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Influence of Calcium on K^+/Na^+ Selectivity of Wheat under Saline Conditions

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ABSTRACT

A solution culture experiment was conducted to investigate the influence of calcium on K^+/Na^+ selectivity of wheat at 0, 50 and 100 mM NaCl in the root medium. Wheat (*Triticum aestivum* var. Pasban) seeds were germinated and seven-day old seedlings were foam plugged into plastic pots, filled with 2.5 litre half strength Hoagland's nutrient solution. The pots were kept in growth chamber under controlled conditions. The solution pH was adjusted to 5.9. There were three salinity levels, i.e. 0, 50 and 100 mM NaCl and two calcium levels, i.e. 2 and 8 mM Ca. The experiment was organized in randomized complete block design (RCBD) using three replications. At low concentration of calcium (2 mM), the growth of wheat decreased drastically with increasing concentration of sodium chloride in nutrient solution. On the other hand, plants grown in a high concentration of sodium chloride experienced less damage with high concentration of calcium (8 mM). At high concentration of calcium (8 mM), wheat plants absorbed and translocated relatively more potassium and less sodium than at low concentration of Ca (2 mM) demonstrating the positive role of calcium in averting the toxic effects of salinity on wheat growth.

Key Words: Wheat; K:Na selectivity; NaCl salinity; Ca alleviation effect

INTRODUCTION

Salt-affected soils are characterized by excess salts in soluble, exchangeable and sparingly soluble forms. Excess sodium in salt affected soils is replaced by calcium added mostly in the form of gypsum. Addition of excess calcium inhibits absorption of Na^+ and K^+ by plant roots (La Haye & Epstein, 1971) as well as it replaces the Na^+ ion from soil exchange complex. Under the prevailing conditions, the alleviation effect of calcium needs to be investigated on the growth and ionic uptake. Moreover, selective absorption of Na^+ and K^+ by roots is involved in salt tolerance of plants. Potassium:sodium selectivity of plants is, therefore, used as a yard stick of their salt tolerance. This paper describes the growth response of wheat in varied NaCl salinity and alleviation effect of calcium on NaCl. It also reports on total biomass production, distribution of biomass among root and shoot and uptake of Na^+ and K^+ by wheat grown at low and high levels of calcium supply in a saline root medium.

MATERIALS AND METHODS

The experiment was conducted in solution culture. Wheat (*Triticum aestivum* variety Pasban) seed were germinated on a seed germination assembly and two seven-day old seedlings were foam plugged in lids of the plastic pots containing 2.5 litre of continuously aerated half strength Hoagland's nutrient solution (Epstein, 1972), without calcium salts. The nutrient solution was changed after ten days interval. The pots were kept in growth chamber under controlled conditions having light intensity of 450 $\mu mol\ m^{-2}s^{-1}$. The photoperiod was adjusted 14 hours light and 10 hours dark period. The temperature was controlled at 30±2 °C. The solution pH was adjusted to 5.9 with HCl and NaOH and monitored regularly. There were three salinity levels (0, 50 and 100 mM NaCl) and two calcium levels (2 and 8 mM Ca). The salinity levels were imposed a week after transplanting by incremental addition of 25 mM NaCl on alternate days. Calcium at the two levels was supplied as $CaCl_2$ two days after transplantation. The pots were arranged according to randomized complete block design (RCBD) in three replications. The plants were harvested 36 days after transplanting. They were immediately separated into root and shoot after harvesting and rinsed with deionized water. The plant samples were oven dried at 60 °C to a constant weight. The dried plant samples were ground to pass a 40-mesh screen in a Wiley mill. Ground sub-samples of root and shoot were digested in 2:1 perchloric-nitric di-acid mixture to estimate Na, K and Ca in the digest by atomic absorption spectroscopy. The data were statistically analyzed according to RCBD and treatment means were compared using Duncan's Multiple Range (DMR) test (Gomez & Gomez, 1984). Potassium:sodium selectivity was calculated using following formula (Yeo & Flowers, 1984).

$$K : Na\ selectivity = \frac{(K/Na\ in\ plant\ tissue)}{(K/Na\ in\ root\ tissue)}$$

RESULTS AND DISCUSSION

There was significant ($p<0.05$) main and interactive effect of NaCl salinity and calcium supply on root and shoot growth of wheat (Table I). Decrease in total biomass production with increasing NaCl salinity at both levels of calcium supply was linear and significant ($p<0.05$). Adverse effect of increasing root medium salinity on plant growth have been reported by Hussain and Ilahi (1995). It was more pronounced at lower level (2 mM) of Ca supply than that of 8 mM Ca. In other words Ca supply significantly ($p<0.05$) alleviated the adverse effect of NaCl salinity on total biomass production. Supply of Ca in root medium would affect the ratio of Na in root medium and its absorption by plant roots. Relative reduction in total biomass production at 2 mM Ca supply was 17% at 50 mM NaCl and 28% at 100 mM NaCl. It was 3 and

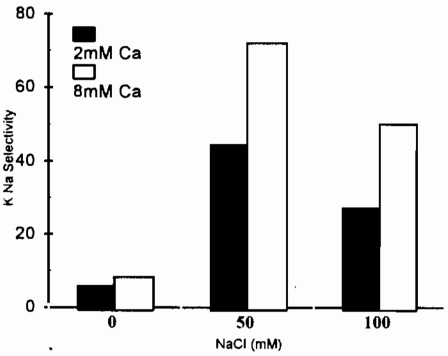
Table I. Effect of calcium on dry matter yield (g/pot) of wheat under saline conditions.

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	12.27 a	13.01 a	7.17 a	7.34 a
50 mM NaCl	10.14b	12.78 a	5.97 b	7.02 a
100 mM NaCl	8.16 c	10.95 b	5.87 b	6.93 a

Means sharing same letters are statistically non-significant at $\alpha = 0.05$

12% at 50 and 100 mM NaCl, respectively at 8 mM Ca supply. More biomass was distributed in shoot than in

Fig. 1a. Effect of calcium on K:Na selectivity under Na Cl salinity (shoot)



root as it was 58 to 65% of total dry matter yield at the two NaCl levels. However, proportion of root biomass increased with increasing salinity. This effect was more prominent at 2 mM (low) Ca supply. At this Ca level, there was 5% more root biomass (dry) at 100

Table II. Effect of calcium on sodium concentration (m mol/kg) of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	110d	70d	70d	50d
50 mM NaCl	380c	330c	270c	220c
100 mM NaCl	790a	720b	540a	460b

Means sharing same letters are statistically non-significant at $\alpha = 0.05$

mM NaCl than that of 0 mM NaCl salinity. Biomass partitioning of plants in response to chemical changes in root medium have also been discussed recently by Meconnaughay (1998). Relative decrease in shoot dry weight was 17% by 50 mM and 34% by 100 mM NaCl salinity at 2 mM Ca supply. Loss in root dry weight was uniform (17 to 18%) by incremental NaCl addition at 2 mM Ca supply. In contrast, depression in shoot and root dry weight was remarkably low at 8 mM Ca supply in the root medium as the relative loss in shoot dry weight was 2% by 50 mM and 16% by 100 mM NaCl salinity. At 8 mM Ca, the decrease in root dry weight was only 4 to 6%. Relative improvement in shoot growth at 8 mM Ca supply was more vivid than that in root growth. As compared to 2 mM Ca, improvement in shoot growth at 8 mM Ca supply was 6% at 0 mM NaCl, 26% at 50 mM NaCl and 34% at 100 mM NaCl salinity. Whereas the concurrent root growth improvement at 8 mM Ca was 2, 17.6 and 18% at 0, 50 and 100 mM NaCl, respectively.

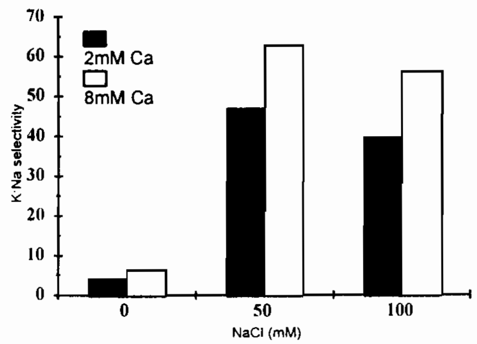
Table III. Effect of calcium on potassium concentration (m mol/kg) of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	1310a	1310a	1210a	1240a
50 mM NaCl	1070c	1240b	720c	950b
100 mM NaCl	940d	1210b	440d	690c

Means sharing same letters are statistically non-significant at $\alpha = 0.05$

Sodium concentration in shoot and root tissues was significantly affected at different salinity levels. Sodium concentration increased with increasing salinity levels (Table II). The increase in sodium concentration with increasing salinity is obviously due to increasing concentration of sodium in the root

Fig. 1b. Effect of calcium on K:Na selectivity under NaCl salinity (root)



medium which ultimately resulted in the increased uptake of sodium by plants (Aslam & Muhammed, 1972). Salinity x calcium interaction revealed that higher level of calcium (8 mM) significantly reduced the sodium concentration at 100 mM NaCl both in shoot and root.

Table IV. Effect of calcium on net potassium uptake (mg/pot) of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	625.68a	662.38a	339.53a	357.17a
50 mM NaCl	488.19b	532.71b	167.71c	259.20b
100 mM NaCl	383.16c	400.31c	100.64d	185.63c

Means sharing same letters are statistically non-significant at $\alpha = 0.05$

Application of calcium significantly reduced the sodium concentration both in shoot and root when plants were grown in 100 mM NaCl concentration. Similarly Jacobson *et al.* (1961), Rains and Epstein (1967), Elzam and Epstein (1969) and La Haye and Epstein (1969) demonstrated that calcium in the root medium depress the absorption of sodium. Direct evidence has been developed from studying the effect that calcium has on the physical characteristics of plant cell membrane. Marinos (1962), in microscopic examination of calcium deficient barley roots, observed disarranged, damaged membrane. Marschner and Gunther (1964) in their study limited the supply of calcium to roots and correlated a reduced capacity for ion absorption with changes in the structure of cell membranes.

Table V. Effect of calcium on K:Na selectivity of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	3.97c	6.24c	5.76d	8.27d
50 mM NaCl	46.93b	62.63a	44.44b	71.97a
100 mM NaCl	39.66b	56.02a	27.20c	50.00b

Means sharing same letters are statistically non -significant at $\alpha = 0.05$

Table VI. Effect of calcium on calcium concentration of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	0.76c	1.34a	1.99a	2.06a
50 mM NaCl	0.75c	1.19b	1.06c	1.63b
100 mM NaCl	0.65c	1.21b	0.67d	0.92c

Means sharing same letters are statistically non- significant at $\alpha = 0.05$

Potassium concentration in root and shoot of wheat was also significantly affected due to salinity levels. The highest concentration in shoot (1310 mmole/kg) and root (1240 mmole/kg) was recorded at 0 mM NaCl (Table III). Reduction in K concentration was evident at 50 and 100 mM NaCl in both root and shoot tissues. However, the concentration of potassium in shoot at 50 and 100 mM NaCl was significantly higher at 8 mM Ca as compared to 2 mM Ca. The decrease in K concentration due to salinity might be related to the competition between K and Na and a resultant increase in the uptake of sodium at the cost of potassium (Aslam & Muhammed, 1972; Kuiper, 1984).

Sodium chloride salinity significantly decreased K uptake both in root and shoot tissues with increasing salinity level (Table IV). The highest K uptake in shoot (644.03 mg/pot) and root (348.35 mg/pot) was recorded at 0 mM NaCl while the lowest K uptake in shoot (406.62 mg/pot) and root (143.13 mg/pot) was recorded at 100 mM NaCl. The effect of calcium levels on K uptake was significant. At 8 mM Ca, plants absorbed and translocated relatively more potassium and less sodium than at low concentration of calcium (2 mM). Pitman (1966) reported that calcium can alter the selectivity of potassium uptake in certain plants. Part of the calcium in this way may have a simple physical effect on root permeability. In addition it seems reasonable to think that calcium acts

Fig. 2. Relationship of K concentration and shoot dry weight

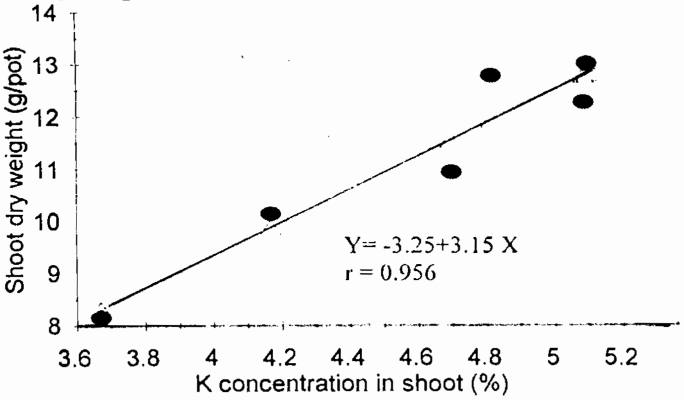
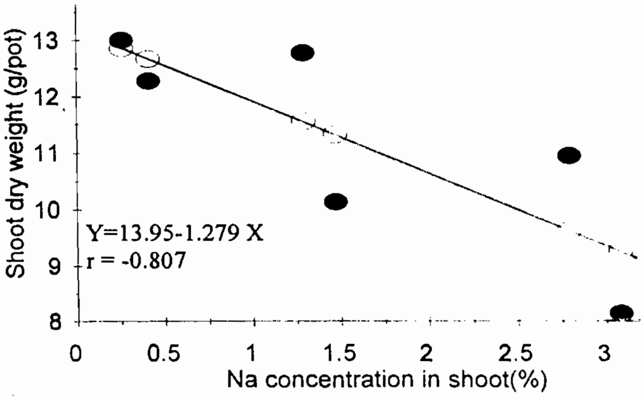


Fig. 3. Relationship of Na concentration and shoot dry weight



on metabolism, in view of its own effect on enzyme system and in particular on certain ATPase systems.

K:Na selectivity in shoot and root was significantly affected by salinity levels (Fig 1 a & b). With increasing salinity levels, K concentrations in root and shoot were drastically decreased. The calcium levels significantly affected K:Na selectivity. At 50 mM NaCl concentration, K:Na selectivity in root and shoot was significantly higher as compared to 100 mM NaCl salinity (Table V). However, K:Na selectivity significantly improved in plants supplied with 8 mM Ca as compared to 2 mM Ca supply. Absorption of potassium is usually accelerated by calcium, though this depends on the concentration of potassium (Marschner *et al.*, 1970) and physiological state of tissue (Rain *et al.*, 1970). Potassium absorption was more from a solution containing a mixture of K and Na when high calcium was included in the solution (Jacobson *et al.*, 1961).

Table VII. Effect of calcium on net calcium uptake (mg/pot) of wheat under saline conditions

Treatments	Shoot		Root	
	2 mM Ca	8 mM Ca	2 mM Ca	8 mM Ca
0 mM NaCl	93.40d	173.99a	141.74b	150.44a
50 mM NaCl	76.59e	151.82b	63.55d	114.34c
100 mM NaCl	53.04f	133.05f	39.06e	63.95d

Means sharing same letters are statistically non-significant at $\alpha = 0.05$

Calcium concentration in shoot tissues of wheat was significantly affected by different calcium levels (Table VI). At all the salinity levels, higher calcium level resulted in higher calcium concentration as compared to lower level of calcium. However, non-significant differences in calcium concentration were recorded among salinity levels. In root tissues, calcium concentration was significantly reduced by increasing salinity levels while calcium levels increased its concentration significantly.

Sodium chloride salinity significantly affected the calcium uptake by plants (Table VII). The highest calcium uptake was recorded by plants in non-saline medium and it was higher at higher calcium level. These results are in accordance with those of Lynch and Lauchli (1988) who reported that salinity stress disturbs intracellular calcium in root protoplast. However, significant decrease in calcium uptake was observed when plants were grown in 100 mM NaCl solution. On the other hand, root tissue behaved little differently. Significant reduction in calcium uptake was observed at both 50 and 100 mM NaCl.

Data in Fig. 2 indicates a significant positive correlation (r=0.956) between shoot dry weight (g/pot) and K concentration in shoot. It indicates higher K accumulation with the increasing shoot dry weight. The analysis show that K was transported preferentially to Na in the presence of 8 mM Ca supply and selectivity became more pronounced in presence of 8 mM Ca as compared to 2 mM Ca. Furthermore, the data in Fig. 3 exhibits negative correlation (r=-0.807) between shoot dry weight and sodium concentration in shoot which is indicative of growth inhibition due to increasing sodium concentration in shoot. The accumulation of Na in shoot decreases plant growth as explained by Salim and Pitman (1983).

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