Relationship between Na Content or K/Na Ratio in Shoots and Salt Tolerance in Several Gramineous Plants*

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Abstract: The relationship between Na content or K/Na ratio and the salt tolerance was investigated in several gramineous plants. Growth inhibition by NaCl treatment was greater in shoots than in roots and less in *Echinochloa oryzicola* Vasing (Tsukuba) than in rice (Nipponbare). Na content of roots in *E. oryzicola* seedlings was higher than that of leaves, whereas it was the reverse in rice seedlings under a saline condition. Rice (Nipponbare) contained more Na in their leaves than *E. oryzicola* (Tsukuba). These suggest that *E. oryzicola* might reduce the transport of Na to shoot more effectively than rice. The decrease of K uptake and the increase of Na uptake by NaCl treatment resulted in lower K/Na ratio in leaves and roots. This trend was greater in rice than *E. oryzicola*. Moreover, this relationship between Na content or K/Na ratio and salt tolerance was also observed in 8 gramineous species examined. Among them, foxtail and corn were comparatively salt-tolerant, and contained higher Na concentration and lower K/Na ratio in shoots, suggesting that these 2 species possess a different salt tolerance mechanism. It was suggested that the salt

tolerance of the gramineous species examined in this study might be related to their different abilities in limiting Na uptake and its transport to shoot and maintaining K in shoot under a saline condition.

Key words: salt tolerance, gramineae, Na content, K/Na ratio

Introduction

Weeds are regarded as important plant species for the amelioration of desertified lands, because some of these species possess many stress-tolerant traits⁹⁾. In desertified regions, salt accumulation on the land surface often progresses gradually and salinity stress is the most serious problem for vegetation formation. Numerous researchers have reported the salt tolerance of crops, but they have not yet been utilized in desertified areas. It has been reported that several weed species could survive in saline soil¹⁷⁾. Therefore, it is very important to identify salt-tolerant weeds which can be utilized as introductory plants to improve salinized desertified land and to understand their salt tolerance mechanism. There is, however, only limited information on the salt tolerance of weeds, especially gramineous weeds^{7,8,15,16)}, with the exception of some halophytes.

Salt tolerance of gramineous species was determined by the different Na concentration in leaves¹⁾. Some *Triticum* species regulated Na uptake from roots and had a low Na concentration in leaves, resulting in consider-

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able salt tolerance^{4,10~12}). Matsushita and Matoh^{7,8}) reported the reed plant (*Phragmites communis* Trinius), a salt-tolerant weed, inhibited the translocation of salt from root to shoot at the shoot base region. Strengthened exclusion of salt conformed to a salt-tolerant accession of silvertopgrass (*Diplachne fusca* (L.) Beauv)¹⁶). Salt tolerance is also dependent on the maintenance of the essential K level in leaves under salinity stress. It was demonstrated that mutants of *Arabidopsis* lacking the ability of K uptake were salt-sensitive and K acquisition was suggested as a possible critical process for salt tolerance in glycophytic plants¹⁸). It was also reported that higher uptake of K or cytoplasmic concentration was related to the salt tolerance in several gramineous species^{2,3,5,6}). No Na-selective channel in the plasma membrane of plants has yet been identified, and Na may be absorbed through a potassium ion channel with some permeability to sodium ion¹³). Therefore, it is assumed the K concentration in a plant may be decreased with the excess uptake of Na ion under the salinity condition, resulting in a lowering of the K/Na ratio. Taleisnik and Grunberg¹⁴) reported the salt-tolerant cultivar of tomato had much higher K/Na selectivity than its salt-sensitive cultivar. However, there were no significant differences in K/Na selectivity of root cells from either salt-tolerant or salt-sensitive wheat species, and this suggests that the relationship of the K/Na selectivity to salt tolerance may vary with plant species¹³).

In our preliminary study, *E. oryzicola* (Tsukuba) was more tolerant than rice (Nipponbare). In this study we sought to elucidate the reason for its salt tolerance by determining the uptake of Na and K compared to rice, a comparatively saltsensitive gramineous species. In addition, the relationship of ion uptake under the salinity stress to

salt tolerance was confirmed in several gramineous species including weeds.

Materials and Method

Seeds of rice (*Oryza sativa* L. cv. Nipponbare) and *Echinochloa oryzicola* Vasing. were germinated at 30°C in the dark for 48hr, then allowed to grow in a growth chamber in Kasugai's nutrient solution. The plants were grown at 25/20°C (day/night), 12h light (200 μ Em⁻²s⁻¹) and 60% RH. These seedlings at the third-leaf stages were treated with Kasugai's nutrient solution containing 0, 50, 100 and 150mM NaCl. Fresh solutions were provided daily which contained the designated NaCl concentration. One week after the initiation of NaCl treatment, shoots and roots of the seedlings were harvested. The seedlings were separated into developing leaves (abbreviated as young leaf) and fully expanded leaves (matured leaf). They were dried at 70°C in an oven for 2 days, weighed, and then stored in a desiccator until ion analysis.

Dried plant materials (100mg) were extracted with 10ml 1.4N-HNO₃ for 10h at 100°C and the extract was diluted with 500ml of ion-exchanged water to get less than 10 ppm of each cation concentration, and the cations analyzed. Na and K concentrations were determined with an inductively coupled argon plasma automatic emission spectrophotometer (Nippon Jarrell - Ash, Model757v)

Eight graminaceous species, rice (*Oryza sativa* L. cv. Nipponbare and Annapurna), *Echinochloa oryzicola* Vasing (collected in Tsukuba and Oomagari), *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi, sudangrass (*Sorghum sudanensis* Stapf), sorghum (*S. bicolor* (L.) Moench), crabgrass (*Digitaria ciliaris* Koeler), foxtail (*Setaria viridis* (L.) Beauv) and corn (*Zea mays* L. cv. Honeybantam) were grown and then anal-

alyzed in the manner described above to learn in detail the relationship between salt tolerance and Na accumulation.

Results and Discussion

Growth of *E. oryzicola* and rice under salt stress

The growth of shoots and roots was greatly inhibited by NaCl treatment in both gramineous species proportional to the concentration of treated NaCl (Fig. 1). Growth inhibition was more severe in the shoots of rice (Nipponbare) than in *E. oryzicola* (Tsukuba). Even at higher concentration of NaCl, it was observed that *E. oryzicola* showed comparatively vigorous growth and put out new leaves. The shoot dry weight of rice was reduced to approximately 28% in contrast to 54% in *E. oryzicola* compared to the salt-untreated control at the concentration of 150 mM NaCl. The reduction in root growth was also dependent on the concentration of treated NaCl but there was little difference in reduction rate between the two species.

Na uptake by *E. oryzicola* and rice

Na content was increased with the increment of NaCl concentration treated in all parts of seedlings (Fig. 2). Na content in roots was higher than that in leaves in *E. oryzicola*, whereas it was lower in rice seedlings under a saline condition, resulting in higher concentration in leaves of rice seedlings than in *E. oryzicola*. The difference in Na content between the matured and young leaves was small in both species regardless of the NaCl concentration, even though the matured leaves contained a little more. But in the young leaves, sodium content was lower in *E. oryzicola* than rice. From the above results, it was suggested that *E. oryzicola* may reduce the transport of Na absorbed into the roots more effectively and this ability

Fig. 1. Effect of NaCl treatment on shoot growth of *E. oryzicola* and *O. sativa*. (The dry weight was 0.19 and 0.13 g/plant in controls of *E. oryzicola* and *O. sativa*, respectively. Vertical bars indicate standard errors.)

may be related to its salt tolerance as proved in reed^{7,8)}.

K/Na ratio of *E. oryzicola* and rice

K/Na ratio of the NaCl-untreated control was higher in the leaves of *E. oryzicola* than rice due to the higher Na content in the

leaves of rice (Fig. 3). It became lower in both species corresponding to the NaCl treatment concentration due to the increase in Na and the decrease in K in the leaves; decrease in the K/Na ratio was greater in rice than *E. oryzicola*, especially in growing young leaves. These results suggested that *E. oryzicola* may possess lower permeability to Na at the channel of plasma membrane, and may absorb K ion selectively in a solution where K and a large quantity Na ion co-exist.

Salt tolerance of several gramineous plants and their Na and K uptake

We believed it doubtful that the relationship between the uptake of Na or K/Na selectivity and the salt tolerance described above is true in other gramineous species. Therefore, the relationship was investigated

in 8 gramineous species which were treated with NaCl 100mM at the 3rd leaf stage (Fig. 4). The correlation between the Na content of shoots and the salt tolerance expressed by dry matter production was highly significant in 6 of the species, except foxtail and corn. The 6 species showing greater Na uptake were more salt-sensitive whereas foxtail and corn were comparatively salt-tolerant despite having high Na content in their shoots. *Echinochloa crus-galli* (L.) Beauv. var. *formosensis* was the most salt-tolerant and two *Sorghum* species and crabgrass were highly salt-tolerant gramineous species which could limit the uptake of Na. Both accessions of *E. oryzicola* collected in Tsukuba and Oomagari were also comparatively salt-tolerant even though the Oomagari accession was a little more sensitive to salt.

Fig. 2. Na contents in seedlings of *E. oryzicola* and *O. sativa* 6 days after NaCl treatment (Vertical bars indicate standard errors.)

Fig. 3. Changes of K/Na ratio in *E. oryzicola* and *O. sativa* 6 days after NaCl treatment (*: Values on the bars indicate the K/Na ratio in the control. Vertical bars indicate standard errors.)

Fig. 4. Relationship between Na content(A) or K/Na ratio(B) and shoot growth in several gramineae species treated with 100mM NaCl at 3rd leaf stage (Regression equations were calculated excluding of foxtail and corn).

- ① rice (*Oryza sativa* L. cv. Nipponbare)
- ② rice (*O. sativa* L. cv. Annapurna)
- ③ *Echinochloa oryzicola* Vasing (Tsukuba)
- ④ *E. oryzicola* Vasing (Oomagari)
- ⑤ *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi
- ⑥ *Sorghum sudanensis* Stapf
- ⑦ *S. bicolor* (L.) Moench
- ⑧ crabgrass (*Digitaria ciliaris* Koeler)
- ⑨ foxtail (*Setaria viridis* (L.) Beauv)
- ⑩ corn (*Zea mays* L. cv. Honeybantam)

Moreover, it was observed that the decrease in the K/Na ratio under salt stress correlated well to the salt sensitivity, indicating that the maintenance of K uptake was also important in salt tolerance of the gramineous species. Crabgrass showed the least decrease in K/Na ratio, probably due to its higher absorption ability to K, and *S. sudanensis* might possess a channel of low permeability to K in spite of its extremely low uptake of Na under salt stress. Changes of the ratios in the other species paralleled their Na contents.

Thus, it was concluded that the salt tolerance of the several gramineous plants tested might mainly reflect their ability to limit Na uptake to shoot and to maintain the permeability of K in the channel of plasma membrane under a saline condition, with exceptions like foxtail and corn; the mechanism of their salt-tolerance is still unknown. Some gramineous weeds have higher salt tolerance compared to some crops and also different patterns of ion uptake, suggesting the existence of different mechanisms of salt tolerance.

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数種イネ科植物の地上部における Na 含量ならびに K/Na 比と耐塩性との関係

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摘 要

数種のイネ科植物を供試し、NaCl を根部に処理することにより耐塩性程度と Na 含量、K/Na 比との関係を比較検討した。塩処理により生育阻害は根部

より地上部で大きく現れ、イネ（日本晴）よりタイヌビエ（つくば産）において小さかった。塩処理時にあつては、タイヌビエでは根部での Na 含量が地上部より高く、イネ（日本晴）では地上部で根部より高い濃度を示した（Fig. 2）。これらの結果は根部から地上部への Na の移動をイネに比べタイヌビエが効果的に制限していることを示唆した。塩処理による K の吸収低下と Na の過剰吸収によって、K/Na 比が低下したが、この傾向はタイヌビエよりイネで顕著であつた（Fig. 3）。さらに、イネ科植物 8 種を用いて耐塩性の程度と Na 含量、K/Na 比との関連

性についても検討したところ、8種のうち6種で上述のような関係がみられた (Fig. 4)。地上部での高い Na 含量と低い K/Na 比にも拘わらず、トウモロコシとエノコログサは比較的高い耐塩性を示し、これらの種はイネ科の中で異なった耐塩性機構を備え

ている植物群であることが示唆された。

以上の結果からこれらイネ科植物での耐塩性程度は Na の地上部への吸収移行制限の能力と K 保持能力が大きく関与しているものと推察される。

キーワード：耐塩性，イネ科，Na 含量，K/Na 比

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