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Article

Sodium exclusion by different maize genotypes under salinity in conferring salt resistance

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Abstract: An experiment was carried out in the pot-house of botanical garden of Bangladesh Agricultural University (BAU), Mymensingh, during June to November, 2014 to investigate the effect of NaCl on growth, Na^+ accumulation and K^+: Na^+ ratio in maize. Four maize genotypes namely BARI Maize 5, BARI Maize 7, Plain maize line and Mosaic maize line were tested against control, without providing any NaCl and salt stress, with NaCl to reach the soil salinity of 10 dS m^{-1}. The experiment was laid out following CRD with four replicates. Under salt stress, relative reduction in shoot fresh masses were 22 and 77% in BARI Maize 5 and BARI Maize 7, whereas the magnitude of reduction was 136 and 155% in Mosaic maize line and Plain maize line, respectively. Seven days exposure to moderate salinity (10 dS m^{-1}) seemed to have significantly reduced total fresh masses with the concomitant increase in Na^+ concentrations but decrease in K^+ concentrations and K^+: Na^+ ratios in both young and old shoots of BARI Maize 5, Plain maize line and Mosaic maize line. In contrast, BARI Maize 7 showed significant reduction in shoot fresh mass under salinity with the concomitant increase in shoot Na^+ content but no significant changes in K^+ concentrations and K^+: Na^+ ratios were observed under salinity. It seemed that young leaf of BARI maize 7 showed unaffected growth despite of higher accumulation of Na^+. It may likely that BARI maize 7 sequestered incoming excess Na^+ ions in the vacuole from the cytosol to combat deleterious effect of this ion to the cytoplasmic enzymes.

Keywords: salinity; maize; sodium; potassium

1. Introduction

Maize is the third most important cereal after wheat and rice and plays a significant role in human and livestock nutrition worldwide (Morris *et al.*, 1999). Due to huge demand, maize growing area is increased in a rate of 20% per year since early 1990s (Banik *et al.*, 2011), and to keep pace with future demand of maize it needs to increase. In the southern belt of Bangladesh about 1.2 million ha of land remains fallow every year due to salinity (Anonymous, 2010) where maize can be grown by adopting suitable variety. Maize is moderately resistant to salinity compared to very salt-sensitive rice (Munns and Tester, 2008) and thus the prospect to grow maize in southern coastal belt is much brighter than rice.

Salt stress increases the accumulation of toxic ions such as Na^+ and Cl^- in different plant parts which affect growth rate (Mengel and Arneke, 1982). For maize, it has been shown that Na^+ toxicity but not Cl^- toxicity, is the major problem in the second phase of salt stress (Fortmeier and Schubert, 1995). Cell membrane function is perturbed due to Na^+ replacing Ca^{2+}, resulting in increased cell leakiness. Excess Na^+ and Cl^- lead to the appearance of symptoms like those of K^+ deficiency. The deficiency of K^+ initially leads to chlorosis and then causes necrosis (Gopal and Dube, 2003).

Regarding the ion-specific effects of salinity, the K^+: Na^+ ratio is another adequate parameter to characterize salt resistance because plant cells have to maintain low cytoplasmic Na^+ concentrations and concurrent high concentrations of K^+ for maintaining optimal growth (Niu *et al.*, 1995; Tiwari *et al.*, 2010). When plants are grown in typical NaCl-dominated saline environments in nature, it comes to an accumulation of Na^+ in the cytosol resulting in a high Na^+: K^+ ratio. This alteration finally disrupts enzymatic functions that are usually achieved in cells. Therefore, it is very important for cells to maintain a low Na^+: K^+ ratio in the cytosol under salt stress (Maathuis and Aontmann, 1999).

The response of maize to salinity varies depending on the stage of development (Maas *et al.*, 1983; Pasternac *et al.*, 1985). Vegetative growth appears to be the most sensitive to salinity (Uddin *et al.*, 2014; Hatzig *et al.*, 2010; Pitan *et al.*, 2009), while plants are much less affected at later stages (Cramer, 1994). Maize excludes Na^+ (Drew and Läuchli, 1985), although there are large differences in Na^+ exclusion ability between different cultivars of maize (Schubert and Läuchli, 1990). It has been reported that due to efficient Na^+ exclusion, newly developed maize hybrids show strongly improved salt resistance in the second phase of salt stress (Schubert, 2009). In the present study four maize genotypes were grown under high NaCl concentration (10 dS m^{-1}) to impose second phase reaction of salt stress. In this context low Na^+ uptake at the root surface would contribute to low root-to-shoot translocation of Na^+ which may contribute to salt resistance of maize plants. Thus this research was based on the following objective.

a) to determine shoot Na^+ content as an index of Na^+ exclusion at the root surface in four maize genotypes;
b) to determine the K^+: Na^+ ratio as a salt-resistance mechanism in maize shoot.

2. Materials and Methods

2.1. Experimental design and treatment

The experiment was laid out following Completely Randomized Design (CRD). Four maize genotypes namely BARI Maize 5, BARI Maize 7, Mosaic maize line and Plain maize line were tested against control (no added NaCl) and salinity (added NaCl to develop the EC 10 dS m^{-1}). Three seeds were sown in individual pot containing 17 kg air dried soil under pot house condition. Only one seedling pot^{-1} was allowed 4 d after seeding. The NaCl treatment started on day 14 with 2.5 dS m^{-1} in the treated pot. It was increased daily with 2.5 dS m^{-1} with NaCl till an EC of 10 dS m^{-1} was reached on day 17 and maintained till harvest on day 23. One plant per pot would in no case can uptake huge NaCl from the 17 kg soil that can reduce soil EC significantly from the value of 10 dS m^{-1}. Fourth and above order leaves were grouped as young shoot whereas rest leaves were grouped as old shoot.

2.2. Determination of Na^+ and K^+

The shoot and root samples were oven-dried to a constant weight at 80° C. The mean seedling dry weight of shoot (mg) was calculated for each treatment. Maize plant samples were analyzed to determine the amount of Na^+ and K^+ content therein. All elemental analyses were conducted on acid digested material through micro-Kjeldahl digestion system. The digested samples were analyzed for Na^+ and K^+ by flame photometer (Model PERKIN-ELMER, 2380). The K^+: Na^+ ratio was calculated from concentrations of Na^+ and K^+ in the plant tissues.

3. Results and Discussion

Salt stress (10 dS m^{-1}) significantly ($P \leq 5.0\%$) reduced shoot fresh mass in all the four maize genotypes namely BARI maize 5, BARI maize 7, Plain maize line and Mosaic maize line genotypes compared to control (Fig. 1). However, maize genotypes did not show reduction in root fresh mass due to salinity except Mosaic maize line. The relative reduction in shoot fresh masses in salt treated plants compared to control was 22, 77, 155 and 136% for BARI Maize 5, BARI Maize 7, Mosaic maize line and Plain maize line, respectively. Thus it appeared that BARI Maize 5 and BARI Maize 7 performed relatively better under salt stress compared to Mosaic maize line and Plain maize line. Several investigations have shown that salt stress imposed by NaCl causes a persistent decrease of the elongation rate of maize leaves (Chazen *et al*., 1995; Neumann, 1993), thereby reducing shoot growth (Uddin *et al*., 2014; Uddin *et al*., 2013; Hatzig *et al*., 2010).

Salt stress (10 dS m^{-1}) significantly ($P \leq 5.0\%$) increased shoot Na^+ content both in young and old shoot of the four maize genotypes (Fig. 2A). The relative increase in shoot Na^+ content of salt treated plants compared to control was 117, 129, 134 and 167% for the young shoot; whereas it was 70, 58, 94 and 72% for the old shoot of BARI Maize 5, BARI Maize 7, Mosaic maize line and Plain maize line, respectively. Thus, it appeared that all these maize genotypes translocated higher amount of Na^+ in their shoot. Maize genotypes which have a capacity to exclude Na^+ from the shoot showed better growth (Fortmeier and Schubert, 1995), or in some cases salt-resistant maize genotypes translocated Na^+ to leaves at a higher rate than salt-sensitive genotypes (Cramer *et al*., 1994). In the later phenomena, maize shoot sequestered excess Na^+ in the vacuole from the cytosol to keep the cytoplasmic enzymes safe.

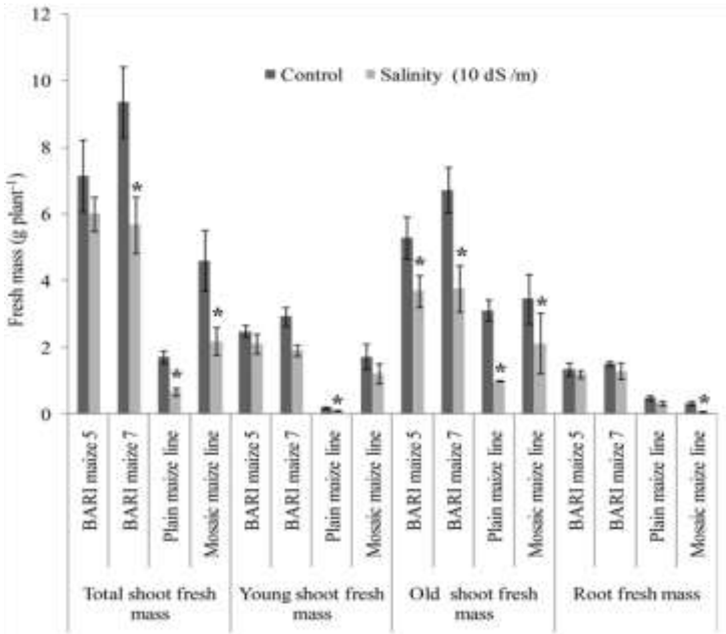

Figure 1. Fresh masses of leaf in four maize genotypes as influenced by salinity. The values are means of four replicates ± SE (n = 4). Significant differences (P ≤ 5%) between two treatments are indicated by asterisk as per student t-test.

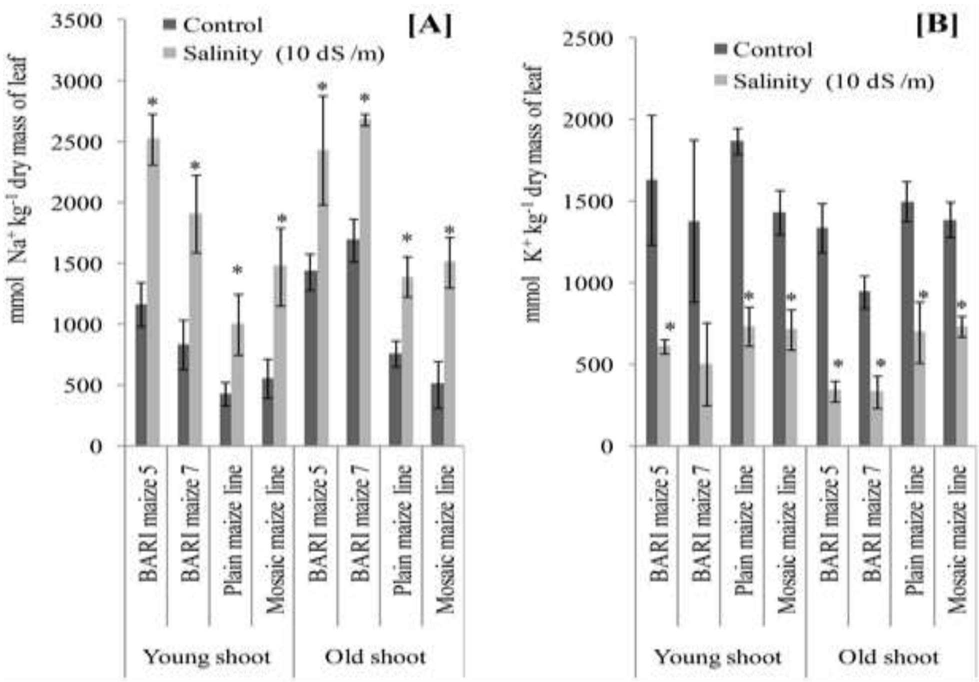

Figure 2. Effect of NaCl on [A] Na^+ and [B] K^+ content in the young and old shoot of four maize genotypes. Standard error bar represents standard error of means (SEM) of four replicates. Significant differences (P ≤ 5%) between two treatments are indicated by asterisk as per student t-test.

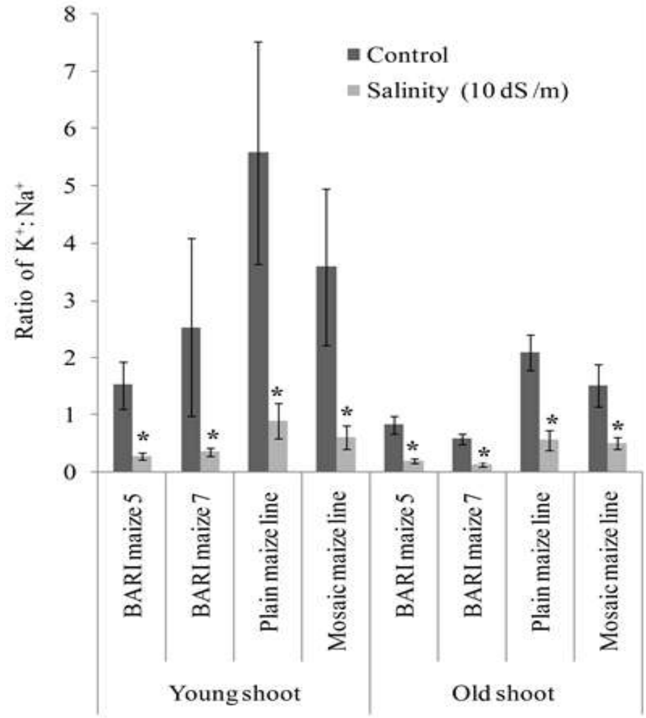

Figure 3. Effect of NaCl on K^+: Na^+ ratio in the young and old shoot of four maize genotypes. Standard error bar represents standard error of means (SEM) of four replicates. Significant differences ($P \leq 0.05$) between two treatments are indicated by asterisk as per student t-test.

In contrast to the Na^+ content, salinity (10 dS m^{-1}) significantly ($P \leq 5.0\%$) decreased shoot K^+ content both in young and old shoots of all maize genotypes except young shoot of BARI maize 7 (Fig. 2B). The relative decrease in shoot K^+ content of salt treated plants compared to control was 172, 63, 61 and 119% for the young shoot; whereas the relative decrease in K^+ content was 337, 64, 53 and 92% for the old shoot of BARI Maize 5, BARI Maize 7, Mosaic maize line and Plain maize line, respectively. Thus it appeared that all these maize genotypes accumulated lesser amount of K^+ in the shoot in contrast to the higher amount of Na^+ under salinity treatment. The relative loss of K^+ content in BARI maize 7 was appeared as minimum compared to BARI maize 5 and Mosaic maize line.

K^+: Na^+ ratio is one of the most important parameters to describe salt resistance feature of monocot plant like maize (Niu *et al*., 1995; Tiwari *et al*., 2010). It appeared that genotypic K^+: Na^+ ratios follow the similar trend to K^+ concentrations (Fig. 3). Due to NaCl stress K^+: Na^+ ratio declined rapidly with the concomitant increase in Na^+ concentration. The relative decreases in shoot K^+: Na^+ ratios of salt treated plants compared to control were 562, 90, 84 and 777.6% for the young shoot; whereas the relative decrease in K^+ content was 230, 78, 74 and 230% for the old shoot of BARI Maize 5, BARI Maize 7, Mosaic maize line and Plain maize line, respectively.

4. Conclusions

In the light of results it can be concluded that the shoot growth of BARI maize 5 and BARI maize 7 appeared as relatively resistant compared to Mosaic maize line and Plain maize line. Relative better shoot growth of BARI maize 7 under salinity may be due to its capability to maintain higher K^+ and K^+/Na^+ ratio. However, relatively better performance of BARI maize 5 under salinity cannot be explained by the current experiment and needs further research.

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Conflict of interest

None to declare.

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