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# Unravelling the Role of *Glomus mosseae* in the Alleviation of Salinity Stress in Mungbean [*Vigna radiata* (L.) Wilczek]

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## ABSTRACT

**Background:** Salinity stress remains a chronic threat to pulses productivity in India. Arbuscular mycorrhizal (AM) fungi play a major role which influences plant growth, nutrient uptake and contributes to ecosystem processes under salt stress. The present study aims, to demonstrate the impact of *Glomus mosseae* (Gm), on physio-biochemical attributes of mungbean exposed to salinity.

**Methods:** Two highly tolerant, two moderately susceptible and two highly susceptible mungbean lines were subjected to salinity stress alone and in presence of Gm under greenhouse.

**Result:** Results revealed that Gm alleviates the salinity stress related alterations by improving the nutrient uptake and by balancing the ratio between K:Na, which impact directly the osmoregulation of the plants. Mycorrhiza inoculation also increased the proline content (23%), water-use efficiency (38%) and activity of different antioxidant enzymes in a significant manner providing efficient protection against salinity stress. All these positive impacts of Gm were duly reflected in a significant increase in grain yield (more than 2 fold increase) in mungbean. Interestingly, salt-induced retarded growth and decline in other biochemical parameters in susceptible lines recorded remarkable recovery following Gm inoculation.

**Key words:** Arbuscular mycorrhizal fungi (AMF), *Glomus mosseae*, Mungbean, Salinity.

## INTRODUCTION

Mungbean [*Vigna radiata* (L.) Wilczek] is a short duration (65-90 days) grain legume of high nutritive values. The average yield of mungbean is very low in India mainly due to low inherent yield potential and susceptibility to stresses (Sehrawat *et al.,* 2013). Among the different abiotic stress salt stress is a chronic threat to mungbean yields, particularly in countries with irrigated agriculture.

Recent database reported that one-fifth of irrigated land are salt affected and 1.5 mhac land are becoming unsuitable for cultivation every year because of high salinization. If this trend continues in such way 50% of the agricultural land will be unproductive by 2050 (Hossain 2019). Previous reports on salinity tolerance in mungbean reported that the threshold limit of salt tolerance of mungbean is 6 m mhos/cm (Hanumantha Rao *et al.,* 2016). In response to salt stress, plant faced severe osmotic stress which ultimately altered different physio-biochemical pathways (Fatma *et al*. 2014). Under salt stress toxic reactive oxygen species (ROS) production in plant cell enhances in a rapid manner which ultimately altered the function of various cellular molecules. But, plants are capable of activating different defence mechanisms to fight against the stress-induced oxidative damage. Enhancement in antioxidant enzymes activities is one of the most important defence mechanisms of fighting against the stress-related oxidative damage (Liu *et al*., 2014). Moreover, by increasing the synthesis and accumulation of compatible solutes as well as different ions, plant can ameliorate the damaging impacts of salinity (Ahanger *et al*., 2014).

However, recent advances in the fields of biotechnology make it possible to introduce salt tolerant transgenic legume germplasm (Nirmala *et al.,* 2016). But this technique is very costly. Therefore, an alternative environment friendly strategy of application of biofertilizers (Evelin *et al.,* 2009) is very much needed for cost-effective legume production under salinity. Previous reports also approved that the application of mycorrhiza under salt stress condition could be influential in the restoration and creation of resistant cultivars (Rodriguez Rosales *et al.,* 1999). Arbuscular mycorrhizal fungi (AMF) inoculation and its symbiotic relationship with plant roots under salt stress corroborate that they will increase the tolerance of plants through the improvement of their growth by the symbiotic relationship (Yano-melo *et al.,* 2003). *Glomus mosseae* (Gm), the most common AMF ever reported to form a symbiotic relationship with wetland plant, is having a role in relieving stress-induced by NaCl (Wang *et al.,* 2012).

Thus, the present work was carried out to unravel the role of *Glomus mosseae* in the alleviation of salt stress

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through agronomic and Physio-biochemical attributes of mungbean.

## MATERIALS AND METHODS

### Experimental materials

Six high yielding (>30g/plant) extra short duration (<58 days) mungbean lines (Sarkar 2017) comprise of two germplasms Pusa-9632 (G4) (Salinity tolerant) and BL2 (G7) (Moderately Susceptible to salinity), two mutant lines CUM13 (Moderately Susceptible to salinity) and CUM8 (Highly susceptible to salinity) along with two hybrid lines CUH8 (Moderately Susceptible to salinity) and CUH1 (Highly susceptible to salinity), were collected from the Department of Genetics and Plant Breeding, University of Calcutta, West Bengal.

*Glomus mosseae* (Gm) was collected from Centre for Mycorrhizal Research, New Delhi. The cultures were being maintained and multiplied in sterile pot sand: soil 1:1 at Department of GPB, University of Calcutta, West Bengal, India.

### AMF inoculation and plant growth condition

Dry soils collected from university farm were sterilized to use as experimental soil. Approximately 4690 *Gm* spores were added to each experimental soil containing open pots (pot capacity: 7Kg dry soil/open pot; pot diameter 51cm) through the planting holes following the method of Ghazi and Al Karaki (2000). Un-inoculated soil was used as a control.

Seeds of selected mungbean lines were sown in inoculated as well as non-inoculated pots in complete randomized block design with five replications under greenhouse condition (25°C Day/ 20°C Night, 65% relative humidity, 16hrs/8 hrs photoperiod, with light intensity of 750 µmol $m^{-2}$ $S^{-1}$) on 12$^{th}$ March 2019. After emergence (5 plants in each pot) the plants were watered as needed and salt-stress (EC was maintained as 5.6 m mhos/cm) was established by the adding NaCl to the irrigation water at 15 days intervals. Salinity stress was imposed and maintained by fertigation technique (Manasa *et al*., 2017). At maturity whole plants were harvested from each treatment/lines/ replication for estimation of growth parameters and fresh root and shoots were collected for further biochemical analysis.

The experimental setup was divided into four treatments/ lines and the experiment was described as a three-way fully crossed factorial design:

Fungus (2 levels: Present and Absent) X salinity (2 levels: Present and Absent) X lines (6 levels) = 24 treatments X 5 replications = 120 pots.

Treatments are as follows: T1 = Non-inoculated plant under non saline condition; T2 = Gm inoculated plant under non saline condition; T3 = Non-inoculated plant under saline condition; T4 = Gm inoculated plant under saline condition.

### Determination of mycorrhizal colonization

The percentage of mycorrhizal root infection was estimated by visual observation of fungal colonization after washing washed roots in 10% KOH and staining with 0.05% trypan blue in lactic acid (v/v), as described by Phillips and Hayman (1970). Gridline intersects method was flowed to calculate the extent of mycorrhizal colonization (Giovannetti and Mosse 1980).

### Estimation of growth parameters

After sowing, days to emergence (DAE), at 10 DAE shoot length & root length and at maturity, plant height, number of branches plant$^{-1}$, number of pods plant$^{-1}$ & seed yield plant$^{-1}$ of all the plants were recorded for each treatment/lines/ replication.

### Physiological measurements

Physiological measurements such as determination of transpiration ratio, stomatal conductance, photosynthesis efficiency and photosynthetic pigments namely, chlorophyll a, b and carotenoids were estimated from leaves following Hiscox and Israelstam, (1979).

### Estimation of metabolites and stress indicators

Total soluble sugars content was determined by boiling the leaf sample with 5 ml 80% ethanol (v/v) following phenol/ $H_2SO_4$ colorimetric assay and starch content was measured by washing the pellets with 52% perchloric acid (v/v) following spectrophotometric assay of Dubois *et al*. (1956). Ascorbic acid estimation was done following the method of Keller and Schwager (1977) using dichlorophenol indophenol solution. Proline estimation was done from leaf samples using ninhydrin solution following Bligh and Dyer (1959). Total phenol was analyzed spectrophotometrically using the Folin-Ciocalteu colorimetric method (Wojdyło *et al*., 2007). After acid hydrolysis of plant samples, sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chlorine (Cl), phosphorus (P) estimation were done in ICP-OES. MDA content was estimated following TCA-TBA method (Heath and Packer 1968).

### Antioxidant enzyme assay

Spectrophotometric assay of Superoxide dismutase (SOD) (Ghosh *et al*., 2013), Peroxidase (POD) (Britton and Mehley 1955), Ascorbate peroxidase (APX) (Nakano and Asada 1987), Catalase (CAT) activity (Aebi 1984) and Glutathione reductase (GR) (Anderson 1996) was done.

### Statistical analysis

Mean data were subjected to three-way analysis of variance (ANOVA) and post hoc Duncan's Multiple Range Test using the statistical package of SPSS *ver* 21.0.

## RESULTS AND DISCUSSION

The results of the spore population and different structural colonization of Gm (Table 1) revealed that salt stress reduced the Gm colonization efficiency in the mungbean plants which is in line with the earlier findings of Hashem *et al*. (2015)

The study on effect of salinity stress on growth parameters in both inoculated and non-inoculated mungbean reported

that salt stress significantly reduced the yield parameters in all the tested lines. But, inoculation of Gm significantly improves the value of these parameters. Moreover, highly susceptible lines also showed remarkable yield improvement over control of 230% in presence of Gm under salt stress (Fig 1).

All the physiological parameters registered remarkable decrease under salinity stress (Table 2) which leads to the reduction on the photosynthetic capacity and water potential of cellular tissue (Sudhir and Murthy 2004). But AMF inoculated plants under salinity showed comparative improvement in all the tested lines. On the other hand, mungbean lines also recorded significant reduction in photosynthetic pigment content under salinity stress which may be due to the inhibition of chlorophyllase activity by the accumulated ions (Guo *et al*., 2014). But in presence of Gm under salinity, the salt-induced damage was ameliorated by increasing the synthesis of photosynthetic pigment content in all the tested lines which may be due to the enhanced amount of magnesium uptake Aroca *et al*. (2013).

Under salinity, tested lines recorded reduction in total sugar and starch content under but in presence of Gm the sugar and starch content was significantly increased over their respective controls (Table 3). In this context, Garg and Bharti (2018) suggested that sucrose molecules experience huge decomposition under salinity, but AMF can play a vital role in enhancement of sugar accumulation under salinity.

Ascorbic acid and phenolics are involved in stress tolerance by scavenging of toxic radicals (Tomar and Agarwal 2013). Present study (Table 3) revealed that salinity caused a significant decrease in ascorbic acid content but Gm inoculated stress induced plants showed a significant improvement of ascorbic acid content in all the tested lines over control. Simultaneously, salinity significantly increased

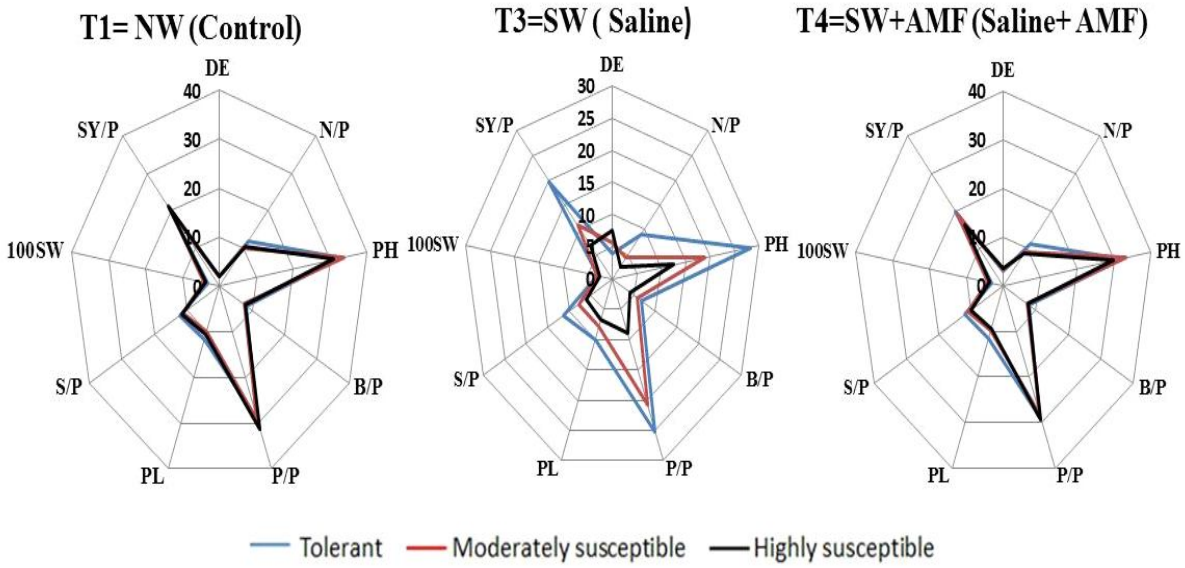


**Fig 1:** Representation of agro-morphological parameters of mungbean in control (T1), saline (T3) and Saline+AMF (T4) treated plants under green house condition. Radial graphs represent results relative to the higher value (indicated as 100%) for each parameter; DE= days to emergence, N/P= nodules/plant, PH= Plant height, B/P= branch/plant, P/P= pods/plant, PL= pod length, S/P= seeds/pod, 100SW= 100 seed weight, SY/P= seed yield/plant.

**Table 1:** Influence of salinity on mycorrhizal root infection in mungbean.

| Mungbean lines | Control + Gm | | | Salinity + Gm | | |
|---|---|---|---|---|---|---|
| | Total spore/g soil | Total colonization % | | Total spore/g soil | Total colonization % | |
| | | M | A | | M | A |
| G4 | 39.06±1.1a | 26±8.9ab | 14±9.5b | 37.66±12.6bc | 17±7.3a | 8±8.2b |
| CUM13 | 38.98±1.2a | 20±7.6b | 13±8.2ab | 26.03±11.4b | 14±8.2ab | 6±8.1a |
| CUH8 | 28.46±0.9a | 22±8.8a | 12±9.5a | 25.46±12.3ab | 13±8.0a | 6±8.9b |
| G7 | 28.56±1.1a | 20±8.6ab | 12±8.6b | 25.86±11.0b | 12±8.5ab | 6±8.7b |
| CUM8 | 27.88±1.1a | 21±7.9b | 11±8.4ab | 17.86±11.9b | 10±7.9a | 5±7.9ab |
| CUH1 | 28.04±1.1a | 20±8.5a | 10±8.2a | 15.23±12.5a | 11±7.2ab | 6±8.6b |
| LSD | 7.0 | 8.2 | 7.2 | 8.6 | 7.8 | 8.3 |

Values are means ± SD. Values followed by different letters within a column indicate significant differences according to LSD ($p<0.05$). M= Mycelium; A= Arbuscules.

**Table 2:** Influence of salt stress on Physiological parameters of six mungbean lines in presence and absence of Gm.

| | | Transpiration ratio (µmol $NO_2$ $g^{-1}$ fr Wt. $Hr^{-1}$) | | | | Stomatal conductance (µmol $CO_2$ $m^{-2}$ $s^{-1}$) | | | | Photosynthesis efficiency (µmol $CO_2$ $m^{-2}$ $s^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 2.63$^{a}$ | 2.96$^{a}$ | 2.62$^{a}$ | 2.79$^{a}$ | 0.39$^{b}$ | 0.41$^{ab}$ | 0.38$^{a}$ | 0.42$^{b}$ | 20.36$^{a}$ | 21.56$^{a}$ | 20.35$^{a}$ | 21.00$^{a}$ |
| MS | CUM13 | 3.69$^{a}$ | 3.98$^{ab}$ | 2.00$^{b}$ | 3.65$^{b}$ | 0.36$^{b}$ | 0.39$^{b}$ | 0.29$^{a}$ | 0.35$^{ab}$ | 36.56$^{ab}$ | 38.65$^{ab}$ | 25.64$^{a}$ | 36.00$^{ab}$ |
| | CUH8 | 3.54$^{a}$ | 3.97$^{ab}$ | 2.16$^{b}$ | 3.62$^{b}$ | 0.45$^{a}$ | 0.48$^{ab}$ | 0.26$^{b}$ | 0.43$^{a}$ | 31.22$^{ab}$ | 33.41$^{b}$ | 21.38$^{a}$ | 31.22$^{ab}$ |
| | G7 | 2.95$^{a}$ | 3.21$^{b}$ | 2.01$^{ab}$ | 3.04$^{ab}$ | 0.35$^{ab}$ | 0.31$^{b}$ | 0.24$^{a}$ | 0.29$^{ab}$ | 25.59$^{a}$ | 28.96$^{ab}$ | 15.42$^{a}$ | 25.56$^{a}$ |
| HS | CUM8 | 5.26$^{ab}$ | 5.69$^{ab}$ | 1.34$^{b}$ | 2.46$^{ab}$ | 0.37$^{b}$ | 0.49$^{b}$ | 0.15$^{a}$ | 0.29$^{ab}$ | 30.24$^{a}$ | 32.14$^{a}$ | 12.56$^{a}$ | 23.41$^{a}$ |
| | CUH1 | 4.96$^{ab}$ | 5.31$^{ab}$ | 1.52$^{b}$ | 2.90$^{ab}$ | 0.42$^{a}$ | 0.55$^{a}$ | 0.18$^{b}$ | 0.32$^{ab}$ | 32.71$^{b}$ | 35.29$^{ab}$ | 10.75$^{a}$ | 20.22$^{a}$ |
| | **Mean** | **3.84** | **4.19** | **1.94** | **3.08** | **0.39** | **0.44** | **0.25** | **0.35** | **29.45** | **31.67** | **17.68** | **26.24** |
| | **LSD** | **1.06** | **1.10** | **0.46** | **0.47** | **0.04** | **0.08** | **0.08** | **0.06** | **5.70** | **5.90** | **5.71** | **6.20** |
| | | Chl a (mg/g DW) | | | | Chl b (mg/g DW) | | | | Total Carotenoids (mg/g DW) | | | |
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 9.20$^{a}$ | 9.79$^{a}$ | 9.19$^{a}$ | 9.69$^{a}$ | 6.45$^{a}$ | 6.98$^{a}$ | 6.43$^{a}$ | 6.95$^{a}$ | 3.69$^{a}$ | 3.78$^{a}$ | 3.68$^{b}$ | 3.76$^{ab}$ |
| MS | CUM13 | 8.96$^{a}$ | 9.11$^{a}$ | 5.69$^{a}$ | 9.00$^{a}$ | 6.49$^{a}$ | 6.59$^{b}$ | 4.56$^{b}$ | 6.35$^{b}$ | 3.55$^{a}$ | 3.96$^{a}$ | 2.33$^{a}$ | 3.69$^{b}$ |
| | CUH8 | 9.56$^{a}$ | 10.93$^{a}$ | 5.26$^{b}$ | 10.59$^{a}$ | 8.69$^{a}$ | 10.96$^{ab}$ | 3.69$^{a}$ | 5.26$^{a}$ | 4.41$^{a}$ | 4.45$^{ab}$ | 2.05$^{a}$ | 3.12$^{b}$ |
| | G7 | 9.00$^{a}$ | 9.73$^{ab}$ | 5.00$^{a}$ | 9.09$^{b}$ | 6.22$^{a}$ | 6.53$^{a}$ | 4.55$^{a}$ | 6.00$^{a}$ | 3.29$^{a}$ | 3.89$^{a}$ | 2.01$^{a}$ | 3.59$^{b}$ |
| HS | CUM8 | 9.05$^{a}$ | 9.88$^{ab}$ | 3.99$^{a}$ | 7.56$^{b}$ | 6.22$^{a}$ | 6.39$^{a}$ | 2.63$^{a}$ | 5.00$^{b}$ | 4.56$^{a}$ | 5.02$^{a}$ | 2.11$^{a}$ | 4.00$^{ab}$ |
| | CUH1 | 11.06$^{a}$ | 11.97$^{a}$ | 3.45$^{a}$ | 6.00$^{ab}$ | 7.56$^{b}$ | 9.88$^{ab}$ | 3.00$^{b}$ | 5.69$^{ab}$ | 4.22$^{a}$ | 4.59$^{a}$ | 2.82$^{b}$ | 4.36$^{ab}$ |
| | **Mean** | **9.47** | **10.23** | **5.43** | **8.66** | **6.94** | **7.89** | **4.14** | **5.88** | **3.95** | **4.28** | **2.50** | **3.75** |
| | **LSD** | **0.35** | **0.43** | **0.59** | **0.36** | **0.41** | **1.15** | **0.52** | **0.35** | **0.21** | **0.20** | **0.16** | **0.18** |

Each bar represent mean ± SE, bars with different letters indicate significant differences according to LSD ($p<0.05$); T1 = Non-inoculated plant under non saline condition; T2 = Gm inoculated plant under non saline condition; T3 = Non-inoculated plant under saline condition; T4 = Gm inoculated plant under saline condition; DAE= Days after emergence. T= tolerant; MS=moderately susceptible; HS= Highly susceptible.

**Table 3:** Influence of salt stress on different biochemical parameters of six mungbean lines in presence and absence of Gm.

| | | Total soluble sugar (g/100g DW) | | | | Starch (g/100g DW) | | | | Ascorbic acid (mg/100g DW) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 8.5$^{a}$ | 9.0$^{c}$ | 8.3$^{a}$ | 8.8$^{a}$ | 46.1$^{cd}$ | 50.2$^{c}$ | 45.3$^{ab}$ | 47.6$^{b}$ | 6.3$^{b}$ | 6.9$^{a}$ | 6.2$^{ab}$ | 6.3$^{a}$ |
| MS | CUM13 | 9.0$^{a}$ | 10.5$^{abc}$ | 6.2$^{ab}$ | 8.6$^{a}$ | 48.3$^{b}$ | 52.6$^{b}$ | 35.2$^{b}$ | 47.6$^{a}$ | 6.5$^{a}$ | 7.0$^{a}$ | 5.7$^{bc}$ | 6.4$^{a}$ |
| | CUH8 | 9.1$^{a}$ | 10.8$^{a}$ | 6.0$^{bc}$ | 8.8$^{a}$ | 48.9$^{ab}$ | 56.4$^{a}$ | 32.4$^{c}$ | 47.1$^{a}$ | 6.4$^{ab}$ | 7.2$^{a}$ | 5.2$^{c}$ | 6.3$^{a}$ |
| | G7 | 8.9$^{a}$ | 9.8$^{bc}$ | 6.8$^{ab}$ | 8.0$^{a}$ | 47.5$^{bc}$ | 56.1$^{a}$ | 31.0$^{c}$ | 47.0$^{a}$ | 6.8$^{a}$ | 7.1$^{a}$ | 5.5$^{c}$ | 6.7$^{a}$ |
| HS | CUM8 | 8.6$^{a}$ | 10.4$^{abc}$ | 5.3$^{cd}$ | 8.0$^{a}$ | 49.3$^{a}$ | 56.8$^{a}$ | 28.6$^{d}$ | 49.1$^{a}$ | 6.4$^{ab}$ | 7.0$^{a}$ | 5.0$^{c}$ | 6.3$^{a}$ |
| | CUH1 | 9.3$^{a}$ | 11.0$^{a}$ | 5.0$^{d}$ | 8.9$^{a}$ | 46.5$^{d}$ | 55.4$^{a}$ | 29.1$^{d}$ | 45.8$^{a}$ | 6.5$^{ab}$ | 7.2$^{a}$ | 4.9$^{a}$ | 6.4$^{a}$ |
| | **Mean** | **8.90** | **10.24** | **6.27** | **8.52** | **47.77** | **54.58** | **33.60** | **47.38** | **6.49** | **7.09** | **5.43** | **6.40** |
| | **LSD** | **0.12** | **0.22** | **0.39** | **0.16** | **0.52** | **1.06** | **1.78** | **0.56** | **0.08** | **0.04** | **0.16** | **0.07** |
| | | Total phenolic content (mg/g) | | | | Proline (µg/g) | | | | Malondialdehyde (MDA) (µM/g) | | | |
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 11.3$^{c}$ | 13.7$^{c}$ | 11.3$^{a}$ | 13.4$^{c}$ | 180$^{a}$ | 176$^{b}$ | 182$^{ab}$ | 180$^{b}$ | 4.3$^{a}$ | 4.0$^{a}$ | 4.3$^{ab}$ | 4.0$^{a}$ |
| MS | CUM13 | 12.6$^{a}$ | 18.0$^{b}$ | 13.3$^{b}$ | 19.6$^{a}$ | 200$^{a}$ | 198$^{b}$ | 310$^{ab}$ | 210$^{ab}$ | 4.2$^{a}$ | 4.1$^{a}$ | 7.4$^{b}$ | 4.8$^{ab}$ |
| | CUH8 | 11.0$^{bc}$ | 18.0$^{b}$ | 14.5$^{a}$ | 18.5$^{b}$ | 198$^{a}$ | 195$^{a}$ | 296$^{c}$ | 200$^{ab}$ | 4.1$^{a}$ | 4.0$^{b}$ | 7.6$^{ab}$ | 4.3$^{b}$ |
| | G7 | 11.5$^{b}$ | 19.6$^{a}$ | 12.6$^{c}$ | 19.8$^{a}$ | 210$^{a}$ | 200$^{b}$ | 298$^{ab}$ | 215$^{b}$ | 4.2$^{a}$ | 4.1$^{b}$ | 7.1$^{b}$ | 4.8$^{b}$ |
| HS | CUM8 | 11.3$^{bc}$ | 18.2$^{b}$ | 13.3$^{b}$ | 19.6$^{a}$ | 200$^{a}$ | 185$^{a}$ | 360$^{bc}$ | 210$^{a}$ | 4.4$^{a}$ | 4.0$^{a}$ | 8.3$^{ab}$ | 4.9$^{a}$ |
| | CUH1 | 11.6$^{bc}$ | 14.9$^{d}$ | 13.9$^{b}$ | 19.6$^{a}$ | 196$^{a}$ | 189$^{a}$ | 375$^{ab}$ | 200$^{b}$ | 4.6$^{b}$ | 4.2$^{a}$ | 8.9$^{ab}$ | 4.8$^{b}$ |
| | **Mean** | **11.54** | **17.07** | **13.20** | **18.42** | **197** | **190** | **303** | **202** | **4.30** | **4.07** | **7.28** | **4.61** |
| | **LSD** | **0.22** | **0.16** | **1.41** | **0.19** | **0.23** | **0.20** | **0.20** | **0.21** | **0.16** | **0.12** | **0.15** | **0.16** |

Each bar represent mean ± SE, bars with different letters indicate significant differences according to LSD ($p<0.05$); T1 = Non-inoculated plant under non saline condition ; T2 = Gm inoculated plant under non saline condition;T3 = Non-inoculated plant under saline condition; T4 = Gm inoculated plant under saline condition; T= tolerant; MS=moderately susceptible; HS= Highly susceptible.

the amount of total phenolic content in all the lines but Gm inoculation under salinity increased the amount of phenolic over respective controls in all the tested lines. Such increased synthesis of phenolics and decreased accumulation of ascorbic acid was in lieu with the earlier reports of Dawood *et al*. (2014).

Our results reported that salinity induced a significant reduction in uptake of potassium, magnesium and calcium ion but increase of sodium, phosphorus and chloride ion in mungbean plants in all tested lines (Fig 2), which is in line with the report of Kohler *et al*. (2009). Increased accumulation of sodium ion within the root zone directly affects the uptake of several essential elements like potassium as sodium shares an antagonistic relationship with potassium. But Gm inoculation under salinity significantly increased the ion content in both root and shoot

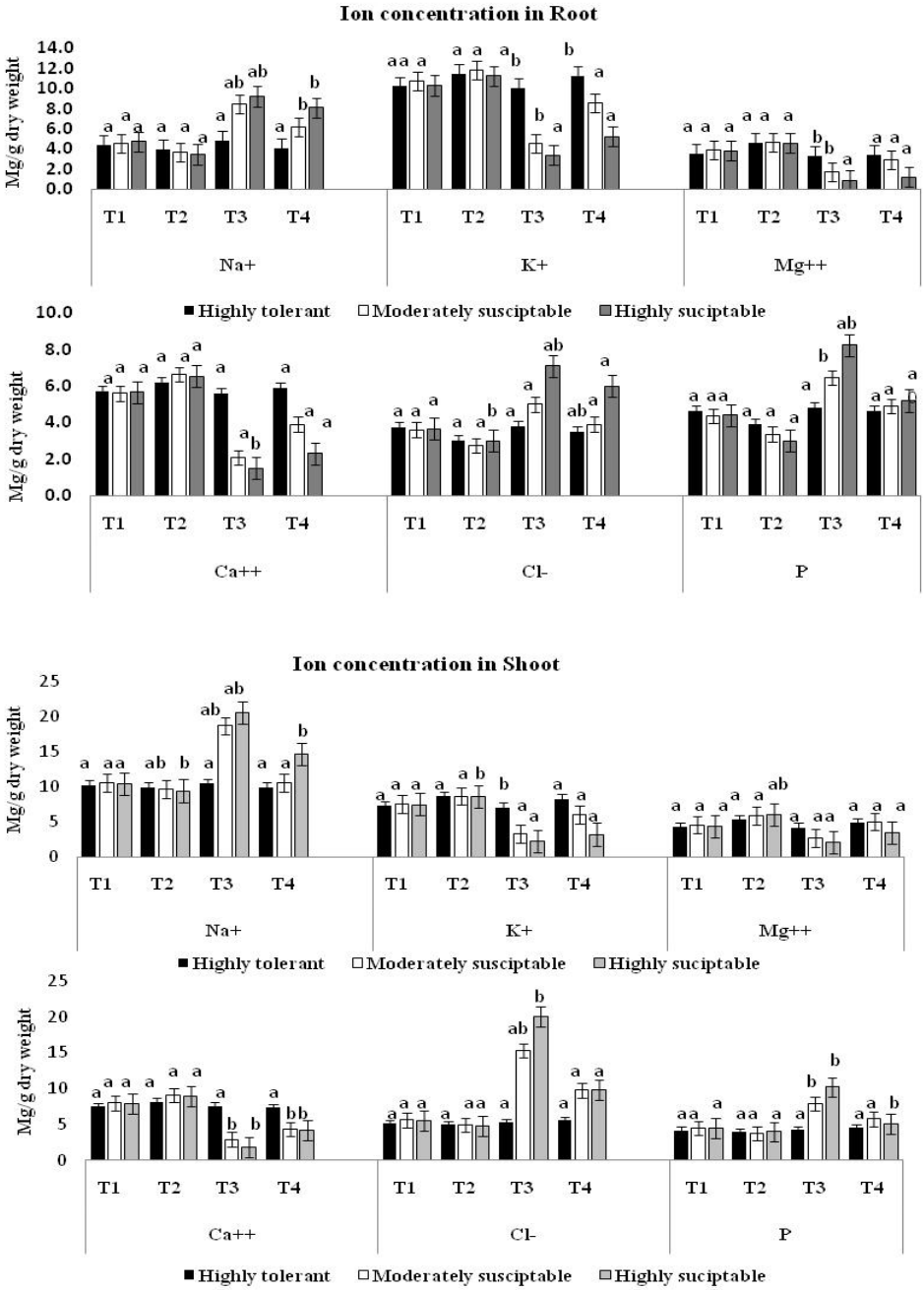


**Fig 2:** Effect of NaCl in presence and absence of Gm in ion accumulation (mg/g dry weight) in root and shoot in tested mungbean lines [Each bar represent mean ± SE, bars with different letters indicate significant differences according to LSD ($p<0.05$); T1 = Non-inoculated plant under non saline condition; T2 = Gm inoculated plant under non saline condition; T3 = Non-inoculated plant under saline condition; T4 = Gm inoculated plant under saline condition].

**Table 4:** Influence of salt stress on antioxidant enzyme assay of mungbean in presence and absence of Gm.

| | | SOD (u/mg protein) | | | | POD (u/mg protein) | | | | CAT (u/mg protein) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 20.3$^{a}$ | 23.5$^{a}$ | 20.3$^{a}$ | 28.5$^{a}$ | 20.6$^{b}$ | 24.5$^{a}$ | 20.7$^{a}$ | 25.3$^{a}$ | 20.2$^{a}$ | 28.5$^{a}$ | 21.5$^{ab}$ | 25.2$^{b}$ |
| MS | CUM13 | 20.5$^{a}$ | 22.1$^{a}$ | 32.6$^{ab}$ | 42.6$^{ab}$ | 21.5$^{ab}$ | 23.6$^{a}$ | 30.6$^{b}$ | 36.5$^{b}$ | 21.3$^{ab}$ | 24.5$^{b}$ | 30.2$^{ab}$ | 40.2$^{ab}$ |
| | CUH8 | 21.6$^{a}$ | 22.9$^{ab}$ | 30.5$^{ab}$ | 39.6$^{ab}$ | 20.8$^{ab}$ | 22.3$^{b}$ | 32.5$^{ab}$ | 40.2$^{b}$ | 21.6$^{b}$ | 26.9$^{ab}$ | 35.2$^{ab}$ | 48.9$^{ab}$ |
| | G7 | 22.4$^{a}$ | 24.5$^{a}$ | 31.2$^{ab}$ | 42.2$^{a}$ | 20.7$^{b}$ | 22.5$^{ab}$ | 30.9$^{b}$ | 46.2$^{ab}$ | 21.4$^{ab}$ | 24.8$^{b}$ | 31.5$^{b}$ | 49.6$^{b}$ |
| HS | CUM8 | 23.3$^{a}$ | 25.6$^{ab}$ | 42.6$^{a}$ | 65.2$^{b}$ | 20.4$^{a}$ | 23.6$^{ab}$ | 40.5$^{b}$ | 75.6$^{ab}$ | 22.1$^{b}$ | 29.6$^{a}$ | 40.2$^{a}$ | 72.5$^{ab}$ |
| | CUH1 | 21.6$^{a}$ | 23.9$^{ab}$ | 40.2$^{a}$ | 68.5$^{b}$ | 21.6$^{a}$ | 24.6$^{a}$ | 42.6$^{a}$ | 78.6$^{a}$ | 20.1$^{a}$ | 27.8$^{a}$ | 35.2$^{b}$ | 61.2$^{ab}$ |
| | **Mean** | **21.62** | **23.77** | **32.96** | **47.80** | **20.94** | **23.52** | **33.03** | **50.44** | **21.15** | **2707** | **32.35** | **49.65** |
| | **LSD** | **2.3** | **2.2** | **2.9** | **2.6** | **1.6** | **1.9** | **2.0** | **1.9** | **1.6** | **1.8** | **1.6** | **3.6** |

| | | APX (u/mg protein) | | | | GR (u/mg protein) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | T1 | T2 | T3 | T4 |
| T | G4 | 15.6$^{a}$ | 18.2$^{a}$ | 15.9$^{ab}$ | 20.1$^{b}$ | 25.6$^{a}$ | 30.2$^{ab}$ | 25.7$^{a}$ | 30.2$^{ab}$ |
| MS | CUM13 | 14.9$^{b}$ | 17.5$^{a}$ | 20.5$^{ab}$ | 25.9$^{b}$ | 23.5$^{ab}$ | 43.0$^{a}$ | 36.2$^{b}$ | 49.6$^{a}$ |
| | CUH8 | 15.2$^{a}$ | 19.6$^{b}$ | 21.5$^{a}$ | 28.5$^{ab}$ | 25.9$^{a}$ | 45.1$^{b}$ | 38.9$^{b}$ | 50.2$^{ab}$ |
| | G7 | 15.6$^{a}$ | 17.5$^{b}$ | 21.0$^{b}$ | 29.2$^{a}$ | 25.4$^{a}$ | 45.0$^{a}$ | 35.4$^{a}$ | 46.5$^{b}$ |
| HS | CUM8 | 15.8$^{a}$ | 17.2$^{b}$ | 29.6$^{a}$ | 46.0$^{b}$ | 25.7$^{a}$ | 45.4$^{a}$ | 45.0$^{a}$ | 72.1$^{ab}$ |
| | CUH1 | 15.4$^{a}$ | 16.9$^{ab}$ | 30.2$^{b}$ | 49.6$^{ab}$ | 25.2$^{a}$ | 45.6$^{ab}$ | 45.7$^{b}$ | 75.6$^{ab}$ |
| | **Mean** | **15.47** | **17.87** | **23.15** | **33.26** | **25.26** | **37.8** | **37.83** | **54.07** |
| | **LSD** | **1.3** | **1.9** | **2.0** | **3.2** | **1.2** | **1.6** | **2.0** | **3.9** |

Each bar represent mean ± SE, bars with different letters indicate significant differences according to LSD ($p<0.05$); T1 = Non-inoculated plant under non saline condition; T2 = Gm inoculated plant under non saline condition; T3 = Non-inoculated plant under saline condition; T4 = Gm inoculated plant under saline condition.

tissues of all the tested lines over their respective controls following Wu *et al*. (2010). A higher concentration of $Na^+$ hampers many growth and metabolic processes in plants. Therefore, to mitigate salt-induced deleterious changes in plants maintenance of an appropriate ratio of K:Na is very much important strategy (Tomar and Agarwal 2013). In the present study, Gm inoculation leads to the selective uptake of some essential ions over deleterious sodium ion and ultimately resulting in maintaining lower Na:K ratio.

Study reported that salinity stress enhanced the accumulation of proline and MDA content in all the lines over control but in presence of Gm under salinity, a significant decrease over control was registered (Table 3). Proline maintains the water balance of plants to alleviate the stress-induced defects (Ahanger *et al*., 2014). In presence of Gm, proline and MDA accumulation was hampered which leads to maintain cellular water content thus alleviates the stress (Hashem *et al*. 2015). Antioxidant enzymes act as a protector by scavenging toxic effect of ROS and oxidative stress-induced deleterious effects. In our study (Table 4), salinity increased the antioxidant enzyme activity following the trend of Rasool *et al*. (2013) but Gm under salinity further increased the activity of the same by influencing the ROS production to save the metabolic processes (Abdel and Chaoxing 2011).

## CONCLUSION

We can conclude that under salt stress, the uptake of important mineral elements become lesser and the activity of hydrogen peroxide and lipid peroxidation become higher than control plant resulting in loss of membrane integrity. But inoculation of Gm alleviated the salt-induced alterations by restricting the excess uptake of Na+ and enhancing uptake of different important ions. Further under salt stress condition, Gm inoculation actively participated in antioxidant defence mechanism, to protect cells from oxidative damage. Therefore The colonization of AM fungi appears to be a practical eco-friendly approach to attenuate the adverse effects of salinity on the growth and productivity of mungbean.

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