Bangladesh J. Bot. **54**(1): 91-98, 2025 (March) DOI: https://doi.org/10.3329/bjb.v54i1.78108

# EFFECTS OF WATERLOGGING ON ION ABSORPTION, TRANSLOCATION AND BIOCHEMICAL RESPONSES IN MAIZE

**RIFAT SAMAD***

*Department of Botany, University of Dhaka, Dhaka-1000, Bangladesh*

*Keywords*: Maize, Ion transport, Biochemicals, Sugar, Protein, Proline

## Abstract

An experiment was conducted to investigate the impact of waterlogging on ion absorption, transport and some biochemical parameters, including the concentration of reducing and total sugar, proline, protein and antioxidant enzymes in the root and shoot of maize plants grown in solution culture. Waterlogging suppressed the accumulation of $K^+$, $NO_3^-$, $Ca^{2+}$ and $Mg^{2+}$ in maize plants. On the other hand, the waterlogged state dramatically increased the accumulation of $Na^+$ and $Fe^{2+}$ in different parts of the maize plants. Waterlogging stimulated the level of total and reducing sugars as well as proline in the root and shoot of maize plants. Activities of different antioxidant enzymes were found higher under waterlogged condition.

## Introduction

Waterlogging has an impact on crop productivity in agricultural areas as well as plant dispersal in their natural environments. This is one of the most hazardous natural occurrences that constitute major threats to food supply. Waterlogging affects over 16% of the world's agricultural area (Ploschuk *et al.* 2018). Each year, flooding affects over 17 million $km^2$ of land surface around the world; causing severe damage to plants and crop production (Voesenek and Sasidharan 2013). With the accelerated climate change, abundant precipitation events are projected to increase flooding by about 7% for every 1°C increase in global warming, leading to increased flood hazard severity (IPCC 2021).

Low-lying rainfed locations experience substantial waterlogging problems. Several areas of Bangladesh endure waterlogging as a result of extreme weather events, improper drainage caused by unplanned infrastructure development and poor flood-control structure design. In addition to obstructing natural water flow, river siltation has also caused waterlogging. North-eastern region, south-west region and south-central region are some of the worst waterlogged areas in Bangladesh.

Due to waterlogged condition, the $K^+$ content was significantly reduced but the opposite trend was found in the $Na^+$ content in *Suaeda glauca* (Duan *et al.* 2018). Inhibitory effect of waterlogging on nitrate accumulation was observed in sunflower (Heidari and Karami 2014). Sharma *et al.* (2022) reported that peanut under waterlogged condition had a lower soluble sugar content. Proline content was significantly increased in cucumber in response to this stress condition (Barickman *et al.* 2019). Waterlogging treatment significantly increased the activity of superoxide dismutase (SOD) enzyme while reduced the activity of peroxidase (POD) and catalase (CAT) enzymes in wheat (Alizadeh-Vaskasi *et al.* 2018).

Maize (*Zea mays* L.) is one of the major cereal crops of Bangladesh. Maize was selected as the experimental plant material since there were a few data on the impact of waterlogging on ion accumulation and its correlation with growth and biochemical parameters in this plant. Therefore, an attempt was undertaken to study the response of maize plants by analyzing the physiological and biochemical changes of the plant growing under waterlogged condition.

---

*Author for correspondence: <rifatsamad@gmail.com>.

## Materials and Methods

Seeds of maize were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur. Maize seeds were surface sterilized with 5.25% sodium hypochlorite solution. The sterilized seeds were scattered over a cotton gauge placed in a lid having holes (1 cm in diameter) and the lid with the cotton gauge and seeds was set on top of a beaker that contained 500 ml of distilled water. To prevent the roots from being exposed to light, the beakers were covered with a black plastic sheet.

Following germination, modified half-strength Hoagland solution (Hoagland and Arnon 1950) was applied to the seedlings, and the beakers containing the seedlings were set up in a light bank. The day/night temperature for maize seedlings were maintained at $25^oC\underline{+}1^oC$ /$18^oC\underline{+}1^oC$ and the photoperiod was 10/14 hrs (day/night). Using an air compressor, the solution was continually aerated through a bubbler (Rockyvac 320). The solution was replenished every 48 hrs. Fourteen days old seedlings were placed in black-painted plastic buckets with holes in the lid and treated to aerobic (control) and anaerobic (treatment) conditions for up to 21 days. After 3, 7, 14 and 21 days of waterlogged treatment, roots, and shoots were collected in triplicate.

Flame photometer (Jenway, PEP-7, UK) measurements of $K^+$ and $Na^+$ ions were made at wavelengths of 589 and 767 nm, respectively. The method of Cataldo *et al.* (1975) was used to determine the amount of nitrate. With the aid of an atomic absorption spectrophotometer (Perkin-Elmer, Model: AAnalyst 200), the concentrations of $Ca^{2+}$, $Mg^{2+}$ and $Fe^{2+}$ in the extract were measured at wavelengths of 422.67, 285.21 and 248.33 nm, respectively. According to the Somogyi-Nelson (Nelson 1944, Somogyi 1952) and Dubois *et al.* (1956) methods, reducing and total sugar were identified. Lowry *et al.* (1951) technique and Bates *et al.* (1973) method were used to determine the amount of protein and proline, respectively. Activities of different antioxidant enzymes {e.g. superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT)} were estimated following the protocol of Zhang *et al.* (2005).

## Results and Discussion

Waterlogging stress caused the reduction of $K^+$ content in both root and shoot of maize plants. Accumulation of $K^+$ in the root of maize was gradually decreased from 2.0 to 77.3% at 3 to 21 days of waterlogged treatment and similar pattern of inhibition of $K^+$ transport and accumulation was observed in shoot of maize plants, which was ranged from 12.6 to 73.0% from 3 to 21 days of treatment (Fig. 1). This result is in agreement with the work of Dodd *et al.* (2013) in cotton due to waterlogging state.

Accumulation of $Na^+$ was increased from 45% to 2.3-fold from 3 to 21 days of waterlogged treatment. From 3 to 21 days after treatment, waterlogging revealed an increasing slope in $Na^+$ content in shoot ranged from 25% to 4.2-fold (Fig. 2). Similar trend of escalation in $Na^+$ content was found in cotton by Rochester (2010).

In case of nitrate accumulation in root, at first 12 to 30% increment were noted from 3 to 14 days of treatment followed by a decrement of 30% at 21 days of waterlogging treatment. Similar magnitude of inhibition was also observed in the shoot from 3 to 21 days of treatment (Fig. 3). This result is supported by Herzog *et al.* (2015) who found that waterlogging resulted in shoot nitrogen deficiency.

In the root of maize, waterlogging caused a gradual inhibition in the accumulation of $Ca^{2+}$ from 26.6 to 47.9% from 3 to 21 days of treatment. Similar gradual decrease in $Ca^{2+}$ accumulation was observed in the shoot following waterlogging treatment (Fig. 4). Similarly, calcium content was reduced in jute plants treated with waterlogged stress (Parvin and Karmoker 2013).

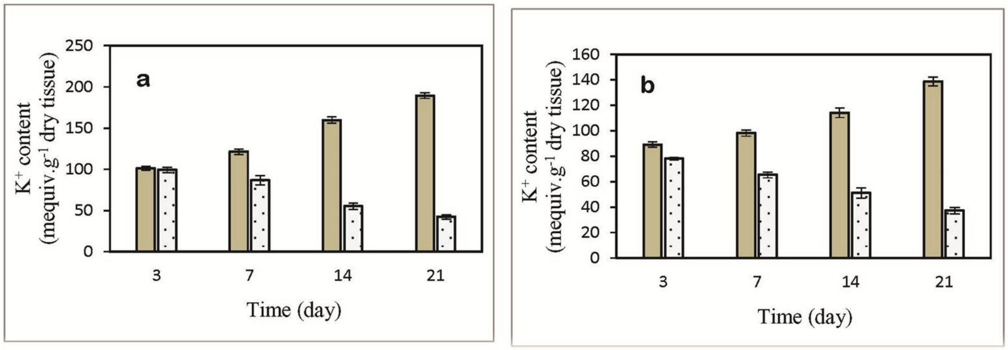

Fig. 1. Effects of waterlogging on the accumulation of $K^+$ in the root (a) and shoot (b) of maize plants. ■ represents control and □ waterlogged treatment. Each value is the mean of three replicates. Bars represent ± standard error of the mean value.

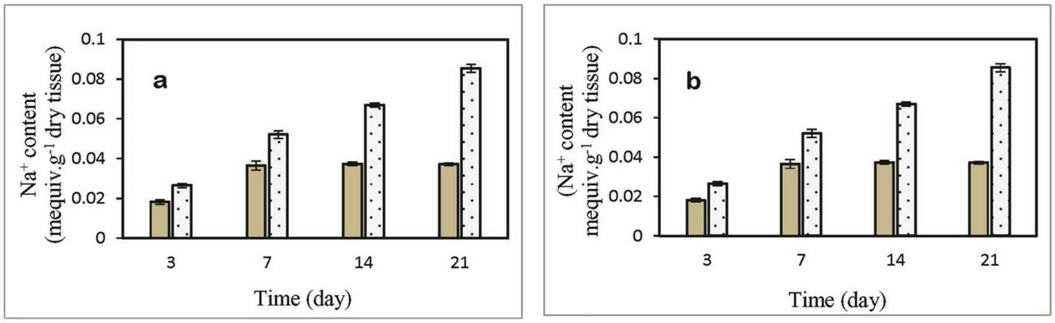

Fig. 2. Effects of waterlogging on the accumulation of $Na^+$ in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

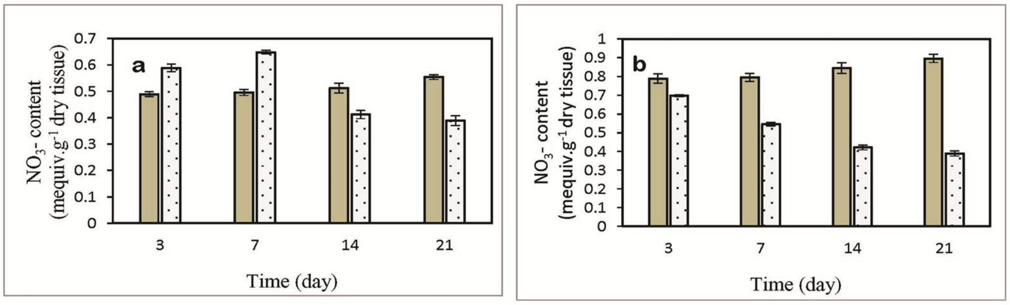

Fig. 3. Effects of waterlogging on the accumulation of $NO_3^-$ in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

During the course of the experiment, the accumulation of $Mg^{2+}$ in the maize root decreased from 23.53 to 30.6%. $Mg^{2+}$ accumulation in the shoot was also inhibited and the highest reduction by 23.0% was found at 21 days of waterlogging stress (Fig. 5). The application of waterlogging stress significantly reduced $Mg^{2+}$ accumulation in soybean (Board 2008).

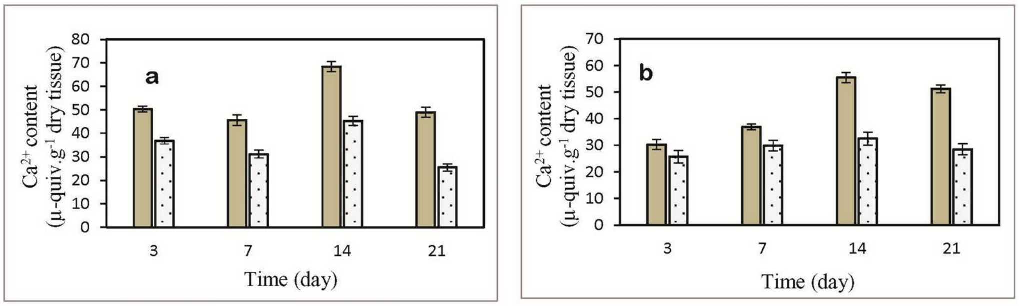

Fig. 4. Effects of waterlogging on the accumulation of Ca$^{2+}$ in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

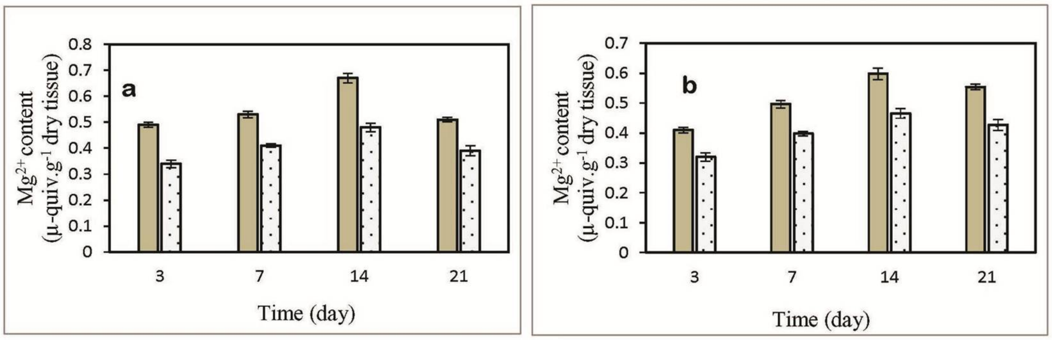

Fig. 5. Effects of waterlogging on the accumulation of Mg$^{2+}$ in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

Waterlogging treatment showed stimulating effect on Fe$^{2+}$ accumulation in the root with the increments of 33.47 to 45.7% within 3 to 21 days of treatment (Fig. 6). In the shoot, Fe$^{2+}$ accumulation was also increased and the highest accretion by 2- fold was observed at 21 days of treatment (Fig. 6). Increased concentration of Fe$^{2+}$ in the shoots of wheat during waterlogged state was reported by Khabaz-Saberi *et al.* (2012).

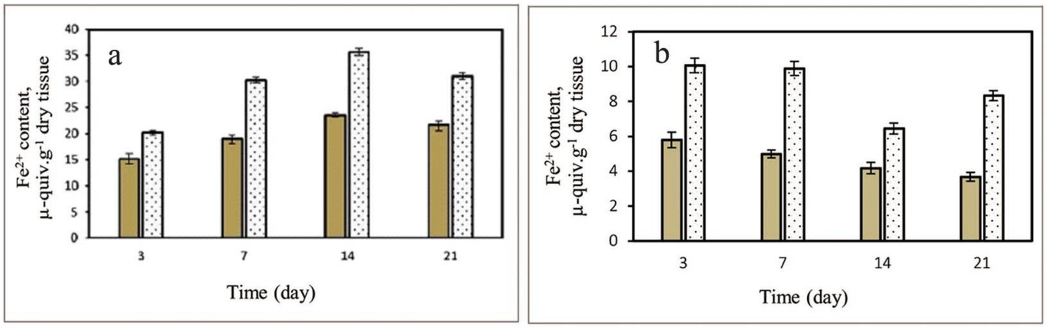

Fig. 6. Effects of waterlogging on the accumulation of Fe$^{2+}$ in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

Waterlogged condition accelerated the reducing sugar content in both root and shoot. In the root, waterlogging treatment enhanced the reducing sugar content whereas the maximum enhancement was visible by 7.57 to 19.6% within 3 to 21 days of treatment. In the shoot, the amount of reducing sugar got increased by 6.88 to 23% due to waterlogging within 3 to 21 days of treatment (Fig. 7). In *Paeonia lactiflora* an increased level of soluble sugar content due to waterlogging was also found by Liu *et al.* (2021).

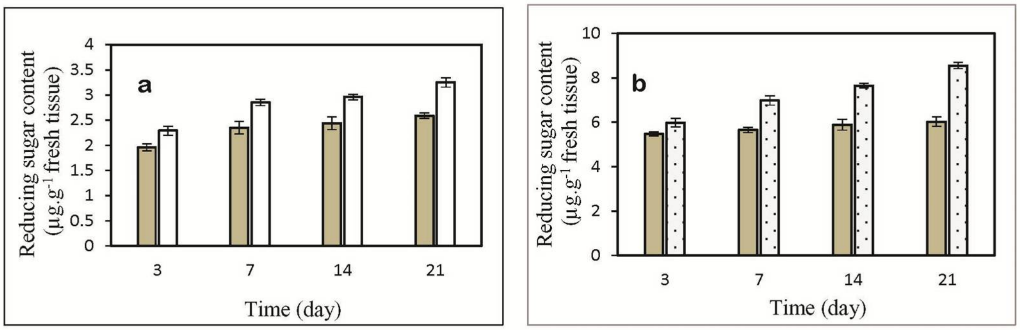

Fig. 7. Effects of waterlogging on the accumulation of reducing sugar in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

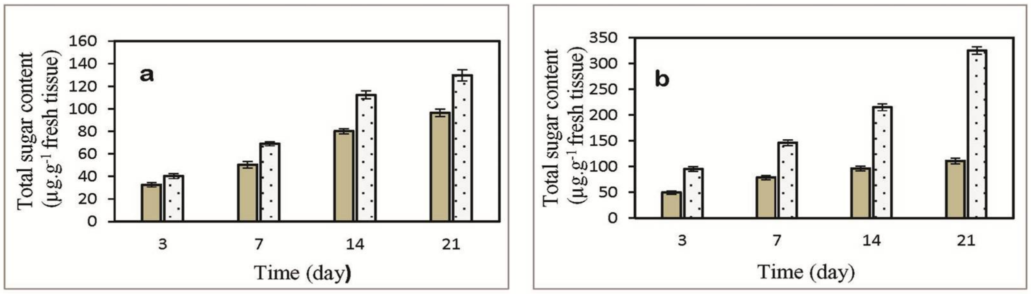

Fig. 8. Effects of waterlogging on the accumulation of total sugar in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

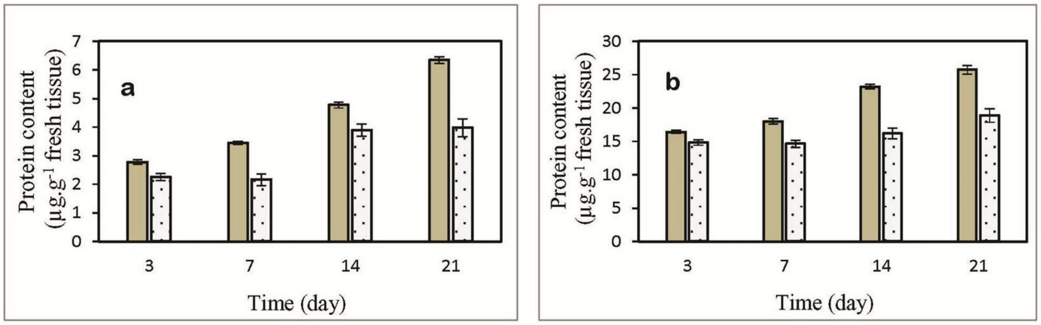

Fig. 9. Effects of waterlogging on protein content in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

Stimulation of total sugar content in root and shoot was noteworthy. In the root, the maximum stimulation was observed with the increment that ranges within 87% to 2-fold (Fig. 8). Orsák *et al.* (2021) have also reported an increment in the total sugar content of potato tubers under waterlogging stress.

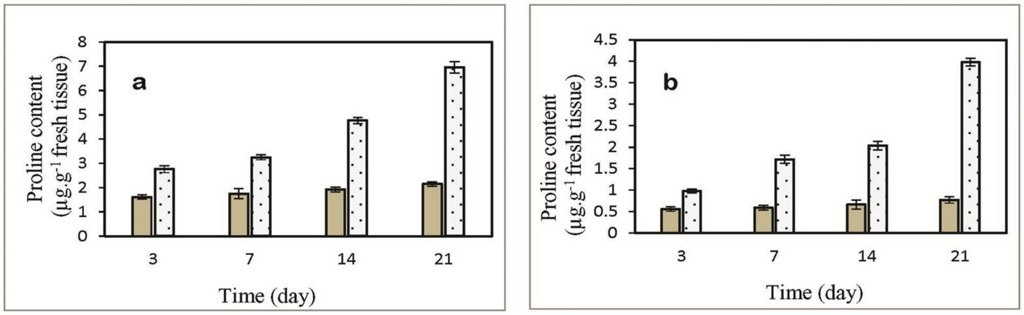

Fig. 10. Effects of waterlogging on proline content in the root (a) and shoot (b) of maize plants. Otherwise same as in Fig. 1.

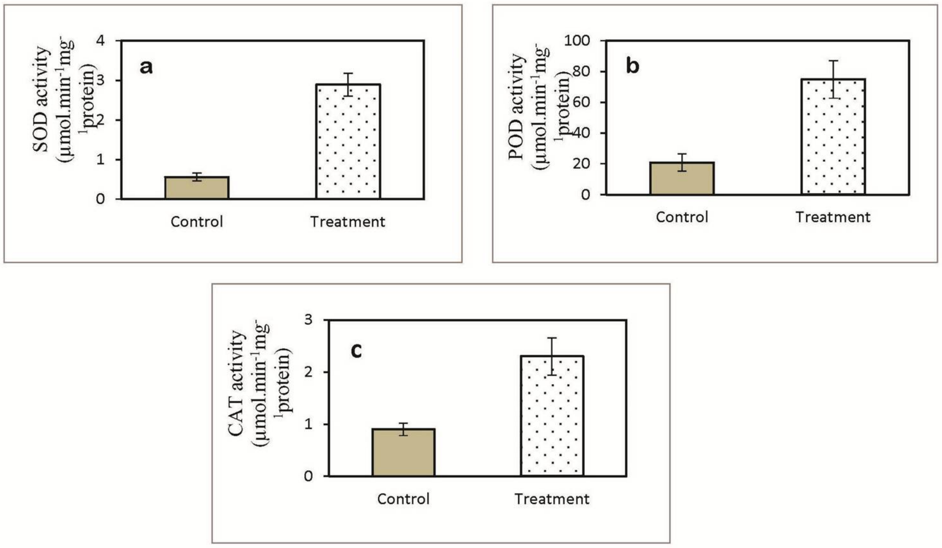

Fig. 11. Effects of waterlogging on the activity of superoxide dismutase (a), peroxidase (b) and catalase (c) in the leaves of maize plants at 14 days of treatment. Each value is the mean of three replicates ± standard error.

Maize root showed a descending trend in protein content by 19.2 to 37.3% over the period of time. In the shoot, waterlogged condition exhibited the highest inhibition of protein by 26.7% at 21 days of treatment (Fig. 9). Similar trend was also observed by Otie *et al.* (2019) in *Zea mays.*

Waterlogging showed stimulating effect on proline content with the increments of 71.42% to 3.2- fold. In shoot, the waterlogged condition showed the highest 5-fold increase in proline content at 21 days of treatment (Fig. 10). Bajpai and Chandra (2015) reported a significant accumulation of free proline in leaf of sugarcane.

Waterlogged stress increased superoxide dismutase (SOD) activity in the leaf of maize plants by 5- fold at 15 days of treatment. Peroxidase activity was found to increase in the leaves by 3.6-fold following 15 days of exposure to waterlogged stress. The activity of catalase of the waterlogged maize plants increased by 2.5- fold in response to waterlogging stress (Fig. 11). Similarly, waterlogging stress significantly increased the SOD and CAT activities in banana plants (Teoh *et al.* 2022). Liu *et al.* (2021) also reported that POD activity in herbaceous peony was stimulated by waterlogging stress.

This study concluded that waterlogging significantly impacted on ion transport and biochemical responses in maize plants. It suppressed the uptake and accumulation of essential ions like $K^+$, $NO_3^-$, $Ca^{2+}$, and $Mg^{2+}$, while causing a significant increase in the accumulation of $Na^+$ and $Fe^{2+}$. Waterlogging also stimulated stress-related biochemical responses, including increased levels of reducing sugar, total sugar, and proline, in both roots and shoots. Increase in reducing and total sugar concentration caused by waterlogging stress might enhance the ability of cells to absorb and retain water, leading plants to attempt adaptation to the waterlogged state. An increase in proline concentration during waterlogging condition suggests that proline was one of the common compatible osmolytes under waterlogging stress. Furthermore, the elevated antioxidant enzyme activities under waterlogging stress indicated that they possessed efficient reactive oxygen species (ROS) scavenging mechanisms to counteract oxidative stress caused by the adverse environment. The findings emphasized the physiological and biochemical adjustments maize plants undergo to cope with waterlogging stress. These insights highlight critical areas for further research, offering a foundation to develop climate-resilient maize varieties capable of withstanding waterlogging stress, relevant in the context of future climate challenges.

## Acknowledgement

This research was financially supported by Centre for Advanced Studies and Research in Biological Sciences (CARS), University of Dhaka, Bangladesh, which is gratefully acknowledged.

## References

Alizadeh-vaskasi F, Pirdashti H, Araei AC and Saadatmand S 2018.Waterlogging effects on some antioxidant enzymes activities and yield of three wheat promising lines. Acta Agric. Slov. **111**: 621-631.

Bajpai S and Chandra R 2015. Effect of waterlogging stress on growth characteristics and sod gene expression in sugarcane. Int. J. Sci. Res. Pub. **5**: 1-8.

Barickman TC, Simpson CR and Sams CE 2019. Waterlogging causes early modification in the physiological performance, carotenoids, chlorophylls, proline, and soluble sugars of cucumber plants. Plants **8**:160-174.

Bates LS, Waldren RP and Teari D 1973. Rapid determination of free proline for water stress studies. Plant Soil. **39**: 205-207.

Board JE 2008.Waterlogging effects on plant nutrient concentrations in soybean. J. Plant Nutr. **31**: 828-838.

Cataldo DA, Haaron M, Schrader LF and Youngs VL 1975. Rapid colorimetric determination of nitrate in plant tissue by titration of salicyclic acid. Commun. Soil Sci. Plant Anal. **6**: 71-81.

Dodd K, Guppy CN, Lockwood PV and Rochester IJ 2013. Impact of waterlogging on the nutrition of cotton (*Gossypium hirsutum* L.) produced in sodic soils. Crop Pasture Sci. **64**: 816-824.

Duan H, Ma Y, Liu R, Li Q, Yang Y and Song J 2018. Effect of combined waterlogging and salinity stresses on euhalophyte *Suaeda glauca*. Plant Physiol. Biochem. **127**: 231-237.

Dubois M, Gilles KA, Hamilton JK, Rebers PA and Smith F 1956. Colorimetric method for determination of sugars and related substances. Ann. Chem. **28**: 350-358.

Heidari M and Karami V 2014. Effects of different mycorrhiza species on grain yield, nutrient uptake and oil content of sunflower under water stress. J. Saudi Soc. Agric. **13**: 9-13.

Herzog M, Striker GG, Colmer TD and Pederse O 2015. Mechanisms of waterlogging tolerance in wheat – a review of root and shoot physiology. Plant Cell Environ. **39**: 1068-1086.

Hoagland DR and Arnon DI 1950.The water culture method for growing plants without soils. Berkeley: California Agricultural Experimental Station, pp. 347.

IPCC 2021. Climate Change 2021: The physical science basis. Contribution of working group 1 to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom.

Khabaz-Saberi H, Barker SJ and Rengel Z 2012. Tolerance to ion toxicities enhances wheat (*Triticum aestivum* L.) grain yield in waterlogged acidic soils. Plant Soil **354**: 371-381.

Liu M, Zhang Q, Xu J, Bao M, Zhang D, Xie A and Sun X 2021. Effects of waterlogging stress on the physiological characteristics and secondary metabolites of herbaceous peony (*Paeonia lactiflora* Pall.) American J. Plant Sci. **12**: 536-557.

Lowry OH, Rosebrough NJ, Farr AL and Randall RJ 1951. Protein measurement with the Folin Phenol reagent. J. Biol. Chem. **193**: 265-275.

Nelson N 1944. A photometric adaptation of the Somogyi method for determination of glucose. J. Biol. Chem. **153:** 375-380.

Orsák M, Kotíková Z, Hnilička F and Lachman J 2021. Effect of drought and waterlogging on saccharides and amino acids content in potato tubers. Plant Soil Environ. **67**: 408-416.

Otie V, Ping A and Eneji E 2019.Brassinolide effects on maize (*Zea mays* L.) growth and yield under waterlogged conditions. J. Plant Nutr. **42**: 954-969.

Parvin D and Karmoker JL 2013. Effects of waterlogging on ion accumulation and sugar, protein and proline contents in *Corchorus capsularis* L. Bangladesh J. Bot. **42**: 55-63.

Ploschuk RA, Miralles DJ, Colmer TD, Ploschuk EL and Striker GG 2018. Waterlogging of winter crops at early and late stages: Impacts on leaf physiology, growth and yield. Front. Plant Sci. **9**: 1863-1877.

Rochester IJ 2010. Phosphorus and potassium nutrition of cotton: interaction with sodium. Crop Pasture Sci. **61**: 825-834.

Sharma S, Bhatt U, Sharma J, Darkalt A, Mojski J and Soni V 2022. Effect of different waterlogging periods on biochemistry, growth, and chlorophyll a fluorescence of *Arachis hypogaea* L. Front. Plant Sci. **13**: 1-17.

Somogyi M 1952. Notes on sugar determination. J. Biol. Chem. **195**: 19-23.

Teoh EY, Teo CH, Baharum NA, Pua TL and Tan BC 2022. Waterlogging stress induces antioxidant defense responses, aerenchyma formation and alters metabolisms of banana plants. Plants **11**:2052-2074.

Voesenek L and Sasidharan R 2013. Ethylene- and oxygen signaling-drive plant survival during flooding. Plant Biol. **15**: 426-435.

Zhang H, Jiang Y, He Z and Ma M 2005. Cadmium accumulation and oxidative burst in garlic (*Allium sativum*). J. Plant Physiol. **162**: 977-984.

*(Manuscript received on 10 March, 2024; revised on 29 November, 2024)*