



Amelioration of Salt Stress in Maize (*Zea mays* L.) by Seed Treatments with Glutathione

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Abstract: Salinity stress is one of the abiotic stress factors which reduces the crop production, and threat to global world food security. There is need to reduce the deleterious effects of salts in soil or irrigation water to minimize yield losses. The present study aims to evaluate the role of glutathione in alleviating the negative effects of salt stress in maize seedlings under controlled laboratory conditions. The study was conducted in complete randomized block design in quadruplicates. One hundred surface sterilized seeds of maize (*Zea mays* L.) cv J 1007 were treated with water (hydration) and solutions of glutathione (GSH) 100 and 500 ppm for 12 hours followed by surface drying. The treated seeds were subjected to salt stress levels of 0, 50, 75 and 100 mM NaCl. Ten days old seedlings were assessed for percent germination, seedling vigour indices and total soluble sugars and proteins. The results showed that both hydration and glutathione treatments significantly enhanced percent germination, length of lamina and sheath, vigour index I and II, total soluble sugars and total soluble proteins content than control. The glutathione 500 ppm is found to be effective as seed treatment in ameliorating deleterious effects of salt stress in maize than hydration and GSH 100 ppm.

Keywords: Glutathione, Maize, *Zea mays* L., Salt stress, Seed treatment.

1. INTRODUCTION

Maize (*Zea mays* L.) is a widely domesticated cereal crop which originated in America. It belongs to the family Poaceae. Currently, around 1148 Mt of maize is produced by around 170 countries from an estimate area of 185 Mha with average productivity is around 5.6 t/ha (Bamboriya et al., 2020). India ranks 4th in the area and 7th in the production among the maize growing countries. In India, maize is currently being cultivated on area of 9.6 Mha with 28.26 Mt production (Bamboriya et al., 2020). Among cultivated forage crops, maize is most suitable crop for fodder as well as silage because of its high yielding ability and excellent nutritional profile. Maize has a high TDN (total digestible nutrients) of around 85-90% and also contains comparatively higher amount of energy amongst all other cereal grains (Kaul et al., 2019). Maize is categorized as glycophytes, and it has potential to survive under low saline environments ($\leq 2 \text{ DSm}^{-1}$) (Himabindu et al., 2016). The early vegetative growth stage of maize is more sensitive to salt stress than reproductive stage.

Salt stress is one of the major abiotic stresses, which limits plant growth and yield especially in arid and semi-arid areas of the world (Hussain et al., 2019; Polash et al., 2019).

Land clearing, unsustainable irrigation practices, poor drainage, intensive use of fertilizers and increasing pressures for bringing marginal lands contributed for soil salinity, and affected plant growth and production. Around 1125 million ha of land is under the effect of salt stress, of which approximately 76 million ha is affected by human induced sodification and salinization (Hossain, 2019). Excess salts affect the metabolism of soil flora and fauna, ultimately leading to the destruction of all soil life, converting productive and fertile lands into barren deserts.

In Punjab, the salt affected areas and water logged soils mainly lies in Bathinda, Muktsar, Ferozepur and Mansa districts. Salt affected soils lie along or across Bikaner canal, Bathinda and Kotla branches of Bhakra canal and Sirhind canal. Soil salinity of these regions may be attributed to the seepage from Rajasthan feeder canals and also appears to be the cause of waterlogging (Singh, 2013). This is affecting cropping patterns, crop productivity and soil fertility in different parts of Punjab.

The damaging effects of salt stress depend on various factors such as plant species and varieties, salt concentration in soil, stress type, environmental conditions and plant growth stages (Shahverdi et al., 2018). Salinity alters the

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plants apostrophe morphological and anatomical characteristics, physiological processes and plant metabolism which ultimately leads to loss in agricultural production and causes disturbances in plant metabolism, impairs cell membrane integrity, interrupts enzyme activities and induces sodium ions toxicity (Banerjee et al., 2019; Singh et al., 2020). Salinity stress causes ionic and osmotic imbalance in soil as well as disturbs plant cellular osmotic potential and $K^+ : Na^+$ ratios that results in increased oxidative damages and hampered plant growth (dos Santos et al., 2022; Choudhary et al., 2023; He et al., 2023). Numerous studies demonstrated the negative effects of salt stress in terms of change in seedling vigour attributes, concentration of cellular metabolites and photosynthetic pigments, enzymatic and non-enzymatic antioxidants and yield attributes in various cereal crops (Singh et al., 2025a; Singh et al., 2025b; Chhatwal et al., 2025). Osmotic adjustment is an one of the important aspect to impart tolerance against abiotic stresses in plants. The change in the cellular content of osmolytes especially soluble sugars plays an important role in the adjustment of osmotic pressure under unfavorable conditions, and preventing the cells from dehydration and maintains the cellular integrity (Fu et al., 2017; Bhagat et al., 2025).

Glutathione (GSH) is the one of the most abundant and widely distributed water soluble non-protein thiol compound in cellular compartments of plants. Exogenously applied GSH under salt stressed conditions regulates both enzymatic and non-enzymatic antioxidants as well as osmoprotectants (Thind and Goyal, 2012). As non-enzymatic antioxidants, detoxify reactive oxygen species and attenuates the negative effects of oxidative stress in plants. The potential of glutathione in preventing lipid peroxidation and protecting the plasma membrane and other bio membranes has been also reported. Diverse roles of GSH in different metabolic activities showed that its metabolism has great impact in imparting plant tolerance against abiotic stresses through diverse ways (Ramzan et al., 2023). Numerous studies reported the exogenous application of glutathione through foliar or seed priming to enhance plant tolerance against aging and different abiotic stresses such as salt, heat and cold stress (Parcha and Gupta, 2017; Gaba et al., 2018; Chhatwal et al., 2025, Saeed et al., 2023 & 2025). Glutathione application as foliar spray @ 0, 0.4 and 0.8 mM in chilli pepper enhanced osmoprotectants, ascorbate, glutathione, capsaicin, and phenolic contents, as well as WUE under salt stress conditions (Al-Elwany et al., 2020). Thus the present investigation was planned to assess the

effect of glutathione on seed vigour parameters of maize seedlings grown in salt stress environment under controlled laboratory conditions.

2. MATERIALS AND METHODS

2.1. Location and Experimental Set Up

The present study was conducted in Department of Botany, Punjab Agricultural University, Ludhiana. The seeds of maize (*Zea mays* L.) cv J 1007 were procured from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. The study was designed to investigate the role of glutathione (100 and 500 ppm) on germination percentage, seedling growth and seedling vigour, total soluble sugars and total soluble proteins in ten days old maize seedlings, subjected to salt stress under controlled laboratory conditions. The experiment was conducted in completely randomized block design and replicated four times.

Seeds were treated with 0.1 % mercuric chloride ($HgCl_2$) for surface sterilization followed by thorough washings with autoclaved water three-four times. For glutathione treatments, seeds were soaked in freshly prepared solutions of 100 and 500 ppm glutathione for 12 hours. Salinity treatments were induced by soaking the germination paper in the NaCl solution of desired salinity levels (0 (control), 25, 50, 75 and 100 mM NaCl). The untreated and treated seeds were kept on germination paper and allowed to germinate in an incubator, maintained at 25°C and 60±5 % relative humidity. Ten days old uniform seedlings were used to record following parameters:

2.2. Germination Percentage

Twenty seeds were placed in each petri plate for each treatment and replicated thrice. Seeds were considered germinated when the emergent root reached 2 mm in length. Final count of normal seedlings was recorded after 10 days of setting for germination.

2.3. Lamina and Sheath Length

The length of expanded part of the leaf i.e. lamina and sheath covering the shoot was noted and was expressed in millimeters. The mean of lamina and sheath length of ten seedlings was considered as one replication.

2.4. Vigour Index (VI)

The seedling vigour index was recorded (Abdul-Baki and Anderson, 1973)

Vigour Index I = Germination (%) x Seedling length (cm)

Vigour Index II = Germination (%) x Seedling dry weight (g)

The root and shoot length of ten representative seedlings was measured. The shoot length was recorded from the

collar region to the point of attachment of cotyledons. Seedling length was recorded as sum of shoot length and root length. For seedling dry weight, the seedlings were oven dried at 70°C until the constant weight was obtained. The weight of same seedlings was recorded. The mean of seedling length and seedling dry weight of ten seedlings was considered as one replication.

2.5. Speed of Germination (Maguire, 1962)

Speed of germination was recorded by placing 20 seeds on top of paper in each petri plates. Data on the emergence of seedlings was recorded daily basis till the 100 percent germination or the final count *i.e.* 10th day.

$$\text{Speed of germination} = \sum (n_1/d_1 + n_2-n_1/d_2 + \dots + n_n - n_{n-1}/d_n) = \sum n/d$$

Where n = number of seeds germinated, d = number of days taken for germination

2.6. Total Soluble Sugars

0.1 g dry seedlings were homogenized in 80% ethanol followed by centrifugation at 5000 rpm for 15 minutes. The residue was re-extracted using ethanol and the supernatants were pooled and final volume was made 10 ml. The supernatant was used for estimation of total soluble sugars content using the method of Dubois et al. (1956). The standard curve of glucose (10-100 µg/ml) was prepared and used to estimate total soluble sugars content and recorded as mg/g dry weight.

2.7. Total Soluble Proteins

0.1 g fresh seedlings were macerated in 5 ml of 0.1 N NaOH followed by centrifugation at 5000 rpm. The extraction procedure was repeated twice and total volume was made 10 ml. 1 ml of protein extract and 1 ml of 15% trichloroacetic acid (TCA) was mixed and kept at 4°C for 24 hours. The same mixture was later centrifuged for 20 minutes at 5000 rpm. The precipitate so obtained were dissolved in 0.1 N NaOH and used for the estimation of total soluble proteins following the procedure of Lowry et al. (1951). The protein content was recorded as mg/g fresh weight.

2.8. Statistical Analysis

The Analysis of Variance (ANOVA) was done to find significant differences among treatments at 5% level of significance using SAS computer package.

3. RESULTS AND DISCUSSION

3.1. Percent Germination

Seed percent germination was significantly reduced by salt stress in untreated seeds and ranged from 95.00% (0 mM NaCl) to 76.67% (100 mM NaCl) (Table 1). The percent germination decreased rapidly as salt concentration reached

100 mM. GSH 100 and 500 ppm significantly improved the percentage germination of maize seeds. At 75 mM salt stress, it increased the percentage of germination from 88.33 to 93.67% (100 ppm GSH) and 94.33% (500 ppm GSH). GSH 500 ppm also showed significant increment in germination percentage from 76.67 to 83.33% at 100 mM salt concentration. Singh et al. (2025a) evaluated the percent germination of 78 *Berberis* introgression lines of wheat under salt stress and reported mean 31.60% reduction in percent germination under salt stress as compared to control. Pei et al. (2019) observed that GSH treatment significantly increased germination percentage of maize seeds under drought, salt and chilling stress.

3.2. Lamina and Sheath length

The decrease in lamina and sheath length was observed with increase in salt stress levels. This reduction was reversed when seeds were treated with water and GSH. The lamina and sheath length ranged from 1.2-3.1 cm and 5.6-9.0 cm respectively in seedlings developed from untreated seeds under control and salt stress conditions. At 50 mM salt stress, sheath length ranged from 8.32 cm to 11.15 cm. GSH @ 500 ppm seed treatment showed significant improvement in sheath length in the seedling as an increment from 5.60 cm (control) to 9.27 cm at 100 mM NaCl stress. Sheath length is also an important parameter in indication of salt stress. The gradual reduction in sheath length was reported in oat seedlings subjected to salt stress (Kaur and Gupta, 2020). Decreased lamina and sheath length with increase in salt stress is attributed to lesser supply of metabolites to young parts of plant.

3.3. Seed vigour index I and II

Water and glutathione seed treatments improved the seedling vigour index I and II in maize at different salinity levels (Table 1). At 75 mM salt stress level, seedling vigour index I ranged from 1367.34-2678.51. The highest seedling vigour index I was observed with seed treatment GSH 500 ppm at 75 mM salt stress. Similarly, seedling vigour index II of untreated seeds ranged from 2.28-4.07 under control and salt stress conditions. At 100 mM NaCl, seedling vigour index II varied from 2.28-3.23. GSH 500 ppm increased the seedling vigour index II from 2.86 to 4.52 at 75 mM salt stress. Seed vigour is a physiological property of the seed which governs its capability as how fast it can produce a seedling in soil and to what extent the seed can tolerate different stress conditions. Seed vigour is directly related to the initial growth of the crop and affects the competitive ability of a plant against weeds (Dias et al., 2011). Increasing salinity levels decreased the seed vigour

index in different genotypes of oats and wheat (Kaur and Gupta, 2020, Singh et al., 2025). Seed priming however increased seed vigour in sorghum (Komalasari and Arief, 2020).

3.4. Speed of Germination

Reduction in speed of germination was reported with the increasing salt stress levels (4.75-2.51 number of seeds/day) but it gradually increased with the application of treatments

Table 1. Influence of glutathione seed treatments on seed vigour parameters in maize cv J 1007 seedlings under salt stress conditions

| Salt stress levels Treatment | 0 mM NaCl (No stress) | 50 mM NaCl | 75 mM NaCl | 100 mM NaCl |
|--|-----------------------|------------|------------|-------------|
| Germination percentage | | | | |
| Control | 95.00 | 93.33 | 88.33 | 76.67 |
| Hydration | 96.67 | 93.33 | 91.33 | 80.00 |
| GSH 100 ppm | 96.67 | 94.67 | 93.67 | 81.67 |
| GSH 500 ppm | 98.33 | 95.33 | 94.33 | 83.33 |
| CD (p-0.05) | 3.13 | 8.89 | 6.28 | 7.84 |
| Lamina length (cm) | | | | |
| Control | 3.1 | 2.6 | 1.9 | 1.2 |
| Hydration | 4.2 | 3.8 | 10.3 | 6.3 |
| GSH 100 ppm | 8.6 | 8.2 | 5.9 | 3.0 |
| GSH 500 ppm | 12.8 | 10.9 | 12.7 | 7.4 |
| CD (p-0.05) | 0.46 | 0.42 | 0.55 | 0.54 |
| Sheath length (cm) | | | | |
| Control | 9.0 | 8.32 | 7.31 | 5.60 |
| Hydration | 9.3 | 8.55 | 8.83 | 6.44 |
| GSH 100 ppm | 10.97 | 10.40 | 10.48 | 8.32 |
| GSH 500 ppm | 11.55 | 11.15 | 11.89 | 9.27 |
| CD (p-0.05) | 0.25 | 0.51 | 0.86 | 0.87 |
| Vigour index | | | | |
| Control | 1888.61 | 1638.75 | 1367.34 | 972.94 |
| Hydration | 1989.47 | 1836.87 | 2009.86 | 1557.05 |
| GSH 100 ppm | 2389.68 | 2402.25 | 2349.09 | 2079.37 |
| GSH 500 ppm | 2731.60 | 2647.04 | 2678.51 | 2256.67 |
| CD (p-0.05) | 216.11 | 270.21 | 157.53 | 209.30 |
| Vigour index II | | | | |
| Control | 4.07 | 3.61 | 2.86 | 2.28 |
| Hydration | 4.20 | 3.86 | 3.71 | 3.49 |
| GSH 100 ppm | 4.90 | 4.59 | 4.12 | 3.74 |
| GSH 500 ppm | 5.34 | 4.91 | 4.52 | 3.93 |
| CD (p-0.05) | 0.43 | 0.74 | 0.52 | 0.57 |
| Speed of Germination (Number of seeds germinated/day) | | | | |
| Control | 4.75 | 4.66 | 3.47 | 2.51 |
| Hydration | 4.81 | 4.80 | 3.67 | 2.79 |
| GSH 100 ppm | 5.52 | 5.32 | 4.18 | 3.82 |
| GSH 500 ppm | 5.97 | 5.89 | 5.02 | 4.72 |
| CD (p-0.05) | 0.21 | 0.34 | 0.24 | 0.52 |

Table 2. Influence of seed treatments on total soluble sugars and total soluble proteins content in maize (*Zea mays* L.) cv J1007 seedlings under salt stress conditions

| Salt stress level Treatment | 0 mM NaCl (No stress) | 50 mM NaCl | 75 mM NaCl | 100 mM NaCl |
|---|--------------------------|------------|------------|-------------|
| Total soluble sugars (mg/g DW) | | | | |
| Control | 30.32 | 44.28 | 51.81 | 60.16 |
| Hydration | 35.11 | 49.01 | 62.87 | 73.42 |
| GSH 100 ppm | 66.89 | 86.23 | 106.09 | 114.21 |
| GSH 500 ppm | 84.78 | 114.81 | 123.09 | 129.89 |
| CD (p-0.05) | 1.03 | 1.73 | 1.14 | 2.46 |
| Total soluble proteins (mg/g FW) | | | | |
| Control | 16.45 | 19.71 | 25.57 | 30.25 |
| Hydration | 22.56 | 28.85 | 34.44 | 65.16 |
| GSH 100 ppm | 33.54 | 40.93 | 68.71 | 90.32 |
| GSH 500 ppm | 45.23 | 66.43 | 94.55 | 98.90 |
| CD (p-0.05) | 1.87 | 2.12 | 3.69 | 3.29 |

with GSH. Hydration seed treatment depicted a non-significant increase in speed of germination. The significant increase in speed of germination was observed with GSH 500 ppm seed treatment where it enhanced from 3.47 to 5.02 and 2.51 to 4.72 at 75 and 100 mM NaCl stress respectively. The significant reduction in germination velocity was found in dill, fenugreek, savory and dragonhead plants with increasing salt concentrations (Saberali and Moradi, 2019).

3.6. Total Soluble Sugars

Total soluble sugars content in seedlings developed from untreated seeds ranged from 30.32-60.16 mg/g DW under control and salt stress conditions. At 75 mM salt stress, hydration seed treatment increased the sugar content from 51.81 to 62.87 mg/g DW. The highest increase in sugar content was with GSH 500 ppm seed treatment which increased from 51.81 to 123.09 mg/g DW at 75 mM salt stress. Enhancement of total soluble sugars depicts their role in imparting tolerance by maintaining water potential under heat and salt stress conditions in wheat and Barley (Singh et al., 2025a; Singh et al., 2025b). The role of sugars to impart tolerance by foliar application of glutathione in salt stressed chickpea plants was reported by Sadak et al.(2017). The increased leaf soluble sugars under the impact of salinity, signified that maize employed soluble sugars for osmoregulation under salinity stress (El-Katony et al., 2019; Yu et al., 2025). Foliar application of glutathione helps to reduce the negative effect of salinity in sour passion fruit. The application of glutathione is reported to increase the total soluble sugars (de Souza et al., 2025) which contribute to the stress condition signaling process (Saddhe et al., 2021).

3.7. Total Soluble Proteins

Hydration and GSH 100 and 500 ppm seed treatment improved total soluble proteins content significantly under control (0 mM NaCl) and salt stress conditions. GSH 500 ppm increased the protein content from 25.57 (untreated seeds) to 94.55 mg/g FW at 75 mM NaCl (Table 2). Similar findings were reported by Jain and Vaishnav (2019) and Perveen and Nazir (2018) where the total protein content of the maize leaf segments was found to gradually increase with the application of NaCl. Ahmed et al. (2025) demonstrated that GSH increased the expression of stress responsive proteins and helped the plant to adapt to adverse conditions.

4. CONCLUSION

Salt stressed and water logged soils affect the plant establishment and growth by affecting various physiological processes. The damaging effects of salt stress can be mitigated by seed treatments with antioxidants like glutathione which improves the seed germination and vigour parameters under salt stress conditions.

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Authors' Contributions

Himani Chhatwal collected the data related to research

work, performed data analysis and interpretation and prepared rough draft of manuscript; Namrata Gupta outlined and supervised the research work, interpreted the data and edited the manuscript; P. Goyal supervised the research work, assisted in interpretation of data and manuscript editing; Meenakshi Goyal helped in biochemical analysis and manuscript editing; Gurjit Kaur Gill performed conceptualized and provided the maize germplasm; Nitika Garg analyzed the data statistically and helped in manuscript preparation.

Conflict of Interest

The authors declare that they have no conflicts of interest of reported research work in this manuscript.

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