

Effect of salinity stress on the morpho-physiological and yield components of some lentil genotypes

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RECEIVED 07.02.2026

ACCEPTED 15.06.2026

AVAILABLE ONLINE 17.09.2026

Abstract: Salt stress is a critical abiotic factor severely limiting crop productivity globally. Development of salt-tolerant genotypes can help address this challenge. Lentil is a very valuable legume, with high-quality proteins. However, it is susceptible to salinity stress. Sustainable lentil production in saline lands imposes crucial efforts to identify lentil germplasm with salinity tolerance. This pot experiment was conducted on six lentil genotypes using two types of soil: sandy and clay. The field capacity was determined for the clay soil after seven hours and for the sandy soil after two hours. The irrigation solution was prepared using saline solutions composed of CaCl_2 and NaCl (1:1) at different concentrations ($\text{dS}\cdot\text{m}^{-1}$). The seeds were planted after being sterilised with fungicides, and bacterial inoculation was performed immediately after planting. Salinity stress was applied in stages, and several measurements were taken at different growth stages. The control group was irrigated with fresh water with a concentration of $0.5\text{--}0.7\text{ dS}\cdot\text{m}^{-1}$. The plots were irrigated at 75% of field capacity. The study revealed significant differences among the local lentil genotypes tested at the morphological, physiological, and agronomic levels under salt stress conditions. Genotypes L.7678 and L.7210 showed better seed production capacity at a higher salinity level ($4\text{ dS}\cdot\text{m}^{-1}$), while only genotype L.7678 was able to maintain a good level of this trait at the highest salinity level ($6\text{ dS}\cdot\text{m}^{-1}$). Genotype L.7678 also exhibited significantly higher seed yield and biomass under all salinity levels (i.e., all treatments except the control group).

Keywords: leaf water potential, lentil, salinity stress, seed mass

INTRODUCTION

Salinity is recognised as one of the most critical abiotic stresses constraining agricultural productivity, particularly in arid and semi-arid regions (Shuvo *et al.*, 2020). Globally, it poses a significant challenge, with more than 800 mln ha of land affected by elevated salt concentrations (Shahid, Zaman and Heng, 2018). Shekhawat *et al.* (2024) examined 100 diverse lentil accessions for photosynthetic traits under both control and saline ($5\text{ dS}\cdot\text{m}^{-1}$) conditions and found that different genotypes from various clusters can be used as parents in hybridisation breeding programs to get transgressive segregants. Salinity limits crop

productivity primarily by impairing water and essential nutrient uptake, thereby reducing plant growth, development, and yield (Munns and Tester, 2008; Schleiff, 2008; Shrivastava and Kumar, 2015; Hussain *et al.*, 2017). Furthermore, it disrupts plant water and nutrient homeostasis, leading to ionic toxicity, osmotic stress, and oxidative damage, ultimately exacerbating water deficit conditions (Abdelgawad *et al.*, 2016; Hussain, Elnaggar and El-Keblawy, 2021).

Legumes are generally sensitive to salinity (Singh, Tewari and Singh, 1993; Mamo, Richter and Heiligttag, 1996). Among them, lentils (*Lens culinaris* Medik.) are an important cool-season food legume and rank as the fourth most significant legume crop

globally. It serves as an affordable source of dietary protein, playing a vital role in ensuring nutrition for economically disadvantaged populations in developing countries (Chatterjee *et al.*, 2023). Lentils contain 24–30% protein, making them a popular dietary component across all population segments and a staple in most meals. Shuvo *et al.* (2020) reported that salinity levels of 25, 50, 75, and 100 mM NaCl significantly reduced lentil growth and yield in experiments conducted in Bangladesh. Higher salinity concentrations decreased seed germination, branch number, and flower production. The study concluded that sodium chloride has an adverse effect on all yield-related traits in lentils and that there is variation in salinity tolerance among cultivars in Bangladesh. Similarly, Nadeem *et al.* (2019) observed that lentils exposed to 3 dS·m⁻¹ salinity (~30 mM NaCl) suffered approximately 90% yield loss, compared to other crops such as barley (10% yield loss at 66 mM NaCl), wheat (10% at 49 mM NaCl), and canola (10% at 73 mM NaCl).

Therefore, most farmers avoid cultivating lentils in saline environments; however, several studies have demonstrated significant variation in salt tolerance among lentil accessions. Panuccio *et al.* (2022) compared the responses of four lentil cultivars ('Castelluccio di Norcia', 'Eston', 'Ustica', and 'Pantelleria') grown in the field and irrigated with 100 mM NaCl to those of the same cultivars grown in non-saline soil. They reported that the tolerant cultivars accumulated sodium primarily in shoots and roots and were able to accumulate proline, which they utilised as an osmotic regulator.

The screening parameters most commonly employed to identify salt-tolerant genotypes include germination and prolonged seedling growth under saline conditions. These traits are utilised due to their high heritability, despite being quantitative, and because of the extreme sensitivity of the seedling stage compared to established plants (Arshi, Abdin and Iqbal, 2002). Shekhawat *et al.* (2024) evaluated several photosynthetic traits of 100 lentil accessions under normal and saline (5 dS·m⁻¹) conditions and selected genotypes from different clusters as possible parents in hybridisation breeding programs. Several researchers have conducted experiments to study the effects of salinity on lentil growth and early seedling parameters (Hossain, Ludwig and Leemans, 2018; Foti, Khah and Pavli, 2019; Pandey and Sengar, 2020; Yasir *et al.*, 2021). Muscolo *et al.* (2020) cultivated three lentil cultivars in soil with salinity levels below 4 dS·m⁻¹ to evaluate the nutritional and bioactive compounds of the edible parts, comparing them with lentils grown in non-saline soil. They found that salinity enhanced dietary properties such as protein content, minerals, ascorbic acid, tocopherols, carotenoids, flavonoids, and total phenols. Based on these results, they recommended that these three lentil cultivars could be grown on marginal lands, including semi-arid regions where soil salinity can reach 8 dS·m⁻¹. Cultivating these salt-tolerant cultivars was found to be particularly beneficial under conditions of water scarcity or when irrigation water is highly saline. This practice can improve the functional properties of the final product. They also recommended incorporating these tolerant cultivars into breeding programs to develop lentil varieties with high nutritional value. In a separate experiment in Iran, Saeidi (2022) studied lentils under rainfed conditions and five salinity levels of irrigation water with electrical conductivity of 0.5 (S0), 2 (S1), 4 (S2), 6 (S3), and 8 (S4) dS·m⁻¹. The researcher concluded that irrigation water with salinity levels up to S2 (4 dS·m⁻¹) could be

used for lentil cultivation, as biomass, grain, and straw yields at 4 dS·m⁻¹ were comparable to those under rainfed conditions.

Our study focused on evaluating the tolerance of six lentil genotypes selected from previous greenhouse screenings of several genotypes.

MATERIALS AND METHODS

The response of six lentil genotypes, obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA), was evaluated based on the initial screening of 200 genotypes. Their response to salt stress was assessed at all stages of germination, growth, and yield. Six genotypes with varying responses to salinity were selected using a laboratory screening technique at the seedling stage to differentiate between sensitive and resistant genotypes. These genotypes were tested using two soil types: sandy soil and clay soil. Physical and chemical characteristics of soils used in the experiment are presented in Table 1.

Table 1. Physical and chemical characteristics of soils used in the experiment

Characteristics	Soil type	
	clay	sandy
Clay (%)	62	0
Sand (%)	16	100
Silt (%)	22	0
Organic matter (%)	1.01	0.30
Calcium carbonate (%)	24.0	15.9
Electrical conductivity (dS·m ⁻¹)	0.24	0.50
pH	7.5	7.7

Source: own study.

The experiment was conducted in the greenhouse at ICARDA, with a day/night temperature of 30/20°C and 60% relative humidity and a light intensity of 20,000 lx for 12 h·d⁻¹.

The field capacity was determined after seven hours for clay soil (2 dm³) and after two hours for sandy soil (1.5 dm³). The irrigation solution was prepared using saline solutions composed of calcium chloride (CaCl₂) and sodium chloride (NaCl) at different concentrations (dS·m⁻¹). Salinity concentration was measured using a laboratory salinity meter and a field salinity sensor at the following concentrations: 0, 2, 4, and 6 dS·m⁻¹. In Table 2, the final soil salinity and acidity after finishing the experiment are shown.

Before sowing, NPK fertilisers were applied at a rate of 5 g·pot⁻¹. The seeds were sown after sterilisation with fungicides, and bacterial inoculation (with *Rhizobium leguminosarum* var. *viciae*) was performed immediately after sowing. Salt stress was applied at the following stages by applying 100 cm³ of the equivalent saline solution at each stage: germination, seedling development, vegetative development, branch initiation, onset of flowering, onset of podding, pod filling, seed filling, and onset

Table 2. The final soil salinity and acidity after finishing the experiment

Characteristics	Soil					
	clay			sandy		
Salinity level (dS·m ⁻¹)	2	4	6	2	4	6
Electrical conductivity (dS·m ⁻¹)	1.62	2.4	5.2	1.4	2.2	4.5
pH	7.2			7.5		

Source: own study.

of seed maturation, and several phenological (shoot mass (g), root mass (g), number of flowers), physiological (at 50% and 100% flowering), and reproductive (number of pods and seeds (g), mass of pods and seeds (g), and seed and biological yield (g)) measurements were taken. The experiment was laid out in a randomised complete block design (RCBD) with six replicates and three uniform plants per replicate. Analysis of variance (2-way ANOVA) was used to compare the means of genotypes, salinity levels, and their interaction ($p \leq 0.05$), and Fisher's least significant difference (LSD) test was used to indicate the significantly different means. All data presented in tables are the mean of six replicates $\pm$ standard error (SD).

RESULTS AND DISCUSSION

BRANCH NUMBER PER PLANT

Significant differences were observed among salinity treatments and genotypes under both clay and sandy soil conditions (Tab. 3). In both soil types, increasing salinity levels resulted in a reduction in the number of branches per plant; however, the percentage decrease varied significantly among genotypes. Under

salinity treatments, genotype L.7678 exhibited the highest number of branches in sandy soil, while genotype L.7210 showed the highest number in clay soil. Compared to the control treatment, the average reduction in branch number under the highest salinity level was 53.2% and 56.3% in sandy and clay soils, respectively. Our findings are consistent with those of Varalakshmi *et al.* (2025), who reported that increasing NaCl concentrations from 25 mM to 100 mM reduced the number of branches per plant in lentil, with significant variation among the five genotypes studied. Similar trends have also been reported in chickpea, where the reduction was greatest under the severe salinity treatment, where the number of branches, pods, and seeds per plant decreased by 53%, 45%, and 60%, respectively, while seed yield and biomass were reduced by 60% and 54%, respectively (Yasir *et al.*, 2021). Previous studies have confirmed that salt stress negatively affects shoot and root elongation due to excessive salt accumulation, which causes cell walls to become rigid, reducing elasticity and turgor pressure, ultimately limiting cell expansion and elongation. This leads to reduced root and shoot growth (Tefaye, Petros and Zeleke, 2014; Foti, Khah and Pavli, 2019; Rao, Peng and Xue, 2023). The present findings are in full agreement with earlier reports in lentil (Tefaye, Petros and Zeleke, 2014; Hossain, Ludwig and Leemans, 2018; Askari-Khorasani *et al.*, 2021).

Table 3. The effect of different salinity treatments on the branch number of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	3.3 $\pm$ 0.2	3.0 $\pm$ 0.3	1.7 $\pm$ 0.1	1.0 $\pm$ 0.1	2.3	3.7 $\pm$ 0.3	3.3 $\pm$ 0.3	2.7 $\pm$ 0.1	2.7 $\pm$ 0.1	3.1
L.7678	3.7 $\pm$ 0.3	3.7 $\pm$ 0.3	3.0 $\pm$ 0.3	2.3 $\pm$ 0.1	3.2	8.3 $\pm$ 0.5	5.7 $\pm$ 0.4	3.7 $\pm$ 0.3	3.3 $\pm$ 0.2	5.3
L.7553	4.7 $\pm$ 0.3	2.3 $\pm$ 0.1	2.0 $\pm$ 0.2	1.7 $\pm$ 0.2	2.7	3.3 $\pm$ 0.2	2.7 $\pm$ 0.1	2.3 $\pm$ 0.1	2.0 $\pm$ 0.1	2.6
L.7210	3.7 $\pm$ 0.1	2.7 $\pm$ 0.2	2.7 $\pm$ 0.2	1.7 $\pm$ 0.1	2.7	6.7 $\pm$ 0.3	6.3 $\pm$ 0.4	4.3 $\pm$ 0.2	3.3 $\pm$ 0.3	5.2
L.2501	2.7 $\pm$ 0.1	2.7 $\pm$ 0.1	2.0 $\pm$ 0.1	1.7 $\pm$ 0.1	2.3	6.0 $\pm$ 0.4	3.7 $\pm$ 0.1	2.7 $\pm$ 0.1	2.7 $\pm$ 0.1	3.8
L.590	2.7 $\pm$ 0.2	2.7 $\pm$ 0.2	2.3 $\pm$ 0.2	1.3 $\pm$ 0.1	2.3	9.7 $\pm$ 0.5	4.3 $\pm$ 0.1	4.3 $\pm$ 0.2	2.3 $\pm$ 0.2	5.2
Mean	3.5	2.9	2.3	1.6	2.6	6.3	4.3	3.3	2.7	4.2
LSD 5% genotype	0.57*					***0.77				
LSD 5% salinity treatment	0.47***					0.63***				
LSD 5% genotype $\times$ salinity treatment	1.15ns					*1.54				

Explanations: LSD = least significant difference, ns = not significant, * $p \leq 0.05$, *** $p \leq 0.001$.

Source: own study.

ROOT MASS

In lentil, gene expression regulation is more affected by salt stress in the root tissues than in the leaf tissues, leading to complicating the highlighted mechanisms by which those tissues respond to salt stress and magnifying the importance of root trait analyses under salinity conditions (Goudarzi *et al.*, 2024). Significant differences in this trait were observed among genotypes, salinity treatments, and their interaction (Tab. 4). In most genotypes, the control treatment produced the highest root dry mass in both soils. Increasing salinity levels resulted in a reduction in root dry mass, with the highest salinity level producing significantly lower values compared to the control in both soils. The lowest salinity level had a variable effect on this trait relative to the control; however, the differences became more pronounced at higher salinity levels (4 and 6 dS·m⁻¹). This result is in line with similar findings (Inal *et al.*, 2009; Shaheen, Tsadilas and Rinklebe, 2013; Meriem *et al.*, 2014; Kapoor and Pande, 2015).

Among genotypes, L.7678 exhibited the highest root dry mass, significantly greater than most other genotypes regardless of salinity treatment. Root dry mass was generally higher in sandy

soil than in clay soil, irrespective of genotype and salinity level. Similar findings were reported by Varalakshmi *et al.* (2025), who noted that salinity stress severely inhibited root elongation, resulting in reduced water uptake and salt toxicity, which ultimately decreased seedling growth under saline conditions compared to the control.

YIELD COMPONENT TRAITS

Flower number per plant

Analysis of variance of the data for flower formation showed that NaCl treatment had a significantly adverse effect on flower formation. Different genotypes responded differently to NaCl treatment (Tab. 5). The differences in flower number per plant among genotypes, among salinity treatments and within the interaction genotype×salinity treatment were all highly significant. Moreover, the soil type as well had an effect on this trait. In the sandy soil, all the genotypes failed to produce any flowers and deteriorated. Even in the control treatment, the genotypes showed large and significant differences in their ability to produce flowers, where L.7553 stood out as the genotype with the highest

Table 4. The effect of different salinity treatments on the root dry mass (g) of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	0.66 ±0.05	0.34 ±0.01	0.29 ±0.02	0.23 ±0.01	0.38	0.26 ±0.01	0.21 ±0.01	0.15 ±0.01	0.12 ±0.01	0.19
L.7678	1.25 ±0.01	1.14 ±0.06	0.78 ±0.07	0.36 ±0.02	0.88	0.66 ±0.04	0.57 ±0.03	0.46 ±0.03	0.34 ±0.02	0.51
L.7553	1.15 ±0.02	0.97 ±0.05	0.61 ±0.05	0.33 ±0.02	0.77	0.49 ±0.03	0.46 ±0.02	0.45 ±0.03	0.32 ±0.02	0.43
L.7210	1.09 ±0.01	0.7 ±0.06	0.38 ±0.03	0.17 ±0.01	0.59	0.49 ±0.04	0.55 ±0.04	0.32 ±0.01	0.13 ±0.01	0.37
L.2501	0.46 ±0.03	0.47 ±0.03	0.29 ±0.01	0.12 ±0.02	0.34	0.44 ±0.02	0.28 ±0.02	0.12 ±0.01	0.07 ±0.01	0.23
L.590	0.89 ±0.05	0.73 ±0.04	0.32 ±0.02	0.25 ±0.01	0.55	0.29 ±0.01	0.20 ±0.01	0.11 ±0.01	0.07 ±0.01	0.17
Mean	0.92	0.73	0.45	0.24	0.59	0.44	0.38	0.27	0.18	0.32
LSD 5% genotype	0.046***					0.117***				
LSD 5% salinity treatment	0.038***					0.095***				
LSD 5% genotype×salinity treatment	0.093***					0.234***				

Explanations: LSD, *** as in Tab. 4.

Source: own study.

Table 5. The effect of different salinity treatments on the flower number per plant of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	34.7 ±2.9	31.0 ±1.6	na	na	32.8	13.7 ±1.0	7.7 ±0.3	4.7 ±0.1	1.7 ±0.1	6.9
L.7678	41.0 ±3.3	35.3 ±2.2	na	na	38.2	55.3 ±4.1	31.7 ±2.3	13.0 ±0.5	10.0 ±0.4	27.5
L.7553	91.0 ±5.7	44.7 ±4.1	na	na	67.8	61.7 ±3.8	17.7 ±1.0	5.7 ±0.1	na	28.3
L.7210	9.7 ±0.3	3.7 ±0.1	na	na	6.7	31.7 ±1.2	24.7 ±0.7	21.7 ±1.6	4.0 ±0.1	20.5
L.2501	36.7 ±2.5	36.0 ±2.1	na	na	36.3	51.7 ±2.9	36.0 ±2.2	7.0 ±0.1	na	31.6

cont. Tab. 5

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.590	9.3 ±0.1	9.0 ±0.2	na	na	9.2	35.0 ±1.1	25.0 ±1.3	2.0 ±0.1	na	20.7
Mean	37.1	26.6	na	na	31.9	41.5	23.8	9.0	5.2	19.9
LSD 5% genotype	3.524***					2.478***				
LSD 5% salinity treatment	2.877***					2.023***				
LSD 5% genotype×salinity treatment	7.048***					4.956***				

Explanations: na = not applicable, LSD, *** as in Tab. 4.

Source: own study.

number of flowers per plant, whereas both L.7210 and L.590 had much lower values of this trait. Under salinity treatment (2 dS·m⁻¹), L.2501 could keep this trait at a very similar level compared to its control counterpart. However, L.7553 had the highest number of flowers per plant under this salinity treatment as well, although the decrease in flower number as compared to the control was significant, with a 50.9% decrease. In clay soil, most of the genotypes could produce more flowers per plant in the control treatment as compared to their counterparts in the sandy soil, but salinity decreased this trait drastically, especially at the highest salinity level, where only three genotypes could produce a significantly lower number of flowers per plant compared to their control counterparts. The L.7553 genotype had the highest number of flowers per plant in this soil as well when salinity was absent; however, even the lowest level of salinity resulted in a significantly lower number of flowers per plant, indicating its high susceptibility to salinity stress. The L.7678 genotype, could maintain a relatively high number of flowers under the lowest salinity level, but a significantly lower number when the salinity level was higher.

A similar conclusion was reported earlier by Katerji *et al.* (2001), who mentioned that lentils are very sensitive to salinity, much more than other legumes such as broad bean and soybean. Salt tolerance varies with weather conditions and variety. The authors reported decreased flower number of the two lentil genotypes tested when salinity levels increased from 0.7 to 2.0 and 3.1 dS·m⁻¹. The reduction was more pronounced under the highest salinity level compared to the other levels. Our result was consistent with the results of Shuvo *et al.* (2020) on lentils and showed that higher concentrations of salt have a negative impact on flower and pod numbers, and with Mohamedin, Abd El-Kader and Badran (2006), who also reported that salinity-induced water deficit reduced the plant growth and development of sunflowers.

Pod number per plant

A similar tendency was recorded in the number of pods per plant as well as in the flower number per plant, as highly significant differences were recorded among genotypes, among salinity treatments, and within the interaction genotype×salinity treatment (Tab. 6). In this trait, the soil type had an effect. In the

Table 6. The effect of different salinity treatments on the pod number per plant of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	33.3 ±2.6	26.0 ±1.0	na	na	29.7	13.0 ±0.1	6.3 ±0.1	3.0 ±0.1	0.7 ±0.02	5.8
L.7678	40.0 ±3.1	35.0 ±1.7	na	na	37.5	54.0 ±4.1	31.0 ±2.9	10.7 ±0.2	8.7 ±0.2	26.1
L.7553	89.7 ±5.9	43.7 ±2.2	na	na	66.7	63.7 ±3.9	17.0 ±1.1	3.7 ±0.1	na	28.1
L.7210	9.3 ±0.2	3.3 ±0.1	na	na	6.3	35.3 ±1.4	24.0 ±1.3	18.3 ±0.1	2.7 ±0.1	20.1
L.2501	36.3 ±2.1	35.0 ±1.8	na	na	35.7	60.3 ±5.1	38.7 ±3.6	4.7 ±0.1	na	34.6
L.590	9.3 ±0.1	9.0 ±0.1	na	na	9.2	33.3 ±2.7	24.3 ±1.3	2.0 ±0.1	na	19.9
Mean	36.3	25.3	na	na	30.8	43.3	23.6	7.1	4.0	19.5
LSD 5% genotype	3.676***					2.752***				
LSD 5% salinity treatment	3.001***					2.247***				
LSD 5% genotype×salinity treatment	7.351***					5.505***				

Explanations: LSD, *** as in Tab. 4, na as in Tab. 6.

Source: own study.

sandy soil, the genotypes showed large and significant differences in their ability to produce pods. Under both control and lowest salinity level conditions, L.7553 could produce the highest number of pods per plant; however, the decrease in pod number as a result of salinity stress was significant. Both L.7678 and L.2501 genotypes were able to maintain this trait at a similar level as compared to their control counterparts. In clay soil, the effect of salinity stress was more pronounced, with even the lowest level of salinity causing significant reductions in this trait. The L.2501 could maintain a relatively high number of pods under the lowest salinity level, but a significantly lower number when the salinity level was higher, whereas L.7678 and L.7210 could better tolerate the higher salinity level ($4 \text{ dS}\cdot\text{m}^{-1}$), with L.7678 showing even better tolerance under the highest salinity level, where the reduction of pod number was not significant. According to Saeidi (2022), salinity negatively affects pollination and seed development in the pods. Our results are in line with Yasir *et al.* (2021), who concluded that salinity stress severely inhibited the length of roots and shoots, the relative water content, the number of branches and pods, and salt accumulation disrupted plant–water relations (Morari *et al.*, 2015; Monsur *et al.*, 2020). It disrupts the metabolism in plant cells by inducing water inadequacy, oxygen insufficiency, and nutrient imbalance. The results are also supported by those of Singh, Sharma and Chillar (1988) and Patil *et al.* (2016), who reported decreased number of pods, total dry matter, and harvest index under salinity.

Seed number per plant

In both soils, the number of seeds per plant was significantly affected by the genotypes, the salinity levels, and their interaction (Tab. 7). As expected, L.7553 had the highest number of seeds when salinity stress was not imposed in the sandy soil; however, that was not the case in the clay soil, where L.2501 produced significantly higher numbers of seeds. Salinity had a significant effect on this trait as well, but the genotypes responded differently. In the sandy soil, L.2501, L.7678, and L.7214

genotypes had the lowest percentages (14.8%, 18.8%, and 28.3%, respectively) of decrease in seed number under salinity stress conditions. However, L.7553 could still produce a significantly higher number of seeds than any other genotype. In the clay soil, L.7678 and L.7210 showed better ability to produce seeds under higher ($4 \text{ dS}\cdot\text{m}^{-1}$) salinity level, whereas only L.7678 could maintain a fair level of this trait under the highest ($6 \text{ dS}\cdot\text{m}^{-1}$) salinity level. This result is in line with that of Pandey and Sengar (2020), that the decrease of pod mass was due to the effect of salinity stress on plant pollination and lack of grain filling, and seed number. According to Muscolo *et al.* (2015), the changes in water relations, transpiration, nutritional imbalances, and oxidative damage due to salt stress all contribute to a drop in yield; this has a considerable impact on crop reproductive responses and yield-contributing qualities, resulting in yield loss.

Seed yield

From a crop physiological perspective, seed yield is determined by two components: the amount of live mass at maturity, and the percentage of dry matter available for seed production, i.e., the harvest index. The harvest index is affected by the strength of the effluent (grain size $\times$ number of grains), as well as by the rate of distribution and transport of photosynthetic products between different parts of the plant. Generally speaking, the greater the amount of dry matter available for fruit growth, and the greater the rate of transfer of photosynthetic products to the grain, the greater the number of seeds formed per pod, the greater the degree of seed filling, and consequently the mass of 100 seeds. Lentil can face yield loss up to 90% under severe salinity stress conditions (Shekhawat *et al.*, 2024). In our experiment, the seed yield was significantly affected by both the genotype and the salinity treatment, and also by the interaction between these two factors (Tab. 8). Regardless of the genotype, increasing the salinity level was accompanied by a reduction in the seed yield in both soils. Among genotypes, L.7678 had significantly higher seed yield under all salinity levels (i.e., all treatments except for the control),

Table 7. The effect of different salinity treatments on the seed number per plant of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level ($\text{dS}\cdot\text{m}^{-1}$) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	33.00 $\pm$ 1.4	23.67 $\pm$ 1.1	na	na	28.3	17.7 $\pm$ 0.6	9.7 $\pm$ 0.8	3.3 $\pm$ 0.1	0.7 $\pm$ 0.01	7.8
L.7678	39.00 $\pm$ 1.5	31.67 $\pm$ 1.9	na	na	35.3	51.3 $\pm$ 2.8	27.0 $\pm$ 1.1	8.7 $\pm$ 0.4	7.3 $\pm$ 0.1	23.6
L.7553	91.33 $\pm$ 5.1	44.00 $\pm$ 2.6	na	na	67.7	55.0 $\pm$ 3.1	12.0 $\pm$ 0.3	2.0 $\pm$ 0.1	na	23.0
L.7210	9.33 $\pm$ 0.1	3.00 $\pm$ 0.1	na	na	6.2	31.3 $\pm$ 1.1	19.7 $\pm$ 0.9	13.3 $\pm$ 0.1	1.3	16.4
L.2501	36.00 $\pm$ 2.6	30.67 $\pm$ 1.3	na	na	33.3	75.3 $\pm$ 4.9	51.3 $\pm$ 3.8	5.7 $\pm$ 0.2	na	44.1
L.590	9.67 $\pm$ 0.5	8.00 $\pm$ 0.1	na	na	8.8	40.3 $\pm$ 1.5	25.3 $\pm$ 1.1	1.3 $\pm$ 0.06	na	22.3
Mean	36.4	23.5	na	na	30.0	45.2	24.2	5.7	3.1	19.6
LSD 5% genotype	4.293***					2.391***				
LSD 5% salinity treatment	3.505***					1.952***				
LSD 5% genotype $\times$ salinity treatment	8.586***					4.782***				

Explanations: LSD, *** as in Tab. 4, na as in Tab. 6.

Source: own study.

Table 8. The effect of different salinity treatments on the seed yield per plant of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	0.89 ±0.02	0.83 ±0.02	na	na	0.86	0.86 ±0.04	0.49 ±0.01	0.09 ±0.002	0.03 ±0.001	0.37
L.7678	2.69 ±0.06	1.31 ±0.004	na	na	2.00	2.75 ±0.04	1.54 ±0.01	0.48 ±0.01	0.25 ±0.01	1.26
L.7553	2.79 ±0.01	1.01 ±0.005	na	na	1.90	1.28 ±0.02	0.32 ±0.02	0.03 ±0.001	na	0.54
L.7210	0.59 ±0.02	0.08 ±0.002	na	na	0.34	1.81 ±0.01	0.75 ±0.05	0.48 ±0.01	0.05 ±0.001	0.77
L.2501	0.98 ±0.04	0.77 ±0.04	na	na	0.88	1.68 ±0.02	1.05 ±0.03	0.09 ±0.003	na	0.94
L.590	0.30 ±0.02	0.19 ±0.01	na	na	0.25	2.35 ±0.06	0.94 ±0.05	0.02 ±0.001	na	1.10
Mean	1.37	0.70	na	na	1.04	1.79	0.85	0.20	0.11	0.74
LSD 5% genotype	0.166***					0.06***				
LSD 5% salinity treatment	0.135***					0.0489***				
LSD 5% genotype×salinity treatment	0.332***					0.12***				

Explanations: LSD, *** as in Tab. 4, na as in Tab. 6.

Source: own study.

confirming the earlier conclusion of its tolerance to salinity stress. Moreover, this genotype had the highest seed yield when salinity was not applied in the clay soil, but not in the sandy soil, where L.7553 had relatively higher seed yield, but without the ability to produce any seeds in both soils under the highest salinity level. As a result, the grain yield was very sensitive; the reason was the effect of salinity stress on plant pollination and lack of grain filling (Rodríguez Coca *et al.*, 2023). Similarly, Kim *et al.* (2014) reported differences in the physiological and biochemical activities under saline conditions. Thus, salinity exerts significant and varied impacts on overall growth, yield, potential, as well as the quality and seed composition (Bouzroud *et al.*, 2023).

Biomass

In both sandy and clay soils, the dry biomass was significantly ($p < 0.001$) affected by salinity treatment, genotype, and the interaction of these two factors (Tab. 9). Unsurprisingly, the control treatment resulted in the best biomass in both soils. Increasing the salinity level was accompanied by decreased biomass in all genotypes. Even the lowest salinity level (2 dS·m⁻¹) caused a significant decrease in the biomass of most of the genotypes as compared to the control, with more pronounced differences in the clay soil. Except for the highest salinity level (6 dS·m⁻¹) in the sandy soil, L.7678 genotype could maintain the highest biomass under all salinity levels in both soils. This ability

Table 9. The effect of different salinity treatments on the dry biomass (g) of six lentil genotypes sown in sandy and clay soils

Genotype	Salinity level (dS·m ⁻¹) in soil type									
	sandy					clay				
	control	2	4	6	mean	control	2	4	6	mean
L.7214	1.26 ±0.04	1.1 ±0.02	0.32 ±0.01	0.14 ±0.01	0.71	1.09 ±0.01	0.96 ±0.03	0.45 ±0.02	0.23 ±0.02	0.68
L.7678	2.05 ±0.07	1.72 ±0.03	0.32 ±0.02	0.26 ±0.01	1.09	5.6 ±0.07	4.74 ±0.09	2.68 ±0.05	1.43 ±0.06	3.61
L.7553	3.67 ±0.05	1.75 ±0.04	1.16 ±0.05	0.23 ±0.02	1.70	4.19 ±0.05	2.18 ±0.08	1.62 ±0.04	1.01 ±0.04	2.25
L.7210	1.56 ±0.02	1.43 ±0.06	0.33 ±0.03	0.2 ±0.01	0.88	3.43 ±0.05	1.94 ±0.04	1.55 ±0.02	0.83 ±0.02	1.94
L.2501	0.88 ±0.02	0.68 ±0.03	0.62 ±0.04	0.34 ±0.02	0.63	2.83 ±0.03	1.89 ±0.02	0.59 ±0.02	0.43 ±0.02	1.44
L.590	1.27 ±0.04	1.23 ±0.01	0.33 ±0.01	0.33 ±0.02	0.79	3.33 ±0.02	2.1 ±0.03	1.01 ±0.01	0.46 ±0.01	1.73
Mean	1.78	1.32	0.51	0.25	0.97	3.41	2.30	1.32	0.73	1.94
LSD 5% genotype	0.153***					0.121***				
LSD 5% salinity treatment	0.125***					0.099***				
LSD 5% genotype×salinity treatment	0.306***					0.243***				

Explanations: LSD, *** as in Tab. 4.

Source: own study.

to maintain relatively high biomass under salinity conditions can be attributed to the ability of this genotype to maintain inner homeostasis through osmotic adjustment as a result of scavenging accumulating Na ions into the vacuoles, in addition to the osmolyte synthesis (Sahin *et al.*, 2018). Soil salinity increases Na⁺ and Cl⁻ ions in the plant cells, causing a reduction in the K⁺/Na⁺ ratio (Singh *et al.*, 2017). This ion accumulation leads to ionic imbalance and, consequently, to osmotic stress, resulting in negative effects on the development, biochemical processes, and plant biomass, and leading eventually to plant death (Zhang *et al.*, 2013).

CONCLUSIONS

Salinity exerted significant and varied impacts on overall growth, yield, and potential of lentil genotypes. Increasing the salinity level was accompanied by a decrease in several phenological, physiological and yield component traits in all genotypes studied. The lowest salinity level (2 dS·m⁻¹) caused a significant decrease in the biomass of most of the genotypes as compared to the control, with more pronounced differences in the clay soil. Except for the highest salinity level (6 dS·m⁻¹) in the sandy soil, the L.7678 genotype could maintain the highest biomass under all salinity levels in both soils.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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