Indian Journal of Agricultural Sciences **93** (9): 984–990, September 2023/Article
https://doi.org/10.56093/ijas.v93i9.139270

Exploring the impact of salinity on citrus (*Citrus* spp.) rootstock seed germination and seedling biomass

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Received: 14 July 2023; Accepted: 08 August 2023

ABSTRACT

An experiment was conducted at the screen house of the Department of Horticulture, CCS Haryana Agricultural University, Hisar, Haryana during 2018–19 and 2019–20 to assess the impact of 5 different salinity levels [0.07 (control), 2.5, 4.0, 5.5, and 7.0 dS/m] on the seed germination and biomass of 9 citrus (*Citrus* spp.) rootstock seedlings (Rough lemon, Pectinifera, Cleopatra mandarin, Rangpur lime, Alemow, Volkamer lemon, NRCC-4, NRCC-3 and CRH-12). Experiment consisted of 45 treatment combinations and 3 replications in a completely randomized design (CRD). Under the influence of soil salinity, the number of days taken for seed germination, seed germination percentage, fresh and dry root and shoot biomass were adversely affected across all rootstocks compared to the control treatment (0.07 dS/m). Among the tested rootstocks, Volkamer lemon exhibited the highest seed germination rate (57%), followed by Rangpur lime (53%) and CRH-12 (50%). Conversely, Pectinifera showed the lowest seed germination percentage (37%), followed by Alemow (43%) at 7 dS/m. The minimum reduction at 7 dS/m over control in fresh shoot and root and dry shoot and root biomass was observed in Rangpur lime (37.7, 16.2, 27.8 and 27.3%, respectively), followed by Volkamer lemon (38.0, 16.2, 28.3 and 28.5%, respectively). On the other hand, Pectinifera exhibited the highest reduction in biomass (51.9, 40.5, 47.0 and 43.9%, respectively), followed by Alemow (45.7, 30.9, 46.5 and 39.9%, respectively). Among all the rootstocks, Rangpur lime, Volkamer lemon and Cleopatra mandarin displayed better tolerance to salinity, exhibiting relatively lower reduction in biomass at the highest salinity level (7 dS/m) compared to the control. Cleopatra mandarin, Rough lemon and NRCC-3 showed a moderate response, while Pectinifera, NRCC-4, and Alemow were found to be less tolerant, exhibiting higher reduction in terms of count of seed germination days, seed germination percentage, fresh and dry root biomass, and shoot biomass at 7 dS/m compared to the control treatment.

Keywords: Biomass, Citrus, Germination, Rootstock, Salinity

Citrus (*Citrus* spp.), a commercially significant fruit crop and glycophyte, holds great economic significance in the horticultural sector, faces a major challenge due to its sensitivity to salt, particularly in tropical and subtropical regions where drought and salinity are increasingly prevalent. In India, citrus ranks third most important fruit crop, contributing 13.7% of total fruit production, following banana and mango. The country has 1,098 thousand hectares of citrus cultivation, yielding a production of 14,757 thousand metric tonnes (Anonymous 2023). Specifically in Haryana, with 24.40 thousand hectares and 570.88 thousand metric tonnes of citrus production, salinity affects approximately 2.96 million hectares of cultivated land in India, including 2.32 lakh hectares in Haryana (Anonymous 2021). Salinity poses a significant environmental obstacle, particularly in arid and semi-arid climates, hampering plant productivity due to osmotic potential effects. While salts occur naturally in soils in low concentrations, elevated levels can harm citrus plants (Fathi *et al.* 2017). Salinity also delays seedling emergence, reduces shoot and root biomasses, and affects citrus rootstocks' overall salt tolerance (Mass 1993). Salinity leads to the accumulation of soluble salts, causing ion toxicity, chlorosis, and necrosis, which disrupts various physiological processes by increasing the osmotic potential (Ψs) of the soil matrix and impeding water intake by plants (Garcia-Sanchez *et al.* 2006). Recommended rootstocks for Haryana, such as Rough lemon, Cleopatra mandarin and Pectinifera are appropriate for Kinnow mandarin, Blood Red and Mosambi and sweet oranges respectively (Singh *et al.* 2012). Rangpur lime has been identified as more tolerant to high soil salinity attributed to its ability to exclude Na^+ ions (Sahin-Cevik *et al.* 2020). However, potential rootstocks like Pectinifera, Volkamer lemon, Alemow, NRCC-4, NRCC-3

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and CRH-12 still need evaluation for salinity acceptance in the western agroclimatic region of Haryana. The selection of the proper rootstock is crucial as it acts as the first filter for salt ions entering the root system, thereby enhancing the plant's salt tolerance potential through increased antioxidant activities and limited levels of Na^+ and Cl^- in the leaves. This selection process is vital to meet the evolving trends and requirements of citrus crops (Stover *et al.* 2018, Shahid *et al.* 2019). Considering the aforementioned factors, this experiment was conducted to investigate the influence of salinity on seed germination and biomass of 9 citrus rootstock seedlings.

MATERIALS AND METHODS

The present study was carried out at CCS HAU, Hisar, Haryana from 2018 to 2020, which has a semi-arid climate characterized by hot and dry summers with extremely cold winters. Soil samples were collected from the sand dunes of Balasmand village, Hisar. The collected soil was sieved through a 2 mm sieve and imperilled to chemical and mechanical examination. The soil was sandy in texture, low in organic carbon, had medium availability of nitrogen and phosphorus and showed an alkaline reaction with a saturation capacity of 25%. Plastic pots filled with 10 kg of dune sand were used for growing the crops, and Hoagland nutrient solution was supplied at regular intervals. Salinity was induced in the soil using artificial water with different ionic compositions (Table 1). Chloride and sulphate salts of Na^+, Ca^{2+} and Mg^{2+} ($NaCl$, $CaCl_2.2H_2O$, $MgCl_2.6H_2O$ and $MgSO_4.7H_2O$) were added in the vital amounts to achieve the desired salinity levels. The salts were dissolved in water in a 100-litre bucket, and the final volume was adjusted to 75 litres for each salinity level. From this solution, 2.6 litres per pot was added to pots containing 10 kg of soil by thoroughly mixing after drying to maintain the respective salinity level.

The study consisted of 9 different citrus rootstocks and 5 levels of chloride-dominated salinity. Fruits of Rough lemon (*Citrus jambhiri* Lush.), Pectinifera (*Citrus depressa* Hayata), Cleopatra mandarin (*Citrus reshni* Tanaka), Alemow (*Citrus macrophylla* Wester), Rangpur lime (*Citrus limonia* Osbeck), Volkamer lemon (*Citrus volkameriana*), NRCC-4 (Rough lemon × Trifoliate orange), NRCC-3 (Rough lemon × Trifoliate orange), and CRH-12 [*Citrus sinensis* (L.) Osbeck × *Poncirus trifoliata*] were collected from a single tree of each rootstock from CCRI, Nagpur and CCS HAU, Hisar. The seeds were taken-out from fruits, washed, air-dried under shade, and preserved with Bavistin at a rate of 2 g per 100 g of seeds. They were sown at a depth of 1 cm in 3 replications with 10 seeds per replication in pots and covered with soil having salinity levels of 0.07 (control), 2.5, 4.0, and 7.0 dS/m. The experimental design was a Completely Randomized Design (CRD). Observations were recorded for the number of days taken for seed germination, seed germination percentage, fresh root and shoot biomass after 3 months of germination, and dry root and shoot biomass calculated by oven-drying the seedlings at 48°C until a constant dry weight was obtained, and expressed in grams per plant. The collected data were analyzed using a two-factorial completely randomized design (CRD) with 5% critical difference (CD) and subjected to statistical analysis with OP Stat software (http://14.139.232.166/opstat/index.asp), CCS HAU Hisar (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Days taken for seed germination: Salinity reduces germination or emergence in citrus trees by accumulation of excessive concentrations of Cl^- in leaves (Banuls and Primo-Millo 1995). The results of present investigation indicate that the days taken for seed germination delayed with increase in salt concentration from control (0.7 dS/m) to 7 dS/m (Table 2) in different citrus rootstocks significantly. Among different rootstocks, the maximum number of days (43) were taken by Alemow, whereas, the minimum number of days (24) were taken by Volkamer lemon, irrespective of the salinity level. The minimum days taken (14) for seed germination were found in Pectinifera at control and maximum (59) in Alemow at 7 dS/m salinity level in the year 2018–19. Similar results were observed in the year 2019–20 with very slight variations in number of days taken to germination by different rootstocks. The results of present study are in conformation with the findings of Murkute *et al.* (2010) who revealed that the number of days required for *in vitro* shoot initiation was prolonged from 8.8 (control) to 22.46 days in C. *jambhiri* and from 7.8 (control) to 25.6 days in C. *karna* when exposed to 100 mM NaCl salt stress.

Seed germination (%): Salt-induced soil salinity adversely affects seed germination by reducing water uptake and causing excessive ion absorption (Ucarli 2021). The outcomes of present study specify that the per cent seed germination decreased significantly with increase in salinity levels from control to 7 dS/m (Table 2) in both the years of study. Seed germination was maximum (96.67%) in Volkamer lemon at control (0.07 dS/m), whereas, it was found minimum (36.67%) in Pectinifera at 7 dS/m in the year 2018–19. The reduction in germination with the increased salinity stress was rootstock specific and this was observed minimum in Volkamer lemon (97 to 57%) and Rangpur lime (93 to 53%), followed by CRH-12 (90 to 50%), whereas, in Pectinifera, it was found maximum

Table 1 Ionic composition for the preparation of chloride-dominated saline water

EC_e level (dS/m)	Total dissolved salts (TDS)	Na^+	Cl^-	Ca^{2+}	SO_4^{2-}	Mg^{2+}
		me/l				
2.5	30.50	15.25	21.35	3.81	9.15	11.43
4.0	50.0	25.0	35.0	6.25	15.0	18.75
5.5	66.50	33.25	46.55	8.31	19.95	24.93
7.0	86.0	43.0	60.20	10.75	25.80	32.24

Table 2 Effect of salinity on number of days taken for seed germination and seed germination (%) in different citrus rootstocks

Salinity level (dS/m): Number of days taken for seed germination

Rootstock	2018–19						2019–20					
	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean
Rough lemon	4.28 (17.33)	4.36 (18.00)	4.86 (22.67)	5.32 (27.33)	6.58 (42.33)	5.08 (25.53)	4.61 (18.67)	4.60 (19.00)	5.21 (24.33)	5.65 (29.00)	7.05 (45.33)	5.42 (27.27)
Cleopatra mandarin	4.80 (22.00)	4.80 (22.00)	5.07 (24.67)	5.57 (30.00)	6.45 (40.67)	5.34 (27.87)	5.09 (23.33)	5.08 (23.33)	5.34 (26.00)	5.81 (31.33)	6.82 (43.00)	5.63 (29.39)
Pectinifera	3.92 (14.33)	3.96 (14.67)	4.69 (21.00)	5.48 (29.00)	7.44 (54.33)	5.10 (26.67)	4.28 (15.67)	4.41 (16.33)	5.06 (22.67)	5.98 (31.67)	8.12 (59.33)	5.57 (29.13)
Rangpur lime	4.62 (20.33)	4.62 (20.33)	4.97 (23.67)	5.39 (28.00)	6.06 (35.67)	5.13 (25.60)	4.92 (21.67)	4.92 (21.67)	5.25 (25.00)	5.71 (29.67)	6.45 (38.00)	5.45 (27.20)
Alemow	5.72 (31.67)	5.77 (32.33)	6.38 (39.67)	7.09 (49.33)	7.75 (59.00)	6.54 (42.40)	6.02 (33.33)	6.07 (34.00)	6.70 (41.67)	7.43 (51.67)	8.14 (62.00)	6.87 (44.53)
Volkamer lemon	4.40 (18.33)	4.47 (19.00)	4.83 (22.33)	5.16 (25.67)	6.00 (35.00)	4.97 (24.07)	4.72 (19.67)	4.78 (20.33)	5.12 (23.67)	5.50 (27.33)	6.40 (37.33)	5.30 (25.67)
NRCC-3	5.39 (28.00)	5.45 (28.67)	5.89 (33.67)	6.40 (40.00)	7.33 (52.67)	6.09 (36.60)	5.58 (29.00)	5.64 (29.67)	6.06 (34.67)	6.62 (41.33)	7.56 (54.33)	6.29 (37.80)
NRCC-4	4.55 (19.67)	4.58 (20.00)	5.07 (24.67)	5.48 (29.00)	6.51 (41.33)	5.24 (26.93)	4.85 (21.00)	4.81 (21.00)	5.41 (26.33)	5.73 (30.33)	6.93 (44.00)	5.55 (28.53)
CRH-12	4.62 (20.33)	4.69 (21.00)	5.06 (24.67)	5.69 (31.33)	6.30 (38.67)	5.27 (27.20)	4.92 (21.67)	4.99 (22.33)	5.34 (26.00)	5.99 (33.00)	6.68 (41.00)	5.58 (28.80)
Mean	4.70 (21.33)	4.74 (21.78)	5.20 (26.33)	5.73 (32.19)	6.71 (44.41)		5.00 (22.67)	5.03 (23.07)	5.49 (27.81)	6.05 (33.93)	7.13 (47.15)	
CD (P=0.05)	Rootstock = 0.08 Salinity = 0.06 Rootstock × Salinity = 0.17						Rootstock = 0.09 Salinity = 0.07 Rootstock × Salinity = 0.19					
	Original data given in parentheses were subjected to square root $\sqrt{(x+1)}$ transformation.											

Salinity level (dS/m): Seed germination (%)

Rootstock	2018–19						2019–20					
	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean
Rough lemon	9.18 (83.33)	8.99 (80.00)	8.81 (76.67)	8.22 (66.67)	6.65 (43.33)	8.37 (70.00)	9.00 (80.00)	8.81 (76.67)	8.60 (73.33)	8.02 (63.33)	6.40 (40.00)	8.17 (66.67)
Cleopatra mandarin	9.71 (93.33)	9.71 (93.33)	9.36 (86.67)	8.81 (76.67)	6.90 (46.67)	8.90 (79.33)	9.53 (90.00)	9.36 (86.67)	9.18 (83.33)	8.62 (73.33)	6.65 (43.33)	8.67 (75.33)
Pectinifera	9.18 (83.33)	8.81 (76.67)	8.41 (70.00)	8.02 (63.33)	6.13 (36.67)	8.11 (66.00)	8.99 (80.00)	8.62 (73.33)	8.22 (66.67)	7.57 (56.67)	6.13 (36.67)	7.91 (62.67)
Rangpur lime	9.71 (93.33)	9.54 (90.00)	9.18 (83.33)	8.62 (73.33)	7.36 (53.33)	8.88 (78.67)	9.53 (90.00)	9.53 (90.00)	9.17 (83.33)	8.43 (70.00)	7.12 (50.00)	8.76 (76.67)
Alemow	9.53 (90.00)	9.36 (86.67)	8.81 (76.67)	7.79 (60.00)	6.65 (43.33)	8.43 (71.33)	9.34 (86.67)	9.18 (83.33)	8.60 (73.33)	7.59 (56.67)	6.4 (40.00)	8.22 (68.00)
Volkamer lemon	9.88 (96.67)	9.71 (93.33)	9.36 (86.67)	8.81 (76.67)	7.59 (56.67)	9.07 (82.00)	9.71 (93.33)	9.71 (93.33)	9.18 (83.33)	8.38 (70.00)	7.34 (53.33)	8.86 (78.66)
NRCC-3	9.36 (86.67)	9.18 (83.33)	8.81 (76.67)	8.22 (66.67)	6.65 (43.33)	8.44 (71.33)	9.17 (83.33)	8.99 (80.00)	8.60 (73.33)	8.22 (66.67)	6.37 (40.00)	8.27 (68.67)
NRCC-4	9.53 (90.00)	9.36 (86.67)	8.81 (76.67)	8.21 (66.67)	6.90 (46.67)	8.56 (73.33)	9.36 (86.67)	9.18 (83.33)	8.81 (76.67)	7.98 (63.33)	6.62 (43.33)	8.39 (70.67)
CRH-12	9.54 (90.00)	9.53 (90.00)	9.18 (83.33)	8.02 (63.33)	7.12 (50.00)	8.68 (75.33)	9.36 (86.67)	9.18 (83.33)	8.99 (80.00)	8.02 (63.33)	6.90 (46.67)	8.49 (72.00)
Mean	9.51 (89.63)	9.35 (86.67)	8.97 (79.63)	8.30 (68.15)	6.88 (46.67)		9.33 (86.30)	9.17 (83.33)	8.82 (77.04)	8.09 (64.81)	6.66 (43.70)	
CD (P=0.05)	Rootstock = 0.28 Salinity = 0.38 Rootstock × Salinity = NS						Rootstock = 0.25 Salinity = 0.35 Rootstock × Salinity = NS					
	Original data given in parentheses were subjected to angular transformation											

Table 3 Effect of salinity on fresh shoot and root biomass (g/plant) in different citrus rootstocks

Rootstock	Salinity level (dS/m)																							
	Fresh shoot biomass (g/plant)												Fresh root biomass (g/plant)											
	2018–19						2019–20						2018–19						2019–20					
	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean
Rough lemon	33.17	32.88	30.63	23.89	17.50	27.61	30.03	29.77	27.73	22.63	16.62	25.36	9.84	9.75	9.54	8.78	7.98	9.18	8.79	8.71	8.53	7.85	7.16	8.21
Cleopatra mandarin	17.98	17.67	15.98	13.47	10.96	15.21	15.00	14.74	13.33	11.57	9.38	12.81	7.83	7.72	7.58	6.93	6.18	7.25	6.84	6.74	6.62	6.05	5.43	6.33
Pectinifera	20.45	20.14	17.73	14.00	9.83	16.43	17.40	17.14	15.09	12.05	8.89	14.11	6.93	6.80	6.09	5.15	4.12	5.82	5.91	5.80	5.20	4.39	3.62	4.98
Rangpur lime	37.90	37.54	35.78	31.80	23.61	33.33	35.15	34.82	33.18	29.49	22.24	30.98	10.12	10.02	9.86	9.34	8.48	9.56	9.20	9.11	8.97	8.49	7.73	8.70
Alemow	18.10	17.88	15.57	12.71	9.83	14.82	15.04	14.86	12.94	10.86	8.51	12.44	4.59	4.46	4.35	3.80	3.17	4.07	3.57	3.47	3.38	2.96	2.50	3.18
Volkamer lemon	36.83	36.50	32.87	28.14	22.83	31.43	33.84	33.54	30.20	25.86	21.49	28.98	10.15	10.05	9.86	9.36	8.51	9.59	9.15	9.07	8.89	8.44	7.69	8.65
NRCC-3	29.69	29.24	26.94	23.12	17.00	25.20	26.69	26.29	24.22	20.78	15.74	22.74	7.60	7.48	7.33	6.78	5.78	6.99	6.60	6.50	6.37	5.89	5.05	6.08
NRCC-4	18.89	18.50	16.94	13.79	9.88	15.60	15.80	15.47	14.17	11.53	8.64	13.12	4.29	4.19	3.98	3.45	3.01	3.78	3.26	3.18	3.03	2.79	2.32	2.92
CRH-12	19.52	19.35	17.89	15.55	12.00	16.86	16.67	16.52	15.28	13.28	10.48	14.45	7.21	7.12	6.94	6.15	5.38	6.56	6.26	6.18	6.03	5.54	4.71	5.74
Mean	25.84	25.52	23.37	19.61	14.83		22.85	22.57	20.68	17.56	13.56		7.62	7.51	7.28	6.64	5.85		6.62	6.53	6.33	5.82	5.13	
CD (P=0.05)	Rootstock = 2.82 Salinity = 2.49 Rootstock × Salinity = 4.62						Rootstock = 2.67 Salinity = 2.23 Rootstock × Salinity = 4.34						Rootstock = 0.46 Salinity = 0.35 Rootstock × Salinity = 0.67						Rootstock = 0.36 Salinity = 0.30 Rootstock × Salinity = 0.55					

Table 4 Effect of salinity on dry shoot and root biomass (g/plant) in different citrus rootstocks

Rootstock	Salinity level (dS/m)																							
	Dry shoot biomass (g/plant)												Dry root biomass (g/plant)											
	2018–19						2019–20						2018–19						2019–20					
	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean	(Control)	2.5	4.0	5.5	7.0	Mean
Rough lemon	11.26	11.01	9.78	8.03	6.16	9.25	10.48	10.24	9.10	7.57	5.96	8.67	4.48	4.43	4.14	3.77	3.18	4.00	4.17	4.12	3.85	3.51	2.99	3.73
Cleopatra mandarin	6.63	6.50	6.10	5.35	4.50	5.82	5.88	5.77	5.41	4.75	4.05	5.17	3.89	3.84	3.46	3.06	2.57	3.36	3.52	3.47	3.13	2.77	2.36	3.05
Pectinifera	5.85	5.70	5.06	4.18	3.10	4.78	5.09	4.96	4.40	3.64	2.61	4.14	3.66	3.56	3.35	2.98	2.05	3.12	3.28	3.19	3.00	2.67	1.87	2.80
Rangpur lime	12.61	12.50	11.80	10.80	9.10	11.36	11.93	11.82	11.16	10.21	8.68	10.76	5.17	5.10	4.74	4.27	3.76	4.61	4.83	4.76	4.42	4.01	3.54	4.31
Alemow	5.95	5.80	5.30	4.50	3.18	4.55	5.19	5.05	4.62	3.92	2.78	4.31	2.18	2.10	1.87	1.62	1.31	1.81	1.80	1.73	1.54	1.33	1.11	1.50
Volkamer lemon	12.20	12.10	11.30	10.05	8.75	10.88	11.45	11.36	10.61	9.56	8.31	10.26	5.19	5.11	4.88	4.31	3.71	4.64	4.82	4.74	4.53	4.03	3.48	4.32
NRCC-3	10.54	10.41	9.84	8.56	7.10	9.29	9.79	9.67	9.14	7.95	6.70	8.65	4.16	4.04	3.67	3.29	2.67	3.57	3.78	3.68	3.34	2.99	2.47	3.25
NRCC-4	5.90	5.75	5.05	4.35	3.50	4.91	5.13	5.00	4.39	3.78	3.13	4.28	2.36	2.25	2.15	1.98	1.59	2.07	1.98	1.88	1.80	1.66	1.34	1.73
CRH-12	6.08	5.98	5.58	5.08	4.25	5.40	5.37	5.28	4.93	4.48	3.80	4.77	4.28	4.21	3.97	3.56	3.05	3.81	3.92	3.86	3.64	3.26	2.83	3.50
Mean	8.56	8.42	7.76	6.77	5.52		7.81	7.68	7.08	6.21	5.11		3.93	3.85	3.58	3.20	2.65		3.57	3.49	3.25	2.91	2.45	
CD (P=0.05)	Rootstock = 0.72 Salinity = 0.67 Rootstock × Salinity = 1.28						Rootstock = 0.69 Salinity = 0.63 Rootstock × Salinity = 1.23						Rootstock = 0.35 Salinity = 0.29 Rootstock × Salinity = 0.84						Rootstock = 0.31 Salinity = 0.25 Rootstock × Salinity = 0.79					

(83 to 37%), followed by Alemow (90 to 43%) in the year 2018–19. Similar pattern of seed germination percentage of different rootstocks was also observed in the year 2019–20. The data revealed non-significant interaction for per cent germination among rootstocks and salinity levels in both the years. The results of present study corroborate the earlier findings (Sharma *et al.* 2013, Fadli *et al.* 2015, Alam *et al.* 2020) who stated that seed germination deceased with increase in salinity in various citrus rootstocks.

Fresh root and shoot biomass (g/plant): The outcomes of existing study specify that salinity level and rootstock; both influenced the fresh shoot and root biomass significantly and observed a gradual decrease in fresh shoot and root biomass with an increased salinity level from control to 7 dS/m in both the years of study (Table 3). The maximum fresh shoot biomass was observed in Rangpur lime at control, which was at par (37.90, 37.54 and 35.78 g/plant) with Rangpur lime at 2.5 and 4.0 dS/m and Volkamer lemon (36.83 and 36.50 g/plant) at control and 2.5 dS/m, respectively, while the minimum fresh shoot biomass (9.83 g/plant) was recorded in Pectinifera and Alemow at 7 dS/m in the year 2018–19, which was also at par with NRCC-4. The maximum fresh root biomass (10.15 g/plant) was recorded in Volkamer lemon, which was statistically at par with Rangpur lime and Rough lemon at control, 2.5 and 4.0 dS/m, while the minimum fresh root biomass (3.01 g/plant) was recorded in NRCC-4 at 7 dS/m, which was at par with Alemow (3.17 g/plant) at 7 dS/m in the year 2018–19. Like pattern was detected in the succeeding year.

Dry shoot and root biomass (g/plant): The outcomes of existing study specify that dry shoot and root biomass were significantly influenced by different salinity levels and rootstocks and found a gradual decrease in different citrus rootstocks as the salinity level was increased (Table 4) in both the years. The maximum dry shoot biomass was observed in Rangpur lime at control (12.61 g/plant), which was at par with Rangpur lime (12.50 and 11.80 g/plant) and Volkamer lemon (12.20 and 12.10 g/plant) at control and 2.5 dS/m, respectively, while the minimum dry shoot biomass (3.10 g/plant) was recorded in Pectinifera at 7 dS/m, which was statistically at par with Alemow, CRH-12 and NRCC-4. The maximum (5.19 g/plant) dry root biomass was recorded in Volkamer lemon (5.19 g/plant), at control which was at par with Volkamer lemon at 2.5 and 4.0 dS/m, Rangpur lime at control, 2.5 and 4.0 dS/m and Rough lemon at control and 2.5 dS/m, while the minimum dry root biomass was recorded in Alemow (1.31 g/plant) in the year 2018–19. The same trend was observed in the following year as well.

As salinity levels increased from control to 7 dS/m, a significant reduction (Table 3 and 4) in fresh shoot (37.7, 38.0, 38.5 and 52.0%) and fresh root biomass (21.0, 22.0, 26.0 and 40.6%) and dry shoot (27.8, 28.3, 30.1 and 47.0%) and dry root biomass (26.9, 27.6, 28.7 and 43.9%) over control was recorded minimum in Rangpur lime, followed by Volkamer lemon and CRH-12, whereas, the reduction was found maximum in Pectinifera, respectively in the year 2018–19. Additionally, a similar trend was observed in the fresh and dry shoot and root biomass of all citrus rootstocks in the subsequent year (2019–20). The current study has results in accordance with the plant biomass reported by Balal *et al.* (2012), Sharma *et al.* (2013), Adams *et al.* (2019) and Shahid *et al.* (2019) concluded increase in salt concentration leads to reduction in total plant dry weight.

This study provides valuable insights as salinity levels increased from 0.07 to 7.0 dS/m, seed germination percentage decreased, while the number of days required for seed germination increased across all rootstocks. Additionally, there was a decline in the fresh and dry shoot and root biomass. Among the tested rootstocks, Rangpur lime, Volkamer lemon, and CRH-12 demonstrated superior performance with relatively lower reduction in biomass, on the other hand, Cleopatra mandarin, Rough lemon, and NRCC-3 exhibited a moderate response with comparatively less reduction in biomass. In contrast, Pectinifera, Alemow, and NRCC-4 were found to be less tolerant, displaying higher reduction in biomass at 7 dS/m compared to the control. Notably, the reduction in these parameters was less pronounced up to 4.0 dS/m, but showed a sharp decline thereafter. These findings hold significant implications for citrus growers and researchers by enhancing the sustainability and productivity of citrus orchards by selecting suitable rootstocks for cultivation in saline conditions depending on tolerance. Furthermore, such insights can facilitate the development of new and improved cultivars through breeding programmes or genetic engineering approaches.

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