vigour in cv. Merlot varied according to the different rootstocks. The rootstock affects the vegetative growth, which boosts a vine's capacity for photosynthetic rate and ultimately influences vegetative growth. The rootstock affects the changes in the grafted vine's biochemical components, which enables the vine to store enough food. The grafted vines show changes in their major nutritional status, underlining the need for using the better rootstock for long-term control of their nutrition (Somkuwar *et al*., 2015). In Indian viticulture, rootstocks are given significant importance to combat numerous abiotic and biotic challenges, like vine vigour, salinity and drought. In addition, they aid in the better adaptation of a genotypes to local conditions. Consequently, choosing a rootstock is one of the most crucial decisions, and the right rootstock depends on the soil and climate of the area (Walker & Clingeleffer, 2009).

The Indian wine industry is growing and currently undergoing a significant transition (Kumar *et al*., 2016). Most wine varieties are grafted onto Dogridge (*V. champinii*), a rootstock initially recommended for table grapes (Chadha & Shikhamany, 1999). However, Dogridge is not ideal for wine grape varieties, as it tends to accumulate higher potassium levels in berries under warm conditions, which is undesirable (Hale, 1977; Kodur *et al*., 2013). In addition, wine varieties grafted onto Dogridge exhibit several quality issues, including increased total phenol and tannin levels, lower titratable acidity, and higher pH in the berries. These issues result in wines with a higher tannin content, reduced colour intensity, and lower total proline, ultimately causing a deterioration in wine quality (Hedberg *et al*., 1986; Ausari *et al*., 2024). When used as rootstocks, different *Vitis* species, such as *Vitis berlandieri*, *V. rupestris*, *V. champinii*, *V. riparia*, *V. longii* and *V. parviflora*, have an inherent capacity to modulate the physiological and biochemical properties of the vine, which in turn may modify the vine physiology of the grafted scion variety (Satisha & Prakash, 2006; Satisha *et al*., 2007). However, the choice of proper rootstock is becoming increasingly difficult, since specific rootstocks are required for different abiotic stresses (Loreti & Massai, 2006).

Therefore, it is imperative to study the influence of rootstocks on scions in terms of growth and development, including the physiological characteristics, to decide on appropriate rootstocks for the intended benefits. The environmental factors and interaction between scions and rootstocks also influence the above-mentioned characters, ultimately influencing the yield and quality of the grapevine. Syrah, a famous seeded black grape variety that originated in France that has almost 80 synonyms, including Marsanne Noir, Syra, Syrac, Serine, Serene, etc. (Maul *et al*., 2019), is a hybrid between Mondeuse Blanche x Dureza, which belongs to *Vitis vinifera* subsp. *vinifera.* It is used on its own or blended with other varieties for red wine vinification. Though widely grown in European countries, and in Argentina, Chile, New Zealand, South Africa, etc., the variety Syrah has no specific commercial rootstocks recommended for cultivation. Hence, keeping in view the immense potential of different rootstocks on the scion, the present study was conducted with seven different inter-specific hybrid grape rootstocks on Syrah to determine the influence of these rootstocks on growth, physiological and biochemical parameters. The aim was further to discover the impact of inter-specific hybrid grape rootstocks on fruit yield and berry quality.

MATERIALS AND METHODS

Location and experimental material

The investigation was conducted on well-established 10-year-old vines at the Division of Fruits and Horticultural Technology, ICAR-Indian Agricultural Research Institute, New Delhi, (28.6377° N, 77.1571° E). The vines of Syrah were grafted on seven interspecific hybrid rootstocks (Table 1). All the observations were recorded on grafted vines of Syrah on different rootstocks, which were grafted and planted. The vines were trained on a four-arm 'Kniffin' system and irrigated using the furrow method. All the standard cultural practices were followed to raise a healthy crop. Each parameter was assessed using three independent replications to ensure statistical reliability.

Parameters studied

Vine growth parameters

The cane length, diameter and internodal length were measured in June each year. The length was measured using a

TABLE 1
The interspecific *Vitis* rootstocks and their parentage

Rootstock	Parentage
SO4	(*V. berlandieri* Planch × *V. riparia* Michx)
110R	(*V. berlandieri* Planch × *V. rupestris* Scheele)
P1103	(*V. berlandieri* Planch × *V. rupestris* Scheele)
140Ru	(*V. berlandieri* Planch × *V. rupestris* Scheele)
Fercal	(*V. berlandieri* Planch × *V. vinifera* L cv. Ugni Blanc B*)*
3309 C	(*V. riparia* Mich × *V. rupestris* Scheele)
41B	(*V. vinifera* L. (Chasselas Blanc) × *V. berlandieri* Planch)

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standard measuring scale and expressed in cm. The cane diameter was measured using Vernier callipers between the fourth and fifth nodes from the apex. The internodal length was taken close to the pruned region and the pruned wood weight was measured at the end of the experimental season (first week of January). All the vines in the experiment were pruned and weighed and expressed in kg vine^{-1}. Pruned canes were weighed and dried in the open sun until a constant dry weight was recorded. Each dried sample was then weighed and expressed in kg vine^{-1}. The number of days taken from the date of pruning to the date of the first bud burst was recorded and expressed as the days to bud burst. Additionally, the buds that emerged on pruned shoots were expressed as the percentage of bud burst. In grapevines, flowers open after pollination, and this is marked by the detachment of calyptra from the flower base, followed by their shedding, which exposes the androecium and gynoecium. The number of days taken for inflorescence opening (anthesis) was recorded at 50% anthesis occurred per vine for each treatment, and the days taken to full bloom were recorded.

Leaf physical and physiological parameters

The leaf area was measured with the help of a leaf area meter (Li-Cor Model 3100). The presence of trichomes on the leaf were observed under a simple microscope and classified based on the *Vitis* descriptors of the International Plant Genetic Resources Institute (IPGRI). The stomatal density was obtained according to D'Ambrogio de Argüeso (1986) and observed under a compound microscope (40 x Nikon). The length and width of the stomata were calculated based on photographs taken from Magnus Prosoftware. Eight fully opened leaves from the apex were selected to measure the gas exchange parameters (leaf net photosynthesis, stomatal conductance, intercellular CO_2 concentration, leaf transpiration, and intrinsic water use efficiency) with the help of an infrared gas analyser (LCi-SD Ultra Compact Photosynthesis System, ADC Bio Scientific, UK). The fourth to sixth leaves from the apex region were taken to determine the relative water content as suggested by Barrs and Weatherley (1962).

Leaf biochemical parameters

Total chlorophyll, chlorophyll '*a*', chlorophyll '*b*' and total carotenoids were estimated by using the dimethylsulfoxide (DMSO) method (Hiscox & Israelstam, 1979). Chlorophyll '*a*', '*b*' and total chlorophyll were determined by formulae provided by Arnon (1949), while the total leaf carotenoids were derived using the formula of Lichtenthaler and Wellburn (1983). The total phenols in the leaves were estimated by the method described by Singleton *et al*. (1999) using Folin-Ciocalteau reagent. Total flavonoid content was measured using a spectrophotometer (UVD-3200, Labomed Inc., USA) as per the procedure described by Zhishen *et al*. (1999). The absorbance was recorded at 510 nm. The rapid colorimetric method was adopted, as suggested by Bates *et al*. (1973), to estimate the proline content. The amount of carbohydrates present was calculated as described by Saha and Brewer (1994), measured at 490 nm. Peroxidase activity was estimated using phosphate buffer (100 mM; pH 6.1) according to Robinson *et al*. (1989).

Leaf nutrient status

Leaf samples (petiole + lamina) were collected during the post-harvest phenological stage in September for nutrient analysis. Leaves were washed with double-distilled water to remove the adhering dirt. Samples were dried (hot-air oven) at 70°C for 48 h and ground using a Wiley mill and sieved (1 mm sieve). The fine powder was used for the analysis of major nutrients. For nitrogen content, 500 mg of air-dried sample was taken and estimated using the Kjeldahl method on a digestion system (Kjeltec™ 8200 Foss-Tecator, 3400 Hillerød, Denmark) until the appearance of a light green colour. Finally, the distillation of the digested samples and total nitrogen were determined (Kjeltec 2300 analyser). The fine powder was subjected to wet digestion using a diacid mixture of concentrated nitric acid and perchloric acid in a 9:4 ratio. The filtrate obtained was used for the estimation of phosphorus, potassium, calcium, sulphur, magnesium, zinc, copper, manganese and iron. The phosphorus concentration was measured using a spectrophotometer (UVD-3200, Labomed Inc., Culver City, USA) at a wavelength of 420 nm. The potassium content was determined with a flame photometer (Model 128, Systronics) using the diacid digest. The data obtained in ppm were multiplied by the dilution factor and the potassium content was expressed as a percentage. The micronutrient concentration was estimated from the diacid digest with the aid of an atomic absorption spectrophotometer (GBC-Avanta PM, GBC Scientific Equipment, Victoria, Australia), using an air-acetylene flame. The concentrations of Cu, Fe, Mn and Zn were measured at a wavelength of 386 nm (lamp current 7 mA), 22.6 nm (lamp current 3 mA), 403.1 (lamp current 5 mA) and 213.9 nm (lamp current 5 mA), respectively. The final concentrations were calculated by multiplying the concentrations with the appropriate dilution factor.

Bunch and berry parameters

The date of berry ripening was recorded on the basis of the change in colour and the maximum TSS. The number of bunches per vine were counted manually. The weight of the bunches and berries were recorded simultaneously using a weighing balance. The fruit yield per vine was measured, while the length and width of the bunches and berries were measured in centimetres using Vernier callipers. Berry firmness was determined with a texture analyser (model: TA+Di, Stable Microsystems, UK). Juice recovery was determined and expressed in g/100 g berries.

Berry quality parameters

The berry total soluble solids were determined using a hand refractometer. The titratable acidity was expressed in tartaric acid (Association of Official Analytical Chemists [AOAC], 1985). The ascorbic acid content was expressed in mg/100 ml of juice (AOAC, 2000). The reducing sugars of the fresh grape juice were determined using Fehling's solution and methylene blue indicator (Ranganna, 1999). Total soluble monomeric anthocyanins were measured using the pH-differential method (Wrolstad *et al*., 2005) at wavelengths of 510 nm and 700 nm. The total phenolic content was estimated using Folin-Ciocalteu reagent by measuring the absorbance of the reaction mixture at 650 nm. The results obtained

were expressed as gallic acid equivalents (GAE)/100 ml of extract (Singleton *et al*., 1999). The total flavonoid content was measured at a wavelength of 510 nm and expressed as quercetin equivalent (QE) using a standard curve drawn from authentic quercetin (Zhishen *et al*., 1999). Total antioxidant activity was determined by the cupric reducing antioxidant capacity (CUPRAC) (Apak *et al*., 2004) and DPPH assays, as outlined by Brand-Williams *et al*. (1995) and Sánchez-Moreno *et al*. (1999).

Berry and juice colour parameters

The Commission Internationale de l'Éclairage (CIE; International Commission on Illumination) colour values (L^*, a^* and b^*) of the samples were measured for both the berry peel and the extracted juice using a colour meter (Color Tec PCM/PSM, USA). In the CIE (L^*, a^* and b^*) colour space, abbreviated CIE L^* a^* b^*, the lightness co-efficient, L^*, ranges from black = 0 to white = 100. The coordinates (a^* and b^*) locate the colour of the rectangular coordinate grid perpendicular to the L^* axis. The colour at the grid origin ($a^* = 0$ and $b^* = 0$) is achromatic (grey). On the horizontal axis, positive a^* indicates a hue of red-purple, and negative a^* a bluish-green. On the vertical axis, positive b^* indicates yellow and negative b^* blue.

Statistical analysis

The experiments were carried out following a randomised block design, and the data were analysed using univariate analysis of variances (ANOVA). SAS software (version 9.3) was employed for statistical analysis, including correlation amongst tests. The treatment means were compared using Duncan's multiple range test (DMRT) at a significance threshold of $P \leq 0.05$.

RESULTS

Vine physical parameters

The data presented in Table 2 show a significant difference ($P < 0.05$) when the rootstocks are considered as a factor. The maximum cane length was recorded on SO4 (131.89 cm) and 41B (129.33 cm), while it was shortest on rootstock 140Ru (76.33 cm). The maximum cane diameter was recorded on rootstock 140Ru (0.92 cm) and Fercal (0.91 cm), while it was the thinnest on rootstock 3309 C (0.61 cm). The longest inter-nodal length was observed on rootstock 110R (10.08 cm) and the shortest on Fercal (6.96 cm), followed by 140Ru (6.93 cm). Rootstock 41B induced significantly higher fresh and dry pruned weights (3.26 kg vine^{-1} FW and 1.93 kg vine^{-1} DW), while the lower fresh and dry pruned weights were observed on Fercal (0.77 kg vine^{-1} FW and 0.25 kg vine^{-1} DW). Cultivar Syrah on rootstock 110R showed the earliest bud burst, i.e. 60 days after pruning, followed by rootstock P1103 (61 days), while it was delayed on 140Ru and Fercal (72 days after pruning). Rootstock 110R also showed the earliest time to bloom, at 80 days after pruning, while 3309 C was the last to bloom (88 days after pruning). The highest bud burst was observed on vines grafted onto rootstock 140Ru (86.66%), while the lowest was on 3309 C (53.33%).

Leaf physical and physiological parameters

The maximum leaf area (70.61 cm²) was observed in 'Syrah' grafted onto rootstock 41B, which was on par with that on 140Ru (69.92 cm²) and SO4 (69.24 cm²), while the minimum (63.98 cm²) was observed on the 3309 C rootstock (Table 3). The plants grafted onto rootstock 110R had very dense trichomes. Rootstocks Fercal, 3309 C and 41B also had dense trichomes, while rootstocks 140Ru and P1103 produced the least density (sparse) of trichomes on their leaves (Fig. 1). The stomatal count was found to range from 286.97 mm^{-2} to 464.52 mm^{-2} on different rootstocks (Table 3, Fig. 2). The highest stomatal density was found in the leaves of 'Syrah' grafted onto 3309 C (464.52 mm^{-2}), and it was least on Fercal (286.97 mm^{-2}). The maximum stomatal length was observed on 3309 C (32.09 µm) and the least on P1103 (25.6 µm). Larger stomatal breadth was seen on SO4 (22.19 µm), followed by 3309 C (22.04 µm), while the least was found on P1103 (16.50 µm).

Table 3 and Fig. 3 show that the highest photosynthetic rate was observed on rootstock 140Ru (11.48 µmol CO_2 m^{-2}

TABLE 2
Effect of different interspecific grape hybrid rootstocks on vine growth of cv. Syrah

Rootstock	Cane length (cm)	Cane diameter (cm)	Internodal length (cm)	Weight of pruned wood (kg vine^{-1} DW)		Bud burst		Full bloom (Days after pruning)
				Fresh	Dry	Days after pruning	Response (%)	
SO4	131.89^{a}	0.65^{c}	8.36^{b}	2.50^{b}	1.69^{a}	62 days	70.00^{c}	87 days
110R	111.89^{b}	0.80^{b}	10.08^{a}	1.41^{c}	0.60^{c}	60 days	83.33^{ab}	80 days
P1103	80.22^{cd}	0.66^{c}	9.67^{a}	1.53^{c}	0.60^{c}	61 days	73.33^{bc}	82 days
140Ru	76.33^{d}	0.92^{a}	6.93^{c}	2.35^{b}	1.15^{b}	72 days	86.66^{a}	87 days
Fercal	84.67^{c}	0.91^{a}	6.96^{c}	0.77^{d}	0.25^{d}	72 days	63.33^{cd}	82 days
3309 C	79.55^{cd}	0.61^{d}	8.13^{b}	1.2^{c}	0.54^{c}	68 days	53.33^{d}	88 days
41B	129.33^{a}	0.66^{c}	9.96^{a}	3.26^{a}	1.93^{a}	62 days	63.33^{cd}	85 days

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

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TABLE 3
Effect of different interspecific grape rootstocks on physical and physiological parameters of cv. Syrah

Rootstock	Leaf area (cm^2)	Leaf trichome	Stomatal length (µm)	Stomatal width (µm)	Stomatal density (mm^2)	Net photosynthesis (µmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mmol m^{-2} s^{-1})	Intercellular CO_2 conc. (µmol m^{-2} s^{-1})	Net transpiration (mmol m^{-2} s^{-1})	Intrinsic WUE (µmol $mmol^{-1}$)	RWC (%)
SO4	69.24^{a}	Medium	30.10^{c}	22.19^{a}	366.60^{c}	10.97^{a}	0.112^{b}	243.00^{b}	5.33^{c}	2.06^{b}	84.0^{b}
110R	65.26^{bc}	Very dense	30.65^{bc}	18.42^{c}	311.89^{d}	9.44^{b}	0.102^{b}	209.50^{c}	4.39^{d}	2.15^{b}	86.6^{a}
P1103	67.89^{ab}	Dense	25.6^{f}	16.50^{d}	361.83^{c}	7.52^{d}	0.108^{b}	269.17^{a}	4.69^{d}	1.61^{d}	83.13^{c}
140Ru	69.92^{a}	Sparse	26.60^{e}	18.35^{c}	407.29^{b}	11.48^{a}	0.122^{b}	200.50^{c}	5.73^{b}	2.01^{bc}	82.54^{de}
Fercal	64.07^{c}	Dense	28.11^{d}	19.79^{b}	286.97^{d}	11.46^{a}	0.173^{a}	240.83^{b}	6.30^{a}	1.83^{c}	82.6^{d}
3309 C	63.98^{c}	Sparse	32.09^{a}	22.04^{a}	464.52^{a}	11.12^{a}	0.100^{b}	155.50^{e}	4.58^{d}	2.44^{a}	81.63^{f}
41B	70.61^{a}	Dense	31.01^{b}	18.79^{c}	300.90^{d}	8.82^{c}	0.100^{b}	177.33^{d}	4.45^{d}	1.98^{bc}	82.32^{e}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

FIGURE 1
Trichome density of Syrah grapes on different interspecific rootstocks

s^{-1}), while it was least on the P1103 rootstock (7.52 µmol CO_2 m^{-2} s^{-1}). Leaves on rootstock Fercal showed significantly higher stomatal conductance (0.173 mmol m^{-2} s^{-1}), while the lowest was on 41B and 3309 C (0.100 mmol m^{-2} s^{-1}). The intercellular CO_2 concentration was found to be significantly higher in rootstock P1103 (269.17 µmol m^{-2} s^{-1}), while the lowest value (155.50 µmol m^{-2} s^{-1}) was noted on the 3309 C rootstock. Rootstock 110R showed a lower net transpiration rate (4.39 mmol m^{-2} s^{-1}), while Fercal (6.30 mmol m^{-2} s^{-1}) showed higher values. The water use effectiveness (WUE) was significantly higher on rootstock 3309 C (2.44 **µ**mol $mmol^{-1}$), and the maximum relative water content (RWC) was observed on 110R (86.6%).

Leaf biochemical parameters

Table 4 represents several leaf biochemical parameters of cv. Syrah on seven different rootstocks. Chlorophyll '*a*' was recorded to be the highest on rootstock SO4 (2.85 mg g^{-1}) and 140Ru (2.83 mg g^{-1}) and chlorophyll '*b*' on 41B (0.76 mg g^{-1}), while rootstock SO4 recorded the largest amount of total

chlorophyll (3.08 mg g^{-1}). The maximum total carotenoids were observed on rootstock P1103 (1.37 mg g^{-1}), while the highest total phenols and total flavonoids were found on 110R (298.6 mg $100g^{-1}$ and 14.48 mg QE g^{-1} respectively). The highest proline and leaf carbohydrate contents were observed in vines grafted on the Fercal rootstock (0.27 µ mole g^{-1} FW and 5.74%), while the highest leaf peroxidase activity was recorded on SO4 (5.64 $min^{-1}g^{-1}$).

Leaf nutrient status

Table 5 shows the influence of rootstock on the leaf nutrient status of cv. Syrah. Rootstock 3309 C (3.27%) induced significantly higher nitrogen accumulation, whereas Fercal (2.37%) showed the lowest nitrogen content. Significantly higher phosphorus was recorded on the rootstock SO4 (0.235%), while potassium was found to be significantly higher on Fercal (1.00%) compared to the rest of the vines. A significant variation was also observed in the leaf micronutrient content of cv. Syrah, i.e. a maximum iron content (408.93 µg g^{-1}) was recorded on rootstock 41B and zinc on SO4 (96.67 µg g^{-1}). Rootstock 3309 C showed higher copper

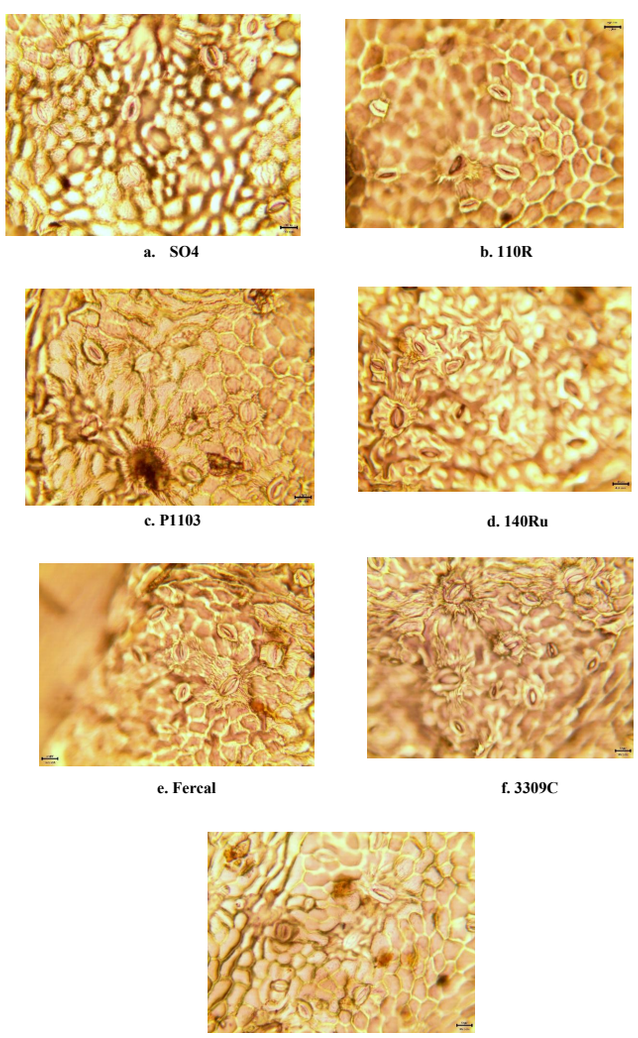

FIGURE 2
Effect of different interspecific rootstocks on leaf stomatal density of Syrah.

TABLE 4
Effect of different interspecific grape hybrid rootstocks on leaf biochemical parameters of cv. Syrah.

Rootstock	Chlorophyll 'a' (mg g^{-1} FW)	Chlorophyll 'b' (mg g^{-1} FW)	Total chlorophyll (mg g^{-1})	Total carotenoids (mg g^{-1})	Total phenols (mg $100g^{-1}$ GAE)	Total flavonoids (mg QE g^{-1} DM)	Proline (µ mole g^{-1} FW)	Leaf carbohydrates (%)	Peroxidase (A_{420} $min^{-1}g^{-1}$)
SO4	2.85^{a}	0.40^{b}	3.08^{a}	0.77^{ab}	144.06^{e}	13.96^{cd}	0.08^{cd}	5.19^{b}	5.64^{a}
110R	2.33^{c}	0.25^{c}	2.67^{b}	1.07^{ab}	298.60^{a}	14.48^{a}	0.20^{b}	5.58^{ab}	3.76^{bc}
P1103	2.22^{c}	0.14^{e}	2.44^{c}	1.37^{a}	269.20^{b}	14.33^{b}	0.06^{cd}	5.60^{a}	1.88^{d}
140Ru	2.83^{a}	0.11^{f}	2.96^{a}	1.17^{ab}	224.46^{c}	14.26^{b}	0.03^{d}	5.58^{ab}	3.12^{cd}
Fercal	2.60^{b}	0.14^{e}	2.68^{b}	0.97^{ab}	190.93^{d}	13.82^{d}	0.27^{a}	5.74^{a}	5.01^{ab}
3309 C	1.62^{e}	0.18^{d}	1.86^{d}	1.11^{ab}	187.00^{d}	13.86^{d}	0.11^{c}	4.93^{c}	4.38^{abc}
41B	2.19^{d}	0.76^{a}	3.02^{a}	0.54^{b}	150.86^{e}	14.02^{c}	0.08^{cd}	5.51^{ab}	3.76^{bc}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

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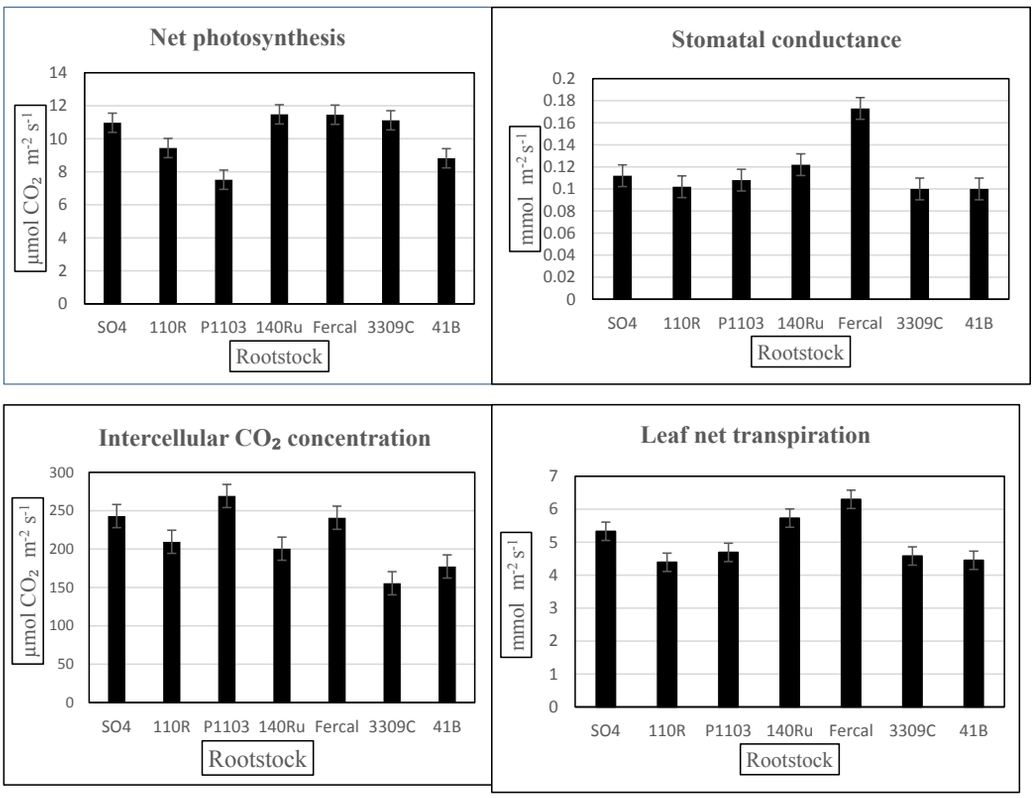

FIGURE 3
Effect of different interspecific grape hybrid rootstocks on leaf physiological parameters of cv. Syrah.

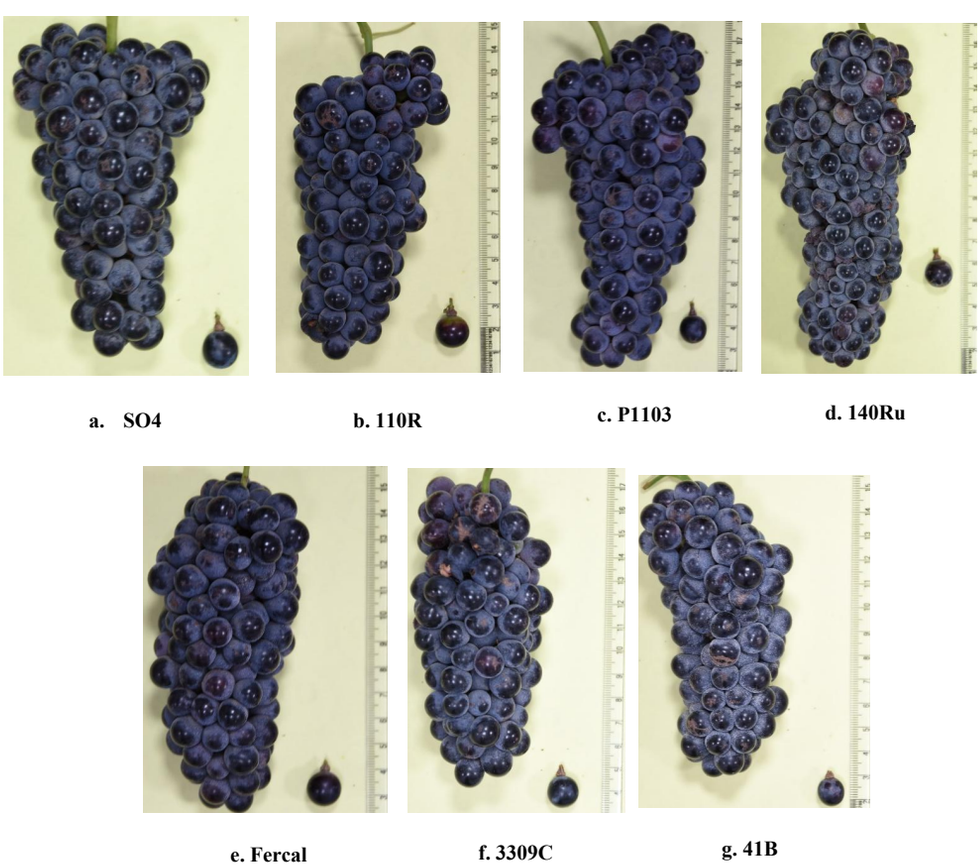

FIGURE 4
Bunches produced on Syrah as affected by different rootstocks.

TABLE 5
Effect of different interspecific grape rootstocks on leaf nutrient status of cv. Syrah

Rootstock	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Iron (µg g^{-1})	Copper (µg g^{-1})	Manganese (µg g^{-1})	Zinc (µg g^{-1})
SO4	2.74^{d}	0.235^{a}	0.97^{b}	398.13^{b}	14.8^{b}	47.53^{b}	96.67^{a}
110R	2.84^{cd}	0.172^{d}	0.69^{e}	287.26^{f}	11.27^{d}	28.33^{d}	49.80^{d}
P1103	2.93^{bcd}	0.181^{c}	0.79^{d}	356.27^{c}	11.73^{d}	42.13^{c}	52.20^{cd}
140Ru	3.06^{ab}	0.147^{f}	0.69^{e}	305.27^{e}	13.93^{c}	42.4^{c}	73.20^{b}
Fercal	2.37^{e}	0.191^{b}	1.00^{a}	339.67^{d}	11.67^{d}	43.46^{c}	76.07^{b}
3309 C	3.27^{a}	0.157^{e}	0.81^{d}	367.13^{c}	15.8^{a}	50.13^{a}	74.60^{b}
41B	3.01^{bc}	0.178^{cd}	0.93^{c}	408.93^{a}	13.87^{c}	29.8^{d}	53.40^{c}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

and manganese status (15.8 µg g^{-1} and 50.13 µg g^{-1}) than the rest of the rootstocks.

Bunch and berry parameters

Table 6 and Fig. 4 show the bunch and berry physical data of Syrah on different rootstocks. Rootstock P1103 showed overall greater performance for bunch parameters like early berry ripening (150 days after pruning), number of bunches (44.67 bunches/vine), bunch weight (168.33 g), bunch length (14.17 cm) and bunch width (8.90 cm), and hence had an overall higher yield (5.86 kg vine^{-1}) than the rest of the rootstocks. Rootstock 41B also showed early ripening, at 150 days, and the SO4 rootstock carried fruits with highest bunch weight (170.53 g). Rootstock SO4 (14.86 g), 140Ru (14.56 g) and P1103 (14.4 g) produced bigger berries, while 140Ru also produced berries with a larger diameter (13.72 mm). The berries were longer on the SO4 rootstock (12.61 mm) and P1103 (12.32 mm), and the minimum berry length was recorded on the 140Ru rootstock (11.27 mm). Rootstock 3309 C produced firmer berries (4.34 N) with high juice recovery (70.34 g 100g^{-1} berries), along with 41B (72.45 g 100 g^{-1} berries).

Berry quality parameters

Table 7 depicts the data on fruit quality parameters. The TSS content in berries ranged from 17.88°B to 22.26°B, with rootstocks 110R (22.26°B), SO4 (21.90°B) and P1103 (21.88°B) producing the maximum TSS. The lowest acidity (0.54%) was found on rootstock 110R, while the maximum of 0.88% was found on rootstock 41B. The maximum reducing sugar content was observed in the berries of 'Syrah' on rootstock 41B (14.91 %) and 110R (14.86%). Rootstock 3309 C produced a significantly higher ascorbic acid content (16.03 mg 100 ml^{-1}), while 110R (406.68 mg kg^{-1}) produced a significantly higher content of total monomeric anthocyanin. A significantly higher level of total phenolics was recorded in cv. 'Syrah' on P1103 (158.43 mg 100 ml^{-1}), while the least total phenolics were recorded with plants grafted onto 3309 C (110.05 mg 100 ml^{-1}). The total flavonoids were observed to be higher on the P1103 rootstock (83.5 mg 100 ml^{-1}) and on 110R (80.28 mg 100 ml^{-1}), while Fercal produced higher antioxidant activity in Syrah berries (64.97 µmol ml^{-1} TE in the CUPRAC method and 8.06 µmol ml^{-1} TE in the DPPH method).

Bunch and juice colour

The study of berry colour using the colourimeter showed that the L* value ranged from 11.05 (41B) to 14.99 (SO4). Furthermore, a^{*} ranged from 1.47 (3309 C) to 3.36 (SO4) and b^{*} ranged from -1.88 (41B) to -4.8 (3309 C). Here, the negative b value indicates the blue colour present in the berries. In the case of juice colour, the *L** value was maximum in the juice of berries of 'Syrah' grapes harvested on rootstock Fercal (12.18), and the minimum was in 140Ru (8.28). The maximum a^{*} value was also obtained from the juice obtained from fruits grafted onto the Fercal rootstock (4.60), and the minimum on 110R (2.09). The *b** value ranged from -7.59 to 1.65. It was interesting to note that, out of seven rootstocks, six showed a *b** that was negative. The negative *b** indicates the blue colour of the juice and the positive *b** indicates yel-

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TABLE 6
Effect of different interspecific grape rootstocks on bunch and berry parameters of Syrah grape

Rootstock	No. of bunches (per vine)	Berry ripening days after pruning	Bunch weight (g)	Yield (kg vine^{-1})	Bunch length (cm)	Bunch width (cm)	Berry weight (g)	Berry diameter (mm)	Berry length (mm)	Berry firmness (N)	Juice recovery (g 100g^{-1} berries)
SO4	30.00^{c}	154 days	170.53^{a}	5.11^{b}	13.00^{ab}	7.83^{ab}	14.87^{a}	13.29^{abc}	12.61^{a}	2.94^{de}	62.73^{bc}
110R	39.67^{b}	152 days	127.47^{dc}	5.05^{b}	9.67^{b}	7.40^{ab}	13.30^{b}	12.73^{bcd}	11.67^{ab}	2.71^{e}	59.02^{bc}
P1103	44.67^{a}	150 days	168.33^{a}	5.86^{a}	14.17^{a}	8.90^{a}	14.40^{a}	13.50^{ab}	12.32^{a}	2.80^{e}	60.71^{bc}
140Ru	25.67^{cd}	156 days	111.07^{d}	2.86^{c}	11.77^{ab}	6.33^{ab}	14.57^{a}	13.72^{a}	11.27^{b}	3.22^{cd}	58.13^{c}
Fercal	24.67^{d}	156 days	130.87^{bcd}	3.22^{c}	11.23^{ab}	6.7^{ab}	11.90^{c}	12.47^{cd}	11.34^{b}	3.46^{c}	63.33^{b}
3309 C	24.67^{d}	156 days	146.60^{abc}	3.61^{bc}	11.67^{ab}	6.07^{b}	13.10^{b}	12.86^{abcd}	12.07^{ab}	4.34^{a}	70.34^{a}
41B	29.67^{cd}	150 days	154.33^{ab}	4.59^{b}	13.17^{a}	8.33^{ab}	12.80^{b}	12.30^{d}	12.05^{ab}	3.97^{b}	72.45^{a}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

TABLE 7
Effect of inter-specific rootstocks on berry biochemical parameters of Syrah grape

Rootstock	TSS (°Brix)	Titratable acidity (%)	Reducing sugars (%)	Ascorbic acid (mg 100 ml^{-1})	Total monomeric anthocyanins (mg 100 g^{-1})	Total phenolics (mg 100 ml^{-1} GAE)	Total flavonoids (mg 100 ml^{-1} QE DM)	CUPRAC antioxidant activity (µmol ml^{-1} TE)	DPPH antioxidant activity (µmol ml^{-1} TE)
SO4	21.90^{a}	0.78^{a}	13.86^{c}	8.23^{d}	354.99^{b}	114.88^{d}	49.13^{c}	31.29^{d}	7.36^{d}
110R	22.26^{a}	0.54^{b}	14.86^{a}	13.40^{b}	406.68^{a}	148.18^{b}	80.28^{a}	49.34^{b}	7.45^{c}
P1103	21.88^{a}	0.78^{a}	14.28^{b}	10.56^{c}	244.59^{d}	158.43^{a}	83.50^{a}	45.21^{c}	7.68^{b}
140Ru	18.13^{c}	0.75^{a}	14.55^{ab}	13.13^{b}	162.86^{e}	115.72^{d}	40.81^{d}	16.68^{e}	7.10^{f}
Fercal	19.59^{b}	0.75^{a}	13.59^{cd}	13.30^{b}	234.26^{d}	115.88^{d}	68.14^{b}	64.97^{a}	8.06^{a}
3309 C	17.88^{c}	0.78^{a}	13.22^{d}	16.03^{a}	304.87^{c}	110.05^{e}	37.61^{d}	17.17^{e}	6.97^{g}
41B	20.46^{b}	0.88^{a}	14.91^{a}	13.27^{b}	355.97^{b}	136.26^{c}	38.89^{d}	31.02^{d}	7.22^{e}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

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lowness in the juice. The data are given in Table 8.

DISCUSSION

In India, the use of rootstocks in commercial viticulture has been initiated primarily for dealing with certain abiotic factors, such as drought and salinity, and for improving scion characteristics (Satisha *et al*., 2010), ensuring early and uniform budburst with increased fruitfulness (Somkuwar *et al*., 2006) and improving berry composition and quality (Somkuwar *et al*., 2014). The Indian wine industry is expanding and is presently in the midst of a vital transition (Kumar *et al*., 2016). Rootstocks also influence berry composition, such as organic acids, sugars, phenolic compounds and potassium (Jogiah *et al*., 2015), but due to a lack of information on rootstocks for wine grapes, most of the wine varieties are grafted onto Dogridge (*V. champinii*), a rootstock recommended for table grapes (Chadha & Shikhamany, 1999). Furthermore, it is not suitable for wine grape varieties due to its ability to accumulate higher K in berries in warm regions (Kodur *et al*., 2013). Therefore, the Syrah variety of wine grapes was evaluated on seven rootstocks during the present investigation.

Stionic influence on plant characteristics

Vine vigour is the most important parameter in morphological observations that can be judged based on the weight of pruning (Chadha & Shikhamany, 1999). In the present study, fresh and dry weight of pruned cane wood was found to be the highest in Syrah on 41B rootstock, followed by SO4 and 140Ru, while the least was observed on Fercal rootstocks, indicating higher vigour produced by the 41B rootstock. The longer vine length and average number of canes per vine were found in Syrah on rootstock SO4 and 41B, the long internode in Syrah on 110R and 41B, while 140Ru and Fercal exhibited the shortest vine length and also thicker cane diameter. Therefore, the rootstocks 41B and SO4 imparted higher vigour to scions, while low vigour was imparted by the 140Ru and Fercal rootstocks.

Somkuwar *et al*. (2014) reported the minimum dry matter percentage of the shoots when Sauvignon blanc was grafted onto Fercal, P1103, 140Ru, 110R and SO4. The influence of rootstocks on different parameters, such as pruned weight, shoot length and diameter, might have contributed to the better efficiency of the root system in absorbing and transporting the water and nutrients to the Syrah scion. Kasimatis *et al*. (1985) observed that the highest weight of pruning per vine was on the St. George rootstock, while the lowest was on the 110R rootstock when compared to other rootstocks. Okanagan Riesling on 5BB (Reynolds & Wardley, 2001), Gruner Veltliner on 5 BB (Wunderer *et al*., 1999) and Seyval Blanc on 3309 C (Striegler & Howell, 2015) also produced more vigour. The rootstocks producing more vigour had one of the parents as *V. berlandieri* or *V. rupestris*, or both. In the present study, both the rootstocks influencing higher vine vigour also had one parent as *V. berlandieri* or *V. rupestris*. This might have contributed to the higher vine vigour in Syrah when we used 41 B and SO4 as rootstocks. Similarly, Iannini *et al*. (1980) reported that shoot vigour in cv. Merlot was highest on *V. berlandieri* x *V. rupestris* 779 P, followed by vines on *Rupestris* du lot, Kober 5 BB, *berlandieri* x *rupestris* 140 Ruggeri, Kober 420 A and *riparia* x *rupestris* 3309 C.

Early fruit maturity is the major objective of grape cultivation in subtropical conditions to avoid pre-monsoon and monsoon showers. The earliest and the maximum budburst were recorded on rootstocks 110R and P1103. Jogiah *et al*. (2013) reported early and uniform budburst of Thompson seedless grape when grafted on 110R. Rizk-Alla *et al*. (2011) reported P1103 rootstock to give the earliest bunch maturity of cv. Red globe. Rootstocks 3309 C, 140Ru and Fercal showed a negative relationship in relation to precocity.

The leaf area of the Syrah grape was also influenced by different rootstocks. Syrah on rootstocks 41B, 140Ru and SO4 exhibited a larger leaf area compared to other rootstocks. Similar results were obtained in grapes when Krakhuna was grafted onto Chasselas x *berlandieri* rootstock (Grant & Matthews, 1996) and Sauvignon blanc on Dogridge rootstocks (Somkuwar *et al*., 2014). The presence of leaf trichomes helps as a defence mechanism against sucking pests and also certain pathogens. Thus, dense trichomes lead to higher resistance against insects, virus-causing vectors and other pathogens. The plants grafted onto rootstock 110R had very dense trichomes. Rootstocks Fercal, 3309 C and 41B also had dense trichomes, whereas 'Syrah' leaves on SO4

TABLE 8
Effect of different interspecific rootstocks on berry and juice colour of Syrah grapes

Rootstock	Berry colour			Juice colour		
	L	a	b	L	a	b
SO4	14.99^{a}	3.36^{a}	-4.69^{bc}	10.30^{c}	4.38^{b}	1.65^{c}
110R	12.09^{e}	1.96^{e}	-3.77^{b}	11.98^{a}	2.09^{e}	-4.60^{b}
P1103	12.23^{g}	2.15^{b}	-4.25^{bc}	8.91^{d}	3.80^{a}	-7.59^{d}
140Ru	12.13^{c}	2.56^{d}	-3.91^{b}	8.28^{e}	4.30^{ab}	-7.21^{e}
Fercal	13.23^{d}	1.97^{cd}	-4.52^{a}	12.18^{b}	4.60^{a}	-8.64^{b}
3309 C	12.27^{b}	1.47^{e}	-4.80^{c}	8.80^{d}	2.59^{d}	-3.85^{a}
41B	11.05^{f}	3.02^{bc}	-1.88^{d}	11.62^{ab}	3.17^{c}	-1.21^{a}

Note: Different letter values specify significant differences ($p \leq 0.05$; DMRT test)

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had moderately dense trichomes. The 'Syrah' on rootstocks 140Ru and P1103 produced the least density (sparse) of trichomes on their leaves. Lazare (2021) reported after his study on avocado that the trichome density was significantly different for 'Hass' leaves grafted onto different rootstocks. The most trichomes were measured in VC 840 leaves and the lowest in VC 804.

Knowledge of stomatal parameters as they are affected by different rootstock scion combinations helps in choosing a rootstock for better productivity in a water-scarce environment (Soar, 2006; Serra *et al*., 2014). In the present study, rootstock 3309 C induced the highest stomatal density among all the rootstocks studied, followed by 140Ru, SO4, P1103 and 110R, while the lowest density was induced by Fercal. Syrah on 3309 C rootstock produced the largest stomatal length and width on rootstock SO4, while P1103 showed the smallest stomatal length and width. The rootstock can induce a change in stomatal density and size in a grafted scion (Serra *et al*., 2014; Boso *et al*., 2016). Boso *et al.* (2016) found higher stomatal density on SO4, but Düring (1980) observed no such variation with Riesling on SO4. American grapes in general have been found to have a higher stomatal frequency (Swanepoel & De Villiers, 1987). In the present study, variable stomatal density and size were observed when using different American grape rootstocks for Syrah.

The data on different gas exchange parameters, namely photosynthesis rate, stomatal conductance, transpiration rate and internal CO_2 concentration of Syrah grafted on seven rootstocks exhibited significant differences. Syrah on 140Ru showed high leaf net photosynthesis, followed by Fercal, 3309 C and SO4. Similar results were obtained by Somkuwar *et al*. (2014) when they evaluated grafted Cabernet Sauvignon on 140Ru rootstock. Riesling grafted onto Kober 5 BB had a significantly higher photosynthetic rate (Düring, 1994). The intercellular CO_2 concentration was high on P1103 and least in the case of 3309 C. The leaf net transpiration rate of Syrah was found to the maximum on Fercal and minimum on 110R rootstock, followed by 41B, 3309 C and P1103. However, the maximum stomatal conductance was recorded on Fercal. High intrinsic water-use efficiency in Syrah was registered on rootstock 3309 C and relative water content on 110R. The results suggest that there was a distinct carboxylation efficiency of the Syrah vines grafted onto different rootstocks. Such effects are specific to scion variety on different rootstocks, and appropriate stionic combinations result in higher carboxylation efficiency, thereby improving productivity in a water-scarce environment through higher water-use efficiency (Düring, 1994).

The photosynthetic pigment content is important in influencing the photosynthetic ability of crop plants and deciding their production capability (Curran *et al*., 1990; Filella *et al*., 1995). Apart from the production ability of the plant, leaf chlorophyll content also indicates their stress and senescence conditions (Merzlyak *et al.,* 1999; Tripathi & Gautam, 2007). Besides chlorophylls, the carotenoids are also involved in the process of photosynthesis (Ong & Tee, 1992) and protect the chlorophyll from photo-oxidative destruction (Siefermann-Harms, 1987; Giri *et al*., 2013). In addition to chlorophyll, carotenoids also play a role in photosynthesis and help protect chlorophyll from damage caused by photo-oxidation. Therefore, having higher photosynthetic content in the scion genotype is beneficial for crop productivity. Enhancing the leaf photosynthetic capacity of both crop species and rootstock genotypes is especially important in composite crop systems. In commercial viticulture, various benefits of using rootstocks have been explored, including the influence of different rootstock genotypes on scion performance.

In the past, several rootstock studies were conducted for their stionic influences on the foliar photosynthetic content of different scion genotypes of grapes. Significant results were recorded in these studies for the stionic influences of the grape rootstock genotypes on grafted grape cultivars. For instance, Rizk-Alla *et al*. (2011) recorded that the Red Globe grape cultivar grafted onto different rootstock genotypes, viz. Dogridge, Salt Creek, Freedom, Harmony, and Paulsen 1103, had higher chlorophyll content compared to own-rooted vines. Similarly, Ingole (2012) also recorded the influences of rootstocks on the grafted grape cultivars and found the highest photosynthetic pigment in Pinot Noir-15 grafted onto rootstock genotype 110R. Furthermore, Ulaş *et al.* (2014) recorded that a combination of Merlot/P1103 had the highest chlorophyll content. Köse *et al*. (2016) recorded the influence of rootstocks on *Vitis labrusca* for chlorophyll content. Similarly, in the present investigation, significant variations in the photosynthetic content of the grape cultivar Syrah were recorded on the seven different rootstocks. The highest chlorophyll a and total chlorophyll contents were recorded on rootstock SO4, while the highest total carotenoids were recorded on rootstock P1103. Thus, these rootstocks could be explored for improving the foliar photosynthetic content and overall performance of the wine cultivar Syrah in the subtropical climate of North India.

The antioxidant enzyme activities, viz. peroxidase in the plant body, have a potential role in scavenging the reactive oxygen species and preventing the plant cells from oxidative damage under various stress conditions (Chaves & Oliveira, 2004). The antioxidant enzymes could serve as important biochemical markers for the selection of potential resistant/tolerant genotypes for various stresses. Several previous studies have been conducted on the antioxidant enzyme activities and stress tolerance ability of grape genotypes. For instance, Kortekamp and Zyprian (2003) elucidated that foliar peroxidase activities are highly correlated with the resistance of grapevine plants to *Plasmopara viticola* under field conditions. Furthermore, Shetty *et al*. (2015) recorded significantly high peroxidase activities in anthracnose-resistant grape genotypes. Furthermore, Sucu *et al*. (2018) also confirmed that the drought-resistant grape rootstock genotypes had higher peroxidase enzyme activity than drought-sensitive rootstocks. Similar observations were also recorded in the present investigation, namely that the foliar peroxidase activity was influenced by the seven inter-specific rootstocks on the scion cultivar Syrah. The rootstock genotype SO4 imparted the highest leaf peroxidase activity to the cultivar Syrah, which was at par with peroxidase activities of Syrah grafted onto Fercal rootstock, and the lowest activity was recorded on the rootstock P1103. Thus, the rootstock SO4 could improve the overall performance of scion genotype Syrah.

The main function of the root system of the grapevine is to absorb and translocate the water and mineral nutrition taken up. This helps in the synthesis and metabolism of plant growth substances, as well as accumulation and storage of carbohydrates. The rootstocks therefore play an important role in the carbohydrate accumulation in the grafted scion genotypes. Satisha *et al*. (2008) recorded that different rootstocks genotypes have different carbohydrate content potential. They found that St. George rootstock had the most carbohydrates, with the least on 110R. Rafaat and El-Gendy (2013) further illustrated that the grape rootstock also influences the carbohydrate content of scion genotypes. They found that the grape cultivars Flame Seedless grafted onto Salt Creek and Freedom rootstocks had a higher carbohydrate content in their leaves than their own-rooted vines. Furthermore, Somkuwar *et al*. (2015) also showed a significant variation in carbohydrate contents in scion grape varieties grafted onto different rootstocks. The scion cultivar Fantasy Seedless grafted onto St. George had the most carbohydrates, followed by *V. longii* rootstock, while the least was on 110R. In the present investigation, the carbohydrate content of the leave of scion Syrah was affected by different rootstocks. The maximum carbohydrate content was recorded in Syrah grafted on Fercal, which is on par with P1103, and a significant minimum was recorded on rootstock 3309 C. Thus, the selection of the appropriate grape rootstock improves the accumulation of carbohydrates in the scion genotype.

The phenols are considered important secondary metabolites that play multiple functions in the plant body. The derivatives of phenolic compounds can react with and oxidise the protein compounds, thus making enzymes non-functional and restricting pathogenic invaders. These compounds are deposited inside the plant cell wall and stand as an important first-line defence against various infections (Schwalb & Feucht, 1999). Besides for acting as a defence mechanism, a positive correlation has been found between the phenolic content and the antioxidant potential of the fruits (Reddy *et al*., 2010). The rootstock genotypes affect several parameters of the grafted scion genotypes, and several studies have shown that the phenol content of scion genotypes is also influenced by the rootstock genotypes. For instance, Wallis *et al*. (2013) observed that. Chardonnay grafted onto rootstock RS3 had a higher level of most of the phenolics, while the least was found in Cabernet Sauvignon/101-14MG. Somkuwar *et al*. (2015) also observed that the grape rootstock genotypes significantly influenced the total phenol content of grafted scion rootstock. The rootstock Dogridge accumulated more total phenol content in leaves on the grafted scion of Fantasy Seedless, followed by the rootstock St. George. Similarly, in the present investigation, seven different rootstocks influenced the total phenolic content in the leaves of the wine cultivar Syrah. The rootstock 110R imparted the highest phenol content, followed by P1103 with the Syrah cultivar.

The nutrient status in the leaves of Syrah vines was influenced by grafting on different rootstocks. It was observed that Syrah grape leaves on rootstock 3309 C recorded the highest nitrogen content, while the 110R and SO4 rootstock exhibited intermediate values; the least was found on Fercal. Habran *et al*. (2016) reported that Cabernet Sauvignon (*V. vinifera* L.) grafted onto 110 Richter increased the nitrogen content in the leaves and petioles. Somkuwar *et al*. (2015) observed a higher N value on Salt Creek, while the lowest was vines grafted onto 41-B rootstock. It was found that SO4 and K5 BB grape rootstocks induced nitrate uptake by influencing low and high affinity (VvNRT2.4like) nitrate transporter genes (Tomasi *et al*., 2015).

SO4 rootstock was the most efficient in phosphorus uptake and Fercal for potassium uptake. The different levels of nutrients observed in the leaves of the Syrah grape could be attributed to the variable ability of rootstocks to take up and transport mineral nutrients to the scion cultivar Syrah. Several studies on different rootstock–scion combinations have reported different uptakes of nutrients by rootstocks and subsequent transport to the scion cultivars (Ruhl, 1991; Brancadoro *et al*., 1995; Garcia *et al*., 2001; Bavaresco *et al*., 2003; Ibacache & Sierra, 2009). Ruhl (1991) revealed in his study that K accumulation in scions is affected by the type of rootstock genotypes used in propagation. Brancadoro *et al*. (1995) studied the influence of 20 different rootstocks on Croatina grapes and reported that the K content in the grape must, leaves and berries was affected significantly by the rootstock. The rootstocks Harmony and 1613C showed a higher K value in Flame seedless, Red Globe and Thompson Seedless (Ibacache & Sierra, 2009)

The micronutrient content in Syrah leaves was also affected by the rootstocks to a great extent. The iron content was found to be maximum on rootstock 41B and manganese on 3309 C, whereas zinc was at a maximum on the SO4 rootstock. The variable micronutrient content might be due to differential uptake and stionic interactions, resulting in the mutual translocation of nutrients and growth regulators between the scion and rootstock (Jackson, 2000; Somkuwar *et al*., 2014). The mechanism by which rootstocks could influence the nutrient concentrations of the scion varieties may be their root architecture, water and nutrient uptake and transport, endogenous plant hormones concentration, etc. (Nawaz *et al*., 2016).

Stionic influence on fruit characteristics

The grape rootstock genotypes are well known for their influence on the yield and berry-related traits in grafted scion cultivars (Kubota *et al*., 1993; Kaserer *et al*.. 1997; Reynolds & Wardle, 2001; Ezzahouani & Williams, 2005). Rootstocks have a positive effect on bunch and berry characteristics. Among the rootstocks, P1103 and SO4 showed superiority for yield traits such as the number of bunches per vine, bunch weight, and bunch and berry size. Both of these rootstocks produced large clusters with bold berries. Fercal produced the lowest yield with the least number of bunches per vine, and small berries in the bunches.

The maximum number of bunches per vine was produced on rootstock P1103, which thus had a higher yield. It also produced bunches with the maximum length and width. The weight of the bunches was recorded as high on rootstock SO4, followed by P1103. This higher bunch weight may be due to higher berry weight and berry length. Brighenti *et al*. (2012) reported a large bunch weight of Cabernet Sauvignon on rootstock 3309 C, even with smaller berries.

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The chromatic coordinate L^* for berry colour showed a high value for the SO4 rootstock, which means the fruit produced on these rootstocks produced dark anthocyanin in their peel. Dark juice colour was found on Fercal rootstocks.

In the present investigation, seven inter-specific rootstock genotypes were found to significantly influence the yield, berry ripening and physical traits of bunches and berries, along with other berry quality traits of the Syrah cultivar. The rootstock genotype P1103 imparts the earliest berry ripening and a higher yield to the Syrah cultivar, while it gives rise to delayed ripening on rootstock 140Ru. The berries with the highest firmness were obtained in Syrah grafted onto the 3309 C rootstock, while the highest juice- recovery percentage was recorded on rootstocks 41B and 3309 C. The highest TSS content of Syrah berries was recorded on the 110R rootstock, which was on par with the berries on rootstocks SO4 and P1103. The maximum acidity and reducing sugar content were recorded on the 41B rootstock. The rootstock 3309 C influences the ascorbic acid content most in the Syrah cultivar, while the maximum total monomeric anthocyanins were recorded on the 110R rootstock. The total phenol content a maximum on rootstock genotype P1103, and the highest total antioxidant activity was recorded on the Fercal rootstock. Similarly, in previous studies, several authors have reported that the grape rootstock influences the berry's physical as well as berry quality traits. For instance, Dias *et al*. (2017) evaluated the performance of the grape cultivar Syrah on different rootstock genotypes. They recorded that the grape rootstock genotypes IAC 766, Kober 5BB and Rupestris du Lot were a more productive rootstock for Syrah. Jogaiah *et al*. (2015) found that grape rootstock genotypes Rootstock 101-14 Mgt and Gravesac imparted the highest total soluble solids, and lowest titratable acidity and fruit yield to the grafted scion genotype Cabernet Sauvignon in comparison to rootstock genotype 110R.

Cheng *et al*. (2017) recorded that 15 grape rootstock genotypes significantly influenced various quality parameters, such as total phenolics, flavonoids, anthocyanins and antioxidant capacity of the grape cultivar 'Red Alexandria' (*V. vinifera* L.). The berries on the rootstock genotype 420A had the lowest sugar fractions, while on the rootstocks Salt Creek and Rupestris du Lot they had the highest fractions of sugar (glucose and fructose). The rootstock genotypes Saltcreek and Rupestris du Lot also imparted the highest peel anthocyanin content, with 420A having the least. Cheng *et al*. (2017) also showed that the berries produced on the rootstock genotype Rupestris du Lot had high reducing sugar, phenolic compounds and antioxidant activities. More recently, Wang *et al.* (2019) evaluated the influences of eight grape rootstock genotypes on the vegetative growth of the vine, berry maturity and ripening and flavonoid content of the Cabernet Sauvignon cultivar. They found that the rootstock genotype SO4 had negative effects on berry maturity and anthocyanin accumulation. The present study also concludes that the rootstock genotype influences most of the physical as well as quality parameters of the berries and bunches of the grafted scion genotype. Thus, the choice of the right type of rootstock is important for successful viticulture and for improving the berry quality and productivity of the vine.

CONCLUSION

Rootstock 110R was shown to be the best rootstock for generating the maximum TSS, reducing sugars, and total monomeric anthocyanins in Syrah fruit, providing a fair amount of acidity, ascorbic acid, and total phenols, as well as antioxidant activity. With very dense trichromes on the leaves, rootstock 110R also produced significant total phenols and flavonoids in the fruit juice of cv. Syrah. The presence of trichromes indicates that there is a defence system against pests and pathogens. It also provides a high relative water content, a fair quantity of proline, and a low transpiration rate, indicating that the rootstock would function well under conditions of water stress. Rootstock P1103 showed the best performance in terms of bunch characters such as bunch weight, bunch length and bunch width, and therefore was the highest yielding rootstock for cv. Syrah. Being the rootstock to induce early maturity of the fruit, it appears to be a suitable rootstock for use in subtropical conditions to avoid rain damage to the fruit. Berries on rootstock 41B had higher juice recovery and reducing sugar content, and a richer colouration of juice. Rootstock SO4 gave rise to larger berry weight and length, thus producing a greater bunch weight. Under Delhi conditions, rootstocks 110R, P1103 and 41B seem promising for wine grape cv. Syrah. However, a more in-depth investigation over a longer period of time is required to determine their commercial viability.

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