



ROLE OF ROOTSTOCKS FOR SALINITY TOLERANCE IN GRAPEVINE: CHANGES IN BIOMASS, PHOTOSYNTHESIS, ABSCISIC ACID AND GLYCINE BETAINE

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SUMMARY

Physiological response of four grape varieties, Cabernet Sauvignon, Sauvignon Blanc, Flame Seedless and Sharad Seedless grafted on rootstocks, Dogridge and 110-R was studied after 30 days of (100 and 250 mM) NaCl salinity stress. NaCl salinity increased Na⁺ and decreased K⁺ content significantly in the varieties raised on Dogridge rootstock, and in Sharad Seedless. Flame Seedless raised on 110-R, recorded high K⁺ and low Na⁺ : K⁺ ratio under salinity stress. The leaf and stem dry mass were negatively influenced by the salinity treatment and Flame Seedless and Cabernet Sauvignon raised on 100-R, showed less reduction in mass under NaCl salinity. Root dry mass of Cabernet Sauvignon and Flame Seedless was higher at 100 mM but declined at 250 mM NaCl treatment, while those on 110-R rootstock contained higher root dry mass. The root : shoot dry mass ratio consistently increased under salinity, and the varieties raised on 110-R rootstock showed high root : shoot dry mass ratio. The leaf water potential (ψ_w), osmotic potential (ψ_o), specific leaf weight, photosynthesis rate (P_n) and chlorophyll content were high in plants raised on 110-R rootstock, and in Flame Seedless variety at both the salinity levels. Abscisic acid (ABA) and glycine betaine (GB) contents were high in Cabernet Sauvignon and Flame Seedless raised on 110-R rootstock under NaCl salinity. Abscisic acid content with Na⁺/K⁺ ratio ($R^2 = 0.811$, $p \leq 0.05$) and GB content with leaf water potential ($R^2 = 0.782$, $p \leq 0.05$) showed high negative relationship due to the salinity. Thus, induction in ABA and GB accumulation under salinity in grafted plants was associated with the rootstock induced salinity tolerance in grapevines. The Flame Seedless vines raised on 110-R accumulated higher ABA and GB under salinity and witnessed low Na⁺ content and Na⁺ : K⁺ ratio, and maintained high leaf water potential and osmotic potential and root : shoot dry mass ratio.

Key words: Abscisic acid, biomass accumulation, glycine betaine, grapevine, NaCl salinity, photosynthesis

INTRODUCTION

Salinity is one of the major constraints associated with decline in grape production in many traditional grape growing areas, owing to its moderate sensitivity to saline environment. The most common symptoms are leaf and bud necrosis under mild stress, and decline in growth and

yield, and loss in quality under severe stress conditions. Some investigations made earlier have revealed threshold EC_e values for salinity in grapevine (Walker *et al.* 2002), however, subsequent studies by Shani and Ben-Gal (2005) reported no threshold salinity values as growth and yield declined at low value of salinity. Use of rootstocks has gained prominence in grapevine

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cultivation because of wide variations in their root distribution and responses on scion vigour, yield, fruit quality (Howell 1987, Kubota *et al.* 1993, Satisha *et al.* 2010, Ozden *et al.* 2010, Rizk-Alla *et al.* 2011), and for improving tolerance to salinity too (Southy and Jooste 1991, Zhang *et al.* 2002, Walker *et al.* 1997). Such effects may be the consequence possible interactions of rootstocks with the physiology of scion varieties.

The information is limited on interactions of rootstocks with grapevine under salinity, though investigations have been made on rootstock potential to tolerate salinity (Singh *et al.* 2000, Upreti and Murti 2010, Southy 1992, Arbabzadeh and Dutt 1987). Some reports have revealed that the rootstock differences in the salinity tolerance are attributed to differences in ion absorption and maintenance of root growth and root : shoot biomass ratio (Upreti and Murti 2010, Fisarakis *et al.* 2004, Southy 1992). Upreti and Murti (2010) have reported that roots of salinity tolerant rootstocks have ability to accumulate higher concentrations of ABA and polyamines-spermine and spermidine. It is not known how the rootstock impart salinity tolerance to vine varieties physiologically. However, improved salinity tolerance of grapevine following use of rootstocks has been widely reported (Walker *et al.* 1997, Zhang *et al.* 2002). Thus, the present investigation reports the effects of salinity on some physiological parameters like biomass accumulation, specific leaf weight (SLW), ion contents, leaf water potential (ψ_w), osmotic potential (ψ_o) and contents of chlorophyll, abscisic acid (ABA) and glycine betaine (GB) in the leaves of four vine varieties grafted on two rootstocks differing in their level of salinity tolerance.

MATERIALS AND METHODS

Plant material and NaCl treatments: Ten months old healthy plants of rootstocks, Dogridge (*Vitis champinii*) and 110-R (*V. berlandieri* x *Vitis rupestris*) raised in polythene bags were used for grafting the scions of vine varieties, Cabernet Sauvignon, Sauvignon Blanc, Flame Seedless and Sharad Seedless. Two rootstocks 110-R (tolerant) and Dogridge (susceptible) were selected for grafting the varieties. The scions were grafted on to rootstocks by bench grafting technique. After two months, well developed plants were transplanted in

earthen pots (15" height) filled with 20 kg of red sandy loam soil, farmyard manure and sand (2:1:1 w/w) having moisture retention capacity of 27.4%. All the grafted plants were grown for 6 months and regularly watered once a day following the standard package of practices. The salinity treatments were imposed by irrigating plants daily once with 1.5 litres of 0, 100 and 250 mM NaCl (Himedia, AR Grade) for a period of 4 weeks duration. 1.5 litres of NaCl solution was optimized for soil saturation without seepage. During the experiment, soil samples were periodically analyzed for salinity build-up. The average soil salinity levels were 1.95, 4.37 and 7.16 dS m⁻¹ after 4 weeks under control, 100 and 250 mM NaCl treatments, respectively. The experiment was designed under CRD with 10 replications. During the experiment, the maximum and minimum temperatures ranged between 27.1-31.6°C and 17.2-21.1°C, respectively, and the average relative humidity at 1.00 pm was 57.3%.

Photosynthesis rate (P_n): Observations on P_n in attached leaves were made between 10.30 to 12.00 h when photosynthetically active radiation (PAR) at leaf surface ranged between 1000-1100 $\mu\text{mol m}^{-2}\text{s}^{-1}$, using portable photosynthesis system LI-6400XT (LI-COR, USA). Five consecutive measurements were recorded under the different treatments.

Dry matter content: Data on dry mass of leaf, stem and root was obtained by gently uprooting the salinity treated plants, ensuring intactness of roots. The roots were washed in running tap water to remove the adhering soil and later dried between the filter paper pads. All the plant parts were hot-air oven dried at 80°C till constant weight recorded. Root to shoot dry mass ratio was derived by dividing respective values of root dry mass with total dry mass of leaf and stem. Specific leaf weight was determined by cutting leaf discs of uniform size from middle of leaf lamella using punch hole (diameter 10.0 mm), and discs (10 Nos.) were hot-air oven dried at 80°C for 48 h. The dry mass of discs was recorded, and mean dry mass calculated. The SLW was calculated by dividing disc dry mass with disc area, and expressed as mg cm⁻².

Leaf water potential (ψ_w), osmotic potential (ψ_o) and sodium and potassium: ψ_w was obtained by cutting leaf

discs of uniform size (5.1 mm diameter) and taking measurements on dew point micro voltmeter (model HR-33T, Wescor, USA). The ψ_{δ} was determined using vapour pressure osmometer (Model 5520, Wescor, USA) by extracting sap from leaves. The values of ψ_w and ψ_{δ} were expressed as - MPa. The Na^+ and K^+ contents in the leaves were estimated after digestion with $\text{H}_2\text{SO}_4 : \text{HNO}_3 : \text{HClO}_4$ (1:7:20 v/v/v) employing flame photometer (Photo Electric Instruments, India).

Chlorophyll, abscisic acid (ABA) and glycine betaine (GB): Leaf chlorophyll content was estimated according to Hiscox and Israelstam (1979). For ABA analysis, the leaves were macerated in chilled 80% methanol and filtered. The filtrate was evaporated *in vacuo* at 35°C, the residue dissolved in water and pH was adjusted to 3.0. The aqueous acidic extract was partitioned twice against equal volumes of chilled diethyl ether. The ether phase was separated and dried over anhydrous sodium sulphate. The extract was kept overnight at 4°C, filtered and after evaporating ether, the residue was dissolved in 20 mM tris buffer, pH 7.8 for the ABA analysis by ELISA employing laboratory raised antibodies (Weiler 1982). For glycine betaine estimation, leaf samples (1.0 g) were extracted in 8.0 ml of 90% ethanol. The supernatant was dried under reduced pressure and residue solubilized in 2.0 ml of water. The aqueous extract was then applied to 10 ml column of AG 50W resin (200-400 mesh, H^+ form), and column was washed with three volumes of water. Glycine betaine was eluted with 10.0 ml of NH_4OH (4.0 mM) (Bessieres *et al.* 1999). The eluate containing glycine betaine was dried under reduced pressure and redissolved in 100 μl of methanol for HPLC. A Sherisorb © 10 SCX column fitted to HPLC (Model - Prominence, Shimadzu, Japan) and UV detector tuned at 204 nm were used. Isocratic run comprising of 50 mM KH_2PO_4 (pH 4.6) in 5% methanol @ flow rate 1.0 ml min^{-1} was employed to resolve GB. The quantification was performed using pure glycine betaine as standard (Sigma, St Louis, USA).

RESULTS AND DISCUSSION

Changes in ionic contents: In the NaCl untreated plants, Na^+ content and $\text{Na}^+ : \text{K}^+$ ratio were high and K^+ content low in the vine varieties raised on Dogridge compared with those raised on 110-R rootstock (Table

1). NaCl salinity significantly increased Na^+ and declined K^+ contents in the grafted plants, and the response varied among the rootstocks (Table 1). Under the NaCl treatments, the increase in Na^+ and decline in K^+ was high in plants raised on Dogridge than those on 110-R, and Sharad Seedless exhibited high Na^+ content and Flame Seedless high K^+ content on either of rootstocks under NaCl salinity. The differences in Na^+ and K^+ contents in the vine varieties across the rootstocks under salinity are suggested as the result of inheritant differential capacity of rootstock genotypes for ion absorption and mobilization, and hydraulic conductivity (Fardossi *et al.* 1995). Upreti and Murti (2010) reported differential increase in Na^+ and decline in K^+ in grape rootstocks under salinity. The salinity induced changes in Na^+ and K^+ contents showed gradual increase in $\text{Na}^+ : \text{K}^+$ ratio, and the ratio was higher in the vine plants on Dogridge than 110-R rootstock and in Flame seedless (Table 1). The salinity induced changes in Na^+ and K^+ leading to increase in Na^+/K^+ ratio has been documented in the barley and maize (Flowers and Hajibagheri 2001, Hajibagheri *et al.* 1987). These results indicated that the rootstock 110-R is more effective in restricting uptake and/or mobilization of Na^+ than the Dogridge in the vine varieties under salinity and Flame Seedless accumulated less Na^+ and maintained high K^+ under NaCl stress suggested it is more salinity tolerant.

Dry mass of plant parts and root:shoot dry mass ratio: In the NaCl untreated vine varieties, dry mass of leaf, stem and root was higher in the Dogridge raised plants (Table 2) but under NaCl salinity, leaf and stem dry mass were reduced by 13.4-55.0% and 16.6-51.7%, respectively in the Dogridge raised vine plants, and 9.8-44.0% and 9.98-37.0%, respectively in the 110-R raised vine plants (Table 2). Among the varieties, Flame Seedless experienced less and Sharad Seedless greater decline in leaf and stem dry mass due to NaCl salinity. The root dry mass was high in the Dogridge raised plants under 100 mM and in 110-R raised plants under 250 mM NaCl. Among the vine varieties, the root dry mass in Cabernet Sauvignon and Flame Seedless increased under 100 mM NaCl in the Dogridge raised, and under both salinity levels in the 110-R raised plants (Table 2). These results indicate that rootstock and salinity interact to influence the dry matter partitioning in the grapevine.

Table 1. Changes in Na⁺, K⁺ and Na⁺ : K⁺ ratio in different rootstock and scion combinations under NaCl salinity. (SEm±, n=4)

Rootstock	Scion	Na ⁺ [nmol g ⁻¹ (d.m.)]		K ⁺ [nmol g ⁻¹ (d.m.)]		Na ⁺ : K ⁺ ratio	
		Control	100 mM	Control	100 mM	Control	100 mM
Dogridge	Cabernet sauvignon	3.32±0.34	5.36±0.67	19.52±1.86	15.08±1.97	0.17±0.014	0.36±0.023
	Sauvignon blanc	4.38±0.52	7.39±0.68	15.63±1.37	12.94±1.24	0.28±0.052	0.57±0.045
	Flame seedless	3.95±0.36	4.81±0.32	22.52±1.98	17.35±1.89	0.18±0.093	0.28±0.029
	Sharad seedless	5.72±0.65	9.35±1.14	26.74±2.89	17.77±1.63	0.21±0.017	0.53±0.056
110-R	Cabernet sauvignon	3.33±0.22	4.91±0.66	30.07±2.86	24.81±2.31	0.11±0.007	0.20±0.009
	Sauvignon blanc	3.85±0.49	5.03±0.25	23.11±3.56	20.08±1.55	0.17±0.008	0.25±0.038
	Flame seedless	3.59±0.28	4.26±0.41	36.76±3.46	26.14±2.87	0.10±0.014	0.16±0.015
	Sharad seedless	3.65±0.56	6.03±0.81	28.44±2.98	22.32±2.65	0.13±0.018	0.27±0.028

Table 2. Changes in leaf, stem and root dry mass in different rootstock and scion combinations under NaCl salinity. (SEm±, n=4)

Rootstock	Scion	Leaf [g plant ⁻¹]		Stem [g plant ⁻¹]		Roots [g plant ⁻¹]	
		Control	100 mM	Control	100 mM	Control	100 mM
Dogridge	Cabernet sauvignon	8.12±0.54	6.32±0.92	5.98±1.05	4.88±0.88	2.35±1.01	2.48±0.26
	Sauvignon blanc	6.87±0.71	5.25±0.76	4.65±0.91	3.26±0.96	1.73±0.33	1.45±0.22
	Flame seedless	8.06±1.06	6.98±0.84	6.01±0.73	5.01±0.78	2.26±0.56	2.53±0.62
	Sharad seedless	7.42±0.75	5.12±0.59	4.95±0.56	3.14±0.51	1.62±0.65	1.32±0.58
110-R	Cabernet sauvignon	6.95±0.84	6.03±1.04	4.89±0.77	4.21±0.68	1.86±0.79	2.07±0.67
	Sauvignon blanc	5.91±0.98	4.75±0.72	4.38±0.65	3.53±0.36	1.45±0.46	1.32±0.53
	Flame seedless	6.52±0.71	5.88±0.36	4.71±0.61	4.24±0.64	1.71±0.77	2.27±0.66
	Sharad seedless	6.62±0.46	5.04±0.72	4.08±0.72	3.01±0.54	1.36±0.63	1.25±0.58

Earlier, Tardaguila *et al.* (1995) reported that rootstocks influenced dry matter partitioning in grapevine. Similarly, salinity induced decline in shoot dry mass in grapevine grafted on different rootstocks has also been reported (Fisarakis *et al.* 2001). Root:shoot dry mass ratio in the salinity untreated plants was high in Dogridge raised plants, with Cabernet Sauvignon revealing high ratio. Following NaCl salinity, the ratio increased consistently in the grafted plants (Fig. 1) and increase was higher in 100-R (13.1-99.8%) raised plants than the Dogridge (13.5-59.1%) raised plants. Among the four varieties, Flame Seedless raised on 110-R rootstock recorded high root:shoot dry mass ratio under NaCl salinity (Fig. 1). The increase in root:shoot dry mass ratio indicated greater vulnerability of shoots than the roots to salinity, and could possibly be the outcome of reallocation of photosynthates to roots under salinity conditions (Chartzoulakis *et al.* 1995). Cheeseman (1988) also stated that salinity imposes additional energy requirement on plant cells, and diverts metabolic carbon in a manner so that less amount is available for shoot growth. The increase in root:shoot dry mass ratio under salinity also suggest that the greater ability of the roots towards osmotic adjustment as suggested by Sharp and Davies (1979). Fisarakis *et al.* (2001) also reported increase in root : shoot dry mass ratio in grapevine cv. Sultana under salinity.

Specific leaf weight (SLW), rate of photosynthesis (P_n) and chlorophyll content: Specific leaf weight declined by 19.9-45.2% in the plants on Dogridge and by 10.0-28.7% in the plants on 100-R rootstock under

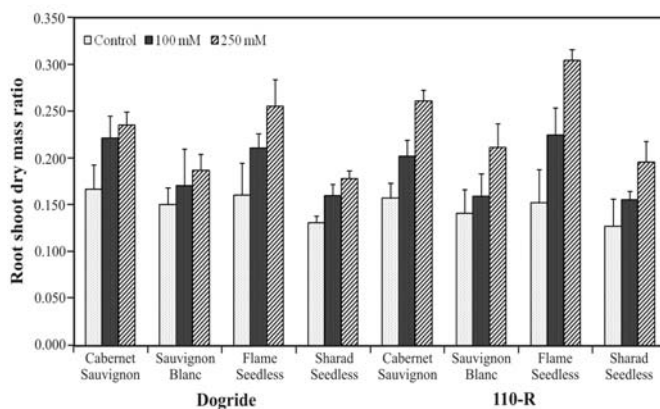


Fig. 1. Root : shoot dry mass ratio in different rootstock scion combinations under NaCl salinity. (SEM±, n=4)

NaCl salinity and with higher SLW on 110-R (Table 3). Flame Seedless under both salinity treatments invariably maintained high and Sharad Seedless low SLW. P_n was reduced by 14.1-33.3% and 25.3-53.2% in grafted plants under 100 and 250 mM NaCl treatments, respectively (Table 3). Under NaCl salinity, decline in P_n was higher in the Dogridge than the 110-R raised plants. Flame Seedless on 110-R with 25.3% decline under 250 mM NaCl showed high P_n , while Sharad Seedless with 53.2% witnessed low P_n (Table 3). NaCl salinity showed declining trends in chlorophyll content and highest reduction was under 250 mM NaCl treatment. Similar, salinity induced decline in chlorophyll has been observed in grape (Divate and Pandey 1981). Among the vine varieties, Cabernet Sauvignon and Flame Seedless showed high chlorophyll under NaCl salinity.

Leaf water potential (ψ_w), osmotic potential (ψ_δ) and glycine betaine (GB) content: Leaf water potential (ψ_w) and osmotic potential (ψ_δ) were negatively influenced by NaCl salinity and with 110-R as rootstock, grafted plants showed lesser decline than with Dogridge under 250 mM NaCl. Flame Seedless under NaCl salinity exhibited lesser decline in ψ_w and ψ_δ and accordingly maintained their high values (Table 4). Sharad Seedless was most affected by salinity in terms of decline in ψ_w and ψ_δ . ψ_w was positively correlated to root:shoot dry mass ratio ($R^2 = 0.826$, $p \leq 0.05$), and ψ_s with K^+ content ($R^2 = 0.786$, $p \leq 0.05$). The decline in ψ_w is representative of water loss from leaves during salinity. The parallel decline in ψ_w and ψ_δ indicated that reduction in ψ_w was compensated by drop in ψ_δ which in turn helped in maintenance of turgor. Similar results in ψ_w reductions under salinity in different graft combinations of grapes have been reported by Vincent *et al.* (2007). The GB concentration in the NaCl untreated vine plants ranged between 0.660-0.919 $\mu\text{mol}/\text{mg}$ (d.m.) with Dogridge as rootstock, and between 1.048-1.336 $\mu\text{mol}/\text{mg}$ (d.m.) with 110-R as rootstock. NaCl salinity increased GB content, more under higher NaCl concentration (Table 4). Between the rootstocks, the GB concentration increased to 1.834-4.713 $\mu\text{mol}/\text{mg}$ (d.m.) in the 110-R and to 1.091-3.298 $\mu\text{mol}/\text{mg}$ (d.m.) in the Dogridge raised plants under NaCl salinity. Amongst the varieties, Flame Seedless followed by Cabernet Sauvignon under salinity showed high GB content and Sharad Seedless low. GB

Table 3. Net photosynthesis rate (P_n), specific leaf weight (SLW) and total chlorophyll content in different rootstock and scion combinations under salinity. (SEM±, n=4)

Rootstock	Scion	Photosynthesis rate [$\mu\text{mol m}^{-2} \text{s}^{-1}$]			SLW [mg cm^{-2}]			Chlorophyll content [mg g^{-1} (d.m.)]		
		Control	100 mM	250 mM	Control	100 mM	250 mM	Control	100 mM	250 mM
		Dogridge	Cabernet sauvignon	12.15±1.37	9.34±1.32	7.22±0.52	1.96±0.12	1.64±0.17	1.39±0.16	0.95±0.036
	Sauvignon blanc	13.24±1.74	9.02±1.08	6.44±0.78	2.04±0.23	1.56±0.19	1.21±0.10	0.74±0.033	0.47±0.022	0.36±0.023
	Flame seedless	14.26±1.58	11.68±1.38	8.55±0.94	2.21±0.18	1.77±0.39	1.65±0.21	0.87±0.19	0.71±0.098	0.55±0.042
	Sharad seedless	13.06±1.27	8.71±0.76	6.11±0.47	1.86±0.12	1.31±0.24	1.02±0.17	0.69±0.085	0.42±0.036	0.34±0.018
110-R	Cabernet sauvignon	10.53±1.04	8.86±0.95	7.56±0.79	1.88±0.23	1.68±0.19	1.54±0.21	0.84±0.052	0.70±0.048	0.62±0.046
	Sauvignon blanc	12.71±0.98	9.45±1.24	7.01±0.64	1.91±0.11	1.63±0.27	1.48±0.13	0.68±0.043	0.51±0.024	0.42±0.025
	Flame seedless	11.85±1.05	10.18±0.86	8.85±0.98	2.01±0.18	1.81±0.22	1.69±0.22	0.79±0.063	0.71±0.019	0.63±0.074
	Sharad seedless	10.94±1.32	8.35±1.19	6.51±0.43	1.67±0.16	1.45±0.11	1.19±0.09	0.63±0.028	0.47±0.063	0.41±0.041

Table 4. Leaf water potential (ψ_w), osmotic potential (ψ_o) and glycine betaine content in different rootstock and scion combinations under NaCl salinity. (SEM±, n=4)

Rootstock	Scion	Leaf water potential [-MPa]			Osmotic potential [-MPa]			Glycine betaine [$\mu\text{mol mg}^{-1}$ (d.m.)]		
		Control	100 mM	250 mM	Control	100 mM	250 mM	Control	100 mM	250 mM
		Dogridge	Cabernet sauvignon	1.57±0.23	1.78±0.25	2.01±0.17	2.13±0.32	2.59±0.36	3.19±0.16	0.900±0.085
	Sauvignon blanc	1.87±0.14	2.25±0.17	2.53±0.21	2.96±0.18	3.46±0.42	3.98±0.39	0.919±0.074	1.665±0.156	2.391±0.324
	Flame seedless	1.36±0.11	1.59±0.12	1.69±0.12	2.27±0.26	2.76±0.28	3.01±0.27	0.908±0.109	1.364±0.124	3.298±0.247
	Sharad seedless	1.84±0.26	2.31±0.25	2.68±0.23	2.48±0.33	2.86±0.35	3.49±0.21	0.660±0.045	1.091±0.102	2.045±0.165
110-R	Cabernet sauvignon	1.35±0.14	1.58±0.14	1.69±0.09	1.85±0.24	2.29±0.33	2.45±0.17	1.214±0.157	2.222±0.185	4.500±0.485
	Sauvignon blanc	1.59±0.19	1.97±0.20	2.29±0.19	2.32±0.26	2.87±0.21	3.44±0.23	1.048±0.144	1.859±0.161	4.265±0.504
	Flame seedless	1.26±0.10	1.44±0.14	1.59±0.12	1.74±0.14	2.08±0.18	2.25±0.11	1.336±0.117	2.056±0.227	4.713±0.569
	Sharad seedless	1.67±0.21	2.08±0.18	2.37±0.22	2.19±0.29	2.47±0.24	2.91±0.28	1.094±0.124	1.834±0.174	3.605±0.226

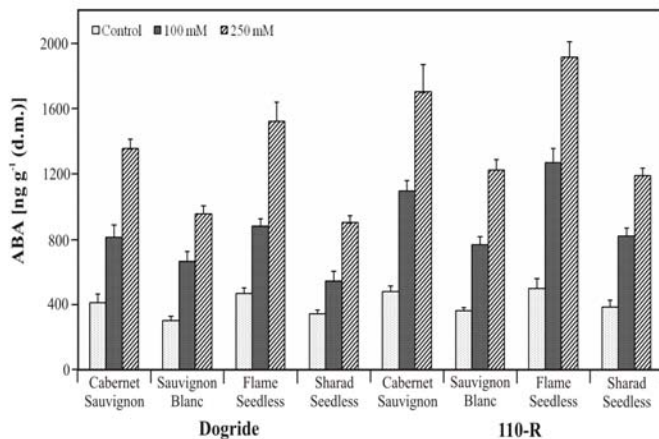


Fig. 2. Abscisic acid content in different rootstock scion combinations under NaCl salinity. (SEM±, n=4)

is well reported as a common compatible solute playing a role in stress tolerance by adjusting osmotic potential, and stabilizing of macro molecular integrity and cell membrane stability (Chen and Murata 2008). Its accumulation under salinity has been reported in sugar beet, sorghum, barley and wheat (Weimberg *et al.* 1984, Rhodes and Hanson 1993, Ashraf and Foolad 2007). Exogenous GB application has also been reported to combat salinity stress by lowering Na⁺ and increasing K⁺ contents (Ashraf and Foolad 2007). Thus, high GB accumulation under salinity is attributed to better salinity tolerance of 110-R in grapevines. The positive relationship between GB concentration with ψ_{δ} ($R^2 = 0.843$, $p \leq 0.05$) and ψ_w ($R^2 = 0.782$, $p \leq 0.05$) in the salinity treated plants indicated salinity tolerance attributable to osmotic adjustment. Good relationship prevailing between glycine betaine and P_n ($R^2 = 0.784$, $p \leq 0.05$) in salinity subjected plants is supported by the findings of Yang and Lu (2005).

Abscisic acid (ABA): Abscisic acid content was significantly influenced by the rootstock and salinity treatments (Fig. 2). Under NaCl-untreated conditions, ABA content ranged between 304-500 ng/g d.m. was high in the plants on 110-R rootstock and in Flame Seedless. The rootstock influencing scion ABA levels have been reported in grapes (Satisha *et al.* 2007) and mango (Murti *et al.* 2000). Under NaCl salinity, ABA content in vine plants on Dogridge as rootstock increased from 304-471 ng/g d.m. to 545-878 ng/g d.m. and 900-1525 ng/g d.m. and in plants with 110-R as

rootstock from 362-500 ng/g d.m. to 769-1268 ng/g d.m. and 1190-1917 ng/g d.m. under 100 and 250 mM NaCl, respectively. The grafted plants of Flame Seedless followed by Cabernet Sauvignon had relatively more NaCl induced ABA increase (Fig. 2). Sharad Seedless invariably showed less ABA increase under NaCl salinity. ABA increase under salinity has been reported in many plant species (Jia *et al.* 2002, Cramer and Quarrie 2002) and is related to adaptation to stress by influencing stomatal and hydraulic conductivities (Fricke *et al.* 2006, Freundle *et al.* 2000). The ABA increase under NaCl salinity in the present study is in accordance with the above studies. ABA content of salinity imposed plants negatively related to Na⁺/K⁺ ratio ($R^2 = 0.811$, $p \leq 0.05$) are suggested as the possible result of negative effects of ABA on Na⁺ xylem transport and plasmalemma influx as reported by Behl and Jeschke (1981). The consistency in the trends of ABA and GB in the salinity treated plants is in accordance with Saneoka *et al.* (2001) that ABA up-regulates GB accumulation under salinity.

In conclusion, salinity levels and rootstocks significantly influenced the physiology of vine varieties as evident from the changes in Na⁺ and K⁺ contents and their ratio, biomass accumulation, ψ_w and ψ_{δ} , P_n and concentrations of glycine betaine and ABA. The NaCl salinity responses on grapevine were differential with respect to rootstock and were dependent upon salinity level. The varieties raised on 110-R rootstock accumulated high GB and ABA under salinity witnessed low Na⁺ content and Na⁺: K⁺ ratio, and maintained high leaf ψ_w and ψ_{δ} , and root:shoot dry mass ratio. Amongst vine varieties, the grafted plants of Flame Seedless were relatively more tolerant to NaCl salinity.

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