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Full Length Research Paper

Effect of phytohormones on growth and ion accumulation of wheat under salinity stress

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A hydroponics experiment was conducted to assess the role of abscisic acid (ABA), benzyladenine (BA) and cycocel (CCC) on growth and ion accumulation of three spring wheat cultivars, cv. Wafaq-2001, cv. Inqulab-91, and cv. SAARC-1 under salinity stress. Seeds of all the cultivars were treated prior to sowing with ABA and BA each at 10^{-5} M and CCC at 10^{-6} M for 24 h. Three weeks old plants of both the cultivars were exposed to 0, 75 and 150 mM NaCl. Thirty day old plants were harvested after sixteen days of salt treatment. Dry weight of shoot and root were decreased with salt treatment. But ABA, BA and CCC treatments caused a significant ameliorative effect on all the cultivars. Concentrations of Na^+ and Cl^- in shoot of all the three cultivars were increased with the increasing level of NaCl. ABA, BA and CCC pre-treatment increased K^+ and Ca^{2+} but reduced Na^+ and Cl^- concentrations in shoot of all the cultivars. However, the magnitude of reduction was higher in ABA pre-treated plants.

Key words: Wheat, salinity, abscisic acid, benzyladenine, cycocel.

INTRODUCTION

Agricultural productivity in arid and semi arid region of the world is very low due to low precipitation and accumulation of salts in soil (Munns, 2002). The damaging effects of salt accumulation in agricultural soils have influenced ancient and modern civilizations. According to Yeo et al. (1999), 20% of the irrigated land is affected by salinity globally. Increasing salinity and the rapid increasing population of Pakistan, suggests that the country will face a large deficit in food grain in near future. To increase agricultural production, either more land must be brought in to cultivation or productivity per unit area must be increased. Chloride and sodium are the most common ions associated with saline conditions. Salinity damages in wheat and other crop species are commonly due to excessive Na^+ and Cl^- uptake by the plant (Yeo and Flowers, 1986; Schachtman et al., 1991); two ions are often taken up similarly by plants and in wheat contribute synergistically to salt toxicity. Thus maintenance of low sodium concentrations in the leaves is associated with salt resistance of wheat and some other species (Wyn Jones, 1984; Ashraf and O' Leary, 1996). It has long been known that NaCl toxicity is largely attributable to the effect of Na^+, and only rarely those of Cl^- (Tester and Davenport, 2003), and that Na^+ toxicity is linked strongly to the plant's ability to sustain the acquisition and in plant distribution of K^+ (Rains and Epstein, 1967; Kader and Lindberg, 2005). It is thought that the depressive effect of salinity on germination could be related to a decline in endogenous levels of hormones (Debez et al., 2001). Incorporation of plant growth regulators during pre-soaking, priming and other pre-sowing treatments in many vegetable crops have improved seed performance. Typical responses to priming are faster and closer spread of times to germination and emergence overall seedbed environments and wider temperature range of germination, leading to better crop stand, and hence improved yield and harvest quality, especially under suboptimal and stress condition in the field (Halmer, 2004). The phytohormones are the signal sent between root and shoot responses to external stress (Zhang Davies, 1989). The present study was aimed to evaluate the comparative effect of abscisic acid (ABA), benzyladenine (BA) and cycocel (CCC) on the amelioration of salt stress on three cultivars of wheat differing in salt tolerance with particular emphasis on ionic relations.

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MATERIALS AND METHODS

The seed material of three spring wheat (*Triticum aestivum L.*) cultivars, that is, Wafaq-2001, Inqulab-91 and SAARC-1 were obtained from National Agricultural Research Centre (NARC) Islamabad, Pakistan. The experiment was conducted in a glasshouse during the winter/spring of 2003-04 with average day/night temperature 30°C ± 8°C and 13 ± 5°C, respectively, and photo period ranging from 10 - 13.5 h. Seeds of wheat were treated for 24 h in aqueous solution of plant growth regulators ABA, BA (10^{-5} M), CCC (10^{-6} M) and distilled water in case of control in black painted well aerated flask. After hormone treatment, seeds were washed with tap water followed by washing with distilled water. After seed treatment, seeds were sown for nursery raising in plastic trays containing silica washed sand. Seven days old seedlings were transplanted into black painted well-aerated plastic boxes of 6 L capacity filled with Hoagland's nutrient solution (Hogland and Arnon, 1950). Solutions were renewed every week and pots were randomly arranged. Salinity of 0.75 and 150 mM was developed by adding NaCl on equivalent basis (Richards et al., 1954). The NaCl solution was applied to 14 days old plants of wheat with five equal splits in five days. Plants (30 d old) were harvested and their shoots and roots were separated. Oven dried shoot were ground finely so pass through a 2 mm sieve. Dried samples were digested in digestion mixture (Nitric acid-perchloric acid) according to the method of Chapman and Prat (1982). The Na^+ and K^+ in shoot were determined using a flame photometer (Sherwood model 410, Japan) Ca^{2+} was determined with atomic absorption spectrophotometer (Shimadzu 6200AA Japan). Chloride was determined by the method of Chapman (1961). Data was statistically analyzed by Minitab soft ware.

RESULTS

Increasing level of NaCl significant decreased plant height of wheat in all the wheat cultivars; however treatment means showed that ABA and CCC significantly affected plant height in Wafaq-2001 (Table 1). In wheat Inqulab-91, ABA and CCC showed significant decrease in plant height, while in SAARC-1 salinity levels and treatments were significantly affected but the interaction between treatment and salinity levels were non significant in all the three cultivars (ANOVA not showed).

Increasing level of salt stress significantly decreased shoot dry weight in all the wheat cultivars (Table 1). Treatment means showed a significant increase in shoot dry weight by ABA, BA and CCC pre-treatment in Inqulab-91 and SAARC-1, while in Wafaq-2001 only ABA and BA increased shoot dry weight significantly. At 50 and 75 mM NaCl levels, ABA significantly increased shoot dry weight in all the three cultivars of wheat (Table 1).

Data showed that salinity levels were significant decreased the root dry weight in all the three cultivars. However, treatment means showed that ABA, BA and CCC significantly increased root dry weight in cv. SAARC-I, while in cv. Inqulab-91 ABA and BA significantly increased root dry weight over control (Table 1). ABA significantly affected Wafaq 2001. Highest root dry weight was recorded with wheat Wafaq-2001.

Data in Table 2 showed that increasing level of sodium chloride significantly increased Na^+ concentration in all the wheat cultivars. Treatment means showed that ABA, BA and CCC significantly decreased Na^+ concentration in all the cultivars. Highest Na^+ concentrations were recorded with Wafaq-2001 and the lowest Na^+ concentrations were recorded with SAARC-1. ABA, BA and CCC pretreatment significantly decreased Na^+ concentration at 75 and 150 mM NaCl stress in cv. Inqulab-91 and cv. SAARC-1 (Table 2).

The increasing level of NaCl significantly decreased K^+ concentration in all the three cultivars, however pretreatment of phytohormones increased K^+ concentrations in the order: ABA > CCC > BA at 75 and 150 mM NaCl stress in all the three cultivars (Table 2). ABA significantly increased K^+ concentration in wheat Wafaq-2001 and SAARC-1, while in Inqulab-91 ABA as well as CCC pretreatment was significant at 150 mM NaCl stress. Average mean of all the three salinity levels showed that ABA, BA and CCC significantly increased K^+ concentration in wheat Wafaq-2001 and Inqulab-91 while in SAARC-1, ABA and CCC were significant.

Data showed that Cl^- concentrations were increased with the increasing level of NaCl in all three cultivars. ABA significantly reduced Cl^- concentration in cv. Wafaq-2001 at all the salinity levels, however ABA and CCC both significantly reduced Cl^- concentrations in cv. Wafaq-2001 under 150 mM NaCl stress (Table 2). ABA and CCC significantly reduced Cl^- concentration at 75 and 150 mM NaCl stress in Inqulab-91, while in SAARC-1 none of growth regulator was significantly different.

Data represented that increasing level of NaCl significantly decreased Ca^{2+} concentrations in all the wheat cultivars (Table 3). Mean data of treatments showed that ABA, BA and CCC significantly increased Ca^{2+} concentration over control (distilled water treated plants). BA pretreatment significantly increased Ca^{2+} concentration at 0, 75 and 150 mM NaCl stress in all the cultivars, while ABA was significant in cv. Wafaq-2001 at 0 and 75 mM NaCl stress and cv. Inqulab-91 at 0 and 150 mM NaCl stress.

The increasing level of induced stress decreased K^+/Na^+ ratio in all the wheat cultivars, however K^+/Na^+ ratio was improved by ABA, BA and CCC in all the cultivars (Table 3). In Wafaq-2001, ABA and CCC pretreatment significantly increased K^+/Na^+ ratio at 0 mM NaCl stress, however average mean data showed that ABA and BA both significantly increased K^+/Na^+ ratio, while in Inqulab-91, treatment mean data showed that ABA was significant.

Data showed (Table 3) that Ca^{2+}/Na^+ ratios were decreased with the increasing level of NaCl stress, however growth regulators improved Ca^{2+}/Na^+ ratio over control (distilled water treated plants). Average of treatment showed that ABA, BA and CCC pre-treated plants significantly increased Ca^{2+}/Na^+ ratio in Wafaq-2001 while it was non significant in Inqulab-91 and SAARC-1.

A significantly negative correlation was found between shoot dry matter yield and Na+ concentrations (Figure 1 a, b and c), while a positive correlations was observed between

Table 1. Effect of ABA, BA and CCC seed soaking on the plant height, shoot and root dry weight of three cultivars of wheat at 0, 75 and 150 mM NaCl stress.

Plant Height (cm)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	40.12 ab	35.20 de	28.40 fg	34.60 b	42.15 ab	37.42 cde	30.35 gh	36.65 a	38.33 ab	29.87 d	23.97 ef	30.70 b
ABA	37.33 cd	33.42 e	27.42 g	32.70 c	39.33 bc	35.35 def	29.47 gh	34.72 b	36.40 b	29.25 d	23.35 f	29.65 b
BA	42.05 a	37.30 cd	30.40 f	36.60 a	43.40 a	39.44 bc	32.50 fg	38.43 a	40.20 a	33.34 c	26.26 e	33.30 a
CCC	38.25 bc	34.29 e	27.34 g	33.30 bc	38.50 cd	34.40 ef	28.40 h	33.77 b	37.30 b	29.30 d	24.27 ef	30.26 b
S. Level	39.44 a	35.06 b	28.40 c		40.80 a	36.65 b	30.18 c		38.00 a	30.45 b	24.50 c	

Shoot Dry weight (gm)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.30 bc	0.21 ef	0.14 h	0.22 c	0.28 b	0.18 def	0.12 h	0.20 b	0.26 bc	0.16 efg	0.12 g	0.18 c
ABA	0.34 ab	0.27 cd	0.20 fg	0.27 a	0.31 ab	0.23 c	0.17 efg	0.24 a	0.29 a	0.14 cd	0.15 ef	0.19 a
BA	0.36 a	0.25 de	0.16 gh	0.26 ab	0.33 a	0.21 cd	0.15 fgh	0.23 a	0.32 ab	0.20 de	0.16 efg	0.22 ab
CCC	0.33 ab	0.23 def	0.16 gh	0.24 bc	0.30 ab	0.20 cde	0.14 gh	0.21 a	0.28 ab	0.17 def	0.16 fg	0.20 b
S. Level	0.33 a	0.24 b	0.16 c		0.30 a	0.20 b	0.15 c		0.29 a	0.17 b	0.15 c	

Root Dry weight (gm)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.18 abc	0.13 de	0.10 e	0.14 b	0.16 b	0.08 cd	0.06 d	0.10 b	0.15 bc	0.07 efg	0.04 g	0.09 c
ABA	0.22 a	0.16 bcd	0.14 cde	0.17 a	0.19 ab	0.11 c	0.09 cd	0.13 a	0.19 a	0.12 cd	0.08 ef	0.13 a
BA	0.21 a	0.15 cd	0.12 de	0.16 ab	0.20 a	0.10 c	0.08 cd	0.13 a	0.18 ab	0.10 de	0.07 efg	0.12 ab
CCC	0.20 ab	0.13 de	0.12 de	0.15 ab	0.18 ab	0.10 c	0.06 d	0.11 ab	0.18 ab	0.09 def	0.06 fg	0.11 b
S. Level	0.20 a	0.14 b	0.12 b		0.18 a	0.09 b	0.072 c		0.18 a	0.10 b	0.06 c	

T, treatment; S, salinity; Values followed by the same letter (s) are not significantly different at $P < 0.05$ according to LSD test.

K+ concentration and shoot dry matter yield (Figure 1d, e and f).

DISCUSSION

Seed pre-soaking in ABA, BA and CCC was explored on three wheat cultivars at 0, 75 and 150 mM NaCl stress under hydroponics culture. ABA, BA and CCC ameliorate the adverse effect of salinity by increasing shoot and root dry weight and reducing Na^+ and Cl^- concentration in shoot of wheat seedlings. However, magnitude of increase was higher in ABA pre-treatment (Table 2). The results of the present study showed that cv. SAARC-1 have lowest Na^+ and Cl^- and higher K^+ concentration in shoot of wheat seedlings, suggesting that SAARC-1 had better ability to exclude harmful ions from the shoot, which in turn contri-

Table 2. Effect of ABA, BA and CCC seed soaking on sodium, potassium and chloride concentrations in shoot of three cultivars of wheat at 0, 75 and 150 mM NaCl stress.

Sodium concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.12 abc	0.74 de	0.80 e	0.55 a	0.10 g	0.68 ab	0.72 a	0.50 a	0.06 e	0.56 a	0.62 a	0.41a
ABA	0.08 a	0.37 bcd	0.46 cde	0.30 c	0.07 g	0.40 f	0.44 f	0.30 c	0.04 e	0.29 d	0.35 cd	0.23 c
BA	0.12 a	0.55 cd	0.69 de	0.45 b	0.08 g	0.53 de	0.61 bc	0.40 b	0.05 e	0.32 d	0.40 bc	0.25 bc
CCC	0.10 ab	0.45 de	0.67 de	0.41b	0.09 g	0.46 ef	0.56 cd	0.37 b	0.05 e	0.36 cd	0.46 b	0.29 b
S. Level	0.10 a	0.53 b	0.65 c		0.08 c	0.52 b	0.58 a		0.05 a	0.40 b	0.46 c	

Potassium concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.96 bcd	0.78 ef	0.72 f	0.82 c	1.14 de	0.92 fg	0.83 g	0.96 c	1.33 abc	1.05 def	0.95 f	1.11 a
ABA	1.20 a	1.12 ab	0.97 bcd	1.09 a	1.52 a	1.45 ab	1.20 cde	1.39 a	1.52 a	1.44 a	1.27 abcd	1.41 a
BA	1.07 abc	0.94 cde	0.78 ef	0.93 b	1.35 bc	1.16 de	0.92 gf	1.14 b	1.42 ab	1.20 bcde	1.02 ef	1.21 a
CCC	1.12 ab	1.04 abc	0.86 def	1.00 ab	1.46 ab	1.30 bcd	1.07 ef	1.28 a	1.53 a	1.37 abc	1.14 cdef	1.35 a
S. Level	1.08 a	0.97 b	0.83 c		1.36 a	1.20 b	1.00 c		1.45 a	1.27 b	1.10 c	

Chloride concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.17 fg	0.42 cd	0.60 a	0.40 a	0.14 f	0.39 c	0.51 a	0.34 a	0.12 a	0.34 a	0.46 a	0.31 a
ABA	0.10 g	0.24 ef	0.38 cd	0.24 c	0.09 f	0.24 e	0.34 cd	0.22 c	0.08 a	0.20 a	0.26 a	0.18 a
BA	0.15 fg	0.38 cd	0.52 ab	0.35 ab	0.12 f	0.34 cd	0.48 ab	0.31 ab	0.11 a	0.30 a	0.42 a	0.28 a
CCC	0.13 g	0.33 de	0.44 bc	0.30 b	0.10 f	0.29 de	0.41 bc	0.27 bc	0.09 a	0.27 a	0.35 a	0.23 a
S. Level	0.14 c	0.34 b	0.48 a		0.11 c	0.31 b	0.43 a		0.10 a	0.27 a	0.37 a	

T, treatment; S, salinity; Values followed by the same letter (s) are not significantly different at $P < 0.05$ according to LSD test.

bute to their salt tolerance. This study also indicates that wheatcv. Wafaq-2001 accumulated relatively highest Na^+ and Cl^- concentrations in shoot of wheat seedlings as compared to Inqulab-91 and SAARC-1 (Table 2). The exclusion of harmful ions (Na^+ and Cl^-) from the shoot had already been found to be associated with genotypic variation in salt tolerance (Greenway and Munns, 1980). For those genotypes that cannot

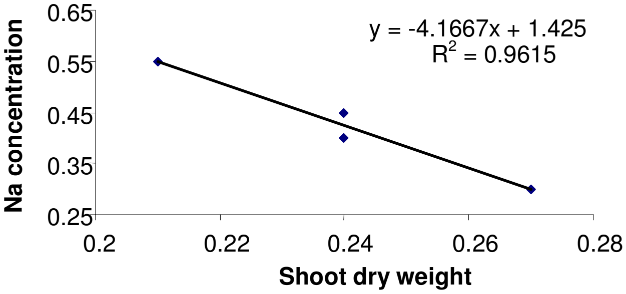

Figure 1a. Relationship between shoot dry weight and Na concentration in Wafaq-2001.

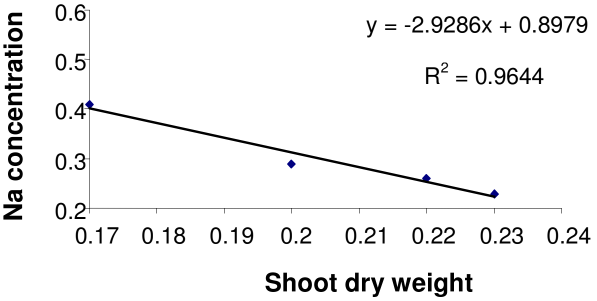

Figure 1b. Relationship between shoot dry weight and Na concentration in SAARC-1.

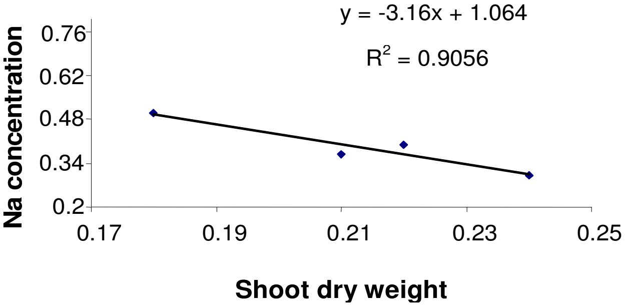

Figure 1c. Relationship between shoot dry weight and Na concentration in Inqulab-91.

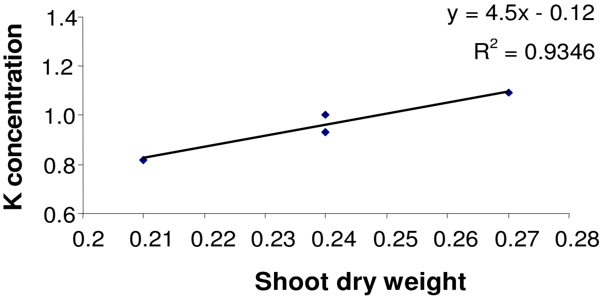

Figure 1d. Relationship between shoot dry weight and K concentration in Wafaq-2001.

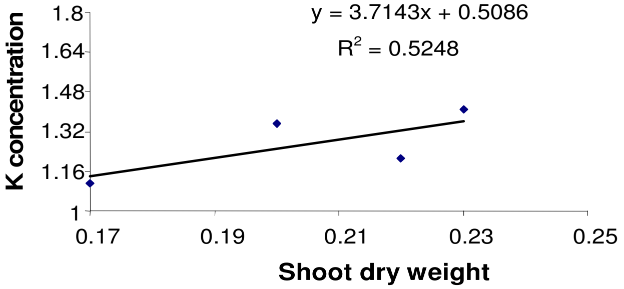

Figure 1e. Relationship between shoot dry weight and K concentration in SAARC-1.

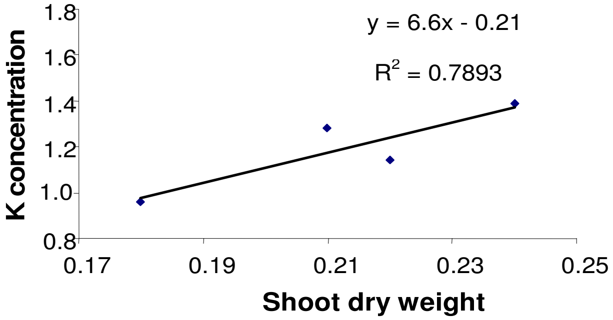

Figure 1f. Relationship between shoot dry weight and K concentration in Inqulab-91.

exclude toxic ions from the shoot, salt built-up to toxic levels in the leaves becoming the major cause of reduced growth (Munns et al., 1993).

The present investigation showed that cv. SAARC-1 accumulated less Na^+ and Cl^- than Inqulab-91 and Wafaq-2001 (Table 2). Iqbal and Ashraf (2005) reported that pretreatment with kinetin reduced Na^+ and increase K^+ in the shoot of salt tolerant cultivar under saline condition. Aldesquy and Ibrahim (2001) observed that seed pre-treatment with GA_3, IAA and ABA seemed to reduce stress by ameliorating Na^+, Cl^- and P^{3+} and at the same time increasing K^+ levels within the developing grains. In the present study, increasing level of NaCl salinity increased Na^+ but decreased K^+ and Ca^{2+} concentration in all three cultivars. Pre-treatment with ABA, BA and CCC caused an improvement in K^+ and Ca^{2+} concentration in shoot of wheat seedlings. The magnitude of increase in K^+ concentration due to ABA was higher than BA and CCC pre-treated plants. Increase in Ca^{2+} concentration due to ABA and BA pre-treatment was statistically at par with each other in cv.

Wafaq-2001 and cv. Inqulab-91 at both 75 and 150 mM NaCl stress (Table 3). Maximum K^+ concentrations were recorded with cv. SAARC-1 which has accumulated lowest Na^+ concentrations by the ABA seed pre-treatment (Table 2). Ca^{2+} is important in preserving the integrity of

Table 2. Effect of ABA, BA and CCC seed soaking on sodium, potassium and chloride concentrations in shoot of three cultivars of wheat at 0, 75 and 150 mM NaCl stress.

Sodium concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.12 abc	0.74 de	0.80 e	0.55 a	0.10 g	0.68 ab	0.72 a	0.50 a	0.06 e	0.56 a	0.62 a	0.41a
ABA	0.08 a	0.37 bcd	0.46 cde	0.30 c	0.07 g	0.40 f	0.44 f	0.30 c	0.04 e	0.29 d	0.35 cd	0.23 c
BA	0.12 a	0.55 cd	0.69 de	0.45 b	0.08 g	0.53 de	0.61 bc	0.40 b	0.05 e	0.32 d	0.40 bc	0.25 bc
CCC	0.10 ab	0.45 de	0.67 de	0.41b	0.09 g	0.46 ef	0.56 cd	0.37 b	0.05 e	0.36 cd	0.46 b	0.29 b
S. Level	0.10 a	0.53 b	0.65 c		0.08 c	0.52 b	0.58 a		0.05 a	0.40 b	0.46 c	

Potassium concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.96 bcd	0.78 ef	0.72 f	0.82 c	1.14 de	0.92 fg	0.83 g	0.96 c	1.33 abc	1.05 def	0.95 f	1.11 a
ABA	1.20 a	1.12 ab	0.97 bcd	1.09 a	1.52 a	1.45 ab	1.20 cde	1.39 a	1.52 a	1.44 a	1.27 abcd	1.41 a
BA	1.07 abc	0.94 cde	0.78 ef	0.93 b	1.35 bc	1.16 de	0.92 gf	1.14 b	1.42 ab	1.20 bcde	1.02 ef	1.21 a
CCC	1.12 ab	1.04 abc	0.86 def	1.00 ab	1.46 ab	1.30 bcd	1.07 ef	1.28 a	1.53 a	1.37 abc	1.14 cdef	1.35 a
S. Level	1.08 a	0.97 b	0.83 c		1.36 a	1.20 b	1.00 c		1.45 a	1.27 b	1.10 c	

Chloride concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.17 fg	0.42 cd	0.60 a	0.40 a	0.14 f	0.39 c	0.51 a	0.34 a	0.12 a	0.34 a	0.46 a	0.31 a
ABA	0.10 g	0.24 ef	0.38 cd	0.24 c	0.09 f	0.24 e	0.34 cd	0.22 c	0.08 a	0.20 a	0.26 a	0.18 a
BA	0.15 fg	0.38 cd	0.52 ab	0.35 ab	0.12 f	0.34 cd	0.48 ab	0.31 ab	0.11 a	0.30 a	0.42 a	0.28 a
CCC	0.13 g	0.33 de	0.44 bc	0.30 b	0.10 f	0.29 de	0.41 bc	0.27 bc	0.09 a	0.27 a	0.35 a	0.23 a
S. Level	0.14 c	0.34 b	0.48 a		0.11 c	0.31 b	0.43 a		0.10 a	0.27 a	0.37 a	

T, treatment; S, salinity; Values followed by the same letter (s) are not significantly different at P < 0.05 according to LSD test.

the cell membrane during salt stress (Rengel, 1992), and is used as secondary messenger in many signal transduction pathway within the cell (Knight, 2000). Shabala et al. (2003) reported that high Ca^{2+} caused almost complete recovery of membrane potential root cells, which may be able to prevent K^+ leakage from the cell. Previous studies emphasized the important role of K^+/Na^+ and Ca^{2+}/Na^+ for salt tolerance (Gorham, 1993;

Table 3. Effect of ABA, BA and CCC seed pre-soaking on the calcium concentration and K^+/Na^+ and Ca^{2+}/Na^+ ratio in three cultivars of wheat at 0, 75 and 150 mM NaCl stress.

Calcium concentration (mM)

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.07 c	0.03 f	0.03 f	0.04 c	0.06 bc	0.03 ef	0.02 f	0.04 c	0.08 bc	0.04 fg	0.03 g	0.05 c
ABA	0.09 b	0.05 de	0.04 ef	0.06 b	0.7 a	0.04 de	0.03 de	0.05 b	0.09 ab	0.05 ef	0.04 fg	0.06 b
BA	0.10 a	0.06 cd	0.05 de	0.07 a	0.08 a	0.05 cd	0.04 de	0.06 a	0.10 a	0.07 cd	0.06 de	0.07 a
CCC	0.09 b	0.04 ef	0.04 ef	0.06 b	0.07 ab	0.04 de	0.03 ef	0.04 b	0.08 ab	0.05 ef	0.04 fg	0.06 b
S. Level	0.09 a	0.05 b	0.04 c		0.07 a	0.04 b	0.03 c		0.08 a	0.06 b	0.04 c	

K^+/Na^+ ratio

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	8.07 c	1.05 d	0.90 d	3.34 c	13.40 b	1.36 c	1.16 c	5.31 b	25.02 b	1.91 c	1.54 c	9.50 a
ABA	15.42 a	3.01 d	2.15 d	6.86 a	25.38 a	3.71 c	2.73 c	10.61 a	46.05 a	5.00 c	3.67 c	18.24 a
BA	9.11 c	1.74 d	1.16 d	4.01 b	18.42 b	2.21 c	1.51 c	7.38 ab	40.84 a	4.00 c	2.68 c	15.82 a
CCC	12.17 b	2.34 d	1.28 d	5.27 bc	17.52 b	2.86 c	1.92 c	7.43 ab	32.55 ab	3.83 c	2.50 c	12.96 a
S. Level	11.20 a	2.04 b	1.37 b		18.68 a	2.53 b	1.83 b		36.12 a	3.67 b	2.60 c	

Ca^{2+}/Na^+ ratio

Treatment	Wafaq-2001				Inqulab-91				SAARC-1			
	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean	0 mM	75 mM	150 mM	T. Mean
Control	0.64 c	0.05 d	0.03 d	0.24 b	0.71 b	0.04 c	0.03 c	0.26 a	1.64 b	0.07 c	0.05 c	0.60 a
ABA	1.20 a	0.12 d	0.09 d	0.47 a	1.23 a	0.10 c	0.08 c	0.47 a	2.70 a	0.18 c	0.12 c	1.00 a
BA	0.87 b	0.11 d	0.07 d	0.35 ab	1.13 a	0.10 c	0.06 c	0.43 a	2.74 a	0.24 c	0.14 c	1.04 a
CCC	0.97 b	0.09 d	0.05 d	0.37 a	0.82 b	0.08 c	0.05 c	0.32 a	1.92 ab	0.15 c	0.08 c	0.72 a
S. Level	0.92 a	0.09 b	0.62 b		0.97 a	0.08 b	0.60 b		2.25 a	0.16 b	0.10 b	

S; salinity, T; treatment

Sharma, 1994). Maathuis and Amtmann (1999) emphasized that one of the key element in salinity tolerance is capacity to maintain a high cytosolic K^+/Na^+ ratio because cytoplasmic Na^+ competes with K^+ binding sites and hence inhibits metabolic processes that crucially depend on K^+. The maintenance of high K^+ and Ca^{2+} content in salt tolerant cultivars may be one of the mechanisms underlying the degree of salt tolerance. Munns and James (2003) suggested that variation in ion selectivity (e.g. K^+) among genotypes of wheat is probably a secondary result of genetic variation in

Na^+ uptake. During the present study both K^+ and Ca^{2+} contents were highest in salt tolerant cv. SAARC-1 and lowest in salt sensitive cv. Wafaq-2001 (Tables 2 and 3). Higher K^+/Na^+ and Ca^{2+}/Na^+ ratios can be considered good indicators for salinity tolerance. ABA, BA and CCC improved K^+/Na^+ and Ca^{2+}/Na^+ ratio in all the wheat cultivars, however higher K^+/Na^+ and Ca^{2+}/Na^+ ratio were recorded with salt tolerant cv. SAARC-1. Highest K^+/Na^+ and Ca^{2+}/Na^+ ratios were recorded with ABA treated plants.

Conclusion

It is inferred from the present investigation that ABA, BA and CCC are effective for partial amelioration in salinity tolerance of all the three wheat cultivars, however SAARC-1 accumulated less Na^+ and higher K^+ concentrations.

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