



Sodium: potassium ratio in foliage as an indicator of tolerance to chloride-dominant soil salinity in oat (*Avena sativa*)

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Oats (*Avena sativa* L) is one of the most important cereal fodder crops grown in the winter (*rabi*) season in the north, western, central and hilly parts of India. It is now extending to the eastern region in areas suited to wheat cultivation. Although, compared with the other cereals, oat is considered a moderately salt-tolerant crop, but still soil salinity is responsible for decreasing seed germination and stunting subsequent development. Genetic variability for the salinity tolerance among the oat (*A. sativa* L.) germplasm have been reported (Zhao *et al.* 2007). The effect of salinity on plant growth is a complex syndrome that involves osmotic stress, ion toxicity, and mineral deficiencies. Dasgan *et al.* (2002) suggested that plants are stressed in three ways in saline soils (i) low water potential of the root medium leads water deficit, (ii) toxic effects of the ions mainly Na⁺ and Cl⁻ and, (iii) nutrient imbalance by depression in uptake and/or shoot transport. According to Munns (2002), exposure to salt stress in the beginning (hours to few days) lead to osmotic stress, followed by ion toxicity in case of prolonged exposure affecting the plant growth and development adversely. However, this hypothesis is still subject to debate. Important mechanisms of tolerance involve Na⁺ exclusion from the transpiration stream, sequestration of Na⁺ and Cl⁻ in the vacuoles of root and leaf cells, and other processes that promote fast growth despite the osmotic stress of the salt outside the roots (Munns *et al.* 2006). Phenotyping with high precision is the key to finding and introducing new genes for salt tolerance into crop plants. Therefore, in the present study, we examined the effects of different levels of chloride-dominant salinity on water relations and ionic toxicity in oat.

The experiments were conducted during 2007–08 and 2008–09 at the research farm of Directorate of Sorghum

Research Hyderabad. Twelve genotypes of oats ('NGB 6370', 'NGB 4462', 'NGB 7253', 'NGB 7021', 'NGB 4871', 'NGB 7245', 'NGB 7022', 'JHO 851', 'JHO 822', 'JHO 99-2', 'HJ 8' and 'OS 6') were evaluated for tolerance to chloride-dominant salinity. A mixture of NaCl, CaCl₂, MgCl₂ and MgSO₄ salts was made to have cations Na: Ca + Mg in the ratio of 1: 1, where Ca: Mg was 1: 3 and anion Cl: SO₄ ratio was 7: 3 to create chloride dominant salinity in plastic pots. The soil was mixed with the recommended dose of fertilizer. Pots of 45 cm diameter were bottom sealed and were filled with uniform quantity of soil (15 kg soil/pot). The pots were saturated with required amount of non-saline or saline solutions of required salinity levels (4, 8 and 12 dS/m). Five seeds were sown in each pot at equal distance. Each treatment was replicated thrice. Six empty pots were kept for weighting on every alternate day to calculate the evaporation from soil surface. Each pot was replenished with 80% of the water transpired on every alternate day till the termination of the trial. After 10 days of emergence, seedlings were thinned to two plants per pot. Growth analysis was performed at 40 and 80 days after sowing. Plants from two pots from each replication were recovered from the pots by washing away the soil. The plants were separated into leaves, stem and root. The dry weights of plant parts were recorded after drying the samples in a hot air oven for 48 hours at 80°C. Physiological parameters (chlorophyll, relative water content, K⁺, and Na⁺ contents in the foliage were also measured at 40 and 80 DAS. The chlorophyll was estimated as SPAD (SPAD 502, Miniolta Corp.; Ramsey, NJ) chlorophyll meter readings (SCMR).

Plant height, shoot weight, root weight and total biomass were reduced more with increasing salinity levels from 4dS/m to 12 dS/m as compared with non-saline treatment. On an average, the plant height reduced from 8.3 to 31.8%, shoot dry weight reduced from 35.0 to 70.6%, root dry weight reduced from 40.7 to 68.5% and biomass reduced from 35.9 to 70.9% under three saline treatments (Table 1). Significant genotypic variations in the reduction in growth parameters under saline treatment as compared with non-saline treatment

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were noticed. The reduction in biomass accumulation ranged from 14.6 to 53.0% at 4 dS/m, 35.8 to 69.0% at 8 dS/m and 58.7 to 88.9% at 12 dS/m levels of salinity as compared to non-saline treatment. The minimum reduction in biomass accumulation was recorded in 'NGB 6370', 'JHO 822' and 'JHO 99-2', which ranged between 14.6 to 18.3% at 4 dS/m, 35.9 to 40.3% at 8 dS/m and 58.7 to 60.6% at 12 dS/m levels of salinity as compared to non-saline treatment. The maximum reduction was recorded in 'JHO 851', 'NGB 4462', 'NGB 4871' and 'NGB 7253', which ranged between 37.1 to 53.0% at 4 dS/m, 48.5 to 69.0% at 8 dS/m and 64.0 to 82.9% at 12 dS/m levels of salinity as compared to non-saline treatment. The trend in reduction in plant height, shoot weight, root weight is similar to that of biomass accumulation. The study affirmed the presence of intraspecific genetic variation for salt tolerance among the

oat genotypes studied as reported in sorghum accessions (Krishnamurthy *et al.* 2007).

Relative water content of leaf tissue was found to be reduced in all the genotypes under all the three levels of salinity as compared with the control. The average reduction in RWC in oat genotypes increased with increasing levels of salinity and the range was 4 to 13% (Table 1). The variations in leaf RWC were significant among the 12 genotypes evaluated and ranged from 1.2 to 6.1% at 4 dS/m, 4.8–13.8 at 8 dS/m and 7.6 to 17.8 at 12 dS/m levels of salinity as compared to control (Table 2). The reduction in RWC was minimum in better performed group of genotypes ('JHO 822', 'NGB 6370' and 'JHO 99-2') and maximum in poorly performed genotypes ('JHO 851', 'NGB 4462', 'NGB 4871' and 'NGB 7253'). Water stress is one of the first and most evident effects of salinity and that the determination of water

Table 1 Average change in growth parameters (plant height, shoot dry weight, root dry weight and biomass), SPAD chlorophyll meter reading, relative water content and Na⁺/K⁺ ratio in foliage in 12 oat genotypes grown under 4 levels of chloride-dominant salinity

Salinity level (dS/m)	Plant height (cm)	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Biomass (g/plant)	SPAD chlorophyll meter reading	Relative water content (%)	Na ⁺ /K ⁺ ratio
Non-saline	66.6	8.0	1.08	9.12	50.4	84.6	0.76
4	61.1 (-8.3) ^a	5.20(-35.0)	0.64(-40.7)	5.85(-35.9)	48.7(-3.37)	81.1(-4.14)	1.29
8	54.1(-18.8)	3.71(-53.6)	0.59(-45.4)	4.29(-53.0)	47.4(-5.95)	77.2(-8.74)	1.68
12	45.4(-31.8)	2.35(-70.6)	0.34(-68.5)	2.69(-70.5)	46.1(-8.53)	73.8(-12.8)	1.85
Mean	56.8	4.81	0.66	5.49	48.1	79.2	1.39
LSD Genotypes (G)	****NS	****NS	****NS	****NS	****NS	****NS	****NS
Salinity levels (S)							
G×S							

**P* < 0.05, ** *P* < 0.01

^a Figures in parentheses are the per cent change in respective parameters under different salinity levels over non-saline treatment.

Table 2 Genotypic variations in relative water content, SPAD chlorophyll meter reading and Na⁺/K⁺ ratio in 12 Oat genotypes grown under 4 levels of chloride-dominant salinity

Genotype	Relative water content (%)				SPAD chlorophyll meter reading				Na ⁺ /K ⁺ ratio			
	Salinity levels (dS/m)				Salinity levels (dS/m)				Salinity levels (dS/m)			
	Non-saline	4	8	12	Non-saline	4	8	12	Non-saline	4	8	12
'HJ 8'	79.50	75.97	73.2	70.0	49.8	48.3	47.8	45.8	0.44	0.87	1.40	2.25
'JHO 851'	85.73	82.63	77.6	73.9	48.7	46.1	44.6	42.8	0.90	1.72	1.77	1.44
'JHO 822'	85.20	82.87	80.5	78.7	46.3	45.8	44.5	43.5	0.17	0.24	0.35	0.65
'JHO 99-2'	88.60	86.83	80.9	77.7	50.2	48.3	47.5	46.6	0.66	0.72	1.04	1.13
'NGB 4462'	85.83	80.6	77.8	72.3	52.2	48.8	47.1	45.5	1.27	2.36	2.67	2.59
'NGB 4871'	87.80	81.2	75.6	72.2	48.6	47.4	45.6	44.7	0.98	1.68	2.65	2.89
'NGB 6370'	85.87	83.6	81.2	78.3	51.7	51.8	49.8	48.5	0.53	0.72	0.71	0.94
'NGB 7021'	83.83	82.8	79.8	75.7	52.1	49.8	48.5	47.7	0.61	1.54	1.95	1.73
'NGB 7022'	78.43	76.0	71.7	69.0	51.7	50.4	47.8	46.0	0.75	1.72	1.82	2.26
'NGB 7245'	80.60	78.4	73.9	70.0	49.6	47.7	46.8	45.8	0.78	1.12	1.37	1.87
'NGB 7253'	87.27	81.0	77.4	73.1	52.2	49.6	49.1	47.8	1.03	1.48	2.04	1.86
'OS 6'	86.27	81.2	77.2	74.3	52.8	50.0	49.2	48.1	0.97	1.37	2.41	1.70
Mean	84.6	81.1	77.2	73.8	50.5	48.7	47.4	46.1	0.76	1.29	1.68	1.85
SEm±		0.92				1.07				0.425		

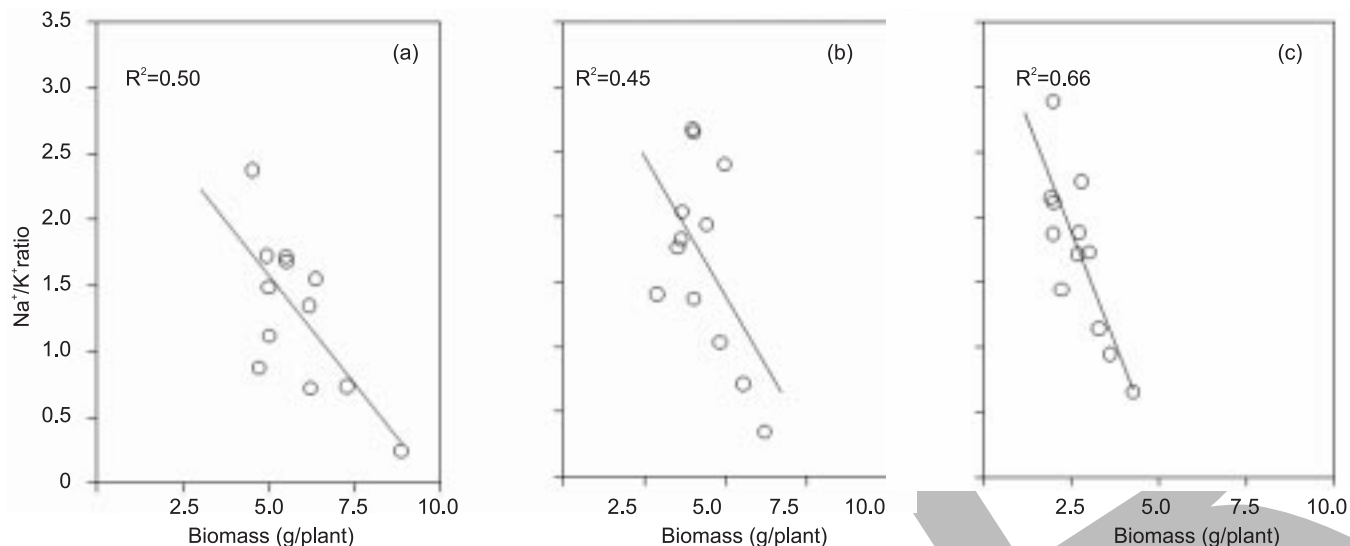


Fig 1 Relationship of the biomass accumulation and ration of Na⁺/K⁺ ions in the foliage of 12 oat genotypes grown under 4 (a), 8 (b) and 12 (c) dS/m levels of chloride-dominant salinity

relations is therefore critical for any study of plant resistance to salinity. Water stress may, however, continue to contribute to growth inhibition also during long-term exposure to salt (Munns 2002). Our data indicate a significant reduction in SCMR under all the three levels of salinity. The average reduction in SCMR in 12 oat genotypes increased with increasing levels of salinity and it was ranged between 3 to 9% (Table 1). SCMR varies significantly among the genotypes evaluated (Table 2). SCMR reduction ranges from 2 to 5% at 4 dS/m, 4 to 10% at 8 dS/m and 6 to 13% at 12 dS/m levels of salinity as compared to control. The group of genotypes with minimum reduction includes 'JHO 822', 'JHO 99-2', and 'NGB 6370' and the genotypes in which maximum reduction was noticed were 'NGB 4462', 'NGB 7022' and 'JHO 851'. Inhibition of growth under salinity by reducing the chlorophyll have been reported widely (Zhao *et al.* 2007), which can be either due to inhibition of chlorophyll synthesis or an acceleration of its degradation or both. The average Na⁺/K⁺ ratio in foliage of 12 oat genotypes increased with increasing salinity levels (Table 1). The ranges of Na⁺/K⁺ ratio in foliage were 0.24 to 2.36 at 4 dS/m, 0.35 to 2.67 at 8 dS/m and 0.65 to 2.89 at 12 dS/m levels of salinity as compared to 0.17 to 1.27 under non-saline conditions. Salinity not only caused high Na⁺ accumulation in plants but also influenced the uptake of essential nutrients such as K⁺ and Ca²⁺ through the effects of ion selectivity. Decline in K⁺ accumulation because of salinity stress has been widely reported in many crops like wheat, sorghum etc. Ratio of Na⁺/K⁺ content under saline conditions is negatively correlated with the biomass accumulation (Fig 1 a-c). There is a strong correlation between salt exclusion and salt tolerance in many species. In those species that retain Na⁺ in woody roots or stems, there is a strong correlation between Cl⁻ exclusion and salt

tolerance. This indicates the higher ratio of Na⁺/K⁺ resulted in the decrease in the growth rates. The higher ratio of these two nutrients is because of both, higher accumulation of sodium as well as decrease of accumulation of potassium. The increase in negative effects on the photosynthetic processes due to potassium deficiency has been reported in barley species (Degl'Innocenti 2009). The genotypes 'JHO 99-2', 'JHO 822' and 'NGB 6370' maintained lower levels of Na⁺/K⁺ ratio in foliage as compared with other genotypes under three levels of salinity. 'NGB 4462' and 'NGB 4871' genotypes maintains higher levels of Na⁺/K⁺ ratio under all the three level of salinity. Our results indicate that there is significant variability for salt tolerance among oat lines, and higher growth rate, and relatively lower tissue Na⁺ accumulation at high salt concentrations appeared to be associated with salt tolerance (Zhao *et al.* 2007). Thus, Na⁺/K⁺ ratio in the foliage tissues can be an indicator of salinity tolerance, and can be a potential tool for salinity screening at early stage of growth in oats.

SUMMARY

The experiments were conducted during 2007–08 and 2008–09 *rabi* seasons to evaluate 12 genotypes of oat under four levels of chloride-dominant salinity (non-saline, 4, 8 and 12 dS/m) created in pots. Significant genotypic variations were noticed for reduction in growth parameter of all genotypes grown under salinity. The reduction in biomass accumulation under salinity was ranged between 35.0 and 70.6%. The minimum reduction in biomass accumulation was recorded in 'NGB 6370', 'JHO 822' and 'JHO 99-2'. These genotypes maintained significantly higher levels of relative water content and SPAD chlorophyll meter readings, but lower levels of Na⁺/K⁺ content in foliage tissue than the other genotypes. Ratio of Na⁺/K⁺ content under saline

conditions is negatively correlated with the biomass accumulation ($R^2 = 50, 45, 66$ at 4, 8 and 12 dS/m, respectively). Our results suggested that tolerant genotypes maintains higher level of chlorophyll content, relative water content and lower Na^+/K^+ ratio in the leaf tissues to adapt to saline environment. Thus, Na^+/K^+ ratio in the foliage tissues can be an indicator of salinity tolerance, and can be a potential tool to screen oat genotypes for tolerance to chloride-dominant salinity.

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