DROUGHT AND ABSCISIC ACID (ABA) INDUCED CHANGES IN PROTEIN AND PIGMENT CONTENTS OF FOUR WHEAT (*TRITICUM AESTIVUM* L.) ACCESSIONS

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ABSTRACT

The response of four wheat (*Triticum aestivum* L.) accessions (011251, 011417, 011320 and 011393) to drought and exogenously applied abscisic acid was determined in a pot study conducted at Quaid-i-Azam University, Islamabad, Pakistan during wheat-growing season 2005 and 2006. For this purpose water, total chlorophyll and carotenoid content of leaves at booting and grain-filling stages were measured. Sampling was done 3, 6 and 9 days after drought induction. Recovery was studied at 48 and 72 hours of re-watering. Marked decreases in leaf water potential as well as pigment content occurred under drought stress. Increase in protein content under drought remained a dominant response except for accession 011251. Accession 011320 was found to be the most sensitive among all accessions on the basis of greater decrease in water potential. The inhibitory effects of water stress on plant water status and biochemical contents were ameliorated by exogenous application of ABA. This ameliorating effect was found to be more significant at booting stage as compared to grain filling particularly in sensitive accession 011320. Upon rewatering, recovery from drought stress was found to be greater in case of abscisic acid treated plants.

KEYWORDS: *Triticum aestivum;* aba; drought; stress; carotenoids; chlorophylls; Pakistan.

INTRODUCTION

The global water crisis is a serious threat to crop productivity particularly in most of the Asian countries where irrigated agriculture accounts for 90 percent of total diverted fresh water (15). The intensity of response to water stress depends on the stress severity and its duration, as well as the plant developmental stage. Wheat crop needs water for whole growth period, but some stages are more vulnerable to water shortage and may result in significant yield losses. The shortage of irrigation water at crown root initiation, booting and early grain fill period results in significant yield losses

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(2). But it is considered that water stress is usually less detrimental to grain yield when occurring early in crop cycle (9). Zhang and Oweis (38) reported that wheat crop was found to be more sensitive to water stress from stem elongation to heading and from heading to milking. Leaf water potential is considered to be a reliable parameter for quantifying plant water stress response (16). From a physiological perspective, leaf chlorophyll content is a parameter of significant interest in its own right. The accessory pigments like carotenoid also have very important role in photosynthesis.

Although sufficient research has been conducted on effect of drought on grain yield of plants and substantial losses in wheat grain yield have been reported due to water deficiency (24), yet information on the effect of drought on biochemical constituents at successive stages of booting and grain filling is scanty. Some proteins are up-regulated under water stress while others are degraded or down regulated. According to Ashraf *et al*. (5) accumulation of proteins in leaves under water stress conditions might be an adaptive mechanism. ABA is known to increase the protein content in several ways. Under water stress condition exogenously applied ABA stimulated the synthesis of proteins in different species (30). ABA also expresses the gene encoding enzymes that participate in the repair of spontaneous protein damage (25). Moreover, ABA induced increase in the osmolyte might also help in stabilizing the proteins under water stress (26).

Response to rewatering and ABA seed soaking treatment in the accessions under test is not well documented. So the present investigation aims at studying the biochemical response of these four wheat accessions at booting and grain filling stages.

MATERIALS AND METHODS

An experiment was conducted under natural condition in a net house of Quaid-i-Azam University, Islamabad, Pakistan during wheat-growing season 2005 and 2006. Seeds of four wheat accessions (011251, 011417,011320 and 011393) were obtained from Plant Genetic Resource Institute, National Agricultural Research Centre, Islamabad. Prior to sowing surface sterilized seeds were soaked for 8 hours in aqueous solution of ABA (10^{-6} M) and in autoclaved distilled water in case of control. The seeds were sown in earthen pots (20 x 30 cm^2) containing soil, sand and farm yard manure in a ratio of 3:1:1. Soil pH and EC were determined with the help of pH and EC meter which were 8.2 and 126.67µs/cm, respectively. Surface sterilization of seeds was done with 10 percent chlorox prior to sowing, after which the seeds were rinsed three times with distilled water. Recommended doses of nitrogen, phosphorus, and potassium fertilizers were applied. Pots were arranged in

RCBD under a rain shelter. One week after germination, the plants were thinned to five per pot. The plants were watered as required. Drought was imposed by withholding water supply for a period of nine days and after that plants were irrigated again. The first drought treatment was started at 50 percent booting and second at 50 percent grain filling, making the treatments as detailed below:-

$T_{0(a)}$	=	Control at booting
T_1	=	Water stress at booting
T_2	=	ABA seed soakig (booting)
T_3	=	Water stress at booting + ABA seed soaking
$T_{0(b)}$	=	Control at grain filling
T_4	=	Water stress at grain filling
T_5	=	ABA seed soaking (grain filling)
T_6	=	Water stress at grain filling + ABA seed soating

Sampling was done 3, 6 and 9 days after start of drought treatment. After 48 and 72 hours of re-watering whole plants and soils were sampled for studying the recovery.

Water potential: Leaf water potential was measured using pressure chamber (33). Flag leaves were excised from the plant and tightly fixed in a sealing sleeve of specimen holder over pressure vessel of instrument. After the leaf had been mounted, pressure was built up within the pressure vessel until the appearance of sap from exposed cut end of the sample. The pressure reading at this point is equivalent to negative force with which the plant water is held within that particular sample. It was recorded and expressed in - MPa.

Protein content: Protein content of leaves harvested at flowering stage was determined following Lowry *et al.* (23) using Bovine Serum Albumen (BSA) as standard.

Chlorophyll and carotenoid content: Chlorophyll contents were estimated by extracting the leaf material (0.05 g) in 10-cm^3 dimethylsulfoxide (DMSO) (14). The samples were heated at 65 °C for 4 hours and then absorbance of extract was recorded at 665, 645 and 470 nm. Chlorophyll contents were calculated as per standard method (3). Carotenoid content was estimated according to the method of Lichtenthaler and Wellburn (22).

The data were subjected to factorial ANOVA and mean values were compared with Duncan's multiple range test (DMRT) using MSTAT-C version 1.4.2

RESULTS AND DISCUSSION

Water potential

The data indicated significant (P< 0.05) effect of water stress on water potential of leaves in all accessions (Table 1). At booting stage after 3 days of water stress period, maximum decrease (55%) in water potential was observed in accession 011393 (Table 1d) while after 6 days of water stress, maximum reduction (130%) was noted in accession 011320 (Table 1c). Accession 011251 showed maximum decrease (189%) after 9 days of water stress (Table 1a). Rewatering caused the recovery of water potential and maximum restoration occurred in accession 011417 (Table 1b) where after 72 hours of rewatering water potential value reached close to that of control plants. At grain filling stage, water potential values were significantly (P< 0.05) lower as compared to that of booting stage and showed linear decrease in all accessions with different periods of water stress. Maximum reduction (250%) was noted in accession 011320 (Table 1c). Moreover after rewatering, water potential of leaves increased again but not to the level of control within 72 hours of rewatering. Recovery was minimum in accession 011320 (Table 1c). In this accession significant (P< 0.05) effect of ABA seed soaking was observed which was found to be most effective in maintaining higher water potential under water stress and better recovery after rewatering at all stages (Table 1c).A sharp decrease in water potential associated with a rapid return to control levels after re-watering was also recorded by other workers (17). These results of water status are also in accordance with the previous findings (13, 29). Pronounced ameliorating effects of ABA on water relations of safflower (21), French beans (28) and *Vigna radiata* L. (11) have also been reported earlier. It is known that tolerant plants are able to maintain relatively higher water status of leaves and recovery is also more pronounced in them as compared to sensitive ones (35).

Protein content

Significant (P< 0.05) increase in protein content of leaves was also noted in all accessions except 011251 (Table 2a) which exhibited a significant (P< 0.05) decrease in protein content of leaves during first 3-6 days of water stress treatment at booting stage while at grain filling stage no significant (P< 0.05) change was observed in this accession. In all other accessions, there was an increase in protein content at booting as well as grain filling due to water stress. But in accession 011320 (Table 2c) and 011393 (Table 2d) this increase occurred only during the shorter period of water stress and later on

Table 1. Effect of water stress and abscisic acid (ABA) on water potential (-MPa.) of leaves at booting and grainfilling stages of wheat.

Treatments	3d	6d	9d	48h (rw)	72h (rw)
			(a) Accession 011251		
T_{0a}	0.7 pqrs	0.67 qrs	0.68 pqrs	0.74 nopq	0.69 pqrs
T_1	1.01 i	1.51 f	1.97 b	1.13 h	0.98 ij
T_2	0.65 st	0.59 t	0.66 rst	0.7 pqrs	0.68 pqrs
T_3	0.88 kl	1.07 gh	1.63 e	0.98 ij	0.83 lm
T_{0b}	0.81 lmn	0.79 mno	0.78 mno	0.83 lm	0.79 mno
T_4	1.23 g	1.71 d	2.3 a	1.51 f	1.13 h
T_5	0.74 nopq	0.73 opqr	0.79 mno	0.75 nop	0.69 pqrs
T_6	0.93 jk	1.21 g	1.79 c	1.23 g	1.09 h
LSD value = 0.0727 at alpha = 0.050					
			(b) Accession 011417		
T_{0a}	0.69 rs	0.62 stu	0.73 lmno	0.65 rst	0.72 opqr
T_1	0.98 l	1.11 h	1.68 c	0.89 j	0.77 klmn
T_2	0.57 u	0.6 u	0.62 tu	0.7 pqr	0.61 u
T_3	0.81 k	0.97 l	1.59 d	0.87 j	0.74 mnop
T_{0b}	0.79 klm	0.73 nopq	0.8 kl	0.7 pqr	0.78 klmn
T_4	1.08 h	1.39 e	1.94 a	1.21 g	1.09 h
T_5	0.68 qr	0.76 klmo	0.71 opqr	0.79 klm	0.69 pqr
T_6	0.97 i	1.27 f	1.81 b	1.19 g	1.02 i
LSD value = 0.05140 at alpha = 0.050					
			(c) Accession 011320		
T_{0a}	0.78 nop	0.79 no	0.77 nopq	0.71 rs	0.74 opqr
T_1	1.03 k	1.82 f	2.1 c	1.71 g	1.38 i
T_2	0.69 rs	0.72 qrs	0.71 rs	0.67 s	0.73 pqr
T_3	0.99 kl	1.11 j	1.89 e	1.01 kl	0.97 l
T_{0b}	0.81 n	0.78 nop	0.87 m	0.79 no	0.82 mn
T_4	1.39 i	1.98 d	2.7 a	2.18 b	2.02 d
T_5	0.73 pqr	0.79 no	0.72 qrs	0.78 nop	0.81 n
T_6	1.13 j	1.79 f	2.2 b	1.79 f	1.57 h
LSD value = 0.05140 at alpha = 0.050					
			(d) Accession 011393		
T_{0a}	0.73 nop	0.71 op	0.66 r	0.69 pq	0.75 mno
T_1	1.13 l	1.47 f	1.89 b	1.21 h	1.01 j
T_2	0.68 pq	0.62 r	0.71 op	0.64 qr	0.71 op
T_3	0.91 k	1.12 i	1.61 e	1.01 j	0.97 j
T_{0b}	0.8 lm	0.77 lmn	0.75 mno	0.81 l	0.79 lm
T_4	1.29 g	1.67 d	2.25 a	1.67 d	1.09 i
T_5	0.75 mno	0.81 l	0.77 lmn	0.75 mno	0.7 op
T_6	1.01 j	1.33 g	1.81 c	1.19 h	1.13 i
LSD value = 0.0514 at alpha = 0.050					

T_0a = Control at booting, T_1 = Water stress at booting, T_2 = ABA seed soaking (booting), T_3 = Water stress at booting + ABA seed soaking, T_0b = Control at grain filling, T_4 = Water stress at grain filling, T_5 = ABA seed soaking (grain filling), T_6 = Water stress at grain filling + ABA seed soaking. d = days after induction of water stress. rw = Rewatering.
Means sharing common letter(s) do not differ significantly.

Table 2. Effect of water stress and abscisic acid (ABA) on protein content (mg/g) of leaves at booting and grain filling stages of wheat accessions.

Treatments	3d	6d	9d	48h (rw)	72h (rw)
			(a) Accession 011251		
T_{0a}	17.5 jklmn	17.8 klmn	17.7 ijklmn	19.3 defghijk	20.1 cdefgh
T_1	12.9 p	12.3 p	13.8 op	16.6 mn	15.7 no
T_2	21.3 abcd	22.4 ab	21.3abcd	20.1 cdefgh	21.4 abcd
T_3	17.9 hijklm	18.1 ghijklm	16.9 lmn	17.7 ijklmn	20.1 cdefgh
T_{0b}	19.8 jklm	21.2 abcd	19.5 defghij	18.7 fghijklm	21.3 abcd
T4	19.7 defghij	19.8 defghi	21.3 abcd	22.1 abc	23.4 a
T_5	18.9 efghijkl	19.7 defghij	21.3 abcd	20.1 cdefgh	20.3 bcdefg
T_6	21.3 abcd	21.1 bcde	19.4 defghij	19.5 defghij	20.9 bcdef
LSD value = 2.215 at alpha = 0.050					
			(b) Accession 011417		
T_{0a}	12.9 k	13.2 k	11.2 lmn	11.7 n	11.3 kl
T_1	14.1 ij	15.7 cdef	16.6 cde	15.3 hi	14.7 hi
T_2	15.1 ghi	15.3 fghi	15.2 ghi	15.3 fghi	14.9 hi
T_3	16.9 abc	16.8 abc	16.9 abc	15.9 defg	15.5 efgh
T_{0b}	11.3 n	12.3 kl	12.2 klm	12.3 kl	11.4 mn
T_4	13.9 j	14.7 hij	15.3 fghi	15.4 efghi	14.8 hi
T_5	16.1 cdef	16.2 cde	16.4 bcd	16.1 cdef	15.9 defg
T_6	17.1 ab	17.1 ab	17.3 a	16.9 abc	15.4 efghi
LSD value = 0.8478 at alpha = 0.050					
			(c) Accession 011320		
T_{0a}	10.4 qr	10.7 pqr	10.9 opq	10.8 opqr	11.3 no
T_1	13.1 hi	14.3 ef	12.2 kl	12.4 jkl	11.9 lm
T_2	12.3 kl	13.2 hi	12.7 ijk	13.3 gh	12.9 hij
T_3	16.3 b	17.1 a	16.4 b	16.5 b	16.7 ab
T_{0b}	10.9 opq	10.3 r	11.2 nop	11.3 no	11.1 nop
T_4	13.9 fg	14.5 e	11.3 no	11.3 no	11.4 mn
T_5	13.3 gh	13.1 hi	14.2 ef	13.3 gh	13.1 hi
T_6	15.1 d	15.7 c	14.1 ef	14.2 ef	14.1 ef
LSD value = 05464 at alpha = 0.050					
			(d) Accession 011393		
T_{0a}	15.9 qrst	15.3 rstu	15.1 stu	14.9 tu	14.7 u
T_1	16.7 nopq	16.79 mnopq	16.8 mnopq	17.1 lmnop	16.9 mnopq
T_2	19.1 efgh	18.4 hijk	19.2 defgh	18.8 fghij	18.7 ghij
T_3	21.4 bc	23.1 a	21.7 b	19.9 def	20.3 cd
T_{0b}	16.1 pqrs	16.3 opqr	15.9 qrst	15.9 qrst	15.1 stu
T_4	17.2 lmnop	17.3 klmno	17.7 jklmn	16.9 mnopq	16.3 opqr
T_5	18.2 hijkl	18.9 fghi	17.9 ijklm	17.3 klmno	17.4 klmno
T_6	22.9 a	21.4 bc	20.1 de	20.3 cd	19.6 defg
LSD value = 1.155 at alpha = 0.050					

T_0a = control at booting, T_1 = water stress at booting, T_2 = ABA seed soaking (booting), T_3 = water stress at booting + ABA seed soaking, T0b = control at grain filling, T_4 = water stress at grain filling, T_5 = ABA seed soaking (grain filling), T_6 = water stress at grain filling + ABA seed soaking. d = days after induction of water stress. rw = rewatering.
All such means which share common letters do not differ significantly.

(6-9d) a small decrease was observed. Significantly higher leaf protein content was recorded in ABA-treated plants under water stress as compared to non-ABA-treated plants in all accessions. Rewatering did not result in any significant (P< 0.05) change in the protein content of leaves except for accession 011251 (Table 2a) which showed an increase in protein content, which was decreased under water stress condition at booting stage. Contrasting reports regarding the changes in protein contents are available in literature. Increasing water stress was found to cause a significant reduction in soluble protein content in moth beans (13) and *Vigna radiata* L. (11). The increase in total soluble proteins under water stress in some accessions and decrease in others is consistent with previous findings (8, 30, 36) water stress increased some soluble proteins and decreased others.

Chlorophyll content

At booting stage under induced water stress minimum reduction in chlorophyll content was observed in accession 011417 (Table 3b) and accession 011393 (Table 3d) and maximum decrease was recorded in accession 011320 (Table 3c). This reduction was slow within first 3 days of water stress (with 15 % decrease), which increased linearly (29 - 39%) from 6-9 days of water stress. Rewatering was unable to restore the chlorophyll content in accession 011320 (Table 3c) while a slight recovery was noted in other accessions. ABA seed soaking under unstressed condition had no effect on chlorophyll content in all accessions except for 011320 (Table 3c) which exhibited an increase (4-5 %) in chlorophyll content. Under water stress condition, ABA seed soaking treatment was able to partially ameliorate the adverse effects of water stress in accession 011251 (Table 3a) and 011320 (Table 3c), while in case of accession 011417 (Table 3b) and 011393 (Table 3d) ABA had no significant (P< 0.05) effects. Changes in chlorophyll content during grain filling stage followed the pattern similar to that of booting stage but total chlorophyll content was significantly (P< 0.05) less at grain filling as compared to that of booting stage. Chlorophyll content is often measured in plants to assess the impact of environmental stress, as changes in pigment content are linked to visual symptoms of plant illness and photosynthetic productivity (27). Similar to the previous results (34), the limitation of water supply induced faster chlorophyll degradation in present experiment. Chlorophyll loss is always associated with reductions in photosynthesis (4). In general water stress is known to decrease chlorophyll content at all growth stages (37). Inhibitory effects of water stress on chlorophyll content were also suggested by many researchers (10, 31, 32). Both reduction in the formation of chlorophyll (7) and increase in breakdown under water stress (6) contributed towards the reduction of chlorophyll under water stress. Increased formation of ROS due to environmental stresses could also be a cause, which is involved in the oxidation of photosynthetic

Table 3. Effect of water stress and abscisic acid (ABA) on chlorophyll content mg/g) of leaves at booting and grainfilling stages of wheat accessions.

Treatments	3d	6d	9d	48h (rw)	72h (rw)
			(a) Accession 011251		
T_{0a}	2.93 abc	2.94 ab	2.94 ab	2.95 ab	2.91 abc
T_1	2.4 efg	2.32 gh	1.98 kl	2.01 jkl	2.12 ij
T_2	2.95 ab	2.94 abc	2.95 ab	2.93 abc	2.96 a
T_3	2.52 de	2.48 def	2.09 ijk	2.11 ijk	2.21 hi
T_{0b}	2.83 abc	2.87 abc	2.84 abc	2.89 d	2.8 c
T4	2.33 gh	2.21 hi	1.88 l	1.99 jkl	2.09 ijk
T_5	2.82 bc	2.82 bc	2.85 abc	2.88 abc	2.87 abc
T_6	2.35 fg	2.21 hi	1.91 l	2.01 jkl	2.16 l
LSD value = 0.136 at alpha = 0.050					
			(b) Accession 011417		
T_{0a}	3.19 a	3.1 cde	3.18 ab	3.15 abc	3.17 ab
T_1	2.87 j	2.72 klm	2.61 o	2.67 no	2.82 j
T_2	3.18 ab	3.17 ab	3.12 bcd	3.17 ab	3.1 cde
T_3	2.85 j	2.74 klm	2.65 no	2.7 lmn	2.81 j
T_{0b}	3.02 gh	3.01 h	3.05 efgh	2.97 l	3.07 efg
T_4	2.74 kl	2.65 no	2.5 p	2.49 p	2.71 klm
T_5	3.04 fgh	3.03 gh	3.09 def	3.01 h	3.05 efgh
T_6	2.77 k	2.63 o	2.53 p	2.54 p	2.69 mn
LSD value = 0.0514 at alpha = 0.050					
			(c) Accession 011320		
T_{0a}	2.13 fgh	2.17 cdef	2.14 efgh	2.19 cde	2.1 gh
T_1	1.82 k	1.53 n	1.3 p	1.3 p	1.35 op
T_2	2.22 abc	2.22 abc	2.25 ab	2.2 bcd	2.27 a
T_3	1.91 j	1.72 l	1.5 n	1.55 n	1.62 m
T_{0b}	2.02 i	2.03 l	2.09 h	1.99 i	2.01 i
T_4	1.62 m	1.32 p	0.99 r	1.03 r	1.14 q
T_5	2.13 fgh	2.14 efgh	2.15 defg	2.13 fgh	2.15 defg
T_6	1.77 kl	1.61 m	1.38 o	1.39 o	1.35 op
LSD value = 0.01817 at alpha = 0.050					
			(d) Accession 011393		
T_{0a}	3.21 bc	3.15 de	3.14 ef	3.2 bcd	3.16 cde
T_1	2.9 m	2.69 opq	2.64 qr	2.65 pqr	2.8 n
T_2	3.29 a	3.24 ab	3.23 b	3.25 ab	3.25 ab
T_3	2.92 lm	2.71 o	2.7 op	2.71 o	2.95 klm
T_{0b}	2.97 jkl	3.07 ghi	3.02 ij	2.99 jk	3.05 hi
T_4	2.81 n	2.62 r	2.32 u	2.51 s	2.67 opqr
T_5	3.11 efg	3.09 fgh	3.11 efg	3.08 gh	3.09fgh
T_6	2.84 n	2.67 opqr	2.4 t	2.55 s	2.7 op
LSD value = 0.05140 at alpha = 0.050					

T_0a = control at booting, T_1 = water stress at booting, T_2 = ABA seed soaking (booting), T_3 = water stress at booting + ABA seed soaking, T_0b = control at grain filling, T_4 = water stress at grain filling, T_5 = ABA seed soaking (grain filling), T_6 = water stress at grain filling + ABA seed soaking. d = days after induction of water stress. rw = rewatering.
All such means which share common letters do not differ significantly.

pigments (1). ABA is also supposed to maintain high chlorophyll and carotenoid contents, the reason could be the increased stability of pigments by ABA (12) by increasing the activities of antioxidant and osmolytes as evident from the present investigation.

Carotenoid content

Carotenoid content (Table 4) was reduced significantly ($P < 0.05$) in all accessions due to imposition of water stress. At grain filling stage the leaf

Table 4. Effect of water stress and abscisic acid (ABA) on carotenoid content (µg/g) of leaves at booting and grainfilling stages of wheat.

Treatments	3d	6d	9d	48h (rw)	72h (rw)
			(a) Accession 011251		
T_{0a}	625.1 g	630.2 ef	631.4 def	629.5 f	634.1 bcde
T_1	600.7 k	572.3 o	550.4 s	558.2 qr	585.2 m
T_2	641.2 a	635.3 bcd	641.3 a	636.2 bc	637.7 ab
T_3	610.2 j	585.3 m	563.7 p	579.9 n	590.4 l
T_{0b}	620.3 h	619.4 hi	617.6 hi	615.7 i	619.5 hi
T4	592.3 l	570.2 o	547.3 s	555.2 r	578.2 n
T_5	632.1 cdef	629.2 fg	628.4 fg	630.5 ef	631.1 def
T_6	602.1 k	580.2 n	561.2 pq	570.7 o	581.1n
LSD value = 3.959 at alpha = 0.050					
			(b) Accession 011417		
T_{0a}	738.2 cde	741.3 cd	735.5 ef	736.9 de	737.4 de
T_1	692.1 k	681.2 lm	660.4 o	671.3 n	680.2 m
T_2	743.2 c	749.3 ab	751.2 ab	748.3 b	754.2 a
T_3	703.2 j	695.4 k	679.2 m	685.9 l	693.2 k
T_{0b}	725.7 hi	734.5 ef	724.9 hi	727.5 gh	721.9 i
T_4	681.7 lm	670.9 n	653.7 p	660.2 o	669.1 n
T_5	732.7 ef	734.9 ef	735.1 ef	730.9 fg	735.3 ef
T_6	691.1 k	682.1 lm	669.2 n	673.1n	681.1lm
LSD value = 4.853 at alpha 0.050					
			(c) Accession 011320		
T_{0a}	550.2 c	543.7 de	551.3 c	550.9 c	541.9 ef
T_1	510.1 i	492.2 k	460.1 no	462.1 no	469.2 m
T_2	569.1 a	567.2 a	560.8 b	561.2 b	559.9 b
T_3	519.9 h	502.7 j	485.9 l	492.2 k	497.9 j
T_{0b}	540.1 efg	539.9 efg	535.7 g	537.2 fg	536.3 g
T_4	501.1 j	481.2 l	452.9 p	453.1 p	457.2 op
T_5	551.1 c	549.2 c	547.3 cd	550.4 c	548.2 cd
T_6	510.1 i	484.2 l	463.2 n	469.1 m	471.2 m
LSD value = 4.722 at alpha = 0.050					
			(d) accession 011393		
T_{0a}	758.2 f	761.3 def	765.3 c	760.9 def	764.4 cd
T_1	721.2 k	713.4 m	699.3 pq	707.6 o	719.3 kl
T_2	769.9 b	772.1 ab	774.5 a	770.7 b	771.9 ab
T_3	739.7 i	730.2 j	710.1 no	719.4 kl	728.2 j
T_{0b}	750.3 h	754.9 g	753.9 g	754.7 g	751.8 gh
T_4	717.6 l	708.8 o	685.2 r	697.2 q	718.3 kl
T_5	759.7 ef	761.9 cde	764.4 cd	760.7 ef	762.2 cde
T_6	720.9 kl	712.1 mn	682.2 r	702.1 p	721.7 k
LSD value = 3.098 at alpha = 0.050					

T_0a = control at booting, T_1 = water stress at booting, T_2 = ABA seed soaking (booting), T_3 = water stress at booting + ABA seed soaking, T_0b = control at grain filling, T_4 = water stress at grain filling, T_5 = ABA seed soaking (grain filling), T_6 = water stress at grain filling + ABA seed soaking. d = days after induction of water stress. rw = rewatering.
All such means which share common letters do not differ significantly.

carotenoid content was significantly (P< 0.05) lower as compared to that of booting stage. At both stages i.e. booting and grain filling, minimum decrease in carotenoid content was found in accession 011393 (Table 4d), which had maximum carotenoid content in leaves at all stages except 3 day after the start of water stress treatment at booting stage. At this stage lowest decrease in carotenoid content was found in accession 011251 (Table 4a). On rewatering carotenoid content recovered over the stressed plants in all accessions. Maximum recovery was recorded in accession 011393 (Table 4d) whereas, minimum recovery was observed in accession 011320 (Table 4c). ABA seed soaking treatment had significant (P< 0.05) effect on carotenoid content under control as well as water stress treatment. But magnitude of this effect differed among the accessions. Under both control and stress conditions maximum response to ABA seed soaking was observed in accession 011320 (Table 4c) at both stages. Carotenoids are also responsible for scavenging of singlet oxygen (18) and hence their comparative levels in a genotype will determine its relative tolerance and the decrease in carotenoid under water stress during present investigation might also have contributed to increased ROS which further oxidized the photosynthetic pigments. Higher chlorophyll and carotenoid contents have been reported in the tolerant genotypes earlier (19). So higher chlorophyll and carotenoid contents in accession 011393 (Table 3d and 4d) and accession 011417 (Table 3b and 4b) might induce tolerance in these accessions and lower chlorophyll and carotenoid content in accession 011320 (Table 3c and 4c) could be one of the reasons of its susceptibility.

CONCLUSION

Present investigation reveals that inhibitory effects of water stress on plant at booting and grain filling stages of wheat can be alleviated by exogenous application of ABA used as seed soaking particularly in relatively sensitive wheat accessions. Effect of ABA appears stage specific and booting stage was found to be more responsive. The possible reason may be that the effects of ABA seed soaking diminished with the developmental changes. Considerable variation in terms of physiological responses to water stress exists in local germplasm which may be used in breeding programmes. On biochemical basis accession 011417 was found to be the most tolerant to water stress and least responsive to exogenous ABA, while accession 011320 was the most sensitive and responsive to ABA. Adverse effects of water stress on biochemical attributes became more pronounced at grain filling as compared to booting stage.

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