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Uptake of Na^+ into roots and its transport into the shoot and leaf of salt tolerant cultivar (FR13A) and salt sensitive rice cultivar (BRRI dhan29)

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Abstract: *In this study, the uptake of Na^+ and K^+ into roots of salt tolerant rice cultivars (Oryza sativa L.cvs FR13A) and salt sensitive rice cultivar (BRRI dhan29) were measured using atomic absorption spectrophotometer. By means of inhibitor analyses the mechanisms for uptake and sequestration of Na^+ in the salt-sensitive indica rice cv. BRRI dhan29 and in the salt-tolerant indica rice cv.FR13A mainly were detected. Lowest amount of Na^+ was taken up into the roots, leaf sheath and leaf blade of FR13A than those of BRRI dhan29. In case of K^+, highest amount of K^+ was found in the roots, leaf sheath and leaf blade of FR13Afollowed by BRRI dhan29. The uptake level of Na^+ is twofold higher in BRRI dhan29 than that of FR13A, on the other hand, the amount of K^+ is twofold higher in FR13A than that of BRRI dhan29. The results indicate that K^+ selective channels do not contribute to the Na^+ uptake in FR13A, whereas they are the major pathways for Na^+ uptake in BRRI dhan29 along with non-selective cation channels. However, non-selective cation channels seem to be the main pathways for Na^+ uptake in FR13A. Therefore, it is likely that the mechanism for fast extrusion of Na^+ out of the cytoplasm is controlled by K^+ selective channels. The results suggest that the salinity tolerance in FR13A depends on reduced uptake of Na^+ through K^+ selective channels and a fast extrusion of Na^+ into the vacuoles.*

Keywords: *Rice, salt stress, sodium and potassium uptake, selective and non-selective channels*

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I. Introduction

Salt stress is one of the most important abiotic stresses affecting natural productivity and causes significant crop loss worldwide. Rice is one of the most important cereal crops in tropical and temperate regions of the world. Under the current climate change context attaining food security, especially in rice, is being considered as a serious issue. However, for the saline-affected coastal area these high-yielding rice cultivars are not suitable since they are very sensitive to salinity stress. On the other hand, rice dominates the cropping pattern in the coastal region of Bangladesh due to its suitability with other agro-climatic conditions such as water stagnation. For plants, the sodium ion (Na^+) is harmful whereas the potassium ion (K^+) is an essential ion. The cytosol of plant cells normally contains 100–200mM of K^+ and 1–10mM of Na^+ (Taiz and Zeiger, 2002); this K^+/Na^+ ratio is optimal for many metabolic functions in cells. Soil salinity affects plant growth in two different phases. In the first phase, called osmotic phase, high concentration of salts in the soil leads to lower soil water potential and consequently reduced plant ability to take up water. This phase starts rapidly, within minutes, upon root exposition to high salt concentration. Such phase, which is independent of ion accumulation, leads to a reduced cell expansion in root tip and young leaves, and causes stomata closure (Roy *et al.,* 2014). Salt stress caused by these changes in Na^+ and K^+ may be the main reason of severe reductions of photosynthetic pigment and the net photosynthetic rate and a sharp increase in membrane permeability (Yang et al.,2009). Additionally, when Na^+ enters cells and accumulates in high levels, it becomes toxic to enzymes. Therefore, it is believed that the maintenance of K^+ and Na^+ homeostasis is crucial for salinity tolerance. To prevent growth cessation or cell death, excessive Na^+ must be extruded or compartmentalized in the vacuole (Zhu, 2003). Many transporters of K^+ and Na^+ have been identified to date. In addition, the regulatory mechanisms that control the expression and activity of the transporters are beginning to be elucidated (Munns and Tester, 2008).At saline conditions, Na^+ competes with K^+ for uptake through common transport systems, since Na^+ and K^+ are physico-chemically similar monovalent cations. Thus, elevated levels of cytosolic Na^+, or in other way high Na^+/K^+ ratios, exert metabolic toxicity by a competition between Na^+ and K^+ for the binding sites of many enzymes (Tester and Davenport, 2003; Munns and Tester, 2008). Though the mechanism of Na^+ entry into plant roots is largely unidentified, it is believed that Na^+ enters via both symplastic and apoplastic

pathways using various ion channels/transporters. Several classes of cation channels including outward- and inward-rectifying K^+-selective channels (Maathius and Sanders, 1995), and non-selective cation channels, NSCCs (Kader and Lindberg, 2005), high affinity potassium transporters have been proposed to mediate substantial Na^+ entry into plant roots (Horie *et al*., 2001; Golldack *et al*., 2002). NSCCs are, however, the dominant pathways for Na^+ influx into root cells (Demidchik *et al*., 2002; Kader and Lindberg, 2005). Furthermore in rice, it has been observed that the rate of Na^+ uptake into shoots mediated by the intrusive apoplastic ion transport is considerably high under salinity stress (Ochiai and Matoh, 2002). Soil salinity is one of the environmental hazards in agriculture worldwide because it limits crop yield and restricts the use of land previously cultivated. One of the principal adverse effects of high salinity in non-tolerant plants is growth inhibition by toxicity to Na^+. Maintenance of a high cytosolic K^+/Na^+ ratio is critical for the function of cells (Zhu et al., 1998). For plant cells, the most important way of keeping the cytosolic Na^+ concentration at a low level is to minimize Na^+ influx into the cytosol, and to maximize the Na^+ efflux from the cytosol, either into the apoplast or into the vacuole (Blumwald et al., 2000; Qiu et al., 2004). Vacuolar compartmentalization is an efficient strategy for plant cells to cope with salinity stress (Fukuda et al., 2004). Antiporters for Na^+/H^+ in the plasma membrane and tonoplasts are expected to fulfil this function (Fukuda et al., 2004; Qiu et al., 2004). Sodium extrusion through these Na^+/H^+ antiporters is driven by an inwardly directed proton gradient created by H^+ ATPases (Blumwald et al., 2000). Rice is the only major cereal crop that is grown in waterlogged conditions and, being a glycophyte, it is especially sensitive to salinity. Both the production and the planting area of rice are greatly affected by soil salinity (Panaullah, 1993). When grown in saline conditions, rice accumulates toxic Na^+ levels in the leaves. Although toxicity from Na^+ accumulation in the important crop rice is well studied at the organ and tissue levels, the mechanism by which Na^+ enters into the cytosol, and its subsequent removal from the cytoplasm via efflux or compartmentalization or both, are still poorly understood. In a recent study, it was also demonstrated that vacuolar compartmentalization is evident under salt stress in the salt-tolerant rice, cv. FR13A, whereas apoplastic sequestration of cytosolic Na^+ is dominant in the salt-sensitive cv. BRRI Dhan29 (Kader and Lindberg, 2005).The aim of this study was to investigate the uptake distribution of Na^+ through root and transport into the leaf sheath and leaf blade and subsequence salt-sensitive and salt-tolerant rice cultivars compartmentalization of Na^+. The intensity of salinity stress is expected to increase in the coastal area of Bangladesh over the years due to climate change impact. Therefore, clear understanding of the tolerance mechanisms rice cultivar FR13A is important for generating the scientific knowledge demonstrating the cellular mechanisms of salinity tolerance. This will facilitate to make the platform for developing more salt tolerant high yielding rice cultivar in the future for improving the livelihood of resource-poor farmers living in the coastal area of Bangladesh.

II. Materials And Methods

Hydroponic rice culture

The experiment was conducted at glass house and Biotechnology laboratory in Bangladesh Institute of Nuclear Agriculture (BINA). Seeds of rice (Oryza sativa L. indica cvs FR13Aand BRRI dhan29) were provided by the Bangladesh Rice Research Institute (BRRI, Gazipur, Bangladesh) and Bangladesh Institute of Nuclear Agriculture (BINA, Mymensingh-2202).They were treated with 10% chlorine solution for 15 min and rinsed with distilled water 5–6 times. Seeds were dipped in 5mM CaSO4 solution for 3h. Rice seeds were kept in oven to break the dormancy and soaked with distilled water in the Petridis. The radical of the pre-germinated rice seeds were carefully sown and inserted in nylon mesh in each hole of the Styrofoam seeding float, then placed in the water. The water was replaced with nutrient solution (Yoshida solution and ferrous sulphate) after three days. Fully established seedlings were placed with salinized nutrient solution as described by (Yoshida *et al*., 1976). The salinity level was measured through electrical conductivity (EC) using the EC meter. New solution was added every eight days and the pH was monitored every day and maintained at pH 5.2. Seedlings were grown in a controlled environment chamber (Glass house) with day/night temperatures of 25/21°C under 14h of light (300μE m^{-2} s^{-1}); humidity was approximately 72%. The plants were stressed by adding NaCl at the rate of 60mM and 120mM to the nutrient solution for 72h for ion estimation from root, leaf sheath and leaf blade. Non-stressed control plants were grown concurrently and harvested at the same time.

Tissue collection and measurement

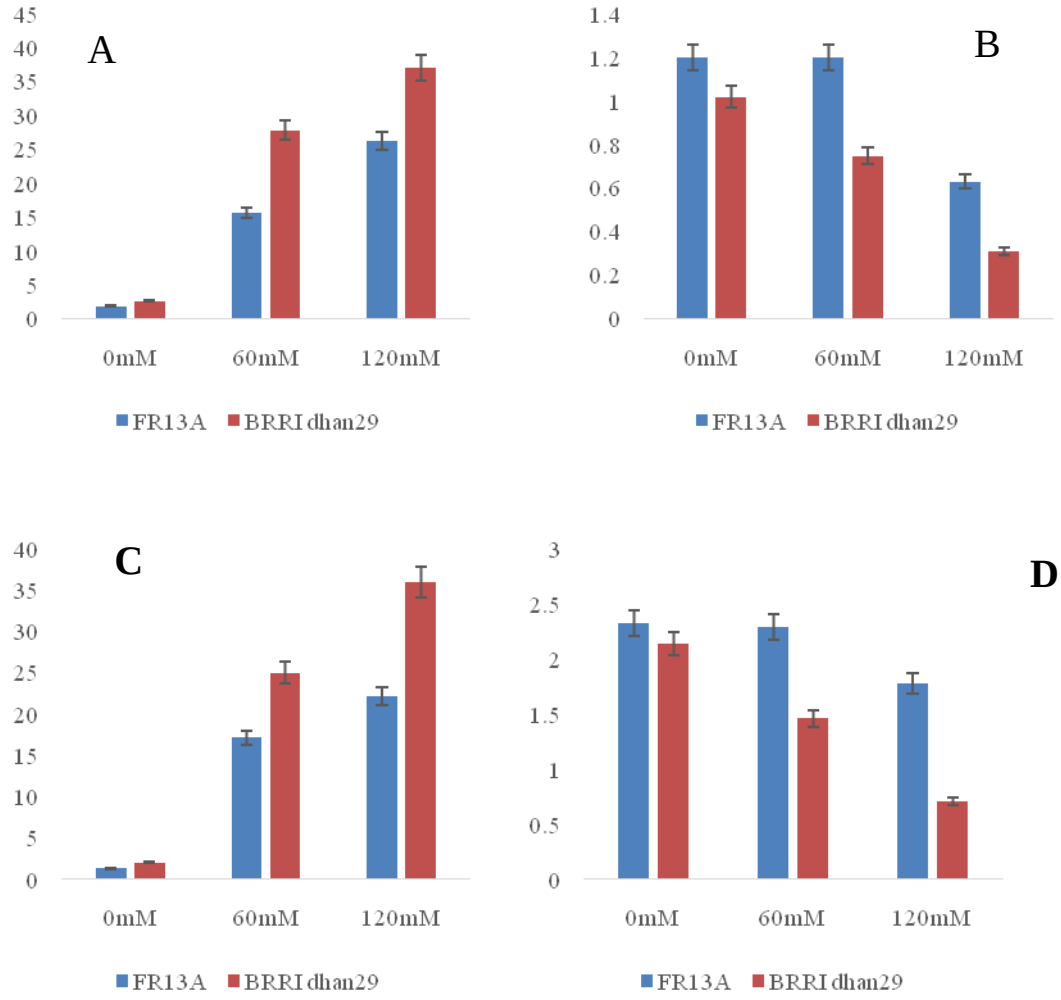
Three-week-old plants having uniform height and number of leaves were subjected to control, 60mM and 120mM NaCl salt stress. The tissues (root, leaf sheath and leaf blade) were harvested at 72h after the application of NaCl and storage at -80^0C. The tissue kept into the oven for drying at 70^0c for 72h. The dried samples were ground into powder using a pestle and mortar. Different weight (g) dried samples was digested with 15 ml of an acid mixture (HNO_3: $HClO_4$:H_2SO_4¼10:4:1) for about 1h at 350^0C on a hot plate. The suspension was filtered and diluted with distilled water to a final volume of 20 ml. The Na^+, K^+ contents were measured using atomic absorption spectrophotometer (Z-8000, Hitachi, Tokyo, Japan) according to (Wang and Zhao, 1995).

III. Results

Ion estimation of Na^+ and K^+ in the tissues (root, leaf sheath and leaf blade) of FR13Aand BRRI dhan29 after 72h of control, 60mM and 120mM NaCl treatments and measured by atomic absorption spectrophotometer.

Na^+ and K^+ uptake by root

Almost similar visible difference in the efficiency of taken up by root the salinity stress was found between the two cultivars at control condition. Upon the 60mM and 120mM salinity conditions the morphological differences increased. Under the addition of 60mM, and 120mM NaCl to the external solution, less Na^+ was taken up by FR13A, compared with that of BRRI Dhan29.Incase of K^+, FR13A uptake highest amount in all salt stress condition. (Fig. A, B)



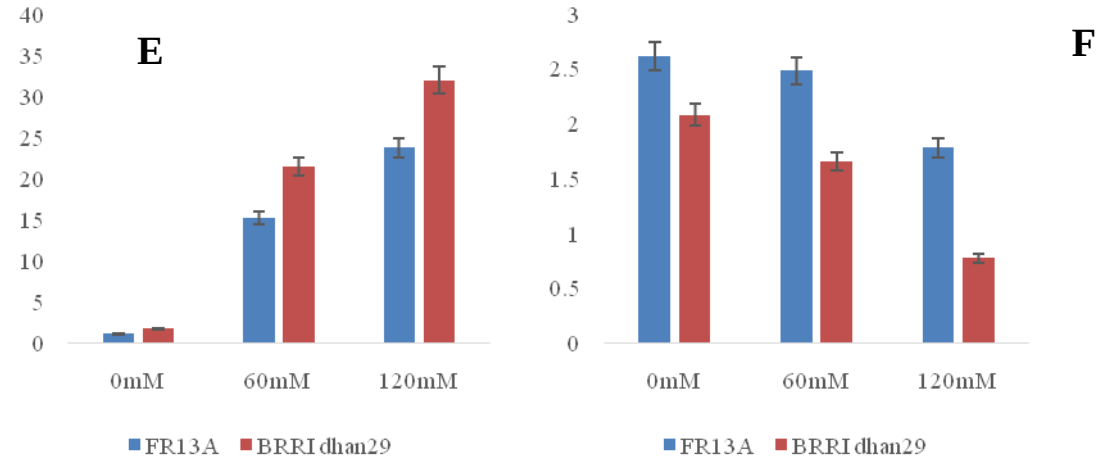


Figure : Cation contents of FR13A and BRRI dhan29 (A) Na^+ uptake by root (B) K^+ uptake by root (C) Na^+ uptake by leaf sheath (D) K^+ uptake by leaf sheath (E) Na^+ uptake by leaf blade (F) K^+ uptake by leaf blade. Samples were taken from control (0mM) and 72h after 60mM and 150mM NaCl stress application. Vertical bars represent the SE of the mean for triplicate determinations.

Na^+ and K^+ uptake by leaf sheath

Here, we see that under control condition both cultivars were uptake almost similar amount of Na^+. Under 60mM, and 120mM NaCl stress condition less Na^+ was uptake in FR13A, compared with that of BRRI Dhan29. In case of K^+, both cultivars taken-up at 60mM and 120mM salinity conditions the highest amount of K^+ in FR13A. (Fig. C, D)

Na^+ and K^+ uptake by leaf blade:

Here we examined that under control condition both cultivar were uptake almost similar amount of Na^+. Under 60mM, and 120mM NaCl stress condition less Na^+ was uptake in FR13A, compared with that of BRRI dhan29. In case of K^+, both cultivars taken-up at 60mM and 120mM salinity stress condition the highest amount of K^+ in FR13A. (Fig. E, F)

IV. Discussion

The present study detected the tissues (root, leaf sheath and leaf blade) in response to salinity stress in a salt tolerant rice cultivar FR13A and salt sensitive cultivar BRRI dhan29. As indicated by our results, along with increasing sodium content in tissues dramatically increased at 60mM and 120mM salinity stress to get rid of excessive Na^+ ions in BRRI dhan29 than FR13A. This phenomenon indicated the important role of salt glands and protection of plant tissues against toxic ions, without losing indispensable nutrients in FR13Acultivar. As explained by (Fukuda *et al.*, 2004)alkalization of vacuolar lumen might regulate the H^+ pump gene expression and its acidification induces Na^+/H^+ antiporters. Over expression of H^+ pumps in coordination with Na^+/H^+ antiporter may govern salt tolerance mechanisms in plants. By use of inhibitors for K^+-selective channels and for non-selective cation channels (NSCCs) it was found that Na^+ influx into the cytosol was mediated by different channels or transporters in these cultivars. The inhibition of Na^+ uptake in BRRI dhan29 by all of these inhibitors indicates that both K^+-selective channels and NSCCs are involved in mediating Na^+ uptake in this cultivar. The non-competitive inhibition of Na^+ uptake of BRRI dhan29 to the K^+ channel protein. This result is consistent with other studies, suggesting that K^+ selective channels contribute to Na^+ influx in rice. (Horie *et al.*, 2001) isolated two isoforms of HKT transporters from rice and suggested that they are a Na+ transporter (*OsHKT1*) and a Na^+ and K^+ coupled transporter (*OsHKT2*). Instead the inhibitor analyses indicate that NSCCs are the main pathways for Na^+ influx in cv. FR13A, since inhibitors for NSCCs almost totally blocked the uptake of Na^+. The NSCCs have been shown to be the major pathways for Na^+ influx for many species (Demidchik and Tester, 2002).In many recent studies, high-affinity K^+ transporter (HKT) family has been shown to mediate important Na^+ tolerance mechanisms in plants.HKT transporters exert vital physiological functions in preventing shoot Na^+ over-accumulation by mediating Na^+ exclusion from xylem vessels. Sodium reabsorption at xylem parenchyma cells mediated by HKT transporters is appeared as a key component for plants to maintain a high K^+/Na^+ ratio in cell cytosol, which confers salt tolerance of the plants during salinity stress (Horie *et al.*, 2012). Once Na^+ enters the cytosol at a toxic level, plant cells can deal with the internal Na^+ by sequestering it either in the apoplast or into the vacuole. Vacuolar compartmentalization of Na^+ has been found as an efficient strategy in rice to cope with salinity stress (Kader *et al.*, 2006). *OsNHX1, OsNHX2* a

tonoplast Na^+/H^+ antiporter in rice, plays an important role in compartmentalization of cytosolic Na^+ into the vacuole, and its over-expression improves the salt tolerance of transgenic rice (Fukuda *et al*., 2004). The simultaneous induction of *OsSOS1* and *OsNHX1,2* in FR13A tissues is determinant and effective factors to control Na^+ translocation and accumulation in FR13A but this mechanisms were absent in BRRI dhan29 tissues as indicated. The induction of *OsHKT* family genes in root epidermis and vascular cylinder cells, as well as in shoot mesophyll cells of salt-sensitive BRRI dhan29, might indicate its involvement in Na^+ uptake by the root and in the subsequent circulation of Na^+ in the leaf mesophyll cells, causing significant cell damage. Since the experimental plants were grown with an optimal K^+ concentration in the growth medium, there should be no K^+deficiency in cells under control conditions. However, under high salt stress conditions, Na^+ competition at K^+ binding sites may result in K^+ deficiency and thus might cause the induction of *OsHKT* in both the cultivars in some extent. Another possibility is that excess Na^+ entering the cytosol increases the optimal cytosolic Na^+/K^+ ratio, which cells might recognize as a K^+ deficiency, thus inducing *OsHKT* in cases of K^+ deficiency. The higher uptake of Na^+ into the cytosol of BRRI dhan29 than that of FR13A is probably caused by a higher induction of *OsHKT* in BRRI dhan29. Under salt stress, both the increased vacuolar compartmentalization ability of Na^+ (by inducing the expression of *OsNHX*) and decreased uptake of Na^+ into the cytosol (by decreasing the expression of *OsHKT*) seem to work more efficiently in the salt-tolerant cv. FR13A than in the salt-sensitive cv. BRRI Dhan29. (Maathuis, 2006) suggested that both the down-regulation of HKT and the up-regulation of an NHX isoform (tonoplast Na^+/H^+ antiporter) could contribute greatly to limiting Na^+ loading in plant tissue, particularly when cytosolic Na^+ contents are concerned. Transcriptional regulation by K^+ supply of the genes encoding AKT1 channels has been shown to depend on the species such as salt stress strongly down-regulates *AtAKT1* and the *Oryza sativa* homolog *OsAKT1* in the salt-sensitive IR29 variety, but not in the salt-tolerant FR13A. *OsHAK* family genes locate to the tonoplast and may be involved in K^+ transport from the vacuole to the cytosol under K^+ starvation conditions in FR13A. The important role of K^+ and K^+ transporters of these HAK family genes may play these functions operating at the tonoplast of the vacuole. Interaction of these transporters with hormone distribution may be an important point of growth regulation but this mechanisms were absent in BRRI dhan29 upon exposed of stress. From these studies it can be suggested that there is a fast efflux (vacuolar compartmentalization) of cytosolic Na^+ from leaf protoplasts of the salt-tolerant FR13A and some sequestration of Na^+ into the apoplast along with some vacuolar compartmentalization from the sensitive cultivar BRRI dhan29. The salt-tolerant cultivar FR13A does not use plasma membrane Na^+/H^+ antiporters for Na^+ extrusion into the apoplast, whereas the sensitive cultivar does. This might make the latter cultivar sensitive to salt stress, since sodium transported from cells by plasma membrane Na^+/H^+ antiporters would cause a problem for the neighbouring cells. Therefore, the lower uptake of Na^+ in FR13A, after pre-treatment with NaCl, might depend on induction of some tolerance mechanisms to Na^+. On the other hand, the somewhat higher uptake of Na^+ in BRRI dhan29 might be due to some toxic effect of an endogenous high concentration of Na^+.

V. Conclusion

The Na^+/K^+ homeostasis seems to be an important salt-tolerance determinant in the salt-tolerant riceFR13A. This mechanism is less efficient in the salt-sensitive rice BRRI dhan29. FR13A also induces the expression of these genes at the onset of high NaCl conditions, most likely to compartmentalize cytosolic Na^+ into the vacuole. This might occur either because of K^+ deficiency in cells (caused by Na^+ competition at transport sites), or by interruption (increased) of the cytosolic Na^+/K^+ ratio, which cells might sense as a K^+-deficiency. However, at a certain stage later on, FR13A down-regulates the expression of these genes. It is concluded that FR13A maintains cytosolic K^+/Na^+ homeostasis by increasing the K^+-Na^+ coupled uptake through the induction of these genes, as well as by increasing the compartmentalization of cytosolic Na^+ into the vacuole. FR13A might also maintain a low influx of cytosolic Na^+, either by means of a conformational change of the transport proteins and/or any post-transcriptional changes of above genes. On the other hand, BRRI dhan29 could not maintain cytosolic K^+/Na^+ homeostasis due to down-regulation of transport proteins. As BRRI dhan29 took much higher Na^+ upon slat stress, which might causes toxic effects in cytosol. The unstable expression of vacuolar transporters in BRRI dhan29 resulting less or no sequestration of excess Na^+ in vacuole causes irreversible organelle damages. We conclude that simultaneous induction and up-regulation of transporters found to be an effective factor to control Na^+ translocation and less accumulation in FR13A. This mechanisms were absent in BRRI dhan29 and as a result this cultivar could not maintain effective K^+/Na^+ homeostasis and long term salinity tolerance.

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