Bangladesh J. Bot. **55**(2): 295-301, 2026 (June) DOI: https://doi.org/10.3329/bjb.v55i2.90982

ZINC-MEDIATED ATTENUATION OF SALINITY STRESS: A STUDY ON PHOTOSYNTHETIC PIGMENT STABILITY, WATER BALANCE, AND YIELD OF SOYBEAN

SADIA AFRIN, FARJANA RAHMAN LOPA, MAISA FARIA AND NAHID AKHTAR*

Plant Physiology and Biochemistry Laboratory, Department of Botany, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh

Keywords: Zinc, Salinity stress, Soybean, Photosynthetic pigments, Plant water status, Yield

Abstract

An experiment was conducted in zinc-treated soil with 0, 50, 100, 150, 200, and 250 mM NaCl salinity to assess their interaction effect on photosynthetic pigment stability, water balance, and yield of soybean. Salinity reduced photosynthetic pigments, RWC, WRC, and exudation rate, while increasing WSD and WUC. Zinc application mitigated these effects by improving pigment levels, water relations, and yield attributes. Moderate salinity (150 mM NaCl) showed the highest response to Zn application in terms of physiological and yield improvements. Zinc also improved seed yield, pod characteristics, and branch number under salinity. These findings suggest that Zn treatment can partially attenuate the toxic effects of Na^+ and Cl^- ions and improve soybean yield by enhancing photosynthetic pigment levels and maintaining water status.

Introduction

Salinity reduces crop development and productivity by nearly twofold (Hasanuzzaman *et al*. 2013). Approximately 1.5 million hectares of the 2.85 million hectares of coastal and offshore land in Bangladesh are affected by varying levels of salinity (Afrin *et al.* 2023). Thus, to survive changes in the external environment, plants utilize internal mechanisms (Khanam *et al*. 2025).

Salinity could abate crop growth by negatively affecting various physiological processes, including osmotic stress and ion toxicity, metabolic imbalance, malnutrition (Khanam *et al*. 2018, Afrin *et al*. 2021), inadequate photosynthesis, and chlorosis (Hasanuzzaman *et al*. 2014). Excessive Na^+ and Cl^- concentrations caused by salinity affect the absorption of many essential nutrients, including K, Ca, Mg, and N (Abdallah *et al*. 2016, Akhtar *et al.* 2021). This leads to reduced stomatal opening and a decrease in intracellular CO_2 caused by competitive interactions affecting the ion selectivity and photosynthetic activity of the cell membrane, as well as affecting plants' water relationships (Akhtar *et al*. 2013).

Zinc plays a critical role in membrane integrity, IAA, protein metabolism, and cell division. Moreover, zinc has catalytic activity in photosynthesis as it is a constituent of many photosynthetic enzymes that assist in the first step of carbon dioxide fixation (Weisany *et al*. 2011), and it could prevent oxidation of chlorophyll. Thereby, the present study aimed to investigate the zinc and salinity interaction on the physiological and yield characteristics of soybean under salinity stress, whether zinc could attenuate the damage induced by NaCl.

Materials and Methods

A pot experiment was conducted at the Plant Physiology and Biochemistry Laboratory, Department of Botany, Jahangirnagar University, Savar, Dhaka. Certified soybean seeds (cv. Shohag) were collected from the Bangladesh Agricultural Research Institute (BARI). The experiment was carried out in a randomized block design with three replications. There were six treatments viz. 0 (control), 50, 100, 150, 200, and 250 mM NaCl, and the cultivar was also treated

---

*Author for correspondence: <nahid_akhtar98@yahoo.com>.

to salinity stress together with zinc sulfate. Before sowing, the optimal dose of $ZnSO_4$ and other nutrients were thoroughly mixed into the soil. Subsequently, soybean seeds were surface sterilized with 0.1% sodium hypochlorite. Seeds were directly sown in the soil on 4th February 2019. Throughout the study period, plants were maintained with regular watering, periodic weed control, and appropriate fertilizer application following standard agronomic practices. Distilled water was applied in all pots up to the emergence of seedlings. After seedling establishment, distilled water in control pots, and 12.5 mM NaCl solution was applied in rest of the pots. When the first leaf appeared, the actual amount of NaCl solution was applied.

Photosynthetic pigments, including chlorophyll a (chl a), chlorophyll b (chl b), total chlorophyll (chl (a+b)), and carotenoids, were estimated using the specific absorption coefficient method (Mackinney 1940) and the formula of Maclachlan and Zalik (1963). Plant water status viz. relative water content (RWC), water saturation deficit (WSD), water retention capacity (WRC), and water uptake capacity (WUC) were measured using the method of Sangakkara *et al*. (1996) based on fresh, turgid, and dry weight of uniform leaves from five seedlings per treatment. The exudation rate (mg/h) was calculated by using the formula of Akhtar *et al.* (2013). At final harvest, data on number of branches/plant, No. of total pods/plant, No. of filled pods/plant, weight of total pods/plant, weight of filled pods/plant, 100-seed weight, and yield per plant were noted. Statistical analysis was conducted via ANOVA in SPSS (v16.0), and means were separated by Duncan's test at the 5% probability level.

Results and Discussion

Result presented in Table 1 revealed that at 100-250 mM NaCl, Chl a decreased by 37.97 to 66.46%, whereas in case of Chl b, it was decreased by 38.73 to 76.76% compared to the control. However, zinc supplementation improved chl a by up to 39.62% and chl b by up to 40.23% under corresponding salinity levels. Similarly, total chl (a+b) decreased by 38.21, 53.16, 57.81 and 71.43% in plants treated with 100, 150, 200, and 250 mM NaCl, respectively. Zn supplementation increased Chl (a+b) content by 29.03, 18.44, 11.03 and 29.07% at those respective salinity levels. The present findings showed that salinity stress significantly reduces chlorophyll content, which was consistent with previous studies (Ahmad *et al.* 2017). However, under moderate salinity (100-150 mM NaCl), zinc supplementation significantly mitigated chlorophyll degradation. The most notable enhancement was observed in chl b at 100 mM NaCl, where Zn increased its level by nearly 40% compared to non-Zn-treated plants. Total chlorophyll increases by 29% under the same salinity level with Zn application. Moreover, chl a content at 150 mM NaCl increased by approximately 21% following Zn treatment. These findings imply that Zn plays a crucial role in protecting chlorophyll molecules from oxidative stress, along with a direct positive influence on Mg uptake, which is an important component of chlorophyll. The previous findings of Weisany *et al.* (2011) and Ahmad *et al.* (2017) on Zn's role in stabilizing photosynthetic pigments and maintaining chloroplast ultrastructure under salt stress show consistent results with the present study.

Table 1 represents that carotenoids content decreased with respect to the control by 24.00, 39.79, 47.16 and 61.69% in plants treated with 100, 150, 200, and 250 mM NaCl, respectively. Batra *et al*. (2022) also found similar results on *Vigna radiata*. In contrast, Zn supplementation markedly improved carotenoid levels across all salinity treatments. In comparison to the corresponding non-Zn treatments, carotenoids increased by approximately 20% at 100 mM, 19% at 150 mM, 21% at 200 mM, and 9% at 250 mM NaCl, which aligns with the study of Al-Zahrani *et al*. (2021). However, zinc supplementation led to significant recovery under moderate (100-150 mM NaCl) salinity. Zn's protective potency can be observed in 200 mM NaCl, which is recorded as the greatest relative improvement (~21%).

Table 1. Effects of zinc on chlorophyll and carotenoid (mg/g) contents in soybean leaves cv. Shohag under salinity.

Treatments	Chl a	Chl b	Chl (a+b)	Carotenoid
0 mM NaCl	1.58 ± 0.47 a	1.43 ± 0.44a	3.01 ± 0.76 a	4.75 ± 0.93 a
100 mM NaCl	0.98 ± 0.02 b (62.03)	0.87 ± 0.06 b (61.27)	1.86 ± 0.08 b (61.79)	3.61 ± 0.54 b (76.00)
100 mM NaCl + Zn	1.18 ± 0.68 a (74.68)	1.22 ± 0.75 a (85.31)	2.40 ± 0.93 a (79.73)	4.33 ± 0.39 ab (91.16)
150 mM NaCl	0.89 ± 0.11 b (56.33)	0.52 ± 0.37 bc (36.62)	1.41 ± 0.33 bc (46.84)	2.86 ± 0.17 bc (60.21)
150 mM NaCl + Zn	1.08 ± 0.24 b (68.35)	0.59 ± 0.47 ab (41.26)	1.67 ± 0.57 b (55.48)	3.39 ± 0.51 bc (71.36)
200 mM NaCl	0.85 ± 0.40 bc (53.79)	0.42 ± 0.21bc (29.58)	1.27 ± 0.54 bc (42.19)	2.51 ± 0.34 cd (52.84)
200 mM NaCl + Zn	0.92 ± 0.29 b (58.23)	0.49 ± 0.22 b (34.26)	1.41 ± 0.46 b (46.84)	3.03 ± 0.95 cd (63.78)
250 mM NaCl	0.53 ± 0.22 c (33.54)	0.33 ± 0.08 c (23.24)	0.86 ± 0.28 c (28.57)	1.82 ± 0.34 d (38.31)
250 mM NaCl + Zn	0.74 ± 0.32 b (46.83)	0.38 ± 0.07 b (26.57)	1.11 ± 0.38 b (36.88)	1.98 ± 0.74 d (41.68)

Each value is the mean (± standard deviation) of nine replicates (Duncan's test, $P < 0.05$). Values within parenthesis indicate percentage relative to the control.

Relative water content (RWC) reflects the current water content relative to the maximum water the tissue can hold at full turgidity. According to the results, RWC remarkably reduced with rising salinity levels. Results showed that RWC decreased with respect to the control by 35.08, 45.29, 53.77 and 71.67% in plants treated with 100, 150, 200, and 250 mM NaCl, respectively (Table 2). Several workers reported a reduction in RWC under saline conditions in different plant species (Boussora *et al.* 2024**)**. It is commonly recognized that salinity affects soil water potential and consequently reduces plant water uptake, resulting in a reduced RWC (Akhtar *et al*. 2013). However, zinc supplementation under the same salinity conditions enhanced RWC by 33.12, 44.77, 50.78 and 51.62%, respectively, compared to plants grown under salinity stress without Zn (Table 2). Exogenous zinc application notably attenuated these adverse effects, particularly under moderate salinity stress (150 mM NaCl). The results are consistent with those found by Ahmad *et al*. (2017), who proposed that Zn may aid in membrane integrity by increasing the level of the antioxidant system, which protects the plant from oxidative damage. Weisany *et al*. (2011) found that Zn improves water absorption and transport capacity in plants, as well as reducing the negative impacts of salt stress.

Water saturation deficit (WSD) is the indicator of water deficiencies in plants. Findings revealed that salinity enhanced the WSD with the increase in salinity levels. Compared with the control, Salinity levels at 100, 150, 200, and 250 mM NaCl caused 218.87, 253.44, 282.14 and 341.11% increases of leaf WSD in non-zinc application plants, respectively (Table 2). The result is in agreement with Akhtar *et al.* (2013), suggesting that plants suffer from osmotic shock under saline circumstances due to the reduced osmotic potential in the soil solution. However, WSD was significantly reduced by 33.28, 32.74, 28.16 and 14.78% at 100, 150, 200, and 250 mM NaCl, compared with NaCl treatments without zinc application, respectively (Table 1).

Water retention capacity (WRC) indicates the capacity of a plant cell to retain water. WRC was significantly decreased with increasing salinity. Results showed that WRC decreased with respect to the control by 42.83, 53.71, 62.47 and 70.03% in plants treated with 100, 150, 200, and 250 mM NaCl, respectively. Compared with these plants, Zn supplementation increased WRC by 41.83, 54.06, and 42.48% under salinity levels at 150, 200, and 250 mM, respectively (Table 2). It was also observed that zinc supplementation did not significantly influence WRC at 100 mM NaCl treatments. A plant grown under a high moisture regime maintains a higher ratio, which could be due to the lower destruction of plant tissues by moisture deficit (Sangakkara *et al.* 1996). The studies reveal that Zn application possesses greater WRC under salinity stress. It has been found that Zn treatment promotes the accumulation of suitable solutes, allowing plants to retain more water (Cakmak 2000).

Table 2. Effects of zinc on water relation papameters of soybean cv. Shohag under salinity.

Treatments	Relative water content (%)	Water saturation deficit (%)	Water retention capacity (TW/DW)	Water uptake capacity	Exudation rate (mg/h)
0 mM NaCl	77.20 ± 6.45 a	22.79 ± 6.46 e	7.54 ± 0.41 a	0.80 ± 0.02 b	212.86 ± 6.53 a
100 mM NaCl	50.12 ± 3.78 bc (64.92)	49.88 ± 3.78 cd (218.87)	4.31 ± 0.39 b (57.17)	1.05 ± 0.26 ab (131.25)	93.80 ± 3.86 bc (44.06)
100 mM NaCl + Zn	66.72 ± 15.46 abc (86.42)	33.28 ± 15.46 bcd (146.03)	4.17 ± 1.10 bc (55.31)	1.20 ± 0.21 bc (150.00)	101.58 ± 17.34 c (47.72)
150 mM NaCl	42.24 ± 6.69 cd (54.71)	57.76 ± 6.69 bc (253.44)	3.49 ± 0.49 bc (46.29)	1.18 ± 0.22 ab (147.50)	76.00 ± 10.18 cd (35.70)
150 mM NaCl + Zn	61.15 ± 4.31 bcd (79.21)	38.85 ± 4.31 bc (170.47)	4.95 ± 1.23 c (65.65)	1.32 ± 0.32 bc (165.00)	83.72 ± 15.91 c (39.33)
200 mM NaCl	35.69 ± 11.72 d (46.23)	64.30 ± 11.72 b (282.14)	2.83 ± 0.24 cd (37.53)	1.38 ± 0.41 ab (172.50)	58.95 ± 2.36d e (27.69)
200 mM NaCl + Zn	53.81 ± 4.43 cd (69.70)	46.19 ± 4.43 b (202.68)	4.36 ± 1.72 c (57.82)	1.61 ± 0.04 b (201.25)	57.80 ± 4.91 d (27.15)
250 mM NaCl	22.26 ± 1.90 e (28.83)	77.74 ± 1.9 a (341.11)	2.26 ± 0.45 d (29.97)	1.52 ± 0.57 a (190.00)	43.25 ± 12.00 e (20.32)
250 mM NaCl + Zn	33.75 ± 5.38 d (43.72)	66.25 ± 5.38 a (290.69)	3.22 ± 0.71 c (42.71)	2.43 ± 0.12 a (303.75)	45.48 ± 7.49 d (21.37)

Each value is the mean (± standard deviation) of nine replicates (Duncan's test, P <0.05). Values within parenthesis indicate percentage relative to the control.

Table 3. Effects of zinc on yield parameters of soybean cv. Shohag under salinity.

Treatments	Branch number/ plant	Total pod number/ plant	Filled pod number/ plant	Total pod weight/ plant (gm)	Filled pod weight/ plant (gm)	100 seed weight/ plant (gm)	Yield (seed weight)/ plant (gm)
0 mM NaCl	4.67 ± 2.89 a	66.67 ± 4.16 a	50.00 ± 3.60 a	6.02 ± 0.27 a	5.47 ± 0.49a	9.70 ± 1.32 a	2.40 ± 0.48a
50 mM NaCl	3.33 ± 1.15 a (71.30)	47.67 ± 13.87 ab (71.50)	32.33 ± 14.01 b (64.66)	2.84 ± 1.38 b (47.17)	2.37 ± 1.05 b (43.32)	8.62 ± 1.22 a (88.87)	1.56 ± 0.46 b (64.89)
50 mM NaCl+Zn	4.00 ± 0.00 ab (85.65)	54.00 ± 4.58 b (80.99)	38.33 ± 5.51 b (76.66)	3.53 ± 0.76 b (58.64)	3.04 ± 0.70 b (55.58)	9.63 ± 0.68 a (99.28)	2.23 ± 0.27 b (92.91)
100 mM NaCl	3.00 ± 0.00 a (64.24)	34.67 ± 19.66 bc (52.00)	21.33 ± 6.51 bc (42.66)	1.80 ± 0.22 c (29.90)	1.43 ± 0.37c (26.14)	6.11 ± 0.33 b (62.98)	0.79 ± 0.19 c (32.87)
100 mM NaCl+Zn	3.00 ± 1.00 ab (64.24)	49.67 ± 13.61 b (74.50)	33.33 ± 5.86 b (66.66)	2.57 ± 0.61 c (42.69)	2.25 ± 0.53 bc (41.13)	7.69 ± 0.97 b (79.28)	1.01 ± 0.09 c (42.08)
150 mM NaCl	2.00 ± 1.00 a (42.83)	26.00 ± 10.14 cd (38.99)	14.33 ± 9.07 cd (28.66)	1.28 ± 0.47 cd (21.26)	1.04 ± 0.35 cd (19.01)	4.31 ± 0.98 c (44.43)	0.53 ± 0.11 cd (22.05)
150 mM NaCl+Zn	2.67 ± 1.15 bc (57.17)	32.00 ± 3.60 c (47.99)	18.33 ± 8.02 c (36.66)	1.73 ± 0.18 cd (28.74)	1.57 ± 0.22 cd (28.70)	5.30 ± 0.13 c (54.64)	0.71 ± 0.04 c (29.58)
200 mM NaCl	1.67 ± 1.52 a (35.76)	11.33 ± 1.53 de (16.99)	7.33 ± 0.58 d (14.66)	0.91 ± 0.06 cd (15.11)	0.69 ± 0.15 cd (12.61)	3.23 ± 0.29 cd (33.29)	0.14 ± 0.06 d (5.82)
200 mM NaCl+Zn	2.33 ± 0.58 bc (49.89)	17.00 ± 8.66 cd (25.49)	10.67 ± 4.50 cd (21.34)	1.01 ± 0.31 de (16.77)	0.91 ± 0.29 de (16.64)	4.18 ± 0.42 cd (43.09)	0.19 ± 0.04 d (7.92)
250 mM NaCl	1.67 ± 2.08 a (35.76)	5.33 ± 0.58 e (7.99)	5.33 ± 0.58 d (10.66)	0.54 ± 0.09 d (8.97)	0.34 ± 0.06 d (6.21)	2.59 ± 0.72 d (26.70)	0.12 ± 0.03 d (4.99)
250 mM NaCl+Zn	1.00 ± 0.90 d (21.41)	8.33 ± 1.52 d (12.49)	7.33 ± 2.08 d (14.66)	0.56 ± 0.29 e (9.30)	0.55 ± 0.28 e (10.05)	3.11 ± 0.97 d (32.06)	0.15 ± 0.05 d (6.25)

Each value is the mean (± standard deviation) of nine replicates (Duncan's test, P <0.05). Values within parenthesis indicate percentage relative to the control.

Water uptake capacity (WUC) measures a plant’s ability to absorb water per unit dry weight relative to its total weight. In this experiment, salinity caused an increase in WUC compared to the control. Salinity levels at 100, 150, 200, and 250 mM NaCl caused 131.25, 147.50, 172.50 and 190.00% increases of leaf WUC in non-zinc application plants, respectively. Interestingly, salinity usually hampers water uptake, but certain tolerant genotypes exhibit elevated water absorption capacity through osmotic adjustment (Akhtar *et al*. 2013, Rahman *et al*. 2016). However, WUC significantly increased by 14.29, 11.86, 16.67 and 59.87% at 100, 150, 200, and 250 mM NaCl, compared with NaCl treatments with zinc application, respectively (Table 2). Zn ions might change the osmotic potential of root cells, enabling them to absorb more water. Additionally, the use of Zn may boost the root system's water uptake capacity by altering the infiltration pattern of root cells (Zhang *et al*. 2020).

The flow of sap from the cut end of the stem against gravity is known as exudation. Under normal conditions, the exudation rate is higher than that under salt stress or any other stress conditions. Therefore, exudation can be used as an indicator to measure stress severity. Results showed that the exudation rate decreased compared to the control by 55.95, 64.30, 72.31 and 79.68% in plants treated with 100, 150, 200, and 250 mM NaCl, respectively. Under salt stress, a reduction in the exudation rate has been observed by Akhtar *et al*. (2013) for wheat, suggesting that reduced water absorption is responsible for lowering the exudation rate. In comparison, Zn supplementation increased the exudation rate by 8.29, 10.16, and 5.16% at salinity levels of 100, 150, and 250 mM, respectively (Table 2). It was also observed that plant exudates were not significantly improved by zinc incorporation at 200 mM NaCl. The study could not establish a clear link between zinc and increased exudation under salinity. Further research is necessary to confirm this relationship.

Salt-stressed soybeans showed statistically similar branch number, whereas zinc application escalated the branch number of soybeans at low and moderate salt stress. Although zinc interaction had a negative role on branch number at maximum salt level, it was improved by 20.12, 33.50, and 39.52% under salinity levels at 50, 150, and 200 mM NaCl, respectively (Table 3).

NaCl treatment significantly reduced the total number of pods per plant, where it was decreased by 28.33, 48.00, 61.01, 83.01, and 92.01% under salinity treatment of 50, 100, 150, 200, and 250 mM NaCl, respectively. Zinc application on NaCl-stressed soybean plants increased the total number of pods by 13.28, 43.26, 23.00, 50.04, and 56.29% under salinity levels at 50, 100, 150, 200, and 250 mM, respectively (Table 3).

NaCl treatment decreased the number of filled pods per plant to a large extent. The number of filled pods decreased by 35.34, 57.34, 71.34, 85.34, and 89.34% under salinity treatment of 50, 100, 150, 200, and 250 mM NaCl, respectively. Zinc application on NaCl-stressed soybean plants increased the number of filled pods per plant by 18.56, 56.26, 27.91, 45.56, and 37.52% under salinity levels at 50, 100, 150, 200, and 250 mM, respectively (Table 3).

Total pod weight was greatly reduced by NaCl stress and decreased by 52.82, 70.10, 78.74, 84.89 and 91.03% under salinity treatment of 50, 100, 150, 200, and 250 mM NaCl, respectively (Table 3). Zinc application on NaCl-stressed soybean plants increased the total pod weight by 24.29, 42.78, 35.16, 10.98 and 3.70% under salinity levels at 50, 100, 150, 200, and 250 mM, respectively.

Weight of filled pods /plant of soybean as influenced by different salinity levels is presented in Table 3. Filled pods weight decreased with respect to the control by 56.68, 73.86, 80.99, 87.39 and 93.79% in plants treated with 50, 100, 150, 200, and 250 mM NaCl, respectively. Zn supplementation increased filled pods weight by 8.41, 28.69, 57.34, 50.96, 46.38 and 61.76% under salinity levels at 50, 100, 150, 200, and 250 mM, respectively.

Table 3 indicates an inverse relation between rising salinity and both the 100-seed weight and yield per plant. Zinc application consistently improved these variables compared to the corresponding non-zinc-treated plants. The greatest improvements in both parameters were observed under moderate salinity levels (100-200 mM NaCl). In this range, zinc application raised 100-seed weight by 25.86, 22.97, and 29.41%, while the yield increased by 27.85, 33.96, and 35.71% at 100, 150, and 200 mM NaCl, respectively.

In the present study, increasing salinity levels consistently reduced key yield parameters, including the number of pods per plant, seeds per pod, and total seed yield. The reduction in seed yield of soybean has been reported by several studies (Khan *et al*. 2016, Ferdous *et al*. 2018). Yield reductions in salt-affected soils result primarily from alteration of various metabolic processes in plants under salt stress (Eynard *et al*. 2005). Moreover, Maas and Hoffman (1977) concluded that the reduction in yield at increased salt levels was possibly due to a reduction in the physiological availability of water with the increase in osmotic concentration and accumulation of ions at a toxic concentration in the plant. In the present study application of Zn to salt-stressed plants significantly enhanced the pod formation, improved seed development, and increased overall yield in soybean compared to salt treatments. A similar trend was noted by Ferdous *et al.* (2018) and Parvin *et al.* (2016). Reduction in branch number with high salinity indicates suppressed vegetative growth and reduced meristematic activity under salt-induced osmotic and ionic stress.

The evidence presented confirms that salinity stress adversely affected photosynthetic pigments, water status, and yield attributes in soybean, leading to reduced plant performance. Zinc supplementation showed a consistent alleviating effect across all stress levels. The most pronounced improvements were observed under moderate salinity (150 mM NaCl). This suggests that zinc could be used as part of soil management in salinity-prone areas to maintain soybean production.

Acknowledgements

This study was supported by a grant from University Grants Commission, Bangladesh.

References

Abdallah SB, Aung B, Amyot L, Lalin I, Lachâal M, Karray-Bouraoui N and Hannoufa A 2016. Salt stress (NaCl) affects plant growth and branch pathways of carotenoid and flavonoid biosyntheses in *Solanum nigrum*. Acta Physiol. Plant. **38**(3): 72.

Afrin S, Akhtar N, Khanam T and Hossain F 2021. Alleviative effects of zinc on biomass yield and antioxidative enzymes activity in leaves of soybean (*Glycine max* L.) under salt stress. Amer. J. Agric. For. **9**(3): 147-155.

Afrin S, Hossain F, Halim M and Akhtar N 2023. Comparative study of salt tolerance between two soybean varieties (*Glycine max* L.) at germination stage. Jahangirnagar University J. Biol. Sci. **12**(1&2): 35-44.

Ahmad P, Ahanger MA, Alyemeni MN, Wijaya L, Egamberdieva D, Bhardwaj R and Ashraf M 2017. Zinc application mitigates the adverse effects of NaCl stress on mustard [*Brassica juncea* (L.) czern and coss] through modulating compatible organic solutes, antioxidant enzymes, and flavonoid content. J. Plant Interact. **12**(1): 429-437.

Akhtar N, Hossain F and Karim A 2013. Influence of calcium on water relation of two cultivars of wheat under salt stress. Int. J. Environ. **2**(1): 1-8.

Akhtar N, Karim A, Afrin S and Hossain F 2021. Effects of gibberellic acid and kinetin on germination and ion accumulation in a Bangladesh wheat variety under salt stress conditions. European J. Biophys. **9**(2): 86-91.

Al-Zahrani HS, Alharby HF, Hakeem KR and Rehman RU 2021. Exogenous application of zinc to mitigate the salt stress in *Vigna radiata* (L.) wilczek - evaluation of physiological and biochemical processes. Plants **10**(5): 1005.

Batra N, Kumari N and Sharma V 2022. Salt stress in plants and amelioration strategies: alleviation of agriculture and livelihood risks after the Covid-19 pandemic. Vegetos **36**(1): 268.

Boussora F, Triki T, Bennani L, Bagues M, Ben Ali S, Ferchichi A, Ngaz K and Guasmi F 2024. Mineral accumulation, relative water content and gas exchange are the main physiological regulating mechanisms to cope with salt stress in barley. Sci. Rep. **14**(1): 14931.

Cakmak I 2000. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. New Phytol. **146**(2): 185-205.

Eynard A, Lal R and Wiebe K 2005. Crop response in salt-affected soils. J. Sustain. Agric. **27**(1): 5-50.

Ferdous J, Mannan M, Haque M, Alam M and Talukder S 2018. Mitigation of salinity stress in soybean using organic amendments. Bangladesh Agron. J. **21**(1): 39-50.

Hasanuzzaman M, Nahar K, Alam MM, Bhowmik PC, Hossain MA, Rahman MM, Prasad MNV, Ozturk M and Fujita M 2014. Potential use of halophytes to remediate saline soils. Biomed. Res. Int. **2014**: 589341.

Hasanuzzaman M, Nahar K, Fujita M, Ahmad P, Chandna R, Prasad MNV and Ozturk M 2013. Enhancing plant productivity under salt stress: relevance of poly-omics. Salt Stress in Plants: 113-156.

Khan MSA, Karim MA, Haque MM, Islam MM, Karim AJMS and Mian MAK 2016. Influence of salt and water stress on growth and yield of soybean genotypes. Pertanika J. Trop. Agric. Sci. **39**(2): 167-180.

Khanam T, Akhtar N, Halim M and Hossain F 2018. Effect of irrigation salinity on the growth and yield of two Aus rice cultivars of Bangladesh. Jahangirnagar University J. Biol. Sci. **7**(2): 1-12.

Khanam T, Kim K, Karim MA, Afrin S, Lopa FR, Hoque MM, Higuchi H, Walitang DI, Roy SK, Sa T and Akhtar N 2025. Salinity tolerance of two rice cultivars is related to enhanced activities of enzymatic antioxidants and higher proline content. Appl. Biol. Chem. **68**(1): 58.

Maas EV and Hoffman GJ 1977. Crop salt tolerance - current assessment. J. Irrig. Drain. Div. **103**(2): 115-134.

Mackinney G 1940. Criteria for purity of chlorophyll preparations. J. Biol. Chem. **132**(1): 91-109.

Maclachlan S and Zalik S 1963. Plastid structure, chlorophyll concentration, and free amino acid composition of a chlorophyll mutant of barley. Can. J. Bot. **41**(7): 1053-1062.

Parvin K, Hasanuzzaman M and Fujita M 2016. Supplemental zinc mitigates salt-induced damages in tomato (*Lycopersicon esculentum* L.). Int. J. Bus. Soc. Sci. Res. **5**(1): 91-97.

Rahman MM, Haque MM, Nihad SAI, Mahmudul-Hasan-Akand M and Ruhul-Amin-Howlader M 2016. Morpho-physiological response of *Acacia auriculiformis* as influenced by seawater induced salinity stress. For. Syst. **25**(3): e071.

Sangakkara UR, Hartwig UA and Nösberger J 1996. Response of root branching and shoot water potentials of french beans (*Phaseolus vulgaris* L.) to soil moisture and fertilizer potassium. J. Agron. Crop Sci. **177**(3): 165-173.

Weisany W, Sohrabi Y, Heidari G, Siosemardeh A and Ghassemi-Golezani K 2011. Physiological responses of soybean (*Glycine max* L.) to zinc application under salinity stress. Aust. J. Crop Sci. **5**(11): 1441-1447.

Zhang L, Yan M, Li H, Ren Y, Siddique KH, Chen Y and Zhang S 2020. Effects of zinc fertilizer on maize yield and water-use efficiency under different soil water conditions. Field Crops Res. **248**: 107718.

(Manuscript received on 20 August, 2025; revised on 25 May, 2026)