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FULL LENGTH ARTICLE

Improvement of wheat yield grown under drought stress by boron foliar application at different growth stages

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Abstract Two field experiments were conducted to determine the effect of boron foliar application and water stress on yield of wheat plant grown in calcareous soil during 2013/2014 and 2014/2015 seasons. The highest mean values obtained against boron application time were potential contributor to total grains mass by improving the plant height (99.42 and 98.32 cm), spike length (11.86 and 11.72 cm), number of spikelets m^{-2} (332.65 and 324.35), grain yield $plant^{-1}$ (21.56 and 20.26 g), 1000-grain weight (35.2 and 37.4 g) and grain yield (1.87 and 1.85 ton $fed.^{-1}$), which were recorded at normal irrigation level (100% from the amount of water consumption for wheat) with boron spraying at booting stage (B_1) in the first and second seasons, respectively. Furthermore, boron application significantly enhanced all studied growth traits under water stress levels (50% from the amount of water consumption for wheat) compared to B-untreated plants. Boron spraying at booting stage enhances also plant pigments contents recording its highest mean values under normal water level (100% from the amount of water consumption for wheat). The reduction in stress markers (proline and H_2O_2) and the enhancement of plant pigments content under water stress levels (50% from the amount of water consumption for wheat) by B spraying suggests an alleviating effect of boron foliar application to water stress in the test plant. This alleviating effect was more pronounced when B applied at booting stage. Therefore, booting stage was found to be the best time for boron application to get higher grains production and consequently, better economic returns of wheat.

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1. Introduction

In Egypt, wheat is one of the oldest and most important cereal crops. Although wheat production per unit area in Egypt has significantly increased during the past years, it still does not supply enough amount for annual domestic demand. During 2011–2012, wheat was shown on an area of 3 million fedan (1.26 million ha^{-1}) in Egypt. The total production of wheat was 8.82 million tons with an average yield of 7 tons ha^{-1} (Anonymous, 2012). Most importantly, Egypt is still one of the largest countries that import wheat. Therefore, increasing wheat productivity occupies a central position in forming agricultural policies. The lacking ability of Egypt to produce sufficient wheat for domestic consumption is attributed to many factors, since poor fertility status of the soil and improper crop management practices are of primary significance. Production of wheat can be increased either by bringing more area under cultivation or by increasing its yield per unit area. In the current situation, it is hard to increase its area under cultivation due to restriction of irrigation water supply and competition with other crops on the cultivated lands. Hence, the most practical approach for increasing wheat production in the country is to obtain higher yield per unit area.

Many environmental stresses are responsible for low grain yield of wheat including drought, high temperature, salinity and insufficient nutrients availability (Subedi et al., 2000). Soils of Egypt are generally alkaline and calcareous soils that usually have some problems associated with poor water retention and low contents of available essential nutrients. It is well known that newly reclaimed soil is often very poor in macro- and micronutrient elements. Micronutrients deficiency is one of the most important biotic stresses in plants grown on calcareous soils (Xudan, 1986).

Boron is known to play different roles in plant vital activities such as cell division, elongation in meristematic tissues, membrane integrity, cell wall formation, leaf expansion, water relations, ion absorption, IAA and carbohydrates metabolism in addition to translocation of sugars and its deficiency may affect all these processes (Marschner, 1995; Gupta and Solanki, 2013; Da Rocha Pinho et al., 2015). Indeed, the key role of boron in plants includes floral organs and flower male fertility, pollen tube growth and utilization of carbohydrates (Blevins and Lukaszewski, 1998). Therefore, the unavailability of boron during grain setting period results in poor anther and pollen development (Cheng and Rerkasem, 1993) and the grain thus formed is often without starch (Dell and Huang, 1997). In the field, sexual reproduction is often more affected by low boron and significant grain yield reductions may occur without visual symptoms expressed during vegetative growth.

According to Dell and Huang (1997) vegetative development of wheat is relatively insensitive to B deficiency. However, lack of B during reproductive development can cause devastating yield loss through sterility (Rawson, 1996; Subedi et al., 1997a, 1997b). The mechanism by which B deficiency induces sterility of wheat includes the poor development of anthers and pollen as well as pollen germination failure (Cheng and Rerkasem, 1993; Rerkasem et al., 1993). It is believed that B deficiency affects pollen development during the pollen mother cell stage which coincides with the booting stage (Growth stage (GS) 45 (Rerkasem et al., 1993). Although it is known that B supply in the stigma and style is important to pollen germination in maize little is available for wheat even though reports of B deficiency in wheat, especially in warmer areas, are becoming more common (Mann and Perkasem, 1992).

The sterility induced by inadequate boron supply in wheat is of major concern in boron deficient soils (Shorrocks, 1997). Therefore, the problem can be handled by ensuring the continuous exogenous boron supply during reproductive development. However, calcareous soil has a serious problem concerning the rapid fixation of applied nutrients, including boron, when added to the soil (Majidi et al., 2010). Keeping this in view, the present study was therefore, designed to determine the effect of foliar application of boron at different growth stages in wheat. Consequently, foliar B application could be suggested as one cost effective solution to the problem of severe yield loss due to boron deficiency in commercially grown wheat crops when grown in water stressed under calcareous soils.

2. Materials and methods

2.1. Experimental design

Two field experiments were carried out in the Agricultural Experiment Station Farm of Assiut University (El-Wady El-Assiuty Agric. Farm), Assiut, Egypt, in 2013/2014 and 2014/2015 seasons to investigate the response of wheat (*Triticum aestivum* L.) to foliar application of boron in two growth stages under different water levels. The physical and chemical properties of experimental site are shown in Table 1.

The randomized complete block design using strip-plot arrangement with three replicates was adopted. Three irrigation levels (I_1 = 50%, I_2 = 75% and I_3 = 100% from the amount of water consumption for wheat) were arranged in main strip, while foliar application of boron (50 ppm) in two growth stages was laid in subplot. Boron foliar applications were sprayed at booting growth stage (B_1) or at anthesis stage (B_2), while (B_0) includes wheat plants sprayed with distilled water that was used as control. The difference among the wheat growth stages was made by using Feeks scale (Hanft and Wych, 1982).

Phosphorous fertilizer was applied in the form of calcium superphosphate (15.5% P_2O_5) at the rate of 31 kg P_2O_5 $fed.^{-1}$ during soil preparation. Nitrogen in the form of ammonium nitrate (33.5% N) at the rate of 100 kg N $fed.^{-1}$ was added in two equal doses after one month and two months later. Potassium fertilizer in the form of potassium sulfate (48% K_2O) at the rate of 24 kg K_2O $fed.^{-1}$ was added in two equal doses. The preceding crop was sorghum in both seasons. The area of each subplot was 10.5 m^2 (3.5 m length × 3 m width). Sowing was carried out on the 2nd and 4th of December in the first and second seasons, respectively. Sprinkler irrigation system used underground water followed by 60 mints of I_1 = 50%, 90 mints of I_2 = 75% and 120 mints of I_3 = 100% every 3 days. The amount of water consumption for wheat at Assiut government used I_1 = 2000, I_2 = 1500 and I_3 = 1000 m^3 $fed.^{-1}$ according to Abdel-Mawgoud et al. (2007), El-Koliey et al. (2001) and Mohamed (2007).

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Table 1 Some physical and chemical properties of representative soil samples in the experimental site before sowing (0–30 cm depth) in 2014 and 2015 seasons.

Soil property	2014[a]	2015[a]
Particle size distribution		
Sand (%)	84.4	86.5
Silt (%)	8.7	7.3
Clay (%)	6.9	6.2
Texture grade	Sandy	Sandy
EC (1:1 extract) dSm^{-1}	1.66	1.74
pH (1:1 suspension)	8.34	8.26
Total $CaCO_3$ (%)	20.26	19.85
Organic matter (%)	0.097	0.095
Soluble cations		
Ca^{++} (meq/l)	8.32	8.63
Mg^{++} (meq/l)	5.36	5.46
Na^{+} (meq/l)	1.86	1.75
K^{+} (meq/l)	0.22	0.23
Soluble anions		
$CO_3^{--} + HCO_3^{-}$ (meq/l)	7.65	8.29
Cl^{-} (meq/l)	6.25	6.65
$NaHCO_3$-extractable P (ppm)	5.54	6.64
NaOAC-extractable K (ppm)	52.45	50.23
Total nitrogen (%)	0.018	0.019
KCl-extractable N (ppm)	28.26	30.64
DTPA-extractable Zn (ppm)	1.83	1.80
DTPA-extractable Mn (ppm)	0.26	0.27
DTPA-extractable Cu (ppm)	1.19	1.18

[a] Each value represents the mean of three replications.

2.2. Measured yield parameters

At harvest, ten guarded wheat plants were chosen randomly for each subplot and plant height, spike length, number of spikelets m^2, grain yield $plant^{-1}$, 1000-grain weight were recorded. One meter for each plot was harvested to determine the grain yield per $meter^2$ and then it was converted into ton $fed.^{-1}$.

2.3. Analytical methods

After 120 days from planting, three flag leaves and root tissues from each subplot were sampled. The roots were only briefly rinsed with deionized water and blotted gently with filter paper. For fresh tissue analysis, the leaves and roots were quickly weighed and immediately frozen in liquid nitrogen and stored at -80 °C for further analysis.

2.3.1. Determination of photosynthetic pigments

The photosynthetic pigments, *via,* chlorophyll a, chlorophyll b and carotenoids were estimated using the spectrophotometric method according to Lichtenthaler (1987). The photosynthetic pigments were extracted from a definite fresh leaf sample in 5 ml of 95% ethyl alcohol in a test tube at 60 °C, until colorless. Then the total volume completed into 10 ml with 95% ethyl alcohol and absorbance readings were determined with a spectrophotometer (Unico UV-2100 spectrophotometer). Chlorophylls and carotenoid concentrations were calculated as mg/g FW at 663, 644 and 452 nm.

2.3.2. Determination of proline

Proline was measured in extracts, which was prepared by grinding plant material (root and leaves samples) with mortar pestle using liquid nitrogen in 3% (w/v) sulfosalicylic acid. Proline was determined as described by Bates et al. (1973), and about 0.3 g root tissue and 0.6 g of leaves were homogenized in 1.5 ml 3% sulfosalicylic acid followed by centrifugation at 10,000 rpm for 10 min. One ml of the supernatant was mixed with 1 ml ninhydrin reagent (250 mg ninhydrin, 20 ml glacial acetic acid, 30 ml 6 M phosphoric acid, dissolved under shaking and slight heating) and boiled in water bath for 1 h. The developed color was extracted in 2 ml toluene and measured colorimetrically at 520 nm against toluene. A standard curve with proline was used for the final calculations.

2.3.3. Determination of H_2O_2

The H_2O_2 content of the shoots and roots samples was colorimetrically measured as described by Mukherjee and Choudhuri (1983). To determine H_2O_2 level, shoot 0.1 g and root 0.2 g samples were extracted with cold acetone. An aliquot (3 ml) of the extracted solution was mixed with 1 ml of 0.1% titanium dioxide in 20% (v:v) H_2SO_4 and the mixture was centrifuged at 6000 rpm for 15 min. The intensity of yellow color of the supernatant was measured at 415 nm. The concentration of H_2O_2 was calculated from a standard curve plotted with known concentration of H_2O_2 and expressed as mg/g FW.

2.4. Statistical analysis

The results were statistically analyzed according to Gomez and Gomez (1984), using the computer MSTAT.C statistical analysis package by Freed et al. (1989). The least significant differences (L.S.D.) at probability level of 5% were manually calculated comparing the differences among means.

3. Results and discussion

3.1. Agronomy traits

3.1.1. Effect of water deficit

The presented data (Table 2) revealed that all studied traits were significantly affected by water deficit in the both seasons. Normal irrigation level ($I_3 = 100\%$) produced the highest mean values of some studied traits, while water stress treatment ($I_1 = 50\%$) showed the lowest one.

The highest mean values of plant height (96.70 and 93.99 cm), spike length (11.71 and 11.43 cm), number of spikelets (327.81 and 319.64 spikelets m^{-2}), grain yield $plant^{-1}$ (19.92 and 18.91 g), 1000-grain weight (35.13 and 35.30 g) and grain yield (1.85 and 1.85 ton $fed.^{-1}$) were obtained by adding the normal irrigation level ($I_3 = 100\%$); however, the lowest mean values were recorded for the plants that received the lowest irrigation level ($I_1 = 50\%$) in the first and the second seasons, respectively.

The inhibitory effect of water stress on plant growth could be attributed to the following: (1) osmotic cellular responses to the decreased availability of soil water (Salter et al., 2007), (2) increased energy demand in stressed plants that induced an increase in plant respiration (Moud and Maghsoudi, 2008),

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Table 2 Effect of water stress and boron application time and its interaction with wheat traits grown in 2014 and 2015 seasons.

Irrigation treatments		Plant height (cm)								Spike length (cm)							
		2014				2015				2014				2015			
		B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
I_1 = 50%		62.13	71.34	68.23	67.23	60.42	70.93	65.63	65.66	9.26	10.54	9.65	9.82	9.14	10.25	9.25	9.55
I_2 = 75%		88.65	94.54	89.25	90.81	86.16	94.44	88.62	89.74	10.42	11.54	10.64	10.87	9.84	11.07	9.96	10.29
I_3 = 100%		94.26	99.42	96.42	96.70	90.42	98.32	93.24	93.99	11.54	11.86	11.72	11.71	11.24	11.72	11.32	11.43
Mean		62.13	71.34	68.23		79.00	87.90	82.50		10.41	11.31	10.67		10.07	11.01	10.18	
LSD 0.05	*I*	4.26				3.24				0.34				0.46			
	B	2.64				4.13				0.12				0.13			
	Int.	4.35				3.67				0.72				0.064			
		Number of spikelets (m^2)								Grain yield plant^{-1} (g)							
I_1 = 50%		277.24	290.35	278.32	281.97	274.22	289.45	275.13	279.60	13.65	15.34	14.96	14.65	12.25	15.34	14.24	13.94
I_2 = 75%		293.54	312.43	296.34	300.77	290.15	313.52	292.23	298.63	16.25	18.62	17.34	17.40	15.45	17.84	16.64	16.64
I_3 = 100%		324.25	332.65	326.54	327.81	316.32	324.35	318.24	319.64	18.87	21.56	19.32	19.92	18.12	20.26	18.74	18.91
Mean		298.34	311.81	300.40		293.56	309.11	295.20		16.26	18.51	17.21		15.17	17.81	16.54	
LSD 0.05	*I*	22.42				19.84				1.35				1.26			
	B	1.56				1.22				1.24				1.13			
	Int.	25.26				36.24				2.16				1.89			
		1000-grain weight (g)								Grain yield (ton fed.$^{-1}$)							
I_1 = 50%		27.50	29.50	28.60	28.53	25.20	27.30	26.60	26.37	1.32	1.57	1.44	1.44	1.38	1.67	1.40	1.48
I_2 = 75%		31.30	33.60	32.50	32.47	31.20	36.20	32.40	33.27	1.54	1.82	1.63	1.66	1.51	1.78	1.53	1.61
I_3 = 100%		33.60	35.20	35.10	35.13	33.20	37.40	35.30	35.30	1.84	1.87	1.84	1.85	1.83	1.85	1.84	1.85
Mean		30.80	32.77	32.07		29.87	33.63	31.43		1.57	1.75	1.64		1.57	1.77	1.59	
LSD 0.05	*I*	2.31				1.42				0.13				0.14			
	B	0.12				0.64				0.14				0.12			
	Int.	1.24				1.12				0.23				0.21			

(3) low photosynthesis (Cramer et al., 1994) and (4) reduced rate of cell division, expansion and enlargement by increasing stiffness of cell wall (Zhu et al., 2004; Baek et al., 2005).

3.1.2. Effect of boron application time

Data presented in Table 2 showed that the mean values of all studied traits obtained against boron application time were potential contributor to total grain mass by improving the plant height, spike length, number of spikelets m^{-2}, grain yield $plant^{-1}$, 1000-grain weight and grain yield ton $fed.^{-1}$.

The highest mean values of plant height (71.34 and 87.90 cm), spike length (11.31 and 11.01 cm), number of spikelets (311.81 and 309.11 spikelets m^{-2}), grain yield $plant^{-1}$ (18.51 and 17.81 g), 1000-grain weight (32.77 and 33.63 g) and grain yield (1.75 and 1.77 ton $fed.^{-1}$) were obtained by boron spraying at booting stage (B_1) as compared to the plants sprayed with distilled water (B_0), in the first and second seasons, respectively. This enhancement in plant growth traits due to B application in booting stage indicates the importance of B in nitrogen and phosphorus usage by plants and subsequently, its role in increasing grain yield (Ahmed, 2001).

These inferences are in accordance with Gunnes et al. (2003), who reported that wheat growth and grain yield increase due to B application at the reproductive stage are more than any other stages. The enhanced wheat crop yield by B spraying at booting stage may be due to provision of B at initial stages which might have enhanced the accumulation of assimilate in the grains (Arif et al., 2006). Furthermore, Cheng and Rerkasem (1993) reported that grain set failure in wheat, caused by B deficiency, is associated with poorly developed pollen and anthers. The higher crop yield under B application is the result of positive role of B in pollen grain formation, pollen tube formation, grain set, pollination, flower set and pollen grains viability at booting stage (Subedi et al., 1997a). Uddin et al. (2008) noticed that boron application at booting stage improves the grain setting by improving the grain filling process and reducing the male sterility often observed in boron deficient condition.

3.1.3. Effect of the interaction between water deficit and boron application time

Data presented in Table 2 revealed that the interaction between water stress and boron application time had a significant effect on all of the studied traits. The highest mean values of plant height (99.42 and 98.32 cm), spike length (11.86 and 11.72 cm), number of spikelets (332.65 and 324.35 spikelets m^{-2}), grain yield $plant^{-1}$ (21.56 and 20.26 g), 1000-grain weight (35.20 and 37.4 g) and grain yield (1.87 and 1.85 ton $fed.^{-1}$) were recorded for the plants that received the normal irrigation level ($I_3 = 100\%$) and sprayed with boron at booting stage (B_1) in the first and second seasons, respectively.

Under normal irrigation I_3 (100%), as the applied boron has a key role in plant metabolism, root growth will be increased and by better use of nitrogen, synthesis of more carbohydrates and proteins, plants use water more efficiently (Ahmed, 2001).

These results are in harmony with those reported by Bellaloui (2011) and Rehman et al. (2012) who recorded that boron application produced statistically higher figures for spike length, number of grain and 100-grain weight, grain mass and biological yield over the control treatment. The role of B in flower set, fruit set, seed set, and seed quality was reported in many species (Brown et al., 2002; Dell et al., 2002). Recently, it was found that foliar B application improved seed protein and seed oleic fatty acid (Bellaloui et al., 2010), seed yield and seed quality of alfalfa (Dordas, 2006).

The major function of boron is in sugar transport to meristematic regions. This is evidenced by the fact that transport of sugars is retarded in boron-deficient plants, resulting in reduced growth. Therefore, boron is considered to be essential for actively growing regions of plants, such as root tips, new leaf, pollen grains and bud development. Boron is also thought to be involved in cell formation and development, flower fertilization, active salt absorption, hormone development, fat, nitrogen and phosphorus metabolism and photosynthesis (Ahmed, 2001).

3.2. Physiological traits

3.2.1. Effect of water deficit

The presented data (Table 3) showed that all of the studied traits were significantly affected by water regime in the both seasons. Concentration of plant pigments (chlorophyll a, chlorophyll b and carotenoids), proline and H_2O_2 (as stress indicators) was determined in response to the studied water levels. The highest mean values of chlorophyll a (29.01 and 28.01 mg g^{-1} FW) and chlorophyll b (9.30 and 9.48 mg g^{-1} FW) were obtained by adding normal irrigation level ($I_3 = 100\%$) in the first and second seasons respectively. On the other hand, the highest mean values of carotenoids (11.40 and 11.37 mg g^{-1} FW), proline in leaves (1.79 and 1.90 mg g^{-1} FW) and roots (0.26 and 0.22 mg g^{-1} FW), H_2O_2 in leaves (4.46 and 4.46 mg g^{-1} FW) and roots (0.22 and 0.22 mg g^{-1} FW) were recorded under the condition of water stress (irrigation level $I_1 = 50\%$) in the first and second seasons respectively.

The reduction in chlorophyll content as one of the most important limiting factors for plant photosynthetic activity under stress conditions was recorded by many other studies (Abdelkader et al., 2007). In this regard, Quaratacci and Navari-Izzo (1992) mentioned that the decrease in chlorophyll content may be the result of the changes in the integrity and composition of the chloroplast membranes. Several evidences indicate that there are changes in the photosynthetic pigments and mechanism in the chloroplasts and those changes in the ultra structure may occur under water stress (Hale and Crcutt, 1979).

In accordance with our results, Ali et al. (1999) and Tonon et al. (2004) found that proline content in test plants under osmotic stress was higher than unstressed plants. The accumulation of cytoplasmic osmotica such as proline, protects the cell by balancing the osmotic pressure of cytosol with that of vacuole and external environment, which in turn, protects cellular compartments from injury caused by dehydration or maintaining turgor pressure during water stress (Hasegawa et al., 2000; Karamanos et al., 2000; Ashraf and Foolad, 2007). On the other hand, it is now well evident that abiotic stress is known to increase the production of reactive oxygen species (ROS) such as H_2O_2, by enhanced leakage of electrons from electron transport chains to molecular oxygen in the chloroplasts and mitochondria (Hernandez et al., 2001). Stress-generated ROS

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Table 3 Effect of water stress and boron application time and its interaction with some physiological traits of wheat grown in 2014 and 2015 seasons.

Irrigation treatments		Chl. a (mg g^{-1} FW)								Chl. b (mg g^{-1} FW)							
		2014				2015				2014				2015			
		B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
I_1 = 50%		20.13	24.83	22.75	22.57	19.89	24.66	22.35	22.30	6.44	7.41	5.14	6.33	5.98	7.24	5.42	6.21
I_2 = 75%		23.65	26.60	23.86	24.70	23.72	26.53	23.56	24.60	6.64	8.93	6.34	7.30	6.36	8.87	7.92	7.72
I_3 = 100%		27.34	31.08	28.62	29.01	26.78	31.42	25.82	28.01	7.85	12.5	7.54	9.30	8.27	11.9	8.27	9.48
Mean		23.71	27.50	23.08		23.46	27.54	23.91		6.98	9.61	6.34		6.87	9.34	7.20	
LSD 0.05	*I*	1.36				1.33				0.21				0.42			
	B	1.45				0.34				0.47				0.73			
	Int.	1.26				1.14				0.94				0.84			
		Carotenoids (mg g^{-1} FW)															
I_1 = 50%		11.02	12.43	10.74	11.40	10.93	12.77	10.4	11.37								
I_2 = 75%		11.17	11.11	11.07	11.12	11.75	11.34	10.95	11.35								
I_3 = 100%		10.91	11.79	11.14	11.28	10.89	11.82	11.12	11.28								
Mean		11.03	11.78	10.98		11.19	11.98	10.82									
LSD 0.05	*I*	0.16				0.02											
	B	0.21				0.28											
	Int.	0.13				0.14											
		Proline concentration of leaves (mg g^{-1} FW)								Proline concentration of roots (mg g^{-1} FW)							
I_1 = 50%		2.16	1.50	1.71	1.79	2.25	1.54	1.91	1.90	0.32	0.23	0.23	0.26	0.29	0.20	0.17	0.22
I_2 = 75%		0.93	1.02	0.83	0.93	0.87	1.68	0.83	1.13	0.22	0.18	0.17	0.19	0.24	0.14	0.16	0.18
I_3 = 100%		0.84	0.59	0.71	0.71	0.89	0.53	0.75	0.72	0.16	0.15	0.09	0.13	0.22	0.13	0.14	0.16
Mean		1.31	1.04	1.08		1.34	1.25	1.16		0.23	0.19	0.16		0.25	0.16	0.15	
LSD 0.05	*I*	0.24				0.13				0.02				0.02			
	B	0.11				0.22				0.02				0.01			
	Int.	0.67				0.72				0.01				0.01			
		H_2O_2 concentration of leaves (mg g^{-1} FW)								H_2O_2 concentration of roots (mg g^{-1} FW)							
I_1 = 50%		4.48	4.45	4.46	4.46	4.47	4.48	4.43	4.46	0.30	0.17	0.20	0.22	0.30	0.15	0.21	0.22
I_2 = 75%		4.47	4.45	4.44	4.45	4.46	4.43	4.43	4.44	0.28	0.15	0.18	0.21	0.29	0.15	0.19	0.21
I_3 = 100%		4.47	4.43	4.43	4.44	4.44	4.42	4.42	4.43	0.29	0.15	0.18	0.20	0.28	0.18	0.17	0.21
Mean		4.47	4.44	4.44		4.46	4.44	4.43		0.29	0.16	0.19		0.29	0.16	0.19	
LSD 0.05	*I*	0.02				0.01				0.01				0.01			
	B	0.03				0.02				0.02				0.03			
	Int.	–				–				0.01				0.004			

in mitochondria, chloroplasts and peroxisomes can destroy the normal metabolism through oxidative damage of lipids, proteins and nucleic acids (McCord, 2000), thereby ultimately damaging cell structure (Mittler, 2002).

3.2.2. Effect of boron application times

The presented data (Table 3) focus that all studied traits were significantly affected by boron application time in both seasons. The highest mean values of chlorophyll a (27.50 and 27.54 mg g^{-1} FW), chlorophyll b (9.61 and 9.34 mg g^{-1} FW) and carotenoids (11.78 and 11.98 mg g^{-1} FW) were obtained by spraying boron at booting stage (B_1) in the first and second seasons respectively. However, the highest mean values of proline in leaves (1.31 and 1.34 mg g^{-1} FW) and in roots (0.23 and 0.25 mg g^{-1} FW) and H_2O_2 concentration in leaves (4.47 and 4.46 mg g^{-1} FW) and in roots (0.29 and 0.29 mg g^{-1} FW) were obtained without B spraying (B_0) in the first and second seasons respectively. Supporting to our findings, boron deficiency was proved to decrease the rate of photosynthesis by reducing the efficiency of photosystem II (El-Shintinawy, 1999) or by lowering photosynthetic enzymes activities by excess hexoses, which lead to decrease in growth (Han et al., 2008).

Many studies suggested that B can act as a signaling molecule and play a regulatory role in plant physiology where B deficiency affects the expression level of genes related to oxidative stress (Kobayashi et al., 2004), nitrogen metabolism (Camacho-Cristóbal and González-Fontes, 2007), B uptake (Kasajima and Fujiwara, 2007), and cell wall physical properties (Camacho-Cristóbal et al., 2008). Kobayashi et al. (2004) concluded that, there is a rapid transfer of the signal from the cell wall to cytoplasm, which could be involved in gene induction that was generated as a result of redox imbalance, caused by deficiency of boron. However, proline and H_2O_2 accumulation in plant cell observed by Eraslan et al. (2007) and Gunes et al. (2006) as a result of higher boron concentrations in plant environment could be due to the very high boron contents that developed boron toxicity.

3.2.3. Effect of the interaction between water stress and boron application time

Data presented in Table 3 notice that all studied traits except H_2O_2 concentration of leaves were significantly affected by interaction between water stress and boron application time in the both seasons.

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The highest mean values of chlorophyll a (31.08 and 31.42 mg g^{-1} FW) and chlorophyll b (12.50 and 11.90 mg g^{-1} FW), in the first and second seasons respectively, were recorded in plants grown under normal irrigation level (I_3 = 100%) and sprayed with boron at booting stage (B_1). However, the highest mean values of proline in leaves (2.16 and 2.25 mg g^{-1} FW) and roots (0.32 and 0.29 mg g^{-1} FW) and H_2O_2 in roots (0.30 and 0.30 mg g^{-1} FW) were recorded in plants grown under water stress conditions (I_1 = 50%) and without boron spraying (B_0) in the first and second seasons respectively. These results are in harmony with those obtained for agronomy traits, where the best time for boron spraying was booting stage and the best water level was 100% from the amount of water consumption for wheat.

Furthermore, the results presented in Table 3 indicated that boron foliar application markedly reliefs water stress in test plant as inferred from the reduction in the mean values of the studied stress markers (proline and H_2O_2) in B treated plants (at booting stage = B_1, and anthesis stage = B_2) compared with the control (plants did not sprayed with B (B_0) under all studied irrigation levels). This stress relief was more pronounced when B was applied at booting stage. Supporting to our findings, González-Fontes et al. (2008) suggested that boron may act as a signal capable of interacting with cellular transcription factors to regulate various plant physiological processes affected by boron deficiency.

4. Conclusion

It is concluded that the mean values obtained against boron application time were potential contributor to total grain mass by improving the plant height, spike length, number of spikelets, grain yield $plant^{-1}$, 1000-grain weight and grain yield $fed.^{-1}$. Foliar boron application at booting stage (B_1) under normal irrigation level (I_3 = 100% from the amount of water consumption for wheat) gave the highest recorded values for all studied trades. Furthermore, our results confirm an alleviating effect of boron foliar application which markedly reliefs water stress in the test plant as inferred from the reduction in the mean values of the studied stress markers (proline and H_2O_2) and the enhancement of plant pigments (Chlorophyll a and Chlorophyll b) accumulation in B treated plants compared with the control plants under all studied irrigation levels. This stress relief increases wheat productivity under water stress levels (50% from the amount of water consumption for wheat) and was more effective when B was applied at booting stage.

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