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MITIGATION OF SALINITY STRESS WITH COMPOST, BIOCHAR, AND PRESSMUD IN CLUSTER BEAN CROP PRODUCTION

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Abstract

Salt stress has an adverse impact on the growth and development of plants. The harmful effects of salt stress differ depending on factors such as duration, severity, timing, the type of plant tissues involved, and the growth stage of the plant. Cluster bean is recognized as one of the most significant industrial crops worldwide, owing to its extensive application in various food and non-food products. The cluster bean crop is somewhat tolerant of salinity stress. But by improving the soil environment by application of organic amendment, improved growth and yield of better cluster bean crops can be achieved. The present greenhouse experiment was carried out to assess the effects of organic amendments (control, biochar, compost, and pressmud) on the yield of four cluster bean genotypes (BR-2017, S-5885, S-6165, and S-6547) in a saline environment with an electrical conductivity of 8 dSm^{-1}.The salinity of 8 dSm^{-1} was developed with NaCl salt in the pot. The experiment was replicated thrice within a Completed Randomized Design (CRD). The application of organic amendments helped to ameliorate the salinity effect. The plant showed better growth where organic amendments over control were no organic amendment was applied. The control exhibited higher sodium levels in both the leaf and root, while lower potassium levels were also observed in the control. Consequently, the sodium-potassium ratio was elevated in control compared to the plots treated with organic amendments. In BR-2017, the application of biochar, compost, and pressmud resulted in sodium contents in the leaf that were 24.3%, 42.1%, and 9.3% lower, respectively, when compared to the control. Among the cultivars, S-6165 displayed higher sodium levels in the root than the other cultivars (BR-2017, S-5885, and S-6547) across all treatments (Control, biochar, compost, and pressmud). Organic amendments can be a helpful option to improve the soil environment for better growth of cluster beans in saline conditions. However, long-term field studies are recommended to revalidate the findings.

Key words: Cluster bean cultivars; Organic amendments; Potassium contents; Salt stress; Soil environment

Introduction

The rise in salinity poses a significant risk to global food security. The extent of salinized areas is steadily growing across various regions worldwide. Approximately 62 million hectares of irrigated land globally face salinity issues (Athar *et al*., 2009). The accumulation of excessive sodium ions in the rhizosphere leads to the formation of soil salinity (Bless *et al*., 2018; Iqbal *et al*., 2020). Mineralizing, sediment, and action in soils are the main natural sources of salinity (Andrade *et al*., 2018). However, the interruption of salt water into the groundwater of seaside areas and atmospheric deposition of oceanic salts are also major sources of soil salinization (Rengasamy, 2006). Due to high evaporation and evapotranspiration processes, salts move upward in areas with low water table depth (Liu *et al.,* 2021).

Salt stress has a detrimental impact on crop productivity. The salt stress effects differ depending on factors such as timing, intensity, duration, plant tissues types, growth stage, and frequency of stress (Munns *et al*., 2000; Srivastava *et al*., 2019). Chaum & Kirdmanee (2009) found decreased in fresh and dry weight and leaf area of seedling when salt stress was gradually increased. Salinity stress causes stunted crop growth and development by disrupting physiological and cellular processes in plants (Munns, 2000; Munns & Tester, 2008; Munns, 2011; Munir *et al*., 2021). Wheat crops subjected to salinity during germination and seedling establishment experienced negative effects on crop stand establishment (Munns *et al*., 2006). Afzal *et al*., (2006) found that high salt concentrations in the wheat rhizosphere reduced the final seed germination and seedling growth retardation. Soil salinity can induce osmotic, ionic, and oxidative stresses (Munns & Tester, 2008; Ali *et al*., 2020; Alvi *et al*., 2025; Munir, 2025). Management of salinity stresses can be achieved through enhanced practices like selection of slat tolerant varieties, timely sowing and use of organic amendments with judicious of fertilizers (Ahmad *et al*., 2024).

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Pressmud serves as a soil enhancer for problematic soils, promoting sustainable high yields and soil health. Application of pressmud was found helpful in many studies to overcome salinity stress (Sheoran *et al*., 2020; Negima *et al*., 2016). The application of pressmud at a rate of 10 Mg ha^{-1} to the top 10 cm of moderately sodic soil resulted in increased relative water content, photosynthetic rate, transpiration rate, and stomatal conductance when compared to the control (Sheoran *et al*., 2020). Mengel & Kirkby (2001) found presumed helpful in dissolving fixed and mineral phosphorus by the production of carbonic acid in the rhizosphere on mineralization of Pressmud.

Biochar, a stable carbon-rich material produced through pyrolysis under limited oxygen conditions, exhibits strong sorption capacity and serves as an effective organic amendment for improving plant growth in highly contaminated or saline soils (Hammer *et al*., 2015; Parkash *et al*., 2020; Yang *et al*., 2020). In a pot experiment with potato, the application of biochar at 5 Mg ha^{-1} under saline stress (2 mM NaCl) significantly enhanced shoot dry weight, root length, root volume, tuber number, and overall tuber yield compared with the no-biochar control (Akhtar *et al*., 2015).

Compost application can enhance soil health by improving the retention of plant nutrients like potassium, phosphorus, and nitrogen. (Chadwick *et al*., 2000; Hristov *et al*., 2009; Misra *et al*., 2016; Nicholson *et al*., 2003). Compost can increase soil aggregation, bulk density reduction, and improving infiltration. The improvement in soil properties helps in mitigating the salinity stress. Naveed *et al*., (2021) found an increase in plant height, shoot fresh weight, and stem diameter of sunflowers grown in pot experiments with salinity stress of 12 dS m^{-1}.

Cluster bean is one of the most important industrial crops all over the globe due to its widespread use in food and non-food products (Sun *et al*., 2007; Sultan *et al*., 2013; Leontopoulos & Arabatzis, 2021). Cluster bean production is badly affected by salinity stress. The salinity stress can be overcome with the use of pressmud, biochar, and compost (Zafar-ul-Hye *et al*., 2021). But limited studies are conducted to compare these organic amendments in cluster bean production under salinity stress. The study was planned to evaluate organic amendment effects on growth, physiology, antioxidant potential, and ionic homeostasis of selected cluster bean genotypes in salinity stress.

Materials and Methods

Experimental SITE: A pot experiment was carried out in a Greenhouse at Muhammad Nawaz Sharif University of Agriculture, Multan, Pakistan. The temperature was fixed at 25°C throughout the experiment.

Treatments: Seeds of four cluster bean genotypes BR-2017, S-5885, S-6165, and S-6547 were obtained from the Directorate of Cluster Bean, Regional Agricultural Research Institute (RARI), Bahawalpur, Pakistan. Compost, biochar, and pressmud were sourced from the local market and analyzed for their physicochemical properties following standard analytical procedures. The analyses revealed that electrical conductivity values were 3.70, 3.32, and 3.79 dS m^{-1}; pH values were 6.24, 10.30, and 6.08; available potassium contents were 0.20, 0.13, and 0.14 mg kg^{-1}; and available phosphorus contents were 0.14, 0.12, and 0.11 mg kg^{-1} in compost, biochar, and pressmud, respectively.

Pot filling: Soil was collected from a depth of 15 cm in the agricultural fields of MNS-University of Agriculture, Multan. After collecting, it was sun-dried for one week, sieved through a 2 mm mesh, and analyzed for its physicochemical characteristics. The soil had an electrical conductivity of 2.01 dS m^{-1}, organic matter content of 0.56%, nitrogen content of 0.20%, available phosphorus of 5.60 mg kg^{-1}, and available potassium of 211.20 mg kg^{-1}. Organic amendments—biochar, compost, and pressmud—were added at a rate of 5% (w/w) following the methods of Shahzad K. *et al*., (2019), Li *et al*., (2019), and Arulazhagan *et al*., (2024). The amendments exhibited electrical conductivity values of 3.70, 3.32, and 3.79 dS m^{-1}; pH values of 6.24, 10.30, and 6.08; available potassium levels of 0.20, 0.13, and 0.14 mg kg^{-1}; and available phosphorus levels of 0.14, 0.12, and 0.11 mg kg^{-1} in compost, biochar, and pressmud, respectively. Soil, water, and the amendments were thoroughly homogenized using a mechanical shaker for ten minutes. The resulting mixture was transferred into plastic pots (12 inches high and 6 inches wide) and compacted to a bulk density of 1.3 Mg m^{-3}. Salinity stress was then induced by adding NaCl to reach an electrical conductivity of 8 dS m^{-1}, as described by Naveed *et al*., (2021).

Greenhouse experiment: The pot was arranged in Compete Randomized Design (CRD) in the greenhouse of MNS University of Agriculture, Multan, Pakistan. Two seeds were planted in each pot in the first week of June. The nitrogen, phosphorus, and potassium fertilizers were applied after 10 days of sowing. The thinning was done after 15 days of sowing. Only one plant was kept in each pot. The irrigation was applied after each week. At 45 days after planting, plants were harvested.

Data collection: The plant was removed from each pot. The height of the plant, along with the shoot and root lengths, was measured using a measuring scale. The fresh weight of the shoot was noted using an electronic balance. Subsequently, the seedling was placed in an oven set to 67 degrees Celsius for a duration of 72 hours. After the drying process, the weight was recorded once more. To calculate the relative water content (RWC), half a gram of fresh leaves was collected, and its weight was noted (Wf). These leaves were then submerged in water for four hours, after which their weight was recorded again (Ws). Finally, the leaves were dried in the oven, and their weight was measured once more (Wd).

RWC (%) was calculated using the following equation:

$$\text{Relative water contents (\%)} = \frac{(W_f - W_d)}{(W_s - W_d)} \times 100$$

Stomatal conductance, photosynthetic and transpiration rates were measured on fully expanded uppermost leaves using a portable photosynthesis system (Infra-Red Gas Analyzer) at light saturating intensity from 9:00 am to 12:00 noon. The SPAD chlorophyll contents were assessed using the SPAD 502 Plus Chlorophyll

Meter. Superoxide dismutase activity was evaluated according to the method established by Giannopolitis & Ries (1977), while Peroxidase activity was determined by the technique of Chance & Maehly (1955), and catalase activity was measured using the methods outlined by Chance & Maehly (1955).

The leaf and root samples were dried in oven, and grinded to convert into powered. Then, samples were digested with di-acid in digestion block. The potassium and sodium contents of leaf and root samples were measured using flame photo meter. The calibration curves for potassium (K) and sodium (Na) were developed using standard solutions of 20, 40, 60, 80, 100, 150, and 200 ppm. The potassium/sodium ratio was measured by dividing the potassium value with sodium value.

Statistical Analysis

The collected data were analyzed using linear mixed models in R software (version 4.1.2). The assumptions of the linear model, normality and homogeneity of variance, were tested using the Shapiro–Wilk test and Levene's test. Treatments and genotypes were considered fixed effects, while replications were treated as random effects. Mean comparisons were performed using Tukey's multiple comparison test, and the emmeans package was used to compare the means.

Results

Plant height and root length: The effect of organic amendments and genotype on plant height was statistically significant at $p<0.05$ (Table 1). The organic amendments (biochar, compost, and pressmud) performed better in variety BR-2017 as compared to other varieties. In BR-2017, the plant height increased by 27.5, 35.8, and 22.8% with the use of biochar, compost, and pressmud over control, respectively (Table 1).

The main effect as well as interaction effects of organic amendments and genotype was significant on the root length at $p<0.05$ (Table 1). Compost application showed higher root length in all cultivars (BR-2017, S-5885, S-6165, and S-6547). However, maximum root length was seen in BR-2017 with the application of compost. Within compost application, BR-2017 showed higher root length by 10.8, 57.2, and 47.8% over S-5885, S-6165, and S-6547, respectively (Table 1).

Shoot length and fresh shoot weight: The effect of organic amendments and genotype on shoot length was statistically significant at $p<0.05$ (Table 2). The organic amendments (biochar, compost, and pressmud) performed better in BR-2017 as compared to other varieties. In BR-2017, the shoot length increased by 35.0, 45.3 and 25.7% with use of biochar, compost, and pressmud over control, respectively.

The effect of organic amendments and genotype was statistically significant on the shoot fresh weight at $p<0.05$ (Table 2). The organic amendments (biochar, compost, and pressmud) performed better in variety BR-2017 as compared to other varieties. In BR-2017, the shoot fresh weight increased by 52.0, 58.6, and 39.1% with use of biochar, compost, and pressmud over control, respectively (Table 2).

Dry shoot weight and relative water contents: The main and interaction effect of organic amendments and genotype were significant on the dry shoot weight at $p<0.05$ (Table 3). The organic amendments (biochar, compost, and pressmud) performed better in BR-2017 as compared to other varieties (S-5885, S-6165, and S-6547). In BR-2017, the dry shoot weight increased by 51.2,58.5 and 39.0% with the use of biochar, compost, and pressmud over control, respectively (Table 3).

The effect of organic amendments and genotype was statistically significant on the dry relative water contents at $p<0.05$ (Table 3). The organic amendments (biochar, compost, and pressmud) performed better in variety BR-2017 as compared to other genotypes (S-5885, S-6165, and S-6547). In BR-2017, the relative water contents increased by 10.6, 14.8, and 5.7% with the use of biochar, compost, and pressmud over control, respectively (Table 3).

Chlorophyll contents and stomatal conductance photosynthetic rate: The main effect as well as interaction effects of organic amendments and genotype was significant on the chlorophyll contents at $p<0.05$ (Table 4). Compost showed higher chlorophyll contents in all cultivars as well as compared to control, biochar, and pressmud. However, maximum root length was seen in BR-2017 with the application of compost. Within compost application, BR-2017 showed higher root length by 2.6, 20.6, and 17.9% over to S-5885, S-6165, and S-6547, respectively.

The main effect of organic amendments and genotype was significant on the stomatal conductance at $p<0.05$ (Table 4). The application of compost showed stomatal conductance in all genotypes as compared to control, biochar, and pressmud. However, maximum root length was seen in BR-2017 with the application of compost. Within compost application, BR-2017 showed higher root length by 10.5, 147.1, and 121.1% as compared to S-5885, S-6165, and S-6547, respectively (Table 4).

Potassium contents in leaf and root: The main effect of genotypes and treatment was found significant on the potassium in the leaf at $p<0.05$ (Table 5). The potassium in leaf and root was increased with the use of organic amendments (biochar, compost, and pressmud) as compared to the control. In S-6165, potassium in the leaf increased by 14.9, 44.8, and 32.8%, with biochar, compost, and pressmud, respectively over control (Table 5). Higher potassium contents were found with the use of compost as compared to control, biochar, and pressmud (Table 5).

Potassium sodium ratio in leaf and root: The effect of genotypes was statistically found significant on the potassium-sodium ratio in leaf and root at $p<0.05$. Highest potassium-sodium ratio was found in S-6165 as compared to other cultivars. The use of biochar, compost, and pressmud increased the potassium-sodium ratio as compared to the control in all cultivars. In BR-2017, biochar, compost, and pressmud increased the potassium-sodium ratio by 22.2, 55.6, and 27.8%, respectively as compared to the control (Table 6). The potassium-sodium ratio in root was also higher in BR-2017 over other cultivars.

Table 1. The impact of organic amendments on the plant height and root length in four cluster bean genotypes.

Treatment	Plant height (cm)				Root length (cm)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	10.23 ± 0.84a	9.12 ± 0.43a	6.11 ± 0.20a	7.03 ± 0.18a	5.75 ± 0.18a	5.23 ± 0.09a	4.12 ± 0.08a	4.65 ± 0.50a
Biochar	13.04 ± 1.47b	12.12 ± 1.11b	6.94 ± 0.27ab	8.2 ± 0.13b	7.08 ± 0.19bc	6.78 ± 0.19c	4.91 ± 0.25b	5.01 ± 0.24a
Compost	13.89 ± 1.81b	12.71 ± 0.98b	7.56 ± 0.32b	8.97 ± 0.23c	7.89 ± 0.87c	7.12 ± 0.64c	5.02 ± 0.13b	5.34 ± 0.15a
Presumed	12.56 ±0.94ab	11.45 ± 0.97b	6.64 ± 0.30a	7.78 ± 0.46b	6.43 ± 0.98ab	6.02 ± 0.13b	4.23 ± 0.20a	4.56 ± 0.40a
Significant difference								
Treatment (T)	***				Treatment (T)	***		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	*		

The values are the mean ± standard deviation (n=3). The values within in variety with same letter (s) are not statistically significant
Significant. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Table 2. The impact of organic amendments on the shoot length and fresh root length in four cluster bean genotypes.

Treatment	Shoot length (cm)				Fresh shoot weight (g)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	9.56 ± 0.16 a	8.99 ± 0.22a	7.02 ± 0.05a	7.22 ± 0.12a	5.12 ± 0.91a	4.76 ± 2.33a	3.71 ± 1.01a	3.98 ± 0.92a
Biochar	12.91 ± 0.36c	12.65 ± 1.23b	8.88 ± 0.44c	9.02 ± 0.11c	7.78 ± 2.24a	7.23 ± 3.19a	4.67 ± 0.99a	4.97 ± 1.19a
Compost	13.89 ± 0.13d	13.45 ± 1.14b	9.23 ± 0.11c	9.67 ± 0.26d	8.12 ± 2.84a	7.88 ± 2.07a	4.99 ± 1.26a	5.34 ± 2.25a
Presumed	12.02 ± 0.53b	11.76 ± 0.26b	8.24 ± 0.15b	8.67 ± 0.13b	7.12 ± 3.02a	6.92 ± 1.12a	4.23 ± 1.73a	4.65 ± 1.2a
Significant difference								
Treatment (T)	***				Treatment (T)	**		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	ns		

Table 3. The impact of organic amendments on the dry shoot weight and relative water contents in four cluster bean genotypes.

Treatment	Dry shoot weight (g)				Relative water contents (%)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	0.41 ± 0.08a	0.38 ± 0.07a	0.3 ± 0.07a	0.32 ± 0.07a	74.45 ± 5.71a	73.45 ± 5.31a	66.12 ± 6.01a	67.13 ± 5.89a
Biochar	0.62 ± 0.10b	0.58 ± 0.08b	0.37 ± 0.08b	0.4 ± 0.06b	82.33 ± 8.10ab	80.48 ± 8.27a	69.23 ± 6.6a	69.97 ± 5.53a
Compost	0.65 ± 0.04b	0.63 ± 0.11b	0.4 ± 0.06b	0.43 ± 0.10b	85.45 ± 2.01b	83.44 ± 0.41a	71.21 ± 8.36a	71.23 ± 6.38a
Presumed	0.57 ± 0.05b	0.55 ± 0.05b	0.34 ± 0.07ab	0.37 ± 0.10ab	78.67 ± 4.40ab	76.57 ± 2.61a	67.78 ± 4.54a	68.24 ± 4.77a
Significant difference								
Treatment (T)	***				Treatment (T)	***		
Genotype (G)	***				Genotype (G)	***		
T × G	***				T × G	ns		

Table 4. The impact of organic amendments on the chlorophyll contents and stomatal conductance in four cluster bean genotypes.

Treatment	Chlorophyll contents (SPAD value)				Stomatal conductance (mmol H_2O m^{-2} s^{-1})			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	54.34 ± 6.51a	52.56 ± 6.50a	43.98 ± 6.16a	44.32 ± 6.74a	0.29 ± 0.08a	0.27 ± 0.08a	0.1 ± 0.06a	0.12 ± 0.06a
Biochar	58.31 ± 7.17ab	57.33 ± 6.33a	49.39 ± 3.95a	50.45 ± 3.95ab	0.39 ± 0.08c	0.35 ± 0.07bc	0.14 ± 0.07a	0.15 ± 0.07ab
Compost	61.87 ± 8.20b	60.33 ± 7.50a	51.32 ± 2.43a	52.46 ± 3.72b	0.42 ± 0.08d	0.38 ± 0.08c	0.17 ± 0.07a	0.19 ± 0.08b
Presumed	56.42 ± 4.62ab	54.35 ± 8.93a	46.51 ± 6.14a	48.53 ± 5.40ab	0.34 ± 0.07b	0.32 ± 0.08b	0.12 ± 0.06a	0.14 ± 0.06ab
Significant difference								
Treatment (T)	***				Treatment (T)	**		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	ns		

Table 5. The impact of organic amendments on the potassium contents in leaf and root in four cluster bean genotypes.

Treatment	Potassium contents in leaf (%)				Potassium contents in root (%)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	0.11 ± 0.05a	0.18 ± 0.07a	0.67 ± 0.13a	0.58 ± 0.12a	0.49 ± 0.11a	0.54 ± 0.08a	1.21 ± 0.15a	1.16 ± 0.07a
Biochar	0.18 ± 0.06b	0.21 ± 0.07b	0.77 ± 0.09b	0.71 ± 0.09ab	0.59 ± 0.09ab	0.66 ± 0.06ab	1.38 ± 0.09ab	1.26 ± 0.09ab
Compost	0.29 ± 0.08c	0.34 ± 0.08d	0.97 ± 0.06c	0.91 ± 0.11b	0.81 ± 0.03b	0.89 ± 0.08c	1.69 ± 0.12b	1.57 ± 0.12b
Presumed	0.22 ± 0.07b	0.27 ± 0.07c	0.89 ± 0.09c	0.82 ± 0.11ab	0.69 ± 0.11ab	0.78 ± 0.03bc	1.59 ± 0.13b	1.48 ± 0.21ab
Significant difference								
Treatment (T)	***				Treatment (T)	***		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	ns		

Table 6. The impact of organic amendments on the potassium/contents in leaf and root in four cluster bean genotypes.

Treatment	Potassium/Sodium ratio in leaf (%)				Potassium/Sodium ration in root (%)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	0.18 ± 0.07a	0.3 ± 0.09a	0.61 ± 0.09a	0.5 ± 0.13a	0.45 ± 0.07a	0.45 ± 0.04a	0.58 ± 0.07a	0.6 ± 0.06a
Biochar	0.22 ± 0.06a	0.24 ± 0.06a	0.55 ± 0.03a	0.53 ± 0.02a	0.5 ± 0.05 a	0.53 ± 0.09a	0.56 ± 0.02a	0.54 ± 0.02a
Compost	0.28 ± 0.100a	0.3 ± 0.06a	0.56 ± 0.06a	0.55 ± 0.08a	0.55 ± 0.05a	0.57 ± 0.01a	0.6 ± 0.04a	0.58 ± 0.03a
Presumed	0.23 ± 0.06a	0.26 ± 0.05a	0.57 ± 0.03a	0.55 ± 0.04a	0.52 ± 0.04a	0.53 ± 0.04a	0.6 ± 0.03a	0.58 ± 0.08a
Significant difference								
Treatment (T)	Ns				Treatment (T)	ns		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	ns		

Table 7. The impact of organic amendments on superoxide and catalase in four cluster bean genotypes.

Treatment	Superoxidase (U/mg protein)				Catalase (U/mg protein)			
	BR-2017	S-5885	S-6165	S-6547	BR-2017	S-5885	S-6165	S-6547
Control	0.55 ± 0.08a	0.66 ± 0.05a	1.04 ± 0.86a	0.99 ± 0.08a	0.07 ± 0.05a	0.09 ± 0.03a	0.21 ± 0.05a	0.18 ± 0.06a
Biochar	0.76 ± 0.07b	0.81 ± 0.07b	1.21 ± 0.05b	1.13 ± 0.07b	0.1 ± 0.06ab	0.12 ± 0.04ab	0.26 ± 0.06ab	0.23 ± 0.08b
Compost	1.02 ± 0.09c	1.09 ± 0.05c	1.61 ± 0.06d	1.49 ± 0.09 d	0.17 ± 0.06c	0.18 ± 0.06c	0.39 ± 0.09b	0.35 ± 0.07d
Presumed	0.89 ± 0.08bc	0.98 ± 0.07c	1.39 ± 0.07c	1.28 ± 0.07c	0.13 ± 0.06b	0.16 ± 0.05bc	0.31 ± 0.05ab	0.27 ± 0.06c
Significant difference								
Treatment (T)	***				Treatment (T)	***		
Genotype (G)	***				Genotype (G)	***		
T × G	ns				T × G	ns		

Superoxidase and catalase activity: The main effect of genotype and treatment was found significant on the superoxidase and catalase activity at $p<0.05$ (Table 7). Superoxidase activity was increased using organic amendments (Compost, biochar and pressmud) over control. The higher oxidase activity was seen in S-6165 as compared to other cultivars. In S-6165, superoxidase activity was increased by 16.3, 54.8, and 33.7% with the use of biochar, compost, and pressmud, respectively over control (Table 7). The catalase activity was increased with the use of biochar, compost, and pressmud by 23.8, 83.7, and 47.6%, respectively over control in S-6165 (Table 7).

Sodium contents in leaf and root: The effect of treatment and genotype was statistically found significant on the sodium in the leaf while the main and interaction effect was significant in sodium in the root at $p<0.05$ (Fig. 1). The low sodium in the leaf was found in BR-2017 in all treatments as compared to other cultivars. The sodium contents decreased with the application of biochar, compost, and pressmud. In BR-2017, biochar, compost, and pressmud showed 24.3,42.1, and 9.3% lower sodium contents in the leaf respectively as compared to the control (Fig. 1). The cultivars S-6165 showed higher sodium in the root as compared to another genotype in all treatments (Control, biochar, compost, and pressmud).

Transpiration rate and photosynthetic rate: The effect of organic amendments and genotype was statistically significant on the transpiration rate at $p<0.05$ (Fig. 2). The organic amendments (biochar, compost, and pressmud) performed better in variety BR-2017 as compared to other varieties. In BR-2017, the transpiration rate increased by 21.6, 29.7, and 10.6% with the use of biochar, compost, and pressmud over control, respectively (Fig. 2).

The effect of organic amendments and genotype was significant on the photosynthetic rate at $p<0.05$ (Fig. 2). The organic amendments (biochar, compost, and pressmud) performed better in BR-2017 as compared to other varieties. In BR-2017, the photosynthetic rate increased by 13.7, 24.6, and 4.3% with the use of biochar, compost, and pressmud over control, respectively (Fig. 2).

Discussion

The current study evaluated the impact of biochar, compost, and pressmud on the productivity of four cluster bean genotypes (BR-2017, S-5885, S-6165, and S-6547) in a salinity environment. The application of organic amendments such as pressmud, biochar, and compost successfully immobilized the soluble salts that significantly improved all growth, physio-biochemical, water-related, and ions distribution in the plant tissues (Munir *et al.,* 2020; Raghunathan *et al.,* 2021) resulting in improved growth and development of crop plants under saline conditions

Retarded growth is a very common symptom that can be seen in plants grown under saline-stressed soil. It might be because of the involvement of toxic ions in plant metabolism, or inhibition of another essential nutrient due to high concentrations of antagonistic toxic ions (Liaqat *et al.,* 2020). In reference to the results of the present study, improved growth in terms of greater root and shoot length and improved fresh and dry biomass of selected cluster bean plants treated with organic amendments that can be attributed to less uptake of toxic ions due to the formation of insoluble complexes (Azadi & Raiesi, 2021). Salinity stress resulted in lower shoot biomass, root length, and shoot length. However, the incorporation of biochar increased shoot biomass, root length, and shoot length observed by Ahmad *et al*., (2019) in maize plants. The organic amendment increases the dry biomass of various plant parts which was observed in a variety of plants by numerous authors (Abou El-Magd *et al*., 2008; Murtaza *et al.,* 2020; Ahmad *et al.,* 2019; Munir *et al.,* 2020; Raghunathan *et al.,* 2021; Parveen *et al.,* 2021). Compost and manure increased markedly the shoot and root growth, this seemed to be related to decreases in the shoot concentrations of Na and Cl and increases in K (Murtaza *et al.,* 2020; Parveen *et al.,* 2021). Organic manures have been shown to increase the K/Na ratio in sweet fennel (Abou El-Magd *et al*., 2008). However, biochar can increase nutrient content and improve the retention of nutrients which ultimately results in better growth and development (Lehmann *et al*., 2003; Mansoor *et al.,* 2020; Murtaza *et al.,* 2020).

Relative water content (RWC) is a key parameter for evaluating plant tolerance under saline environments and serves as an important indicator in studies of environmental stress, particularly salinity stress (Mohammad *et al*., 2020). Salinity hampers water uptake mainly through osmotic effects (Murtaza *et al*., 2020). The accumulation of salts in the root zone decreases osmotic potential, thereby limiting water availability to plant roots (Ahmed *et al*., 2019). Under saline conditions, cluster bean cultivars showed reductions in stomatal conductance, net photosynthetic rate, transpiration rate, and chlorophyll content. These observations align with previous studies reporting that salinity markedly impairs photosynthetic gas exchange parameters (Nounjan *et al*., 2018; Santana *et al*., 2019). Osmotic stress further diminishes photosynthetic efficiency by inducing partial stomatal closure, which restricts CO_2 uptake and disrupts the photosynthetic mechanism. To mitigate these effects, the application of organic amendments such as compost, pressmud, and biochar has been proposed as an effective strategy to enhance crop growth in salt-affected soils. Such amendments improve essential soil properties, including physical structure, nutrient availability, and biological activity (Yaduvanshi & Swarup, 2005; Srivastava *et al*., 2016). Moreover, carbon-rich materials like compost and biochar increase soil cation exchange capacity (CEC), thereby reducing sodium activity by transforming it into an exchangeable form, while simultaneously enhancing soluble and exchangeable potassium concentrations (Tejada *et al*., 2006; Wang *et al*., 2014; Ahmed *et al*., 2019).

We found that salinity stress led to a decline in relative water content and physiological attributes, accompanied by increased cell membrane damage. In contrast, the application of carbon-based amendments such as compost, pressmud, and biochar at optimal rates markedly enhanced these parameters. These observations are consistent with earlier reports indicating that salinity reduces plant water status (Kaymakanova *et al*., 2008; Shahzad H. *et al*., 2019; Abrar *et al*., 2020). Under saline conditions, plants undergo oxidative stress due to the excessive generation of reactive oxygen species (ROS) such as O^{2-}, H_2O_2, and OH (Parida & Das, 2005), which destabilize cellular membranes, impair enzymatic activities, and diminish photosynthetic efficiency (Jithesh *et al*., 2006).

Salinity stress is known to increase the activity of antioxidant enzymes like catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD), which are essential parts of the plant defense system (Parida *et al*., 2004; Xue *et al*., 2008). Significant differences in SOD, POD, and CAT activities were noted in the current investigation when the circumstances were saline. According to Mahmood *et al*., (2009), the use of organic amendments lessened the negative impacts of reactive oxygen species (ROS) by minimizing the decrease in antioxidant enzyme effectiveness. By reducing the overactivity of antioxidant enzymes, compost and biochar treatments also improved plant tolerance. This is probably because they can absorb exchangeable sodium, reduce the buildup of sodium in plant tissues, increase nutrient availability, and generally reduce the effects of salt-induced stress (Fangueiro *et al*., 2015; Niamat *et al*., 2019; Shahzad H. *et al*., 2019; Abrar *et al*., 2020). High salt concentrations interfere with ion homeostasis and upset ionic equilibrium (Parida & Das, 2005). According to earlier studies, potassium (K^+) and sodium (Na^+) compete for absorption sites, and low internal K^+ concentrations are frequently caused by high external NaCl levels (Kaya *et al*., 2007). Under NaCl stress, this restriction in K^+ uptake leads to K^+ deficit, raising the Na^+/K^+ ratio, which impairs plant growth and causes ionic toxicity (Kaya *et al*., 2007). The genotype S-6165 exhibited higher Na accumulation in the current investigation, which is probably related to genotype-specific traits such root structure and ion transport dynamics that could negate the positive benefits of organic amendments (Farooq *et al*., 2024). Moreover, although raising the Na^+/K^+ ratio, rising NaCl concentrations dramatically decreased K^+ absorption.

On the other hand, plants that received organic amendments showed decreased Na^+ buildup and increased K^+ uptake. This improvement is probably the result of soils enhanced with compost or charcoal having a higher cation exchange capacity (CEC), which restricts the absorption of Na^+ while promoting the uptake of K+ in plant tissues (Tejada *et al*., 2006; Wang *et al*., 2014; Zafar-ul-Hye *et al*., 2020; Iqbal *et al*., 2025).

According to earlier research, carbonbased, and organic soil amendments can efficiently remove sodium ions from soil matrices, which lowers the sodium absorption ratio (SAR) and soil electrical conductivity (EC) (Pavla *et al*., 2017; Hafeez *et al*., 2017; Mazhar *et al*., 2017). According to our findings, when compared to untreated controls, organic amendments dramatically reduced the Na^+/K^+ ratio in leaves grown in saline conditions. By interacting with sodium chloride to generate sodium sulfate, which is readily leached from the soil, compost mulching has been shown to reduce salt stress and increase crop yield (Lakhdar *et al*., 2009; Ditta *et al*., 2015). In a similar vein, organic elements like compost and biochar improve soil water infiltration and encourage salt leaching, which successfully lowers the rhizosphere's exchangeable sodium levels (Lakhdar *et al*., 2009; Leogrande & Vitti, 2019).

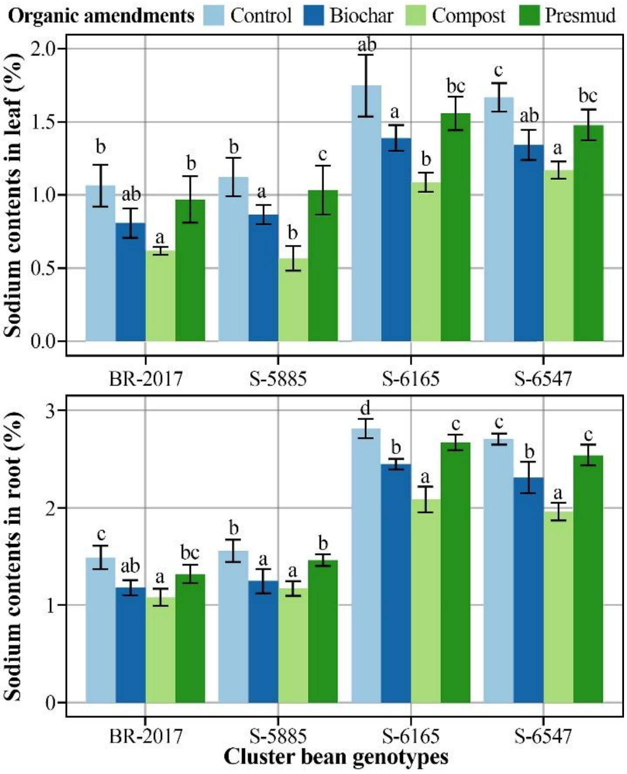

Fig. 1. Impact of organic amendments (Control, biochar, compost, and pressmud) sodium contents in root and leaf in the four cluster bean genotypes (BR-2017, S-5885, S-6165, and S-6547) in a saline environment. Error bars represent the standard (n=3).

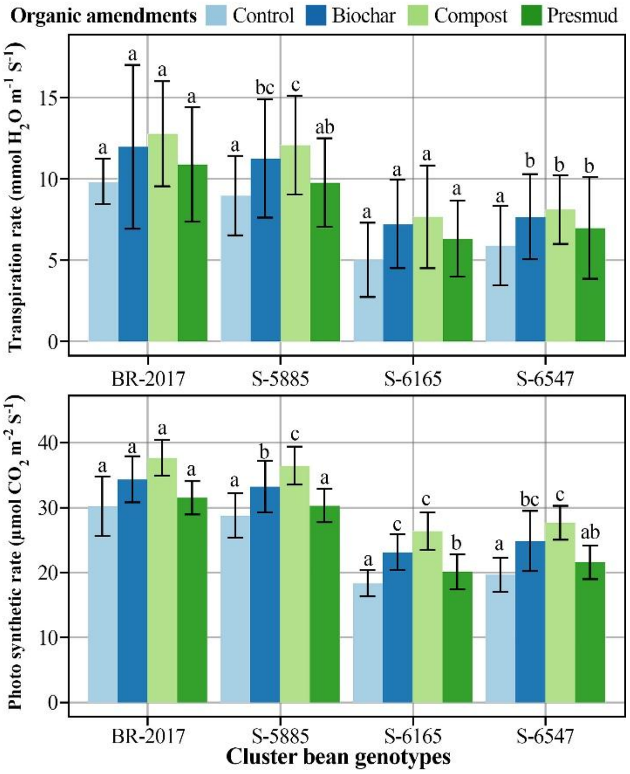

Fig. 2. Impact of organic amendments (Control, biochar, compost and pressmud) on photosynthetic rate and transpiration rate in the four cluster bean genotypes (BR-2017, S-5885, S-6165, and S-6547) in saline environment. Error bars represent the standard (n=3).

Using NaCl as a model salt stressor, this study offers important insights under controlled settings, capturing both osmotic and ionic effects commonly found in saline environments. Three biological replicates were included to allow for natural variability and guarantee accurate treatment response detection. The study emphasizes early vegetative responses that are crucial for predicting subsequent growth and yield outcomes by concentrating on a 45-day span. These precisely specified experimental parameters outline intriguing avenues for further study and enhance the findings' contextual robustness. To extend this work, long-term and field-scale experiments with higher replication, osmotic controls, soil EC and leachate monitoring, and full growth-cycle assessments will be instrumental in validating and broadening the applicability of these results.

Conclusion

The current study evaluated the impact of organic amendments (biochar, compost, and pressmud) on the productivity of four cluster bean genotypes (BR-2017, S-5885, S-6165, S-6547) in a saline environment. The organic amendments application showed improvement in the productivity of cluster bean genotypes as compared to the control where no organic amendment was applied. The leaf and root in the control treatment showed higher uptake of sodium contents and lower uptake of potassium contents. Thus, a higher sodium/potassium ratio was found in the control which might restrict the productivity of cluster beans in control conditions while a higher potassium/sodium ratio was found where organic amendments were applied. Thus, the application of organic amendment can be helpful to improve the productivity of cluster beans in a saline soil environment. However, long-term field studies are recommended to revalidate the current findings.

Conflict of Interest: The authors declare that they have no conflict of interest.

Authors' Contributions: Shahzad Ahmad Junaid contributed to the conceptualization of the study. Muqarrab Ali provided supervision throughout the research process. Hina Ashraf was responsible for visualization, while Syeda Refat Sultana contributed to the methodology. Hafeez Ullah handled the editing of the manuscript. Rahmat Ullah Shah contributed to reviewing and editing, and Khalid Bilal also participated in the review and editing process. Muhammad Mazhar Iqbal performed the statistical analysis.

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