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RESEARCH ARTICLE

Impact of salinity stress on germination and growth potential of sorghum genotypes

Tamilarasan Arikrishnan[1], Vinothini Nedunchezhiyan[2], Vasudev Ramaraj[1], Susi Sivakumar[1] & Jegadeeswaran Mokkaraj[1*]

[1]Department of Genetics and Plant Breeding, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu 603 201, Tamil Nadu, India

[2]Department of Seed Science and Technology, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu 603 201, Tamil Nadu, India

*Correspondence email - jegades@gmail.com

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Abstract

Salinity presents a major challenge to agriculture, negatively impacting crop growth and yield in different ways. As a result, various strategies have been implemented to handle the problem of low productivity. The cultivation of salt-tolerant crops represents a practical solution for achieving profitable yields in saline regions, emphasizing the need for a rapid method to screen for salt-tolerant genotypes, especially in their early growth stages. Consequently, a seed germination test was conducted to assess parameters such as germination percentage, root length, shoot length, fresh weight and dry matter production to identify the salt-tolerant sorghum genotype. The findings indicate that the sorghum genotypes G_{34} (IS6710), G_{48} (IS19159), G_1 (IS6312), G_{50} (IS6316) and G_2 (IS6313) exhibited tolerance to elevated salt concentrations. These physiological parameters can effectively screen large sorghum germplasm collections, facilitating the identification of salt-tolerant lines suitable for cultivation in saline regions.

Keywords: genotypes; germination; NaCl; salt stress; vigour

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) has emerged as a vital grain crop in the quest for global food security and enhanced agricultural sustainability. With its origins traced back to Africa, sorghum ranks as the fifth most significant cereal crop on a global scale, belonging to the extensive Poaceae family. Characterized by a genome size of approximately 730 megabases, sorghum is particularly renowned for its remarkable resilience to drought and moderate salinity. This resilience is essential for cultivating sorghum in semi-arid regions where conventional crops often falter due to insufficient water availability (1, 2). Globally, sorghum production has shown promising growth, reaching 58.28 million metric tons, an increase from 57.53 million metric tons the previous year. The United States leads sorghum production with an output of around 8.07 million metric tons, followed closely by Nigeria at 6.4 million metric tons and substantial contributions from countries such as India, Mexico and Brazil (3, 4).

Salinity in agriculture poses a pervasive threat to productivity, attributable to the excessive buildup of soluble salts in both soil and irrigation water. This phenomenon generates osmotic stress, which hampers water uptake by plants and precipitates ion toxicity, primarily from sodium (Na^+) and chloride (Cl^-) ions. The adverse impacts of salinity stress manifest in various forms, including diminished yields, compromised nutritional quality of crops, imbalanced nutrient uptake and heightened production of reactive oxygen species (ROS). These ROS contribute to oxidative damage and can significantly impair plant health, ultimately affecting crop viability and productivity (5, 6).

Sorghum inherent ability to thrive in moderately saline conditions presents a promising avenue to mitigate the challenges imposed by salinity in agricultural systems. Research has demonstrated that certain sorghum genotypes exhibit salinity tolerance at levels reaching up to 70 mM NaCl. Understanding and exploring the genetic diversity within sorghum germplasm is crucial for the development of resilient, salt-tolerant varieties (7, 8). Furthermore, sorghum plants possess the capacity to accumulate compatible solutes such as proline, carbohydrates and various amino acids. These compounds play a pivotal role in osmotic regulation, helping to maintain cellular function and integrity under salinity-induced stress conditions (9).

During the initial stage of stress imposition, seed soaking emerges as a highly effective and sustainable approach to enhance plant performance under abiotic stresses by facilitating various physiological and biochemical modifications (10). This technique involves the controlled hydration of seeds, which promotes pre-germinative metabolic activities while preventing the premature emergence of the radicle. Research has shown that, under saline conditions, soaking seeds in water can significantly improve germination rates. Additionally, utilizing saline solutions at concentrations of 50 mM, 100 mM, 150 mM and 200 mM NaCl has been demonstrated to mitigate oxidative damage caused by ROS (11). Specifically, NaCl soaking has been associated with increased levels of soluble carbohydrates and proline, enhanced activity of antioxidant enzymes and improved protection of seed membranes from oxidative injury (12). Therefore, this study aims to identify salt-tolerant sorghum genotypes and evaluate their physiological and biochemical traits contributing to resilience under saline conditions.

Materials and Methods

The laboratory experiment was conducted in 2025 at the Genetics and Plant Breeding Laboratory of SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayenpettai, Chengalpattu district. The purpose of the experiment was to evaluate the germination and seedling traits of 100 sorghum genotypes, The 87 genotypes were sourced from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), along with 13 genotypes collected from various locations in and around Tamil Nadu, evaluated under different salinity levels.

The experiment included various treatments designed to assess the effects of salinity on physiological seed quality parameters. The treatments consist of a control group (without soaking - T_0), hydropriming (using distilled water - T_1) and sodium chloride (NaCl) at different concentrations: T_2 (50 mM), T_3 (100 mM), T_4 (150 mM) and T_5 (200 mM). To prepare the treatment solutions, NaCl was dissolved in distilled water. Each treatment was applied in a tray filled with sterilized sand, measuring 15 cm in length, arranged according to a Factorial Complete Randomized Design (FCRD) with four replicates.

Each treatment involved 25 seeds, which were surface sterilized and soaked in the respective NaCl solutions to simulate initial stress conditions. The soaked seeds were sown in the trays for salinity screening. The sterilized sand was exposed to different salinity levels corresponding to each treatment concentration. Throughout the duration of the experiment, germination counts were carefully recorded until all seeds had either germinated or perished, alongside evaluations of physiological seed quality parameters of understanding of seed behavior under varying salinity stresses.

Germination (%)

$$\text{Germination (\%)} = \frac{\text{No. of Seeds Germinated}}{\text{Total No. of Seeds Sown}} \times 100$$

We conducted a germination test on 100 genotypes according to ISTA (13) guidelines and the results are definitive. The germination rate was thoroughly measured over time and on the 14th day, we accurately recorded the number of normal seedlings during the final count.

Root length (cm)

On the 14th day, ten healthy seedlings were randomly selected from each replication and final count of germination was observed. The root length of each seedling was measured from the point where the seed is attached to the tip of the primary root. It is expressed in cm.

Shoot length (cm)

On the 14th day, ten healthy seedlings were randomly selected from each replication and final count of germination was observed. The seedlings used to measure root length are also used to measure shoot length, which is taken from the point of attachment to the tip of the leaf. It is expressed in cm.

Fresh weight (mg 10 seedlings 10^{-1})

The root and shoot biomass of selected seedlings were measured taking initial weights to compare fresh and dry weights. It is expressed in mg 10 seedlings 10^{-1}.

Dry matter production (mg 10 seedlings 10^{-1})

The root and shoot biomass of the selected seedlings were initially placed in a paper cover and shade-dried for 24 hr. Following this step, they were dried in a hot air oven set to 80 °C for 16 hr. It is expressed in mg 10 seedlings 10^{-1}.

Vigor index

Vigour index values were calculated using the formula provided and the mean values were expressed as whole numbers (14).

Vigour Index = Germination % x Total Seeding Length (cm)

Statistical analysis

An analysis of variance was conducted, followed by comparisons using Duncan's Multiple Range Test (DMRT). A mean difference was considered significant at P-values less than 0.05. The statistical analysis was performed using SPSS version 16.0 (SPSS Inc., Chicago, USA).

Results and Discussion

The germination percentage of sorghum was significantly decreased by salinity stress, albeit the extent of the reduction differed depending on the genotype and the concentration of NaCl. The highest germination percentages were continuously shown by genotype G34 at all salinity levels. G1, G48 and G50 were next in line and they likewise showed comparatively stable performance under stress. Competitive germination rates were also demonstrated by G31, G26 and G29 at moderate doses (100–150 mM NaCl). All things considered, the data show that G34 is the genotype that can withstand the highest salinity, whereas G1, G48 and G50 also fare well under rising salt stress (Table 1).

Genotypes showed notable differences in root length between NaCl treatments. With G34 (50 mM) and G1 (100 mM) at the top, G34/G48/G1 formed the leading group at 50 and 100 mM. The best ranking groups were G2, G50 and G48 under greater stress (150 mM), whereas G34 led at 200 mM, followed by G1, with G48 and G26 tied and G50 not far behind. G34, G1 and G48 exhibited the most consistent resistance across concentrations, but overall root length decreased as salt increased (Fig. 1).

The analysis of shoot length data reveals significant variations in shoot growth in response to increasing levels of NaCl concentration. At 100 mM NaCl, the groups exhibiting the longest

Table 1. Effect of salinity stress on vigour index of sorghum genotypes

Genotype (G)	T_0	T_1	T_2	T_3	T_4	T_5
G_1	4321 ± 27.93	5107 ± 20.85	3943 ± 18.78	3316 ± 30.46	2730 ± 20.43	1640 ± 7.81
G_2	3988 ± 2.71	4899 ± 60.00	3753 ± 45.96	3048 ± 10.37	2687 ± 35.65	1473 ± 6.51
G_3	3642 ± 22.30	4038 ± 1.37	3288 ± 19.02	2748 ± 41.14	2161 ± 31.61	1135 ± 12.74
G_4	3416 ± 46.49	4227 ± 63.27	3129 ± 33.00	2533 ± 2.59	2172 ± 5.17	1123 ± 12.99
G_5	3690 ± 1.26	4016 ± 51.92	3320 ± 38.40	2742 ± 42.91	2151 ± 7.32	1081 ± 6.99
G_6	3507 ± 2.39	4010 ± 32.74	3159 ± 37.61	2601 ± 30.09	2072 ± 7.05	1222 ± 2.49
G_7	3459 ± 41.19	4021 ± 38.30	3113 ± 3.18	2503 ± 38.32	2055 ± 31.46	1075 ± 10.24
G_8	3493 ± 20.20	4304 ± 51.25	3291 ± 27.99	2582 ± 15.81	2004 ± 28.63	1235 ± 13.44
G_9	3581 ± 52.39	4164 ± 28.33	3074 ± 34.51	2610 ± 14.21	2197 ± 11.96	1201 ± 0.41
G_{10}	3567 ± 19.42	4354 ± 31.11	3123 ± 3.19	2519 ± 19.71	2100 ± 2.86	1095 ± 3.35
G_{11}	3399 ± 32.38	4147 ± 57.84	3174 ± 47.51	2614 ± 0.89	2095 ± 0.00	1220 ± 5.81
G_{12}	3546 ± 20.51	4144 ± 43.70	3131 ± 38.35	2599 ± 13.26	2153 ± 3.66	1075 ± 10.24
G_{13}	3485 ± 37.94	4046 ± 5.51	3150 ± 13.93	2676 ± 5.46	2093 ± 12.82	1165 ± 13.08
G_{14}	3634 ± 2.47	4015 ± 42.34	3159 ± 20.42	2587 ± 20.24	2166 ± 2.21	1153 ± 16.08
G_{15}	3617 ± 36.92	4242 ± 28.86	3243 ± 36.41	2588 ± 27.29	2175 ± 34.78	1163 ± 1.98
G_{16}	3490 ± 9.50	4103 ± 68.40	3114 ± 38.14	2603 ± 32.77	2199 ± 12.72	1137 ± 0.39
G_{17}	3367 ± 38.95	4122 ± 57.50	3130 ± 23.43	2694 ± 20.16	2102 ± 10.73	1075 ± 13.17
G_{18}	3433 ± 17.52	4296 ± 5.85	3240 ± 11.02	2537 ± 24.17	2175 ± 22.20	1110 ± 2.27
G_{19}	3529 ± 24.01	4194 ± 19.98	3091 ± 13.67	2639 ± 43.09	2141 ± 9.47	1107 ± 4.52
G_{20}	3406 ± 48.67	4029 ± 32.90	3163 ± 37.66	2658 ± 33.46	2112 ± 28.02	1295 ± 20.71
G_{21}	3577 ± 43.81	4248 ± 60.70	3118 ± 22.28	2577 ± 18.41	2163 ± 6.62	1264 ± 6.88
G_{22}	3449 ± 2.35	4222 ± 63.20	3134 ± 21.32	2638 ± 0.00	1979 ± 9.43	1225 ± 10.00
G_{23}	3465 ± 18.86	4176 ± 68.19	3194 ± 1.09	2619 ± 32.08	2213 ± 24.84	1205 ± 17.63
G_{24}	3654 ± 13.67	4111 ± 60.14	3081 ± 4.19	2503 ± 29.80	2032 ± 17.97	1086 ± 0.37
G_{25}	3507 ± 11.93	4017 ± 19.13	3246 ± 25.40	2629 ± 31.30	2188 ± 25.31	1222 ± 8.73
G_{26}	4013 ± 58.71	4998 ± 13.60	3614 ± 59.02	3042 ± 27.94	2689 ± 0.91	1453 ± 19.28
G_{27}	3495 ± 47.56	4162 ± 42.48	3071 ± 40.75	2614 ± 24.01	2048 ± 6.27	1163 ± 2.37
G_{28}	3479 ± 36.69	4077 ± 65.19	3301 ± 11.23	2588 ± 7.04	2095 ± 27.80	1080 ± 2.57
G_{29}	4080 ± 48.58	4875 ± 24.88	3531 ± 40.84	2961 ± 23.17	2602 ± 11.51	1362 ± 14.83
G_{30}	3678 ± 26.28	4021 ± 58.82	3197 ± 10.88	2612 ± 8.89	2071 ± 13.39	1118 ± 7.23
G_{31}	4045 ± 35.78	4768 ± 32.44	3481 ± 29.61	2944 ± 36.06	2487 ± 3.38	1372 ± 21.94
G_{32}	3456 ± 55.26	4181 ± 52.63	3096 ± 14.75	2600 ± 27.42	2056 ± 4.90	1168 ± 9.14
G_{33}	4009 ± 35.46	4789 ± 14.66	3504 ± 56.03	3005 ± 35.78	2568 ± 3.49	1373 ± 13.08
G_{34}	4455 ± 74.27	5256 ± 19.67	4117 ± 14.01	3408 ± 20.87	2883 ± 6.87	1665 ± 26.06
G_{35}	3473 ± 57.90	4271 ± 50.86	3149 ± 36.42	2728 ± 15.78	2114 ± 10.79	1148 ± 15.23
G_{36}	3556 ± 31.45	4228 ± 46.03	3228 ± 39.53	2711 ± 1.84	2181 ± 4.45	1214 ± 11.15
G_{37}	3707 ± 27.75	4146 ± 26.80	3167 ± 49.56	2659 ± 0.90	2129 ± 33.32	1060 ± 11.18
G_{38}	3424 ± 40.77	4244 ± 56.31	3257 ± 28.81	2705 ± 41.41	2162 ± 33.10	1118 ± 14.83
G_{39}	3472 ± 5.91	4027 ± 9.59	3178 ± 20.54	2511 ± 36.73	2143 ± 8.02	1120 ± 0.38
G_{40}	3437 ± 52.62	4061 ± 55.26	3039 ± 35.15	2513 ± 5.13	2114 ± 23.73	1190 ± 16.77
G_{41}	3504 ± 21.46	4064 ± 22.12	3176 ± 49.70	2532 ± 7.75	2215 ± 14.32	1295 ± 18.22
G_{42}	3669 ± 32.45	4023 ± 43.80	3194 ± 11.95	2656 ± 19.88	2185 ± 25.27	1240 ± 4.41
G_{43}	3529 ± 56.43	4122 ± 46.28	3176 ± 41.06	2491 ± 30.51	2146 ± 12.41	1175 ± 4.22
G_{44}	3602 ± 34.31	4281 ± 58.26	3146 ± 11.77	2689 ± 34.76	2142 ± 18.95	1075 ± 5.60
G_{45}	3472 ± 35.44	4175 ± 2.84	3185 ± 36.84	2606 ± 8.87	2161 ± 12.50	1065 ± 7.68
G_{46}	3480 ± 2.37	4003 ± 1.36	3169 ± 2.16	2637 ± 14.35	2038 ± 16.64	1145 ± 3.99
G_{47}	4090 ± 18.09	4727 ± 33.77	3508 ± 22.68	2903 ± 11.85	2548 ± 38.14	1341 ± 14.02
G_{48}	4148 ± 26.81	5224 ± 44.43	3859 ± 18.38	3215 ± 18.59	2748 ± 9.35	1581 ± 10.04
G_{49}	3430 ± 32.67	4195 ± 67.08	3046 ± 34.20	2611 ± 0.89	2065 ± 9.84	1158 ± 2.15
G_{50}	4241 ± 2.89	5059 ± 61.96	3781 ± 43.74	3134 ± 26.66	2694 ± 32.99	1537 ± 18.52
G_{51}	3302 ± 44.93	4019 ± 27.35	3152 ± 45.04	2775 ± 27.38	2173 ± 21.44	1240 ± 3.14
G_{52}	3433 ± 4.67	4365 ± 53.46	3219 ± 40.52	2526 ± 0.00	2124 ± 25.29	1227 ± 8.02
G_{53}	3546 ± 57.91	4292 ± 67.17	3118 ± 16.97	2570 ± 41.97	2190 ± 25.33	1168 ± 16.29
G_{54}	3616 ± 34.45	4356 ± 47.42	3307 ± 41.63	2518 ± 8.57	2263 ± 21.56	1086 ± 4.43
G_{55}	3602 ± 23.28	4261 ± 8.70	3178 ± 23.79	2701 ± 30.32	2046 ± 3.48	1134 ± 4.24
G_{56}	3360 ± 8.00	4117 ± 11.21	3183 ± 12.99	2539 ± 22.46	2045 ± 16.70	1097 ± 13.44
G_{57}	3429 ± 46.66	4178 ± 56.86	3219 ± 16.43	2718 ± 38.84	2205 ± 1.50	1227 ± 0.83
G_{58}	3500 ± 40.48	4180 ± 34.13	3105 ± 13.73	2647 ± 43.23	2037 ± 5.54	1225 ± 1.25
G_{59}	3383 ± 34.53	4211 ± 20.06	3192 ± 22.80	2487 ± 24.54	2177 ± 9.63	1139 ± 13.17
G_{60}	3507 ± 27.44	4025 ± 16.43	3213 ± 24.05	2637 ± 38.58	2271 ± 21.63	1232 ± 18.02
G_{61}	3659 ± 59.75	4156 ± 33.93	3178 ± 36.76	2547 ± 25.13	2238 ± 6.09	1112 ± 15.89
G_{62}	3554 ± 24.18	4196 ± 4.28	3163 ± 10.76	2706 ± 20.25	2163 ± 16.19	1279 ± 18.28
G_{63}	3323 ± 39.57	4229 ± 2.88	3270 ± 53.40	2664 ± 35.35	2153 ± 6.59	1258 ± 20.54
G_{64}	3410 ± 12.76	4365 ± 53.46	3226 ± 34.02	2498 ± 12.75	2099 ± 10.71	1135 ± 6.56
G_{65}	3399 ± 5.78	3991 ± 42.09	3207 ± 44.73	2613 ± 8.00	2137 ± 15.99	1139 ± 15.89
G_{66}	3654 ± 23.62	4394 ± 73.25	3127 ± 20.21	2655 ± 18.07	2165 ± 16.94	1065 ± 6.16
G_{67}	3439 ± 8.19	4204 ± 42.91	3223 ± 36.18	2605 ± 2.66	2248 ± 26.00	1222 ± 0.83
G_{68}	3424 ± 15.14	4308 ± 60.09	3239 ± 23.14	2595 ± 18.54	2264 ± 8.47	1186 ± 1.61
G_{69}	3583 ± 26.82	4186 ± 22.79	3132 ± 42.62	2627 ± 9.83	2107 ± 11.47	1155 ± 4.72
G_{70}	3523 ± 9.59	4263 ± 42.06	3123 ± 7.44	2595 ± 41.49	2113 ± 28.75	1269 ± 20.29
G_{71}	3566 ± 7.28	4105 ± 39.10	3180 ± 8.65	2543 ± 28.55	2181 ± 5.19	1139 ± 17.44
G_{72}	3481 ± 30.79	4037 ± 50.82	3155 ± 25.76	2643 ± 3.60	2122 ± 0.00	1095 ± 16.02
G_{73}	3335 ± 53.33	4196 ± 37.12	3159 ± 20.42	2539 ± 35.42	2228 ± 17.43	1264 ± 11.61
G_{74}	3443 ± 1.17	4223 ± 17.24	3170 ± 8.63	2574 ± 3.50	2005 ± 10.23	1191 ± 4.46
G_{75}	3448 ± 19.94	4186 ± 29.91	3167 ± 5.39	2534 ± 10.35	2081 ± 28.32	1165 ± 16.25
G_{76}	3434 ± 28.04	4254 ± 17.37	3158 ± 34.38	2577 ± 28.93	2149 ± 22.66	1180 ± 15.66
G_{77}	3525 ± 28.78	4075 ± 54.07	3054 ± 47.79	2643 ± 35.07	2196 ± 8.97	1264 ± 15.91

G_{78}	3676 ± 58.78	4104 ± 40.49	3176 ± 44.30	2608 ± 24.84	2121 ± 18.04	1191 ± 8.51
G_{79}	3437 ± 33.91	4104 ± 30.72	3116 ± 50.88	2676 ± 33.68	2126 ± 29.65	1123 ± 11.84
G_{80}	3463 ± 45.95	4167 ± 35.44	3160 ± 31.18	2765 ± 15.99	2198 ± 32.15	1117 ± 3.04
G_{81}	3403 ± 46.31	4165 ± 65.18	3231 ± 3.30	2622 ± 13.38	2106 ± 11.46	1217 ± 2.07
G_{82}	3475 ± 40.20	4235 ± 69.16	3079 ± 35.61	2725 ± 36.16	2270 ± 18.53	1108 ± 11.31
G_{83}	3510 ± 1.19	4276 ± 21.82	3196 ± 38.06	2629 ± 0.00	2145 ± 8.76	1235 ± 1.68
G_{84}	3494 ± 7.13	4152 ± 60.74	3179 ± 23.79	2597 ± 11.49	2143 ± 16.04	1178 ± 5.21
G_{85}	3595 ± 39.14	4234 ± 4.32	3266 ± 50.00	2681 ± 19.15	2146 ± 23.36	1097 ± 17.54
G_{86}	3388 ± 19.59	4041 ± 30.25	3151 ± 1.07	2602 ± 41.61	2224 ± 18.92	1230 ± 0.84
G_{87}	3361 ± 37.73	4001 ± 29.95	3250 ± 22.11	2666 ± 30.84	2128 ± 18.10	1091 ± 11.14
G_{88}	3356 ± 11.42	4370 ± 7.43	3178 ± 42.17	2648 ± 18.02	2230 ± 6.83	1238 ± 0.84
G_{89}	3555 ± 15.72	4171 ± 15.61	3268 ± 27.79	2699 ± 2.75	2162 ± 30.16	1148 ± 12.50
G_{90}	3488 ± 45.09	4240 ± 4.33	3090 ± 51.51	2533 ± 4.31	2202 ± 5.24	1191 ± 15.40
G_{91}	3381 ± 48.31	4330 ± 14.73	3189 ± 35.80	2511 ± 28.19	2229 ± 23.51	1186 ± 6.86
G_{92}	3440 ± 23.41	4110 ± 39.15	3200 ± 52.26	2697 ± 32.11	1997 ± 6.79	1095 ± 9.31
G_{93}	3625 ± 39.46	4400 ± 50.90	3265 ± 11.11	2628 ± 15.20	2040 ± 12.49	1163 ± 10.29
G_{94}	3443 ± 25.77	4431 ± 6.03	3138 ± 12.81	2607 ± 42.57	2139 ± 32.75	1117 ± 15.96
G_{95}	3484 ± 58.08	4206 ± 65.82	3212 ± 6.56	2650 ± 6.31	2249 ± 26.01	1255 ± 2.56
G_{96}	3596 ± 13.46	4135 ± 39.39	3259 ± 39.91	2692 ± 10.07	2155 ± 13.20	1225 ± 1.67
G_{97}	3344 ± 35.27	4111 ± 5.59	3183 ± 8.66	2525 ± 1.72	2153 ± 27.83	1265 ± 9.04
G_{98}	3313 ± 4.51	4174 ± 41.18	3283 ± 53.61	2666 ± 32.65	2157 ± 11.01	1264 ± 0.86
G_{99}	3537 ± 21.66	4209 ± 48.69	3092 ± 26.30	2535 ± 37.95	2139 ± 16.74	1095 ± 5.22
G_{100}	3496 ± 58.28	4290 ± 5.84	3190 ± 49.92	2578 ± 0.88	2050 ± 21.62	1217 ± 12.01
Mean	3559.04	4252.57	3228.99	2662.54	2192.88	1198.30
SEd	48.31	59.29	45.32	35.49	26.62	16.12
CD (5 %)	95.08	116.68	89.20	69.85	52.39	31.72

Vigour index (Mean ± SE, n = 4) of different treatments (T): (T_0 – Control, T_1 – Hydropriming, T_2 – 50 mM of NaCl, T_3 – 100 mM of NaCl, T_4 – 150 mM of NaCl, T_5 – 200 mM of NaCl. The analysis of variance was carried out and compared by Duncan's multiple range test (DMRT) at 5 % significance level.

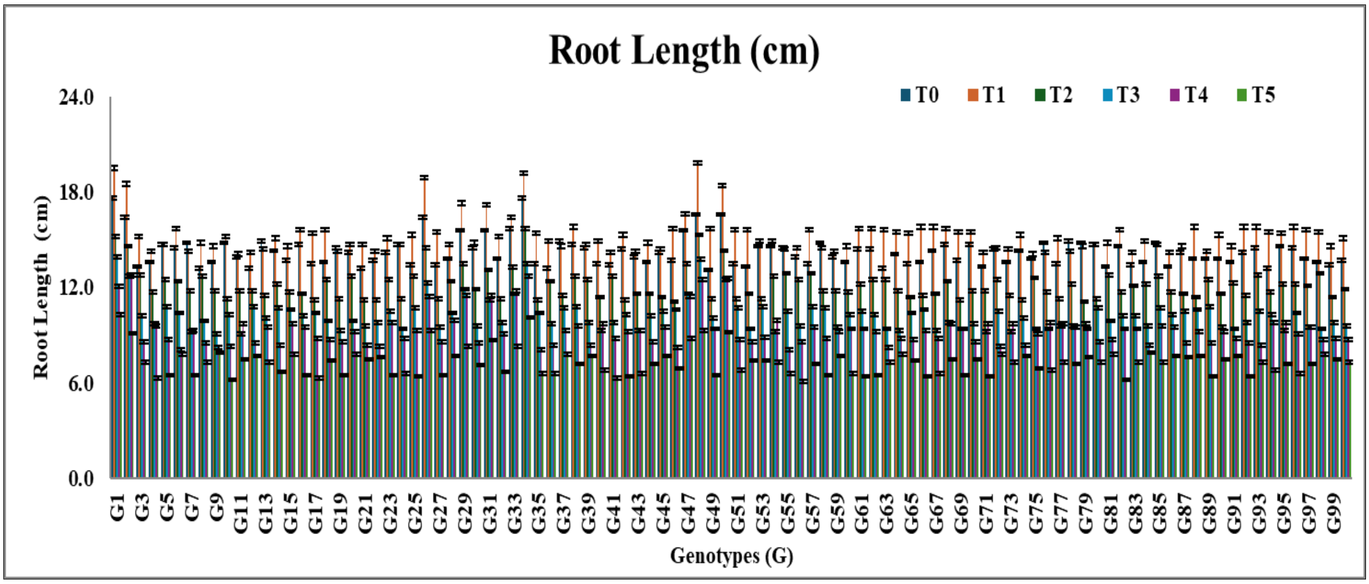

Fig. 1. Effect of salinity stress on root length (cm) potential of sorghum genotypes. Root length (Mean ± SE, n = 4) of different treatments (T): (T_0 - Control, T_1 - Hydropriming, T_2 - 50 mM of NaCl, T_3 - 100 mM of NaCl, T_4 - 150 mM of NaCl, T_5 - 200 mM of NaCl. The analysis of variance was carried out and compared by Duncan's multiple range test (DMRT) at 5 % significance level.

shoot lengths were G_{34}, measuring 35.9 %, followed closely by G_1 at 35.6 %, G_{48} at 34.9 %, G_{26} at 34.5 % and G_{50} at 34.3 %, shows a higher tolerance to saline stress in these groups. As the NaCl concentration increased to 150 mM, G_{34} continued to lead at 31.6 %, with G_1at 31.2 %, G_{50} at 30.8 %, G_{26} at 30.6 % and G_2 at 30.5 %. This pattern indicates that while shoot growth is impeded at higher salinity levels, some groups maintain relatively strong growth. At the highest concentration of 200 mM NaCl, shoot lengths further declined across all groups, with G_1 recording 27.8 %, followed by G_{34} at 27.3 %, G_{26} at 26.9 %, G_{48} at 26.8 % and G_{50} at 26.5 % (Fig. 2). The findings show that although some groups can maintain shoot growth in high salinity, the general trend indicates that high salinity negatively affects shoot development. This highlights the varying levels of salt tolerance among different groups into mechanisms of salt stress resistance.

Salinity significantly impacted both the fresh and dry weights (mg 10 seedling^{-1}) of seedlings across all genotypes. The genotypes G_{34} (498.7), G_1 (490.9), G_{48} (482.8), G_{50} (479.9) and G_2 (477.6) exhibited the highest fresh weights at all salinity levels, including 200 mM NaCl. Additionally, these genotypes recorded the highest dry weights at each concentration, with values of G_{34} (115.5), G_1 (114.3), G_{48} (113.4), G_{50} (112.5) and G_2 (109.2) (Fig. 3 & 4). Overall, these genotypes demonstrated excellent performance in fresh and dry weight measurements under salinity conditions.

The results demonstrated the performance of various genotypes regarding their vigour index (VI) under different salinity levels, revealing significant changes. At a salinity concentration of 150 mM NaCl, the genotypes G_{34}, G_{48}, G_1, G_{50} and G_{26} exhibited the highest vigour index values. When salinity increased to 200 mM NaCl, significant changes were observed again, as genotypes G_{34}, G_1, G_{48}, G_{50} and G_2 continued to achieve the highest vigour index scores indicating their ability to thrive even in more challenging environments (Table 1).

Seed germination is essential for developing resistant

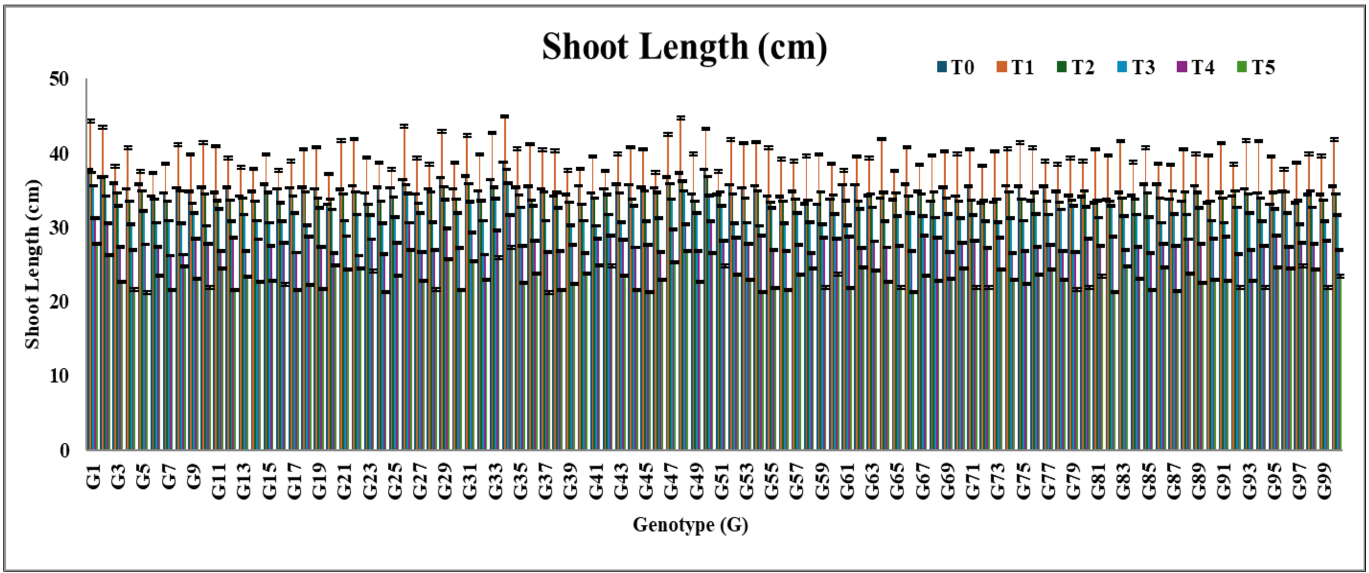

Fig. 2. Effect of salinity stress on shoot length (cm) potential of sorghum genotypes. Shoot length (Mean ± SE, n = 4) of different treatments (T): (T_0 - Control, T_1 - Hydropriming, T_2 - 50 mM of NaCl, T_3 - 100 mM of NaCl, T_4 - 150 mM of NaCl, T_5 - 200 mM of NaCl). The analysis of variance was carried out and compared by Duncan's multiple range test (DMRT) at 5 % significance level.

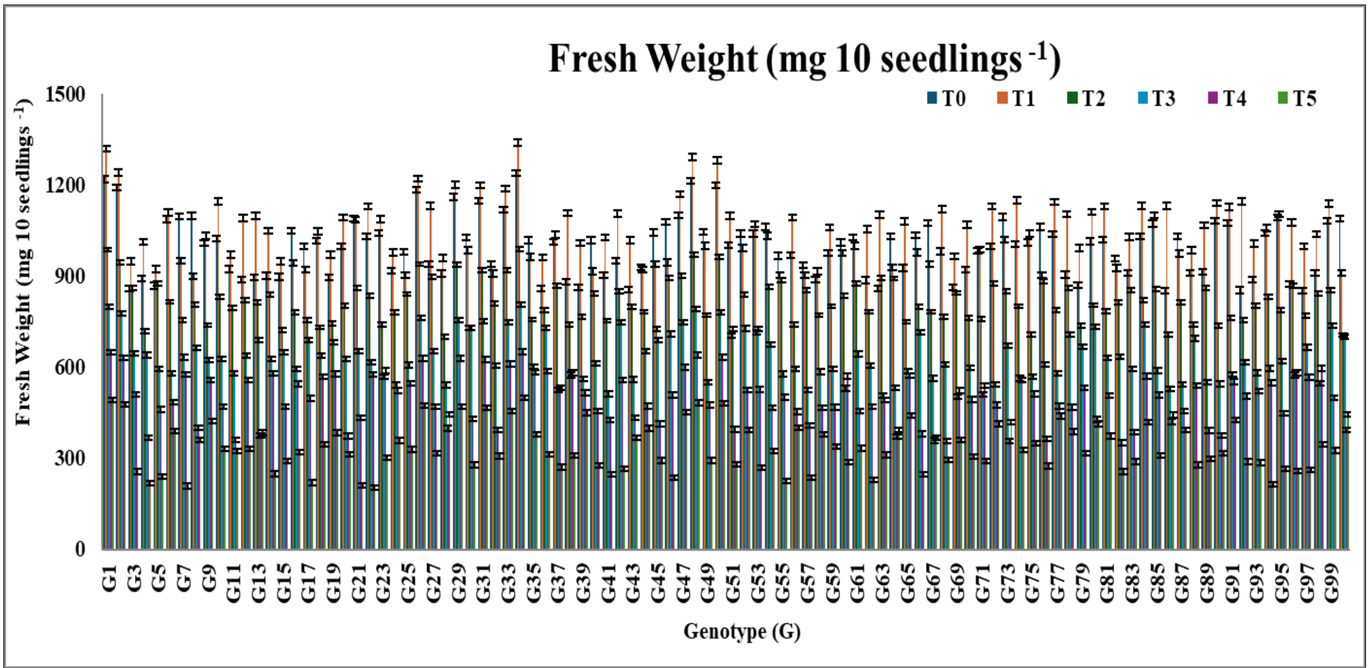

Fig. 3. Effect of salinity stress on fresh weight (mg 10 seedlings^{-1}) potential of sorghum genotypes. Fresh weight (Mean ± SE, n = 4) of different treatments (T): (T_0 - Control, T_1 - Hydropriming, T_2 - 50 mM of NaCl, T_3 - 100 mM of NaCl, T_4 - 150 mM of NaCl, T_5 - 200 mM of NaCl. The analysis of variance was carried out and compared by Duncan's multiple range test (DMRT) at 5 % significance level.

cultivars under salinity stress, as higher salt concentrations would lower water potential and inhibit water absorption (15). Our results show that germination percentage declines with increase in salinity, particularly at 200 mM NaCl across genotypes: G_{34}, G_{48}, G_1, G_{50} and G_2. This reduction is linked to biochemical and physiological changes, including osmotic stress that generates ROS, damaging cells and disrupting protein synthesis necessary for germination. Salinity reduces the germination of seed, due to ionic imbalances and oxidative stress. This is one of the reasons for extended germination time and decreased germination rate (16). Primarily germination percentage is caused due to chloride and sodium toxicity to the embryo and affects protein synthesis (17). The findings suggest that these genotypes may be resilient to lower salinity levels, opening avenues for research on their adaptive mechanisms and the development of more robust cultivars for saline environments.

In several research work reported that salt concentration affects the root growth. It is because root is the first developing organ in the plant (17). The changes in root elongation, root anatomy negatively is due to the excessive salt uptake (18). Research shows that increased salinity causes a notable decline in root length, primarily due to the toxic effects of sodium ions (Na+) on root and overall plant development. In experiments with various sorghum genotypes, NaCl treatments at 100 mM, 150 mM and 200 mM resulted in marked reductions in root length, especially at the highest concentration, where the G_1 variety reached 10.3 cm under control conditions and exhibited less than 50 % reduction in root length at 100 mM NaCl. In contrast, the G_{56} variety had only 6.1 cm. While all genotypes reacted to salinity, the extent of reduction varied, with G_1 and G_{48} showing relative tolerance. The findings emphasize the vulnerability of root growth to salinity, highlighting the need for research into developing salt-tolerant crop varieties to address the challenges posed by salinity for sustainable land management and food security.

Shoot length is influenced by salinity, which induces osmotic

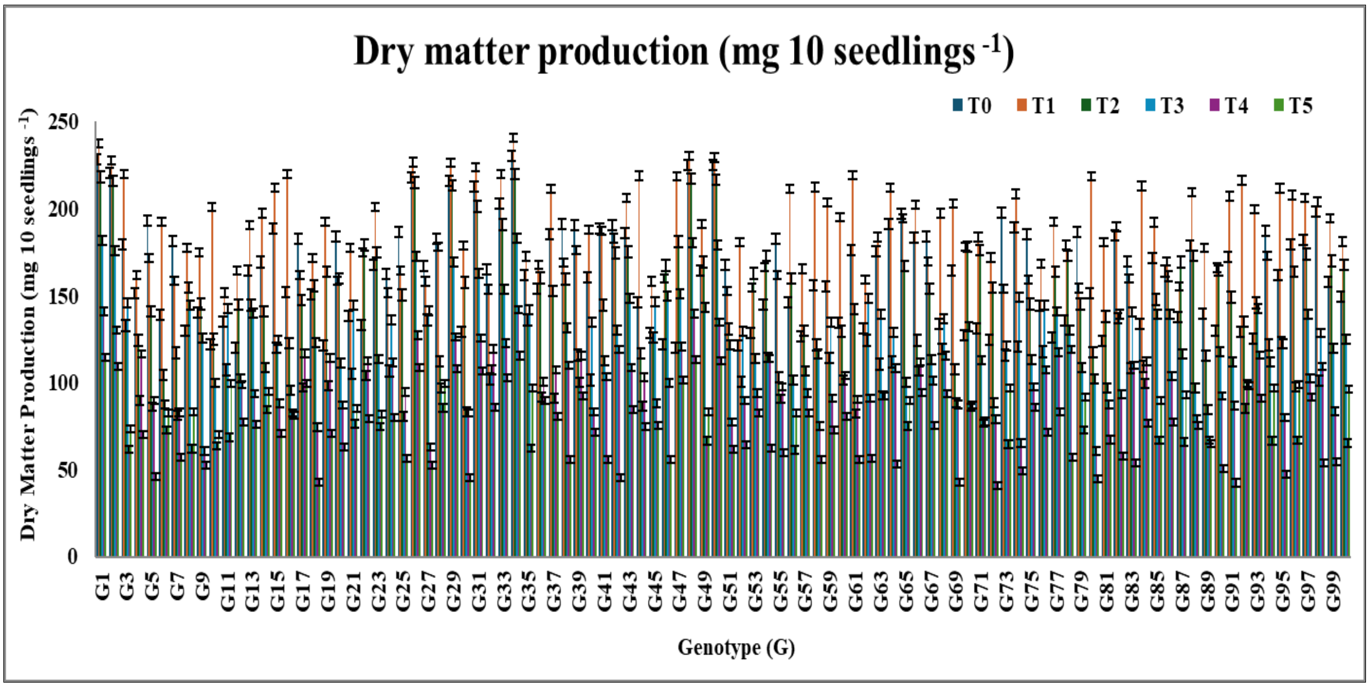

Fig. 4. Effect of salinity stress on dry matter production (mg 10 seedlings^{-1}) potential of sorghum genotypes. Dry matter production (Mean ± SE, n = 4) of different treatments (T): (T_0 – Control, T_1 – Hydropriming, T_2 – 50 mM of NaCl, T_3 – 100 mM of NaCl, T_4 – 150 mM of NaCl, T_5 – 200 mM of NaCl. The analysis of variance was carried out and compared by Duncan's multiple range test (DMRT) at 5 % significance level.

stress, limits water absorption and prioritizes root survival over-growth. Decline in shoot length may be attributed by reduced cell elongation due to lowered transport rate of essential ions, under high saline conditions (19). High salinity can cause ion toxicity, inhibiting shoot growth and stunting roots (20). Under control conditions, G_{34} had the longest shoot at 38.8 cm, while G_{95} was the shortest at 33.1 cm. Increased salinity significantly reduces shoot length; for example, at 100 mM NaCl, G_{34} and G_1 showed over 45 % reduction and over 60 % at 200 mM NaCl (21, 22). Salinity also decreases leaf growth, slows internode expansion and increases leaf drop (23, 24). High salinity during germination limits shoots length and tissue emergence, increasing toxicity and damaging cells (25, 26).

The effects of salinity stress on sorghum biomass show a clear link between higher salinity levels and reduced fresh and dry weights. At 50 mM NaCl (T_2), the mean fresh weight was 990.7 mg, significantly lower than the control group (T_0) at 1239.6 mg, indicating some resilience under moderate stress. However, at 200 mM NaCl (T_5), fresh weight plummeted to 202.62 mg, demonstrating that high salinity severely hinders growth. The decrease in dry biomass supports the idea that increased salinity negatively impacts photosynthesis. T_1 reached a peak dry weight of 237.5 mg, suggesting that lowering salinity can boost biomass. Elevated Na+ concentrations could be causing physical root damage, affecting nutrient and water absorption. This trend emphasizes the detrimental effects of salinity on plant growth and development, with the reduction in shoot fresh weight likely due to nutrient stress and the toxic impact of Na+, resulting in decreased photosynthesis at higher salinity levels, as highlighted by Soujanya (16). Understanding these complexities is crucial for developing effective strategies to mitigate the adverse effects of salinity on plants.

The seedling vigour has increased when NaCl concentration reduced, impacting the overall establishment of the seedlings (27) found that increased salinity significantly reduces seedling vigor, with the vigor index dropping from 4455 in the control group to 1665 at 200 mM NaCl and to 3408 and 2883 at 100 mM and 150 mM NaCl, respectively. This highlights salinity as a major challenge for agricultural productivity, driven by factors like saline irrigation and soil salinization. The chlorophyll content under salt stress condition affects the seedling growth, leading to decreased seedling vigour index (28). High salt levels cause osmotic stress and ionic toxicity, which disrupt vital plant processes and harm germination and seedling growth. To tackle these issues, the agricultural community must focus on identifying and cultivating salt-tolerant genotypes.

High sodium levels in sorghum can lead to the accumulation of harmful substances in the leaves, which inhibits the plant's ability to absorb essential nutrients such as potassium, calcium and magnesium. Research indicates that certain genotypes of sorghum exhibit the highest sodium accumulation alongside the lowest uptake of other minerals, with the exception of potassium, supporting findings by Calone (29). Although these genotypes may maintain a greater fresh shoot weight when exposed to salinity stress, they ultimately experience a reduction in biomass. This decline is likely attributed to increased respiration rates and the release of ethylene, which adversely affects both root and shoot growth (30, 31).

Conclusion

Salinity stress significantly affects sorghum germination and growth; however, genotypes such as G34 (IS6710), G48 (IS19159), G1 (IS6312), G50 (IS6316) and G2 (IS6313) demonstrated higher tolerance to elevated salt levels. These high-performing genotypes effectively accumulate beneficial compounds and activate antioxidant enzymes, enabling them to cope with salinity. These findings highlight the importance of selecting and breeding salt-tolerant sorghum varieties to enhance crop resilience in saline environments. Future research should find the genetic mechanisms behind this tolerance and investigate the potential for combining salinity resistance with other advantageous traits, such as drought tolerance. Ultimately, this research contributes to sustainable agricultural practices and aims to improve food security in regions affected by salinity and climate change.

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Authors' contributions

TA and VR performed the experiments. VN and SS analysed data. TA, SS and VR statistically analysed results. TA, SS and VR wrote the draft of the manuscript. VN and SS conducted the critical revision of the manuscript. VN and JM worked out the concept and design, supervised and funded the experiments. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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