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EFFECT OF DIFFERENT EXTERNAL K^+/Na^+ AND Ca^{2+}/Na^+ RATIOS ON GROWTH, IONIC COMPOSITION AND SELECTIVITY OF RICE LINES VARYING IN SALT TOLERANCE

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Two separate experiments in solution culture were conducted simultaneously under saline conditions with varying external K:Na ratios. Shoot and root yield, their composition and selectivity of K over Na under all set of conditions were calculated for NIAB-6 (salt tolerant) and IR 1561 (salt sensitive). Salinity decreased shoot and root yield drastically but different ratios of K:Na and Ca:Na did not affect these yields in both cultivars. Concentration of K and Ca in tissues increased with their increasing levels in the external solutions. Salinity though reduced K:Na level in shoot and root yet salt tolerant line (NIAB-6) maintained better selectivity (S_{K^+, Na^+}) under saline conditions. The role of Ca in the improvement of K selectivity (S_{K^+, Na^+}) under saline environment has been discussed.

INTRODUCTION

Both Ca^{2+} and K^+ are required in the external medium to maintain the selectivity and integrity of cell membrane (Wyn Jones and Lunt, 1967; Fageria, 1983). The role of Ca^{2+} becomes even more important in a saline environment (Rains, 1972) where plants take up excessive amounts of Na^+ at the cost of K^+ and Ca^{2+} (Wyn Jones, 1981; Kuiper, 1984). Therefore, low Ca^{2+}/Na^+ and K^+/Na^+ ratios in saline environment may impair the selectivity of root membrane and result in passive accumulation of Na^+ in the root and shoot (Kramer *et al.*, 1977). In addition high K^+/Na^+ ratio is equally important for increasing the plant's tolerance and resistance to environmental stress due to K role in osmoregulation, in energy status and in the synthesis of high molecular compounds (Beringer and Trolldenier, 1978).

Saline-sodic soils differ in K^+/Na^+ and Ca^{2+}/Na^+ ratios (Richards, 1954). Plant growth under such conditions is confronted with K^+-Na^+ interaction which may result in reduced yields due to ion imbalance stress (Devitt *et al.*, 1981). A study of the impact of varying external $K^+:Na^+$ and $Ca^{2+}:Na^+$ ratios on growth, Na^+ and K^+ contents and the potassium-sodium selectivity of two rice lines was undertaken to assess their relation to salt tolerance of rice.

MATERIALS AND METHODS

Seedlings (14–day old) of the two rice lines i.e. NIAB–6 (tolerant) and IR–1561 (sensitive) were transferred to 1 cm plugged holes in thermopal sheets floating over 15 liters of Yoshida nutrient solution (Yoshida *et al.*, 1972) in plastic tubs. Eight holes were used for each line, each hole having one seedling. There were four repeats in the experiment. Nutrient solutions were prepared in distilled water and various ratios of K^+ and Na^+, and Ca^{2+} and Na^+ used in different treatments were:

Experiment I			Experiment II		
Ratios		Total salinity	Ratios		Total salinity
K^+ :	Na^+	mol m^{-3} $K^+ + Na^+$	Ca^{2+} :	Na^+	eq m^{-3} $Ca^{2+} + Na^+$
–	(40)	nutrient solution	–	(40)	nutrient solution
1:10	(0.1)	100	1:1	(1.0)	100
1:50	(0.02)	100	1:2	(0.5)	100
1:100	(0.01)	100	1:5	(0.2)	100
1:500	(0.002)	100	1:10	(0.1)	100
1:1000	(0.001)	100	1:20	(0.05)	100
1:5000	(0.0002)	100	1:40	(0.025)	100
1:10000	(0.0001)	100	1:80	(0.0125)	100

Total ($K^+ + Na^+/Ca^{2+} + Na^+$) concentrations were increased by 25 mol m^{-3} day^{-1}. The solutions were changed frequently. After eighteenth day of salt stress, the fresh and dry weights of shoot and root were taken. Potassium, sodium and calcium concentration was determined in the shoot and root sap. Potassium–sodium selectivity (S_{K^+, Na^+}) was calculated in shoot and root according to formula (Pitman, 1976).

$$S_{K^+,Na^+} = \frac{K^+/Na^+ \text{ in plant tissue}}{K^+/Na^+ \text{ in external solution}}$$

RESULTS AND DISCUSSION

Effect of external K^+:Na^+ ratios on:

Shoot and root yield: Fresh weight of shoot decreased drastically with the addition of salts in the nutrient solution (Table 1). Tolerant line NIAB–6 had better shoot yield as compared to the sensitive line IR–1561 at all ratios of K^+:Na^+ at 100 mol m^{-3} ($K^+ + Na^+$) salinity. On the average, yield reduction in the case of tolerant and sensitive lines was 54 and 66 percent, respectively. However, shoot yield indicated no consistent effect of K^+:Na^+ ratio of the external solution. Maximum shoot yield in both the varieties was ob-

Table 1. Effect of external potassium–sodium ratio at 100 mol m^{-3} ($Na^+ + K^+$) on shoot and root fresh weight and selectivity (S_{K^+, Na^+}) of two rice lines

SHOOT

Varieties/ Lines	Control	100 mol m^{-3} ($Na^+ + K^+$)						
		K^+ : Na^+ ratio						
	40	0.1	0.02	0.01	0.002	0.001	0.0002	0.0001
				Fresh weight (g $6p^{-1}$)				
NIAB 6	53.0	17.4	22.2	23.2	33.0	22.9	28.0	24.1
IR 1561	47.2	13.4	15.1	15.1	23.9	15.4	15.3	13.4
				Na^+ (m mol kg^{-1} cell sap)				
NIAB 6	7.5	75.4	94.5	99.8	93.4	101.2	113.4	138.0
IR 1561	7.6	99.8	111.5	119.3	117.8	128.2	150.0	185.9
				K^+ (m mol kg^{-1} cell sap)				
NIAB 6	324	307	277	231	236	217	195	179
IR 1561	330	244	252	211	200	165	156	126
				ROOT				
				Fresh weight (g $6p^{-1}$)				
NIAB 6	48.3	22.0	25.3	25.9	33.4	25.8	27.7	24.3
IR 1561	44.8	17.7	18.9	22.0	22.5	17.7	20.1	17.8
				Na^+ (m mol kg^{-1} root sap)				
NIAB 6	14.6	65.2	67.4	68.7	108.9	126.5	134.3	151.7
IR 1561	15.0	58.7	65.2	66.9	104.3	110.2	127.1	134.9
				K^+ (m mol kg^{-1} root sap)				
NIAB 6	189	236	187	137	86	90	72	71
IR 1561	186	149	112	101	66	58	53	50

served where external K^+:Na^+ ratio was 0.002, while K^+:Na^+ ratio of 0.1 produced the minimum yield under 100 mol m^{-3} (K^+ + Na^+) salinity.

Root yield though decreased with salinity yet the decrease was relatively less than the shoot yield (Table 1). At 100 mol m^{-3} (K^+ + Na^+) salinity, the root yield decreased to about 55 and 43 percent of the respective control in salt tolerant and sensitive lines, respectively. Again the effect of K^+:Na^+ ratios of the external solution did not show any clear relations with rice line. However, the K^+:Na^+ ratio of 0.002 produced the highest and K^+:Na^+ ratio of 0.1 gave the lowest root yield as in the case of shoot yield.

The shoot and root yields seem to be affected by the complex interaction between the substrate salinity, substrate K^+:Na^+ ratios, nature of the tissues involved and the cultivar itself. It is worth noting that at both the salinity levels the adverse effect of K^+:Na^+ ratio of 0.1 was greater than all other ratios studied.

Sodium in shoot and root: Sodium concentration of shoot and root sap in both the rice lines increased progressively with increase in Na^+ concentration (Table 1) in the external solution at 100 mol m^{-3} (K^+ + Na^+) salinity but the sensitive line IR-1561 always had more sodium than NIAB-6 at the comparable K^+:Na^+ ratio in the medium.

It is interesting to note that both the lines maintained their Na^+ to a uniform level when external K^+:Na^+ ratios were decreased from 0.1 to 0.001 after which the control was lost and both the lines showed a rapid increase in Na^+ concentration of root. Similarly, in the case of shoot, Na^+ concentration increased more rapidly beyond K^+:Na^+ ratio of 0.002.

Potassium in shoot and root: Potassium concentration depends largely upon the K^+ level of the external solution (it increased with increase in external K^+ concentration) and was higher in shoot than in root in both the lines. Nevertheless, both in shoot and root, the K+ concentration was maintained at a higher level in the tolerant line(NIAB–6) as compared to the sensitive one (RI–1561) at the comparable K^+:Na^+ ratios in the medium.

Effect of external Ca^{2+}:Na^+ ratios on: Shoot and root yield: Different Ca^{2+}:Na^+ ratios in external medium considerably decreased the fresh weights of shoot and root at 100 mol m^{-3} (Ca^{2+} + Na^+) salinity in both the lines but the decrease was more in the case of salt sensitive line IR–1561 than NIAB–6 (Table 2).

Relatively more reduction in shoot yield was observed at Ca^{2+}:Na^+ ratio of 0.2 and 0.025 in NIAB–6 and IR–1561 respectively (Table 2). In general, the effect of Ca^{2+}:Na^+ ratio on shoot yield was not much. The effect on root yield was similar to the shoot yield at 100 mol m^{-3} (Ca^{2+} + Na^+) salinity. Results are in line with the findings of Yeo and Flowers (1985), who reported little effect of Na^+:Ca^{2+} ratio in culture solution

Table 2. Effect of external calcium:sodium ratio at 100 mol m^{-3} (Na^+, Ca^{2+}) on shoot and root fresh weight and selectively (S_{K^+, Na^+}) of two rice lines.

Varieties/ Lines	Control	100 mol m^{-3} (Na^+ + Ca^{2+})						
		Ca^{2+} : Na^+ ratio						
	40	1.0	0.5	0.2	0.1	0.05	0.025	0.0125
SHOOT								
Fresh weight (g 6p^{-1})								
NIAB–6	53.0	37.9	38.7	29.4	32.4	36.7	30.4	31.7
IR–1561	47.2	25.9	26.1	22.2	25.0	26.7	20.8	24.0
Na^+ (m mol kg^{-1} cell sap)								
NIAB–6	7.5	37.4	43.7	49.3	51.8	63.6	70.0	77.3
IR–1561	7.6	44.5	50.3	63.3	69.0	76.5	82.0	91.1
K^+ (m mol kg^{-1} cell sap)								
NIAB–6	324	304	267	249	232	232	194	169
IR–1561	330	261	202	194	169	174	145	120
Ca^{2+} (m mol kg^{-1} cell sap)								
NIAB–6	6.1	84.2	54.7	21.9	13.9	9.4	5.8	3.5
IR–1561	9.2	92.3	58.2	29.5	20.2	12.3	8.1	5.1
ROOT								
Fresh weight (g 6p^{-1})								
NIAB–6	48.3	36.0	39.6	29.4	29.4	36.9	30.0	41.9
IR–1561	44.8	23.4	24.7	26.7	25.2	27.3	20.7	31.9
Na^+(mmol kg^{-1} root sap)								
NIAB–6	14.6	69.6	70.0	73.9	79.6	80.4	83.9	92.6
IR–1561	15.0	66.5	68.2	70.4	75.2	79.6	84.3	86.0
K^+ (mmol kg^{-1} root sap)								
NIAB–6	189	230	205	178	174	171	149	136
IR–1561	186	159	168	141	135	125	106	94
Ca^{2+} (m mol kg^{-1} root sap)								
NIAB–6	10.2	55.3	31.9	20.2	11.9	11.2	9.9	5.1
IR–1561	11.4	71.7	35.3	24.2	17.9	16.1	11.1	9.0

on the growth of rice plant. However, Muhammad *et al.* (1987) had reported that increasing $Ca^{2+}:Na^{+}$ ratio in saline culture solution increased the dry weight of rice root significantly. The positive response in the later case was probably due to the longer (42 d) growth period.

When the comparison of shoot and root yields at different $K^{+}:Na^{+}$ and $Ca^{2+}:Na^{+}$ ratios at 100 mol m^{-3} salinity was made (the control treatment for both the experiments was the same and these experiments, were conducted simultaneously), it was observed that yield reduction due to addition of Ca^{2+} in the solution was less as compared to the addition of K^{+} to the solution culture to alter the ratio of Na^{+} in solution.

Devitt *et al.* (1981) and Ponnamperuma (1984) associated the decrease in plant and root yield with the effect of salinity whereas Wyn Jones and Lunt (1967) associated this with Ca^{2+} deficiency (ion imbalance).

Sodium and potassium in shoot and root: The results of this experiment for Na^{+} and K^{+} values were almost similar to the results of the experiment–I. The concentration of Na^{+} increased and of K^{+} decreased with decreasing ratio of $Ca^{2+}:Na^{+}$ in the culture solution at 100 mol m^{-3} (Ca^{2+} + Na^{+}) salinity both in the shoot and root of the two rices under study. However, K^{+} concentration in root was higher in the salt tolerant line (NIAB–6) compared with the salt sensitive line (IR–1561), whereas IR–1561 accumulated more Na^{+} in its shoot than NIAB–6 (Table 2).

Calcium concentration in shoot and root: The salt sensitive line maintained higher level of Ca^{2+} in its shoot and root tissues under all conditions (Table 2). Generally, Ca^{2+} concentration in shoot and root decreased progressively with decreasing $Ca^{2+}:Na^{+}$ ratio in the root medium at 100 mol m^{-3} (Ca^{2+} + Na^{+}) salinity. As compared to control, Ca^{2+} concentration increased drastically at 100 mol m^{-3} (Ca^{2+} + Na^{+}) salinity between $Ca^{2+}:Na^{+}$ ratios of 1.0 to 0.05 but after that its concentration was even lower than control in both lines in the shoot and root. This might be due to the deficiency of Ca^{2+} in the system due to decreased $Ca^{2+}:Na^{+}$ ratio.

Potassium–sodium selectivity ($S_{K^{+}, Na^{+}}$) of shoot and root as affected by varying $K^{+}:Na^{+}/Ca^{2+}:Na^{+}$ ratios in the external medium

Calculated $S_{K^{+}, Na^{+}}$ values indicate that in both the lines there was a rapid increase in shoot $S_{K^{+}, Na^{+}}$ with decrease in external $K^{+}:Na^{+}$ ratio below 0.01 and in root $S_{K^{+}, Na^{+}}$ below $K^{+}:Na^{+}$ ratio of 0.02 at 100 mol m^{-3} (Na^{+} + K^{+}) concentration (Fig. 1). There was little selectivity for K^{+} under control conditions and at high external $K^{+}:Na^{+}$ ratios. The $S_{K^{+}, Na^{+}}$ was twice as high in NIAB-6 than the sensitive line IR–1561 at the lowest K^{+} concentration ($K^{+}:Na^{+}$ ratio of 0.0001). This indicated a good correlation between $S_{K^{+}, Na^{+}}$

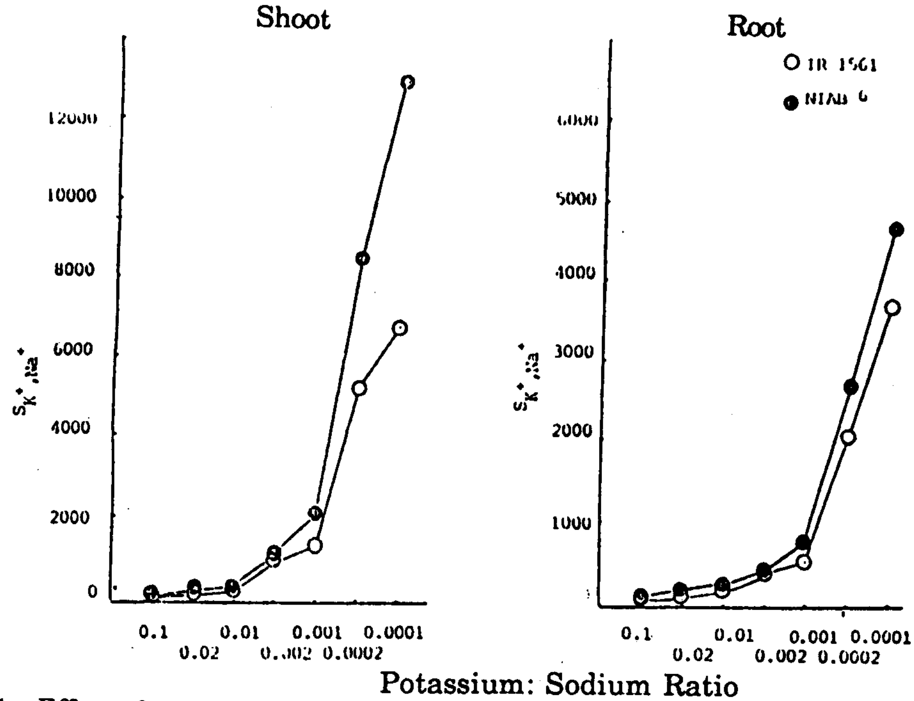

Fig. 1. Effect of external potassium:sodium ratio on shoot and root selectively potassium, sodium (S_{K^+, Na^+}) of two rice lines, grown at 100 mol m^{-3} ($Na^+ + K^+$) salinity level.

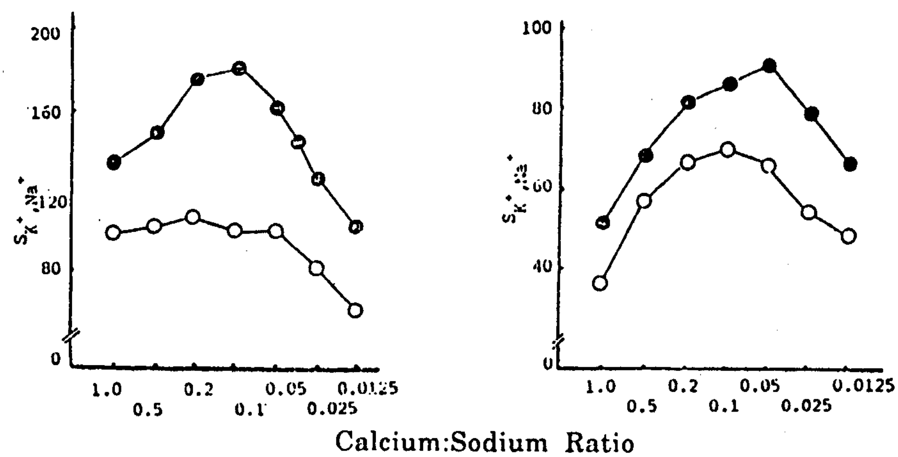

Fig.2. Effect of external calcium:sodium ratio on shoot and root selectivity potassium, sodium (S_{K^+, Na^+}) of two rice lines, grown at 100 mol m^{-3} ($Na^+ + Ca^{2+}$) salinity level.

and salt tolerance pattern of the varieties. The pattern in root selectivity values was similar to that of shoot but the magnitude of the differences between NIAB–6 and IR-1561 was smaller than in the case of shoot.

Selectivity values of shoot under varying ratios of Ca^{2+}:Na^{+} in the external solution at 100 mol m^{-3} (Na^{+} + Ca^{2+}) salinity indicated that shoot S_{K^+, Na^+} increased upto external Ca^{2+}:Na^{+} ratio of 0.1 and below this ratio it again decreased in both the rice cultivars (Fig. 2).

Root S_{K^+, Na^+} pattern (Fig. 2) in both the rice lines was almost the same; the lowest potassium selectivity was observed at Ca^{2+}:Na^{+} of 0.05 in NIAB–6 and at 0.1 in the case of IR–1561. However, root selectivity values for K^{+} versus Na^{+} were also poor in IR–1561 as compared to NIAB–6 but the relative concentration of Ca^{2+}:Na^{+} ratio in the two lines was of the similar order. Comparatively poor growth of rice in high K^{+}:Na^{+} ratio (0.1) in extrnal solution might be due to greater relative proportion of KCl in the medium. Higher toxicity of KCl over NaCl in Sorghum bicolor (Weimberg *et al.*, 1982) have been reported.

Potassium and sodium concentrations in shoot and root were directly related to the K^{+} and Na^{+} composition (K^{+}:Na^{+}) in the growth medium, indicating that their uptake was a function of their concentration and composition in the medium. Similar results have been reported by Devitt *et al.* (1984).

In general, salinity reduced K^{+}:Na^{+} level in shoot and root but the salt tolerant line maintained higher selectivity (S_{K^+, Na^+}) due to preferential uptake of K^{+} over Na^{+} under saline conditions. Similar results have been reported by Pitman (1965), Yeo and Flowers (1984). This phenomenon has also been reported in many other crops (Greenway and Munns, 1980, Wyn Jones, 1981; Gorham *et al.*, 1985).

Although increasing Ca^{2+}: Na^{+} ratio did not increase the shoot or root yield consistently but it decreased Na^{+} concentration, improved K^{+}:Na^{+} ratio in shoot and root and also improved K^{+} selectivity (S_{K^+, Na^+}) for shoot and root in both the lines and this phenomenon is much elaborated in the salt tolerant line., Yamauchi *et al.* (1986) and Muhammad *et al.* (1987) argued that Na^{+} uptake and growth in salinized conditions was affected by concentration of Ca^{2+} and K^{+} ions in the medium which caused the change of selectivity of ions on the surface or membrane of root. This fact clearly indicates that Na^{+} uptake from root is affected partly by selectivity of ions by root. This suggests that an adequate amount of Ca^{2+} in proportion to Na^{+} must be present in the system to improve and/or maintain selectivity (S_{K^+, Na^+}) as well as integrity of the cell membrane.

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