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# Effects of salinity on uptake and distribution of $Na^+$, $Cl^-$ and $K^+$ in two wheat cultivars

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## Abstract

Plants of two wheat (*Triticum aestivum* L.) cultivars differing in salt tolerance were grown in sand with nutrient solutions. 35-d-old plants were subjected to 5 levels of salinity created by adding NaCl, $CaCl_2$ and $Na_2SO_4$. Growth reduction caused by salinity was accompanied by increased $Na^+$ and $Cl^-$ concentrations, $Na^+/K^+$ ratio, and decreased concentration of $K^+$. The salt tolerant cv. Kharchia 65 showed better ionic regulation. Salinity up to 15.7 dS $m^{-1}$ induced increased uptake of $Na^+$ and $Cl^-$ but higher levels of salinity were not accompanied by further increase in uptake of these ions. Observed increases in $Na^+$ and $Cl^-$ concentrations at higher salinities seemed to be the consequence of reduction in growth. Uptake of $K^+$ was decreased; more in salt sensitive cultivar. This was also accompanied by differences in its distribution.

*Additional key words*: ion distribution, ion exclusion, sensitive and tolerant cultivars.

## Introduction

Though most of the crops are glycophytes, they differ greatly in their capacity to tolerate salts and differences exist between them at species and cultivar levels. Salt tolerance in wheat cultivars is largely determined by their ability to exclude sodium and chloride from roots, and to maintain high shoot potassium concentrations (Läuchli 1984, Sharma 1989, Läuchli and Epstein 1990, Gorham 1993).

The current studies were aimed to enhance our understanding of the responses of wheat cultivars differing in responses to salinity in terms of uptake and distribution of $Na^+$, $Cl^-$ and other ions and also to pinpoint salt-tolerance mechanisms.

## Materials and methods

Seeds of two wheat cultivars differing in salt tolerance, cv. HD 4502 (*Triticum durum* L. - sensitive) and cv. Kharchia 65 (*Triticum aestivum* L. - tolerant), were

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sown in 18 kg porcelain pots filled with washed river sand irrigated with half-strength Hoagland's nutrient solution. Plants were grown in a greenhouse. Saline treatments were imposed 35 d after planting. The solution mixture was prepared by adding NaCl, $CaCl_2$ and $Na_2SO_4$ to the base nutrient solutions to give ratios of $Na^+/Ca^{2+}$ (4.5:1) and $Cl^-/SO_4^{2-}$ (7:1), respectively. The electrical conductivities of the irrigation solutions were 1.6, 5.2, 10.8, 15.7 and 20.2 dS $m^{-1}$. Ten seeds were sown in each pot and finally 5 plants per pot were maintained. Desired levels of salinities were maintained through the rest of the crop season by irrigation with these solutions daily and complete flushing of pots with salt solutions at weekly intervals. Plant growth and content and uptake of $Na^+$, $K^+$ and $Cl^-$ were monitored just before salinization and again after 30-d exposure to salinity, coinciding with onset of reproductive growth stage.

After harvesting, plants were separated into roots, stem, leaves and sheath. Another set of plants were separated into individual leaves (the oldest present leaf was numbered 1 and number increased towards the younger leaves). $Na^+$ and $K^+$ were determined in nitric-perchloric acid digests of the plant tissues by flame photometry (*Corning, EEL*, Essex, U.K.). $Cl^-$ was determined in the nitric acid digest by *Digital Chloridometer* (*Buchler*, Lenexa, USA). All observations were recorded in triplicates. Ion content and uptake rate were calculated according to Aswathappa and Bachelard (1986) and Cramer *et al.* (1991).

## Results and discussion

Increase in salinity caused reduction in plant growth (Table 1). The two cultivars showed lesser differences at lower than at higher salinity. Salinity of 20.2 dS $m^{-1}$ in cv. HD 4502 led to plant mortality in seven weeks. On the other hand, cv. Kharchia 65 continued to grow and survive, though at a much lower rate and could complete

Table 1. Dry matter in plant parts [g $plant^{-1}$] as affected by salinity [dS $m^{-1}$].

| Cultivar | Salinity | Sheath | Leaves | Stem | Roots | Total |
|---|---|---|---|---|---|---|
| HD 4502 | 1.6 | 2.428 | 3.001 | 1.676 | 1.008 | 8.113 |
| | 5.2 | 2.173 | 3.197 | 1.544 | 1.022 | 7.936 |
| | 10.8 | 1.923 | 2.821 | 1.770 | 0.568 | 7.082 |
| | 15.7 | 0.731 | 1.117 | 0.672 | 0.157 | 2.677 |
| | 20.2 | 0.565 | 0.107 | 0.103 | 0.049 | 0.824 |
| Kharkia 65 | 1.6 | 2.288 | 3.059 | 2.131 | 1.005 | 8.483 |
| | 5.2 | 1.837 | 2.835 | 1.484 | 0.870 | 7.026 |
| | 10.8 | 1.650 | 2.650 | 1.326 | 0.525 | 6.151 |
| | 15.7 | 1.062 | 1.633 | 0.822 | 0.250 | 3.767 |
| | 20.2 | 0.282 | 0.561 | 0.278 | 0.220 | 1.341 |

C.D. at 5%: cultivars - 0.21; parts - 0.52; salinity - 0.25; parts × salinity - 0.49.

its life cycle. Kingsbury and Epstein (1984) also reported the differences between sensitive and tolerant wheat cultivars only at higher salinities.

Shoot/root ratio increased with salinity and more in HD 4502 than Kharchia 65. However, a decline was observed in Kharchia 65 at the highest salinity. Increasing shoot/root ratio indicated that roots were more sensitive than the shoot to salinity. This observation is in contrast to the reports of Delane *et al.* (1982) and Weimberg *et al.* (1984), who found shoot growth to be affected more.

The disruption in growth caused by salinity in two cultivars was accompanied by increased concentrations of $Na^+$ and $Cl^-$, decreased $K^+$ concentration (Table 2), and increased in $Na^+/K^+$ ratio. HD 4502 had higher concentrations of $Na^+$ than Kharchia 65, which indicated the better ionic regulation in the latter one. This was also substantiated by regressions between dry mass and $Na^+$ concentrations:

dry mass = 2.16 - 0.431 $Na^+$; $r^2$ = 0.294 for HD 4502,
dry mass = 2.48 - 0.834 $Na^+$; $r^2$ = 0.515 for Kharchia 65.

Table 2. Effects of salinity on concentrations of sodium, chloride and potassium [% of d.m.] in different plant parts.

| Salinity [dS m$^{-1}$] | HD 4502 sheath | stem | leaves | roots | mean | Kharchia 65 sheath | stem | leaves | roots | mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Cl^-$ | | | | | | | | | |
| 1.6 | 0.46 | 0.78 | 0.39 | 0.21 | 0.46 | 0.57 | 0.71 | 0.46 | 0.42 | 0.54 |
| 5.2 | 1.52 | 1.66 | 1.14 | 0.64 | 1.24 | 2.2 | 1.95 | 2.12 | 0.28 | 1.64 |
| 10.8 | 2.52 | 2.41 | 1.95 | 1.21 | 2.02 | 2.7 | 2.05 | 2.3 | 1.03 | 2.02 |
| 15.7 | 3.16 | 2.38 | 3.30 | 1.74 | 2.65 | 3.08 | 2.34 | 3.58 | 1.13 | 2.53 |
| 20.2 | 1.77 | 2.52 | 3.83 | 1.74 | 2.47 | 4.36 | 4.44 | 4.89 | 1.63 | 3.83 |
| | $Na^+$ | | | | | | | | | |
| 1.6 | 0.53 | 0.65 | 0.65 | 0.6 | 0.61 | 0.43 | 0.49 | 0.53 | 0.73 | 0.55 |
| 5.2 | 1.11 | 1.58 | 1.24 | 0.85 | 1.20 | 0.73 | 0.84 | 0.74 | 0.84 | 0.79 |
| 10.8 | 1.88 | 1.88 | 1.75 | 1.38 | 1.72 | 1.2 | 1.16 | 1.11 | 1.46 | 1.23 |
| 15.7 | 2.46 | 2.08 | 2.56 | 1.66 | 2.19 | 1.76 | 1.75 | 1.8 | 1.46 | 1.69 |
| 20.2 | 5.01 | 3.92 | 4.49 | 1.75 | 3.79 | 2.36 | 3.13 | 2.76 | 2.2 | 2.61 |
| | $K^+$ | | | | | | | | | |
| 1.6 | 5.15 | 5.78 | 5.23 | 1.96 | 4.53 | 6.82 | 7.5 | 5.12 | 2.39 | 5.46 |
| 5.2 | 3.76 | 3.54 | 3.54 | 1.86 | 3.18 | 5.28 | 6.97 | 3.76 | 1.91 | 4.48 |
| 10.8 | 3.19 | 3.24 | 3.11 | 1.86 | 2.85 | 4.17 | 5.25 | 4.9 | 2.69 | 4.25 |
| 15.7 | 2.59 | 2.54 | 2.78 | 1.68 | 2.40 | 3.81 | 3.61 | 3.81 | 2.01 | 3.31 |
| 20.2 | 2.71 | 1.95 | 1.63 | 1.69 | 2.00 | 3.36 | 4.13 | 3.51 | 2.16 | 3.29 |

C.D. at 5 %: $Na^+$- cultivars - 0.13; parts - 0.22; salinity - 0.16; parts × salinity - 0.33;
$Cl^-$ - cultivars - 0.11; parts - 0.18; salinity - 0.17; parts × salinity - 0.29;
$K^+$ - cultivars - 0.07; parts - 0.82; salinity - 0.56; parts × salinity - 0.33.

Such contrasting differences were not discernible for chloride in the two wheat cultivars and correlation coefficients between dry mass and chloride concentration were low *i.e.* $r^2$ = 0.17 for HD 4502 and 0.11 for Kharchia 65. Higher tolerance for chloride might also be the reason for better performance of Kharchia 65.

$K^+$ concentrations showed a linear decrease with increasing salt concentrations. This decrease was less in Kharchia 65 than in HD 4502. Regression equations were:

dry mass = 0.440 + 0.594 $K^+$; $r^2 = 0.53$ for HD 4502
dry mass = 0.072 + 0.339 $K^+$; $r^2 = 0.38$ for Kharchia 65

$Na^+$ and $Cl^-$ accumulation was much higher in older leaves than in younger leaves (Fig. 1) and flag leaves showed the lowest increase in ions. The differences in salt sensitive and tolerant cultivars were also at individual leaf level. This provided relatively better protection of the younger leaves of Kharchia 65 than of those of HD 4502.

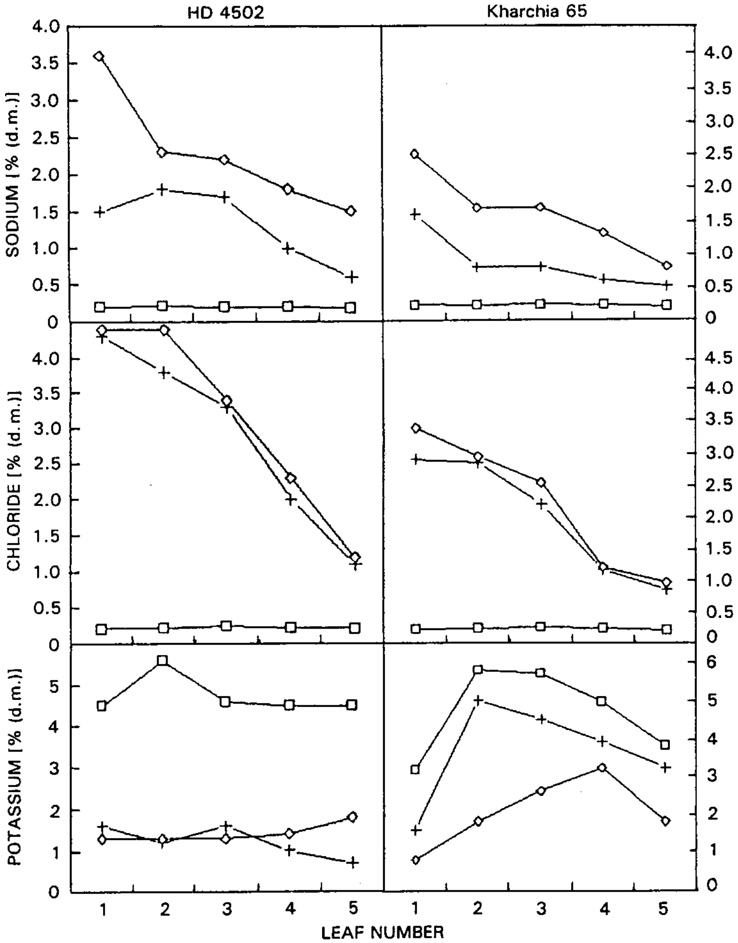


Fig. 1. Effect of salinity (*squares* - control, *rhombs* - 15.7 dS $m^{-1}$, *crosses* - 20.2 dS $m^{-1}$) on concentrations of $Na^+$, $Cl^-$ and $K^+$ ions in leaves of different insertion level (leaves were numbered from the oldest one) in two wheat cultivars. Differences between cultivars, salinity levels and leaves of different insertion were at 1 % level of significance.

Increased concentrations of $Na^+$ and $Cl^-$ were caused by increased transport of these ions from root to shoot ($Na^+$ and $Cl^-$ per g dry mass of root were much higher in HD 4502). Up to salinity 10.8 dS $m^{-1}$ the two cultivars did not differ much but at higher salinities net transport rates increased sharply and this rise was particularly sharp for $Cl^-$. These values were higher for HD 4502 than Kharchia 65, and resulted in higher concentrations of $Na^+$ and $Cl^-$ ions (Table 3).

Table 3. Sodium and chloride content [μg $g^{-1}$(root d.m.)] in the roots of two wheat cultivars as affected by salinity.

| Salinity [dS $m^{-1}$] | HD 4502 $Na^+$ | Kharchia 65 | HD 4502 $Cl^-$ | Kharchia 65 |
|---|---|---|---|---|
| 1.6 | 337.62 | 366.99 | 50.72 | 60.54 |
| 5.7 | 327.41 | 351.12 | 128.42 | 212.08 |
| 10.8 | 542.10 | 509.40 | 401.21 | 433.53 |
| 15.7 | 741.35 | 655.13 | 1898.27 | 1141.41 |
| 20.2 | 731.14 | 265.02 | 5668.30 | 1961.59 |

C.D. at 5 %: $Na^+$- cultivars - 28; salinity - 32; $Cl^-$ - cultivars - 28; salinity - 60.

The uptake of $Na^+$ and $Cl^-$ was higher in the salt sensitive HD 4502 than in the salt tolerant Kharchia 65 (Table 4) over a 5 week period of exposure to salinity. Differences were much higher for $Na^+$ and explain the differential accumulation of this ion in these two cultivars. These differences in $Na^+$ and $Cl^-$ exclusion were primarily due to lower influx rates and not due to differences in efflux rates, similar to those found for $Na^+$ in two cultivars of maize by Schubert and Läuchli (1990).

Table 4. Effects of salinity on $Cl^-$ and $Na^+$ uptake rate [μmol $g^{-1}$(root d.m.) $d^{-1}$] in two wheat cultivars.

| Salinity [dS $m^{-1}$] | Kharchia 65 $Na^+$ | HD 4502 | Kharchia 65 $Cl^-$ | HD 4502 |
|---|---|---|---|---|
| 1.6 | 0.033 | 0.043 | 0.069 | 0.063 |
| 5.7 | 0.091 | 0.142 | 0.133 | 0.090 |
| 10.8 | 0.252 | 0.247 | 0.323 | 0.199 |
| 15.7 | 0.471 | 0.425 | 0.583 | 0.383 |
| 20.2 | 0.336 | 0.238 | 1.124 | 0.235 |

The uptake of both $Na^+$ and $Cl^-$ did not show a proportional increase with salinity of the growth medium, and highest uptake was observed at 15.7 dS $m^{-1}$ and declined thereafter.

Total uptake of $K^+$ decreased from 9.96 in the control plants to 0.51 mmol $g^{-1}$(d.m.) $d^{-1}$ at salinity 20.2 dS $m^{-1}$ in HD 4502, whereas these values were 12.73 and 1.16, respectively in case of Kharchia 65 plants. This reduction in $K^+$ uptake in case of HD 4502 might further be aggravated by negligible proportion of $K^+$ in stem, leaves and roots; as 78 % of the total $K^+$ was restricted to sheath only, which might have been one of the major reason of the premature plant death at the highest salinity. On the contrary, plants of Kharchia 65 showed a fairly good degree of distribution of $K^+$ with their stem and leaves getting a major proportion of $K^+$.

These effects clearly bring out that the disruption in plant growth at 15.7 and 20.2 dS $m^{-1}$ salinities seemed to be more due to the restricted uptake of $K^+$. This is further supported by the absence of increases in $Na^+$ concentrations with the increase in salinity beyond 15.7 dS $m^{-1}$.

Maintenance of physiological $K^+$ concentrations is very important under salinity. Thus, the uptake of $K^+$ by the roots and further translocation and distribution within the plant is better regulated and integrated with growth in the salt tolerant cultivar. On the other hand, these processes are poorly controlled in the more salt sensitive cultivar. Boursier and Läuchli (1990) found $K^+$ to be the predominant cation in sheaths and suggested that $K^+$ ions may be operating as counter ions to $Cl^-$, thereby contributing to osmotic adjustment in salt-stressed sorghum.

The observed increases in uptake of $Na^+$ failed to counteract the decline in $K^+$, and was unable to meet the osmotic demands of plants under salinity. Total uptake of $Na^+ + K^+$ in HD 4502 was lower than Kharchia 65.

Salinity did not cause any clear cut changes in the uptake and concentrations of $Ca^{2+}$ and $Mg^{2+}$; small increases as well as decreases were observed in different plant parts. $Ca^{2+}$ concentrations were relatively higher in Kharchia 65 than HD 4502. The reduction in $Ca^{2+}$ concentration in the leaves of HD 4502 was relatively higher. Salinity also decreased stomatal conductance which was also accompanied by reduced transpiration rate and increased leaf temperature (data not shown).

The results presented here corroborated the significance of salt exclusion and distribution mechanisms in wheat cultivars. However, the capacity of salt exclusion was limited. Above a threshold level of salts in the external medium, the capacity was saturated and then the salt exclusion mechanisms breakdown, leading to high rates of transport of $Na^+$ and $Cl^-$ ions to the shoot (Läuchli and Epstein 1990). This capacity was saturated at a lower level of salinity in the salt sensitive cultivar as compared to the salt tolerant one. However, the integration of these responses at the whole plant level is critical for the survival, growth, and development of plants under salinity.

## References

Aswathappa, N., Bachelard, E.P.: Ion regulation in the organs of *Casuarina* species differing in salt tolerance. - Aust. J. Plant Physiol. **13**: 533-546, 1986.

Boursier, P., Läuchli, A.: Growth responses and mineral nutrient relations of salt-stressed sorghum. - Crop Sci. **30**: 1226-1233, 1990.

Cramer, G.R., Epstein, E., Läuchli, A.: Effects of sodium, potassium and calcium on salt stressed barley. II. Elemental analysis. - Physiol. Plant. **81**: 197-202, 1991.

Cheeseman, J.M.: Mechanisms of salinity tolerance in plants. - Plant Physiol. **87**: 547 - 550, 1988.

Delane, R., Greenway, H., Munns, R., Gibbs, J.: Ion concentration and carbohydrate status of the elongating tissue of *Hordeum vulgare* growing at high external NaCl. I. Relationship between solute concentration and growth. - J. exp. Bot. **33**: 557-573, 1982.

Gorham, J.: Genetics and physiology of enhanced K/Na discrimination. - In: Randall, P.J., Delhaize, E., Richards, R.A., Munns, R. (ed.): Genetic Aspects of Plant Mineral Nutrition. Pp. 151-158. Kluwer Academic Publishers, Dordrecht 1993.

Kingsbury, R.W., Epstein, E.: Selection for salt-resistant spring wheat. - Crop Sci. **24**: 310-315, 1984.

Läuchli, A.: Salt exclusion: an adaptation of legumes for crops and pastures under saline conditions. - In: Staples, R.C. Toenniessen, G.H. (ed.): Salinity Tolerance in Crops. Pp. 177-188. Wiley Interscience, New York 1984.

Läuchli, A., Epstein, E.: Plant responses to saline and sodic conditions. - In: Tanji, K.K. (ed.): Agricultural Salinity Assessment and Management. Pp. 113-137. American Society of Civil Engineers, New York 1990.

Munns, R.: $Na^+$, $K^+$ and $Cl^-$ in xylem sap flowing to shoots of NaCl-treated barley. - J. exp. Bot. **36**: 1032-1042, 1985.

Schubert, S., Läuchli, A.: Sodium exclusion mechanisms at the root surface of two maize cultivars. - Plant Soil **123**: 205-209, 1990.

Sharma, S.K.: Effect of salinity on growth, ionic and water relations of three wheat genotypes differing in salt tolerance. - Indian J. Plant Physiol. **32**: 200-205, 1989.

Weimberg, R., Lerner, H.R., Poljakoff-Mayber, A.: Changes in growth and water-soluble solute concentrations in *Sorghum bicolor* stressed with sodium and potassium salts. - Physiol. Plant. **62**: 472-480, 1984.