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Impact of Silicon Application on Physiochemical Traits of *Vigna radiata* Exposed to Salinity Stress

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ABSTRACT

Background: Salinity stress affects crop yields worldwide. Mungbean, a popular grain legume with protein-rich seeds, is glycophytic and vulnerable to saline stress. Silicon has become a key ingredient that boosts plant enzymatic antioxidant activity and osmoprotectant synthesis, promoting stress tolerance.

Methods: In chloride-dominated salinity conditions of 4 and 6 dSm-1, sodium meta-silicate administration strategies were examined in salt-affected mungbean (MH421). Two application strategies were used: foliar spraying at 50 mg/l and 100 mg/l at 30 and 45 DAS and soil addition at 50 mg/kg soil as a solution during planting. The effects of these treatments were examined at 33 and 48 DAS, three days following foliar sodium meta-silicate application.

Result: Salinity stress reduced dry weight, nodule counts, gas exchange characteristics and plant water relation features, although Si treatment buffered the detrimental effect to a varied amount. Best effects were obtained with 100 ppm foliar application. Lipid peroxidation and electrolyte loss increased with salinity stress, while Si reduces these losses by scavenging free radicals. Silicon supplementation lowered Na+ and increased K+ absorption. Also, Si altered photosynthetic machinery, Na^+/K^+ homeostasis, osmolyte synthesis and oxidative stress in mungbean to reduce salinity stress and increase seed yield.

Key words: Foliar application, Mungbean, Photosynthetic rate, Salinity, Silicon.

INTRODUCTION

The world population has grown rapidly in the previous two decades, requiring higher supply of food (Wang *et al*., 2021). Growing crop yield and quality is a worldwide agricultural concern (Calicioglu *et al*., 2019). However, soil salinization is a global environmental issue that reduces agricultural output. It affects 20% of irrigated agricultural land worldwide and will keep increasing (Gorji *et al*., 2015).

Mungbean, after chickpea and pigeon pea, is India's third most significant grain legume crop. But salinity stress is one of the worst environmental factors affecting mungbean yield in dry and semiarid regions by limiting plant seed germination, growth, blooming and seed setting (Kapadia *et al*., 2022). The late vegetative phase and pod filling are more vulnerable to saline stress than early vegetative growth. In the dry season, salinity stress is worse than in the rainy season because osmotic stress increases, which limits plant growth, morphology, physiology and yield characteristics of mungbean. The situation underscores the significance of mitigating approaches so that mungbean can thrive and provide greater yields in conditions that are stressful. Numerous mitigation and adaptation strategies have been employed to counteract the adverse effects of elevated soil salinity (Manchanda *et al*., 2008). However, very little is known about the mineral status and dynamics of plants and their role in reducing salinity due to comparatively lesser research in this area but nowadays it is gaining attention (Mushtaq *et al*., 2020). The exogenous application of Si is an environmentally sustainable method for enhancing plant salt stress tolerance (Dhiman *et al*., 2021). Most soils have 14-20 mg Si/l but this whole Si is not available to the plants as they can absorb only the orthosilicic acid form of Si. Researchers consider Si a 'quasi-essential' element in plants since Si-supplemented plants grow better. It raises water status (Ghassemi-Golezani and Lofi, 2015), boosts photosynthetic activity, antioxidant system (Mushtaq *et al*., 2020), reduces Na+ uptake, increases K+ absorption and lowers Na+ tissue concentration. Given the above, this work seeks to understand how Si affects mungbean morpho-physiological and biochemical properties under salt stress.

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MATERIALS AND METHODS

The experiment was conducted in the screen-house of the Department of Botany and Plant Physiology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. Seeds of mungbean variety MH 421 were collected from the Pulses section, Department of Genetics and Plant Breeding CCSHAU, Hisar, sowing was done on 25 March 2021 in earthen pots filled with 8 Kg of dunal soil and the chloride-dominated salinity (0, 4 dSm^{-1} and 6 dSm^{-1}) and 50 ppm sodium meta-silicate pentahydrate LR (SDS) was applied in the solution form in the required pots before sowing. The seedlings were thinned to keep 3 uniform plants per pot seven days after germination. Then, 45 DAS foliar application (50 ppm and 100 ppm) of Si was done on plants with salinity as well as without salinity but not on plants with soil application of Si. Sampling was done three days after the foliar application of Si and at the time of physiological maturity. The nutrient solution (Wilson and Reisenauer, 1963) was given to the crop at an interval of 7 days.

Physiological traits

Photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$), stomatal conductance (mmol H_2O $m^{-2}s^{-1}$) and transpiration rate (mmol H_2O $m^{-2}s^{-1}$) of the fully expanded leaf was calculated by the infrared gas analyzer (IRGA LCi-SD, ADC Biosciences). The Water potential of freshly cut leaves was measured, with the help of Pressure Chamber (Model 3005, Soil Moisture Equipment Corporation, Santa Barbara, CA, USA). A psychrometric technique was used to determine leaf osmotic potential of the leaf using a model VAPRO 5520 vapor pressure osmometer (Wescor INC., Lorganan, Utah, USA). Weatherley's (1950) method was used for the measurement of relative water content (RWC), while the chlorophyll content was measured according to the method of Hiscox and Israelstam (1979). The chlorophyll stability index and MSI were determined by the method given by (Sairam *et al*., 1997).

The sodium and potassium contents of the seeds, shoots and roots were determined from the oven-dried (85°C) and grounded material by using Flame Photometer.

Statistical analysis

Data was examined using two factorial CRD designs. Critical difference (CD) at 5% significance was used to compare treatments, environments and their interactions with OPSTAT software. Graphs were generated with IBM SPSS Statistics 23.

RESULTS AND DISUCSSION

Effect of salinity on plant growth and recovery by exogenous application of Si

Salinity, Si and cumulative application of salinity+Si significantly affected the DW of the shoot and roots and nodule numbers of the plant. The shoot dry weight declined dramatically with successive increases in salinity levels, by 19.5% and 41.5% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress, respectively. Fig 1 (a) demonstrates that both soil and foliar application of Si increased the dry weight of the shoot across all conditions. However, the maximum increase in shoot dry

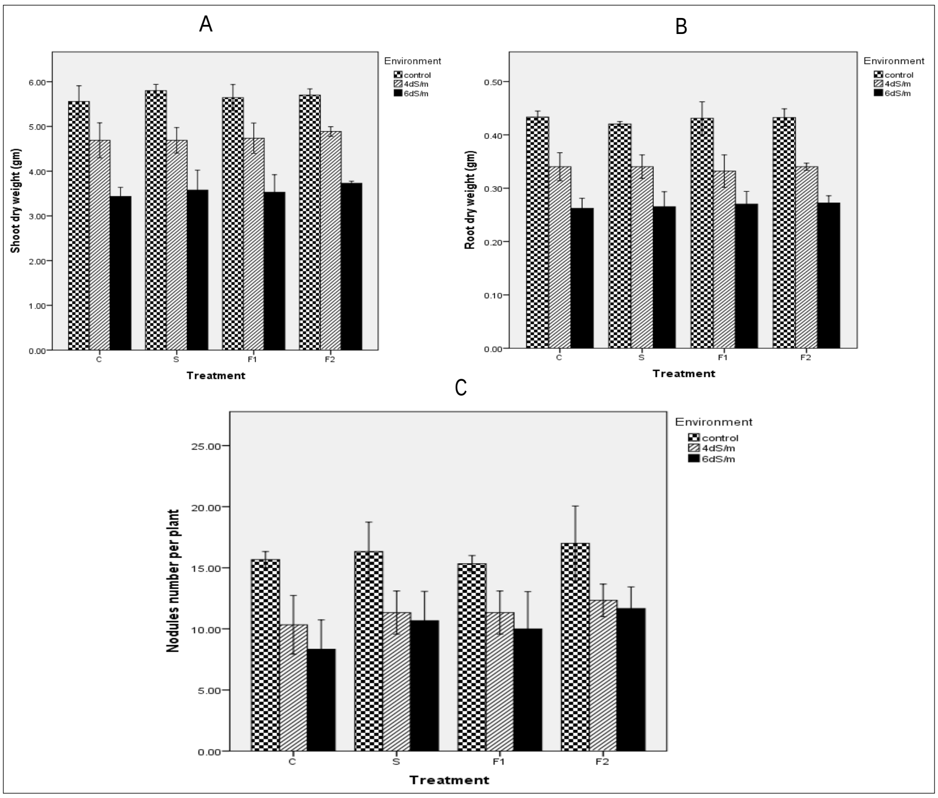

Fig 1: Effects of salinity and Interactive effect of salinity and Si on (A) shoot dry weight, (B) root dry weight, (C) nodule number of mungbean.

weight was observed in plants treated with 100 ppm Si *i.e.*, 9%, 5.0% and 12.1% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress, respectively. Similar results of salinity stress and silicon treatments was noticed for root dry weight and nodule number (Fig 1 (b) and (c) respectively).

Effect of salinity stress on plant water attributes

The results obtained in the present study indicate that the water and osmotic potential becomes more negative under increasing salinity stress as compared to control (Fig 2 (a) and (b) respectively). But, exogenous application of Si increased the water and osmotic potential to the positive side. There was a considerable decrease in the RWC of leaves with increasing levels of salinity from control to 6 dSm^{-1}. Decrease in RWC was 9.4% and 22.2% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively. In plants treated with foliar application of 100 ppm Si maximum increase in RWC was observed *i.e.*, by 9.3%, 6.5% and 6.3% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively.

Effect of salinity on gas exchange attributes

Results showed that salinity stress significantly reduced leaf gas exchange attributes. The photosynthetic rate decreased by 40.4% and 54.8%, the decrease in stomatal conductance was 36.1% and 58.5 % and the decrease in transpiration rate by 20.4%, 35.0% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively. The application of Si in all the modes significantly improved these traits. The photosynthetic rate improved by 100 ppm Si foliar application by 10.1%, 29.4% and 24.6%, increase in stomatal conductance by 22.2%, 31.7% and 52.8% and in transpiration rate by 10.6%, 10.3% and 18.5% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively.

Effect of salinity on membrane stability and chlorophyll stability

Membrane stability index (MSI) and Chlorophyll stability index (CSI) were significantly affected by salinity, Si and cumulative application of salinity and Si (Fig 3). The electrolyte leakage was elevated with increasing salinity stress conditions by 21.7% and 30.7% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively. In plants, treated with foliar application of 100 ppm Si, a maximum increase in MSI was observed compared to other treatments *i.e.*, by 4.6%, 14.9% and 19.3% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively. The chlorophyll stability index was reduced with salinity treatments and an increase was observed by Si supplementation. The CSI decreased by 20.3% and 32.7% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively which was improved by Si supplementation and the maximum increase was with 100 ppm Si foliar application *i.e.*, by 5.8%, 10.9% and 18.4% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively.

Effect of salinity stress on uptake of sodium and potassium ions

Under salinity stress results showed that the uptake of Na^+ ions increased and K^+ uptake was decreased but application

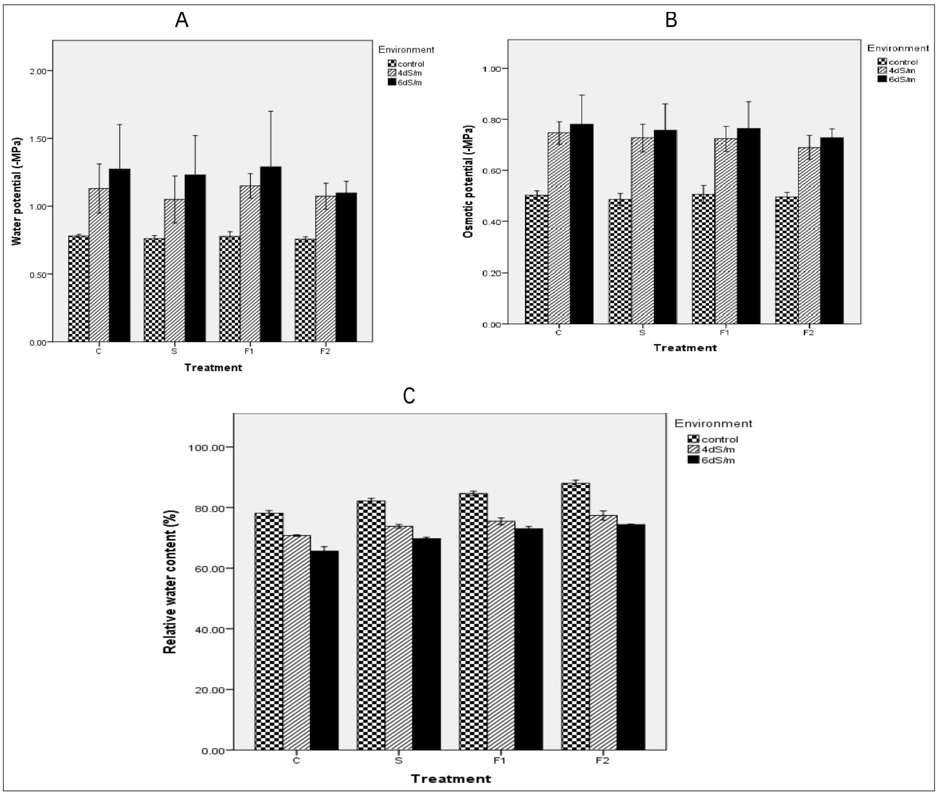

Fig 2: Effects of salinity and Interactive effect of salinity and Si on (A) leaf water potential, (B) leaf osmotic potential, (C) RWC.

of Si improved the uptake of K^+ by decreasing the uptake of Na^+ ions. Under 4 dSm^{-1} and 6 dSm^{-1} salinity stress, sodium content increased by 125.2%, 226.1% in shoots, 98.1% and 224.8% in roots and 69% and 174.6% in seeds, relative to the control condition. The plants treated with 100 ppm Si demonstrated a maximum decrease in Na^+ content *i.e.*, 36.4%, 28.8% and 27.9% in shoots, 18.4%, 25.0% and 24.2% in roots and 46.5%, 29.2% and 35.9% in seeds as compared to control. The decrease in potassium content of shoot was by 30.0% and 42.9% and in roots by 17.0%, 39.0% and in seeds by 35.8%, 53.8% under 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively. The application of 100 ppm Si increased the K^+ ion content by 19.5%, 28.3% and 16.2% and in roots by 7.1%, 6.6% and 10.8% and in seeds by 30.8%, 14.4% and 34.2% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively.

Effect of salinity stress on seed yield and biological yield

Seed yield and biological yield decreased considerably with successive increases in salinity levels. However, Si treatment in both the modes of application *i.e.*, soil and foliar application improved the seed yield and biological yield, however, among all foliar applications of 100 ppm Si was found more capable compared to soil application presented

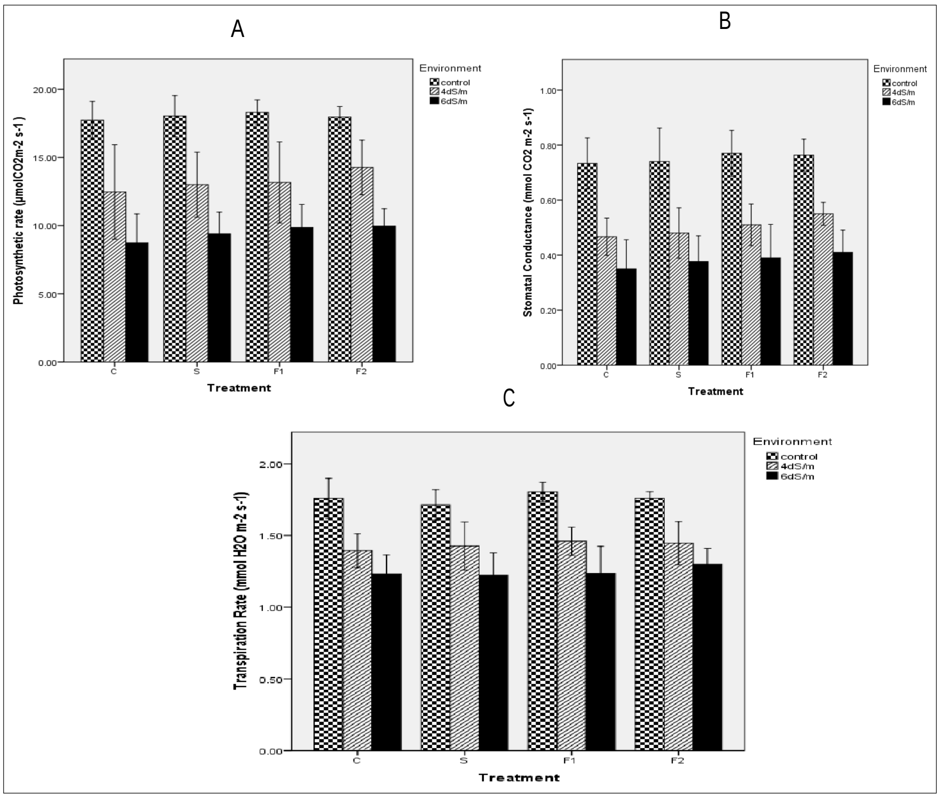

Fig 3: Effects of salinity and Interactive effect of salinity and Si on (A) Photosynthetic rate, (B) Stomatal conductance, (C) Transpiration rate.

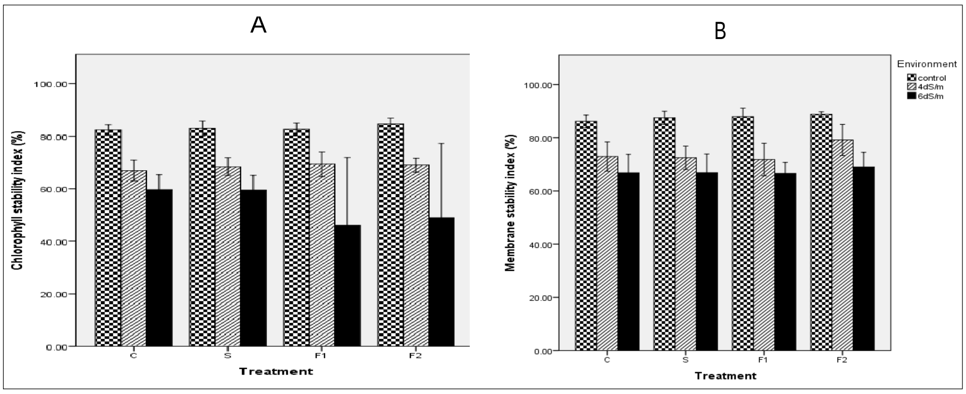

Fig 4: Effects of salinity and Interactive effect of salinity and Si on (A) CSI, (B) MSI.

in Fig 6. In plants treated with foliar application of 100 ppm Si maximum increase in seed yield was observed *i.e*., 9.79%, 6.49% and 15.44% and increase in biological yield was 7.57%, 4.60% and 16.38% under control, 4 dSm^{-1} and 6 dSm^{-1} salinity stress respectively.

Due to poor irrigation water quality and soil salinization from climate change, salinity is growing rapidly, harming plant growth and productivity. In the present work, both shoot and root dry weights decreased with an increase in salinity however, Si treatment ameliorated this reduction (Fig 1). Our findings are supported by (Ahmad *et al*., 2019). The number of nodules decreased with an increase in salinity levels (Fig 1) and Si application improved their number which is following observations of Al-Murad and and Muneer (2022), where the number of nodules formed was relatively limited in the salt stress conditions but Si supplementation significantly improved root nodulation of salt stress treatments. A closer look at the data of water potential (pw), osmotic potential (ps) and relative water content (RWC) in leaves shows that salt treatments had progressively decreasing effects on these

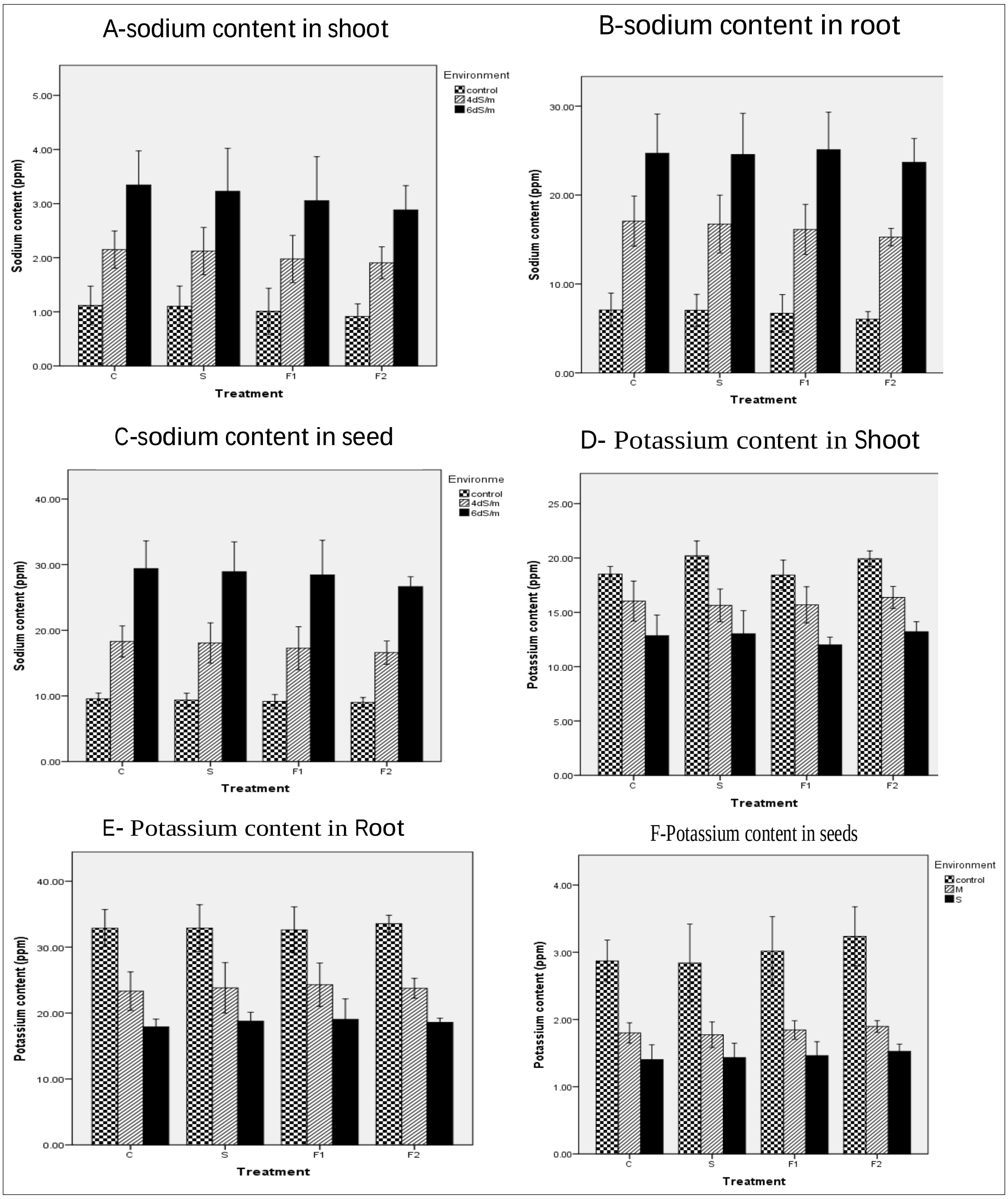

Fig 5: Effects of salinity and Interactive effect of salinity and Si on (A) sodium content in the shoot (B) sodium content in the root, (C) sodium content in seeds (D) potassium content in the shoot (E) potassium content in the root, (F) potassium content in seeds.

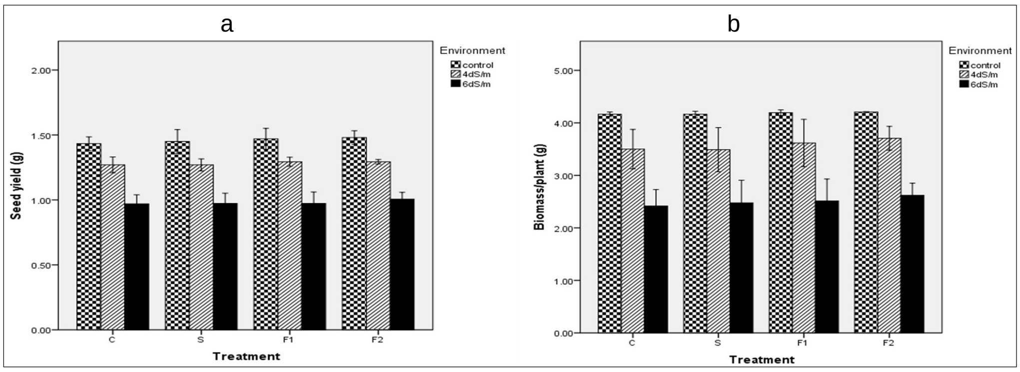

Fig 6: Effects of salinity and Interactive effect of salinity and Si on (A) seed yield (B) biological yield.

parameters (Fig 2), due to the accumulation of ions mainly Na^+ ions inside the cell (Fig 5) which disturb the osmotic balance in the cell, so absorption and translocation of water get reduced in salinity. Si has been widely reported to maintain water balance by osmotic adjustment under variant stress conditions (Wang *et al*., 2021).

Salinity stress decreases the photosynthetic ability of plants by decreasing the chlorophyll content or by decreasing the uptake of minerals involved in chlorophyll synthesis which is increased by Si application under saline as well as non-saline conditions (Fig 3). Our findings are following the previous study on salt-stressed mungbean by Singh *et al*. (2022) where a decrease in the Chlorophyll stability index was observed with an increase in salinity which was reversed by the application of Si in wheat. The chlorophyll stability index (CSI) is an indication of the stress tolerance capacity of plants. A higher CSI helps plants to withstand stress through better availability of chlorophyll. In the present investigation, leaves showed a reduction in CSI with the increasing levels of salinity levels however, Si application reduced this decrease. Si may induce internal Fe and Mg transport, leading to the synthesis of chlorophyll. Similarly, as with the chlorophyll content, the Si treatment increased the chlorophyll stability index as reported by (Aras *et al*., 2020).

Salinity stress causes electrolyte leakage due to lipid peroxidation, dimerization and polymerization of proteins, disrupting cell membranes (Parihar *et al*., 2015). Application of salinity increased the Na^+ content in various plant parts and decreased K^+ content, but Si application altered their status (Fig 4). Silicon builds up in various plant components, such as the roots, leaves and stems, as phytoliths or individual silica solids. Discrete Si bodies bind with Na^+ during this deposition behind the cell walls of the roots, increasing K^+ absorption and decreasing Na^+ transit (Mahmood *et al*., 2016). An investigation by Ibarhim *et al*. (2016) reported that the Si application increased Si concentration in wheat straw and it was proportional to the increase in applied Si under saline as well as non-saline conditions. Si decreased the Na uptake rate and altered Na^+ distribution between the shoot.

For any crop, salinity stress is most damaging during reproduction, resulting in large yield losses (Ehtaiwesh and Rashed, 2020). It reduces seed output by slowing photosynthesis (Zahra *et al*., 2022), owing to decreased stomatal conductance, carbon absorption, metabolism, photochemical capacity, or a combination of these factors (Fig 5). However, using Si in either mode increased the yield status of mungbean. Silicon's beneficial impact on seed yield during salt stress could be related to an improvement in the chlorophyll stability index and stomatal conductance (Fig 6). Many prior investigations on various crops back up these findings (Mahmood *et al*., 2016; Yan *et al*., 2020).

CONCLUSION

The impact of salinity on mungbean plant physiology is seen to be detrimental, as it influences several aspects such as plant-water interactions, chlorophyll stability, membrane stability and gaseous exchange. Consequently, this leads to a decrease in the absorption of minerals and ultimately reduces the yield output. The use of silicon (Si) treatment mitigated the adverse impacts by enhancing the water status, photosynthetic traits, nutrient uptake and overall crop output. The objective of this study is to investigate the potential of Si treatments in enhancing mungbean output under conditions of salt stress.

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Conflict of interest: None.

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