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EFFECTS OF SALINITY AND WATERLOGGING ON ION UPTAKE AND GROWTH OF WHEAT VARIETIES

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Abstract

Salinity and waterlogging are the widespread problems of many areas of Pakistan. Wheat varieties were tested at salinity, waterlogging and saline-waterlogging treatments for their performance to Na^+, K^+, stomatal conductance, SPAD (Special Products Analysis Division) chlorophyll, grain dry weight, ear/plant and grain/plant measurements. Na^+ content in leaves was continuously increased with saline and saline-waterlogged treatments. Also, K^+ content was increased with salinity treatment but decreased with saline-waterlogged treatment. Stomatal conductance decreased with waterlogging, saline and saline-waterlogged treatments but SPAD readings were not influenced by these treatments. Generally, waterlogging increase the grain dry weight, ear and grain number per plant. However, this was greatly reduced by saline and saline-waterlogged treatments in all varieties.

Introduction

Salinity and waterlogging have major effect on crop growth and yield through out the world. Salinity affects 7% of worlds land area, which amounts to 930 million hectares (Szabolcs, 1994; Ghassemi *et al*., 1995). Especially the cereal crop production is declining in Indo-Pak continent. According to Stoner (1988) approximately 40,000 ha of arable land are lost every year due to salinity and waterlogging. Waterlogging and salinity interact to allow large and rapid accumulation of toxic Na^+ and Cl in the shoots of many plants (Barrett-Lennard, 1986) including wheat (Akhtar *et al*., 1994). Two mechanisms for salt tolerance in plants are low rate of salt transport to shoots and tolerance of high salt concentrations by efficient sequestration within cell vacuoles (Flowers *et al*., 1977; Greenway & Munns, 1980). In wheat genetic variation in salt tolerance is associated with low rates of salt transport to shoots, especially low rates of Na^+ transport and high selectivity for K^+ over Na^+ (Gorham *et al*., 1987), rather than with differences in Cl^- transport, for which there is little genetic variation (Shah *et al*., 1987; Gorham, 1990).

Plants have adapted to stressful environments, including saline and waterlogged habitats and so studies of the characteristics of salt resistant are important for characterizing the nature of tolerance. This study was performed to determine the effects of salinity and waterlogging, alone and in combination, on the ion uptake and yield of wheat varieties. The varieties tested were selected on the basis of their contrasting Na^+ uptake in an earlier experiment (data not published).

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Materials and Methods

The experiment was conducted to evaluate the effects of salinity and waterlogging on the growth physiology and yield of four varieties of wheat viz., Pirsabak, Inqlab-91, SARC-6 and HD-2329. They were sown in 2 litre (18x13cm) plastic pots filled with compost (John Innes No.1). A layer of fleece sheet was fitted in the bottom of the pots to contain the compost during waterlogging. The glasshouse was set at 22/18 ± 2.0°C day/night temperature with ambient humidity and 16h photoperiod. Ten days after sowing the total emergence (%) was recorded and plants were thinned to one per pot. Then 22 days after sowing five pots of each variety were transferred to large plastic tanks (80x56.25x32.5cm) for stress treatments. Plastic trays (36.25x21.25cm) were placed upside down at the bottom of each tank to allow the water to drain easily. The large tanks had two holes, one for water incoming from a reservoir and another that controlled the water level in the tank and allowed excess water to return to the reservoir. The large tanks were placed on benches above the reservoirs on floor. Electric pumps were used to pump saline or non-saline water up to the large tanks. The water was drained and re-pumped into the tanks twice a week.

There were 12 tanks, three for each stress treatment, (control, saline, waterlogged, and salinity and waterlogged). A randomized complete block design experiment was used. Major plant nutrients were supplied as Phostrogen (pbi Home & Garden, Ltd., 1 Martinbridge Trading Estate, Lincoln Road Enfield, Middlesex) and micronutrients as Hoagland nutrient solution. Potassium silicate was also added. Then salinity was introduced starting 24 days after sowing. The initial salt concentration was 25mM NaCl. This was raised to 50 mM NaCl after 2 days and to 100 mM after a further 2 days. Extra Ca^{2+} was also added, at the ratio of $20Na^{+}$: $1Ca^{2+}$.

Main shoot length and main stem leaf number were recorded before applying stress. Two month after sowing two plants of each variety were taken from each tank. Main shoot length, main stem leaf number, tiller number and whole plant fresh weights were recorded. The youngest fully expended leaf from each plant was detached, frozen, and then stored in microcentrifuge tubes for ion analysis. Sap was extracted from frozen leaves using the method described by Gorham *et al*., (1997) and used to determine concentrations of Na^{+} and K^{+} by flame photometry. The shoots were kept in paper bags for 10 days in an oven at 50°C and dry weights were recorded. Three pots of each variety remained until maturity. SPAD readings and stomatal conductance were recorded at 70 days after sowing. A chlorophyll meter (Minolta SPAD-502) was used to measure the chlorophyll content of the youngest fully expended leaf of each plant. Three readings were taken ¼, ½ and ¾ way along the lamina of the leaf. Readings were taken on three plants of each variety in each treatment. Measurements of stomatal conductance were made using an automatic diffusion Porometer (AP4). Readings were taken from the centre of the leaf. Four readings were taken from both upper and lower sides of the leaf. After three month of sowing the water was drained from all tanks and pumped in tanks once or twice a week as desirable. The plants from the saline and saline-flooded treatments were harvested at maturity at 114 days of sowing. Then tanks of the control and flooded treatment were harvested at 128 days after sowing. At harvest ear number was counted and shoots were separated and dried in separate bags in an oven at 50°C. After 8 days the number of seeds per plant, seeds per ear and average grain weights, and shoot weights were recorded. The statistical significance of differences between cultivars and treatments was determined by ANOVA using Minitab.

Table 1. Effects of salinity and waterlogging on Na^+, K^+, stomatal conductance and SPAD reading in the leaves of four wheat varieties.

Variety	Saline		Non-saline	
	Saline	Saline and waterlogged	Control	Waterlogged
	Na^+ (mol m^3)			
Pirsabak	9.0	25.0	1.9	2.2
Inqlab-91	6.6	19.0	1.9	1.9
SARC-6	5.3	16.2	1.9	1.9
HD-2329	4.1	25.7	1.9	1.9
Mean	**6.3**	**21.3**	**1.9**	**2.0**
	K^+ (mol m^3)			
Pirsabak	355	290	244	238
Inqlab-91	257	229	183	212
SARC-6	275	255	239	221
HD-2329	227	212	193	215
Mean	**279**	**246**	**215**	**222**
	Stomatal conductance (g_s mmol m^{-2} s^{-1})			
Pirsabak	395	242	676	711
Inqlab-91	190	118	618	589
SARC-6	178	202	518	575
HD-2329	321	130	463	469
Mean	**271**	**173**	**568**	**585**
	SPAD readings			
Pirsabak	46	47	48	48
Inqlab-91	46	39	45	46
SARC-6	51	47	51	50
HD-2329	49	46	49	48
Mean	**48**	**45**	**48**	**48**

Significance levels are shown in the tables by *, **, and *** for 0.05, 0.01 and 0.001% probability levels respectively.

Saline: Na^+ = ***, K^+ = ***, Stom. Cond. = ***, SPAD = N.S

Saline and waterlogged: Na^+ = ***, K^+ = ***, Stom. Cond. = **, SPAD = N.S

Waterlogged: Na^+ = ***, K^+ = *, Stom. Cond. = N.S., SPAD = *

Control: Na^+ = ***, K^+ = ***, Stom. Cond. = N.S., SPAD = ***

Results and Discussion

The Na^+ concentration in leaf sap was approximately same in control and waterlogged and increased under saline and waterlogged conditions (Table 1). The Na^+ concentration in the leaves of all varieties increased 2-4 times in saline treatments than controls and further similar increase in saline–waterlogged conditions. However, in variety HD-2329 leaf Na^+ was six times higher than saline treatments. In the saline treatments, K^+ concentration was decreased by waterlogging but this was not observed under non-saline conditions. There were significant differences of salinity x waterlogging interactions showing that waterlogging have positive effects of salinity. A little increase in K^+ concentration was in Inqlab-91 and HD-2329 leaves and it slightly declined in Pirsabak and SARC-6 in waterlogging conditions. However, K^+ was increased in all varieties under salinity stress but then decreased by combined saline-waterlogging stress in all varieties. There were significant differences of salinity x waterlogging interactions showing that waterlogging have positive effects of salinity. Kong *et al*., (2001) found that Na^+ concentration was increased with enhancing the salinity levels but dry weights were decreased in wheat. The content of Na^+ K^+ Ca^+ and Cl^- in shoots tissues of wheat plants increased with increasing salinity under aerobic conditions, ion accumulation was greater with treatment combination of salinity and oxygen deficiency. Reduction of K^+ accumulation is most likely attributed to the effects of waterlogging on uptake mechanisms of roots (Trought & Drew, 1980). Doubling the nutrient concentration of the waterlogged soils scientifically increased K^+ concentration in the leaves and roots of wheat cv. Savnnah (Huang *et al*., 1995a, b).

The stomatal conductance was significantly decreased by salinity but the SPAD measurement was not affected (Table 1). A little increase in stomatal conductance was observed in varieties Pirsabak and SARC-6 in waterlogged conditions although it decreased in Inqlab-91 and HD-2329. However, stomatal conductance was decreased with salinity stress in all varieties and further reduced by combined stress of saline-waterlogging. There was not any statistically significant difference of salinity x waterlogging interactions. Photosynthesis is generally reduced in plants growing plants in saline conditions and with salt or water stress a decrease in stomatal conductance corresponds to a reduction in photosynthesis (Rivelli *et al*., 2002).

The SAPD readings approximately remained same in the leaves of all varieties in all treatments after 70 days of sowing. The leaves may have not taken much Na^+ and SPAD readings were not affected. Total chlorophyll content in wheat declined with increase in salinity as well as and with the age of plants (Khatkar & Kuhand, 2000). This reduction might happen due to enhancement of chlorophyllase activity at higher salinity levels or due to reduction in *de navo* chlorophyll synthesis (Sudhakar *et al*., 1991). Rivelli *et al*., (2002) also have reported that SPAD (chlorophyll concentration) was significantly higher in salt treated plants relative to control.

Grain dry weight per plant was increased in waterlogged conditions in all varieties. It was higher in varieties Pirsabak and SARC-6 in comparison to HD-2329 and Inqlab-91 (Table 2). Grain weight declined in all varieties with salinity treatments and further declined in saline-waterlogged conditions. Statistically the salinity x waterlogging interaction was significant indicating that waterlogging raw positive effects of salinity. The grain dry weight/plant increased with waterlogging treatments in all varieties except HD-2329. It was dramatically decreased in all varieties in saline and saline-waterlogged treatments. The number of ears/plant in control condition was low in all varieties but was high in SARC-6. In waterlogged conditions ear number was increased in Pirsabak and Inqlab-91 but was similar in SARC-6 and HD-2329 (Table 2). In saline conditions ear number declined in all varieties but then increased in saline-waterlogged conditions. Waterlogging increased the ear/plant in Pirsabak and Inqlab-91 but not in SARC-6 and HD-2329. Salinity reduced ear number but a small increase was found in combine saline-waterlogging treatment in all varieties. The grain number/plant in control condition was observed high in all varieties except SARC-6 (Table 2). In saline and saline-waterlogged conditions grain number was increased in comparison to controls. The salinity x waterlogging interaction was significant indicating that waterlogging increase the effects of salinity. Grain number/plant was high in Pirsabak and SARC-6 in waterlogged treatment and was low in Inqlab-91 and HD-2329 than controls. However, this was not affected by salinity stress in all varieties but declined in SARC-6. Again a mixed trend was observed in saline-waterlogged conditions slightly decreased in Pirsabak and Inqlab-91 but increased in SARC-6 and HD-2329.

Table 2. Effects of salinity and waterlogging on grain dry weight, ear, grain/plant and 1000 grain weight of four wheat varieties.

Variety	Saline		Non-saline	
	Saline	**Saline and waterlogged**	**Control**	**Waterlogged**
	Grain dry weight/plant (gm)			
Pirsabak	2.38	1.31	8.96	12.21
Inqlab-91	2.62	1.63	6.95	7.84
SARC-6	3.45	2.92	8.24	13.03
HD-2329	4.55	2.85	8.68	7.97
Mean	3.25	2.17	8.20	10.26
	Ear/plant			
Pirsabak	3.0	3.7	6.3	10.5
Inqlab-91	2.0	2.6	5.3	8.5
SARC-6	4.6	5.2	9.2	9.2
HD-2329	2.9	3.1	7.3	7.2
Mean	3.1	3.6	7.1	8.8
	Grain/plant			
Pirsabak	35.4	33.8	32.0	37.5
Inqlab-91	36.2	33.2	31.5	22.4
SARC-6	17.8	19.2	15.7	26.1
HD-2329	23.6	31.5	26.6	23.6
Mean	28.2	29.4	26.5	27.4
	1000 grain weight (gm)			
Pirsabak	22.42	10.89	44.26	30.95
Inqlab-91	36.10	19.10	41.42	41.35
SARC-6	42.59	29.20	56.78	54.10
HD-2329	48.69	29.08	44.33	46.70
Mean	37.40	22.06	44.69	43.30

Significance levels are shown in the tables by *, **, and *** for 0.05, 0.01 and 0.001% probability levels respectively.
Saline: Gdwt/P = ***, Ear/p = ***, Grain/p = ***, 1000 Gwt = **
Saline and waterlogged: Gdwt/P = **, Ear/p = N.S., Grain/p = *, 1000 Gwt = N.S.
Waterlogged: Gdwt/P = N.S., Ear/p = **, Grain/p = **, 1000 Gwt = *
Control: Gdwt/P = N.S., Ear/p = ***, Grain/p = **, 1000 Gwt = *

In control conditions the 1000 grain weight was same in all varieties and this declined in waterlogging conditions but a little increase was found only in HD-2329 variety. The grain weight decreased in saline and saline waterlogging conditions (Table 2). Statically there was significant difference of saline and waterlogging. The 1000 grain weight was continuously decreased at waterlogged, saline and saline waterlogged treatments in all varieties but this was reduced to 75% in Pirsabak. Hollington (1998) has concluded that saline hypoxia reduce growth, water use, grain and straw yields in wheat, but NaCl or hypoxia alone had smaller effects.

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