



Seed treatment for improving wheat productivity under deficit irrigation conditions in arid environment

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Abstract

Climate change and frequent drought events in arid regions present challenges for crop production and food security in many parts of the world. Objectives of the present research were to enhance wheat plant tolerance to water stress by applying regulated irrigation deficit scheme and treating seeds with drought-tolerant substances. A field experiment was carried out to study the impact of three irrigation levels (severe, moderate, and full irrigation) and three seed treatments [control, soaking in salicylic acid (SAA), and soaking in ascorbic acid (ASA)] on yield and its attributes and water use efficiency (WUE) of wheat. Moderate water stress significantly decreased total photosynthetic pigments, grain number/spike, spike number/m² and grain yield, however, amounts of water saving by this deficit irrigation rate suggested a feasible option for wheat production in water limited environments without unacceptable yield reduction. Treating seeds with SAA or ASA significantly increased total photosynthetic pigments, relative water content, recovery efficiency, grain number/spike and grain yield compared with untreated seeds. The efficacy of deficit irrigation was increased by treating seeds with SAA which was demonstrated by the increased grain number/spike, grain yield/ha and WUE compared to untreated seeds. These results suggest beneficial effects of drought-tolerant substances on enhancing plants' ability to mitigate the negative water stress impacts.

Keywords: Deficit irrigation, seed treatment, ascorbic acid, salicylic acid, WUE, recovery efficiency

Introduction

Globally, water availability has become an issue in recent years (Smakhtin *et al.* 2004). The Mediterranean region is in prospect to undergo increases in drought occurrences (Robredo *et al.* 2007). Hoerling *et al.* (2012) added that the Mediterranean region has suffered from the change of winter Mediterranean precipitation towards drier conditions which occurred due to region's sensitivity to regular global ocean warming; therefore, Mansour *et al.* (2017) pronounced that crop production was influenced critically by water limitations in arid and semi-arid regions, like Egypt. Bread wheat (*Triticum aestivum* L.) is the most prominent strategic crop in Egypt. Egyptian daily nutritional requirements depend on bread wheat for more than thousands of years. Wheat water requirements are expected to increase by 9% in North Egypt (the Nile Delta) and 18% in both Middle and Upper Egypt in 2040 (Ouda *et al.*, 2016).

Irrigation with less than full crop water requirements termed as deficit irrigation (Attia *et al.* 2015), can be considered a chance to save water resources. Understanding the physiological, biochemical, and ecological obstructions related to drought stress is very important for better

management (Fahad *et al.* 2017). Over-synthesis of reactive oxygen species occurs in plant cells due to water deficit stress (Zhu, 2000). The increased reactive oxygen species levels lead to various cellular mechanisms that result in damage and death of the cell (Ishikawa *et al.* 2009).

Many studies for the influence of water deficit on wheat grain yield and water use efficiency concluded that the grain yield could be largely maintained, while substantial reduction in irrigation volume could be used (Zhang and Oweis, 1999; Abdelraouf *et al.* 2013; Said, 2016; Said and Abd El-Moneem 2016).

Salicylic acid (SAA) is an endogenous growth regulator that belongs to the phenol group that is operative in different plant processes, particularly related to photosynthesis and water relations (Khan *et al.* 2003 and El-Shafey 2017). Salicylic acid plays an important role in enhancing plant resistance to biotic and abiotic stresses (El Tayeb and Ahmed, 2010; Ding and Ding, 2020).

Ascorbic acid (ASA) plays a vital role in regulating cell cycle and in several essential processes of plant growth and development (El-Shafey, 2017) and protecting plant cells against reactive oxygen species effects (Smirnoff, 2000).

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The influence of SAA and ASA, through seed treatment or foliar spraying, on wheat growth, productivity and WUE as well as water saving was investigated by (Amin *et al.* 2008; El Tayeb and Ahmed 2010; Farooq *et al.* 2013; Kotb and Elhamahmy 2013; El Sayed and Mujahed 2015; Said, 2016; Said and Abd El-Moneem 2016).

Objectives of the present research were (i) to enhance wheat plants tolerance to water stress by applying regulated deficit irrigation scheme and treating seeds with drought-tolerant substances in arid environment, and (ii) to determine the best deficit irrigation rate that maximizes the marginal use of unit water applied without significant yield penalty.

Materials and Methods

A two-year field experiment was carried out at Abu-Hammad District, Sharkia Governorate, Egypt (30°32' N latitude, 31°36' E longitude and 74m above sea level), during two successive winter seasons of (2016/2017) and (2017/2018) to study the effect of three irrigation levels and

(1) shows the soil physical and chemical analyses of the experimental site.

Studied factors and Experimental design

A strip plot design with three replicates was used. Horizontal strips were allocated to irrigation levels and the vertical strips were allocated for pre-sowing seed treatments. There were three irrigation levels; severe i.e. 50% of wheat evapotranspiration (ET_c) (230 mm), moderate i.e., 75% ET_c (345 mm) and full i.e., 100% ET_c (460 mm). Irrigation scheduling for all treatments was based on crop evapotranspiration (ET_c) replacement according to the crop coefficient approach (Allen *et al.*, 1998). ET_c was calculated from the reference evapotranspiration ET_o and the FAO crop coefficients (K_c) for wheat (Allen *et al.*, 1998). ET_o was calculated as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Table 1: Physical and chemical analyses of the soil from experimental site (30 cm depth)

Soil characteristics	2016 / 2017	2017 / 2018
Soil particles size distribution		
Sand, %	48.76	48.59
Silt, %	12.79	13.10
Clay, %	38.45	38.31
Textural class	Sandy clay	Sandy clay
Field capacity (FC), %	15.72	15.69
CaCO ₃ , %	0.45	0.42
Organic matter, %	0.48	0.46
pH ¹	7.90	7.91
EC, (dS/m)	1.75	1.73
Soluble cations and anions, (mmolc/L) ²		
Ca ⁺⁺	5.87	5.72
Mg ⁺⁺	4.92	4.65
Na ⁺	3.41	3.37
K ⁺	3.30	3.56
CO ₃ ⁼	0.0	0.0
HCO ₃ ⁻	6.91	6.82
Cl ⁻	4.56	4.63
SO ₄ ⁼	6.03	5.85
Available nutrient, (mg /kg soil)		
N	20.45	20.62
P	11.45	11.32
K	159	161

¹Suspension of 1:2.5 soil : water

²Soil paste extract

Source: Soil Science Laboratory, Faculty of Agriculture, Zagazig University, Zagazig, Egypt

three seed treatments on grain yield, some of its attributes and water use efficiency of wheat cultivar "Shandaweel 1". The experimental field soil was sandy clay in texture. Table

Where:

ET_o = the daily reference evapotranspiration (mm day⁻¹),
 R_n = net radiation at the crop surface (MJ m⁻² day⁻¹),



G = soil heat flux density ($\text{MJ m}^{-2} \text{ day}^{-1}$),
 T = mean daily air temperature at 2 m height ($^{\circ}\text{C}$),
 U_2 = wind speed at 2 m height (m s^{-1}),
 e_s = saturation vapor pressure (kPa),
 e_a = actual vapor pressure (kPa),
 Δ = the slope of vapor pressure curve ($\text{kPa } ^{\circ}\text{C}^{-1}$),
 γ = the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$).

Climatic factors during the experimental period were collected from automated weather station allocated at the experimental location and are shown in Table 2.

ET_c was computed daily and irrigation water was added accordingly in five irrigation events distributed throughout the growing season to maintain the full water requirement for all treatments. Irrigation was terminated at the end of the growing season approximately one month before harvest shown in Table 3. A furrow irrigation system was used to deliver the targeted amount of irrigation water for each treatment and the discharge rate of the gate was estimated by using the formula of immersed orifice according to (James, 1988) as follows:

$$Q = 0.61 \times 0.443 \times A \sqrt{h} \quad (2)$$

Where:

Q =orifice discharge (Lsec^{-1}), A =area of orifice (cm^2),

h =effective water head over the orifice center (m).

Horizontal strips separated by an alley of 3 m wide. Bunds of 30 cm height were constructed along each side of the horizontal strips and were covered by black plastic film inserted to a depth of 30 cm below the soil surface to prevent lateral movement of water.

The second experimental factor was the seed treatments that included three treatments of control (soaking in tap water for 8 h), soaking in Salicylic acid (SAA) (2mM for 8 h) and soaking in ascorbic acid (ASA) (2mM for 8 h). Salicylic acid, also known as 2-hydroxybenzoic acid, is a colorless crystalline organic acid which functions as a plant hormone and the ascorbic acid, also called hexuronic acid, is a white solid which is known for its role as plant anti-stress substance.

General agronomic practices

Each plot area was 18 m^2 ($4 \times 4.5 \text{ m}$). Wheat was preceded by maize in both seasons. Sowing took place on 15th November in both seasons. Sowing was conducted in rows, 15 cm apart, using seeding rate of 400 seeds m^{-2} . Harvest was done during the third week of April in both seasons. Calcium superphosphate (15.5% P_2O_5), ammonium nitrate (33.5% N) and potassium sulphate (50% K_2O) were

Table 2: Average climatic data of the experimental location during the two growing seasons of (2016/2017 and 2017/2018)

Month	Date	2016/2017				2017/2018			
		Max. Temp.	Min. Temp.	Avg. RH	Precip.	Max. Temp.	Min. Temp.	Avg. RH	Precip.
	Avg. From	$^{\circ}\text{C}$	$^{\circ}\text{C}$	%	mm	$^{\circ}\text{C}$	$^{\circ}\text{C}$	%	mm
Nov.	15-31 Nov.	22.9	15.3	58.9	0.51	24.0	15.1	48.4	1.02
Dec.	1-15 Dec.	22.1	13.1	60.5	4.06	22.1	13.1	57.2	0.25
	16-31 Dec.	21.9	14.4	56.7	0	21.9	14.4	50.7	0
Jan.	1-15 Jan.	17.7	9.1	50.4	0	20.1	12.1	55.6	0
	16-31 Jan.	18.8	10.4	55.2	0	18.3	11.6	55.7	5.33
Feb.	1-15 Feb.	19.5	10.6	55.6	0	24.5	13.7	53.8	0.25
	16-28 Feb.	20.5	10.2	56.6	2.03	22.4	14.2	49.2	13.21
Mar.	1-15 Mar.	22.8	14.5	51.1	0	27.1	16.5	49.4	0
	16-31 Mar.	24.8	15.2	48.7	0	28.5	16.3	42.6	2.03
Apr.	1-15 Apr.	26.0	16.1	52.8	4.31	28.4	17.0	48.5	1.02
	16-30 Apr.	29.7	17.6	42.9	0	29.8	19.1	43.4	5.08

Table 3: Irrigation water amounts for the three irrigation levels throughout the growing seasons of wheat

Days from sowing	Growth stage	Length of growth stages (day)	K_c	Water application depth (mm)		
				50% ET_c	75% ET_c	100% ET_c
				(I ₁)	(I ₂)	(I ₃)
1-20	Initial	20	0.70	18.8	28.2	37.6
21-70	Development	50	0.93	51.5	77.5	102.5
71-130	Mid	60	1.15	118.8	178.2	237.6
131-160	Late	30	0.50	40.8	61.5	81.9
			Total	230	345	460



applied at the rate of 215 kg N ha⁻¹, and 75 kg P₂O₅ ha⁻¹ and 60 kg K₂O ha⁻¹, respectively.

All other cultural practices were performed as recommended for wheat production in the study region.

Recorded data

At heading, 104 days after sowing (DAS), 10 guarded plants were selected randomly to measure flag leaf area using the formula (length × maximum width × 0.80) according to Voldeng and Simpson (1967) and total photosynthetic pigments (SPAD value) using Minolta SPAD-502 chlorophyll meter. The total photosynthetic pigments content was recorded as a mean of 30 readings per plot.

During grain filling period (115 DAS) relative water content (RWC) and recovery efficiency at night (RE) were recorded. RWC was determined according to Barrs and Weatherley (1962) formula:

$$RWC(\%) = \frac{(FW-DW)}{(TW-DW)} \times 100 \quad (3)$$

Where: FW is the fresh weight of the leaf sample, DW is the dry weight of the leaf sample, TW is the weight of fresh leaf sample floated in distilled water for 8 h.

RE is the change in RWC at night which represents the plant ability to compensate the loss of water occurring during the day, until ψ_{plant} would come close to equilibrium with the ψ_{soil} at the end of the night. In other words, it is an adaptation mechanism to mitigate the negative impacts associated with water stress on plants. Consequently, RE (%) is the difference between RWC% at sunrise of a day (116 DAS) and the RWC% at the sunset of the previous day

(115 DAS) as follows:

$$RE(\%) = RWC\%_{(\text{sunrise})} - RWC\%_{(\text{sunset})} \quad (4)$$

At harvest, ten spikes were randomly selected from each plot to estimate spike length (cm), number of fertile spikelets spike⁻¹, grain number spike⁻¹ and grain weight spike⁻¹ (g).

At harvest, all wheat plants of central square meter were harvested from each plot to estimate spikes number m⁻² and grain yield (kg ha⁻¹) which was determined from the harvested area of each plot in terms of kg m⁻² and converted to kg ha⁻¹.

Water use efficiency (WUE) was calculated according to James (1988) and Bilalis *et al.*, (2009) as follows:

$$WUE = \frac{\text{Grain yield}}{\text{Total water applied}} \quad (5)$$

Where: WUE is the water use efficiency (kg m⁻³), grain yield (kg ha⁻¹) and the total water applied (m³ ha⁻¹).

Data analysis

The experimental data of both seasons and their combined data were subjected to the analysis of variance according to the standard statistical procedures described by (Gomez and Gomez 1984) by using MSTAT-C statistical program version 2.1 (Mstat 1989). The combined analysis of variance of both trials was calculated after establishing Bartlett's homogeneity test (Steel *et al.*, 1997), since the error variance of the individual seasons was homogeneous. The differences among treatments were compared using Duncan's multiple range test (Duncan 1955), where means

Table 4: Flag leaf area (cm²), total photosynthetic pigments (SPAD value), RWC (%) and RE (%) of wheat as affected by irrigation levels and seed treatments during (2016/2017) and (2017/2018) seasons and their combined data

Main effects and interaction	Flag leaf area (cm ²)			Total photosynthetic pigments (SPAD value)			RWC (%)			RE (%)		
	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.
Irrigation levels (I)¹												
50% ETc	30.95	32.75	31.85b	43.62b	40.96c	42.29c	66.24	64.47b	65.35b	7.58	5.99	6.78
75% ETc	34.11	36.05	35.08ab	49.28a	47.82b	48.55b	72.85	71.93a	72.39a	6.67	5.11	5.89
100% ETc	38.35	40.76	39.56a	51.77a	53.41a	52.59a	76.82	74.91a	75.87a	4.73	4.44	4.58
F. test ²	NS	NS	*	*	*	*	NS	*	*	NS	NS	NS
Seed treatments (S)												
Control	32.07	33.07c	32.57b	47.04	46.21	46.62b	68.14	65.37b	66.75b	3.68b	3.32b	3.50b
Soaking in SAA	34.84	36.13b	35.49ab	49.13	48.03	48.58a	74.63	74.66a	74.64a	8.77a	6.70a	7.73a
Soaking in ASA	36.50	40.37a	38.43a	48.51	47.95	48.23a	73.15	71.28a	72.21a	6.53ab	5.52ab	6.03a
F. test	NS	*	*	NS	NS	*	NS	*	*	*	*	*
Interaction												
I x S	NS	*	*	*	*	*	*	*	*	NS	NS	NS

¹Least significant difference at the 95% confidence level was used to compare between means. Means of irrigation levels or seed treatments followed by the same letter are not significantly different. Columns that do not contain letters indicate no significant difference between treatments.

²* and NS indicate significance at 0.05 level of probability and non-significance of differences, respectively. 50% ETc (230 mm), 75% ETc (345 mm) and 100% ETc (460 mm).



Table 5: Flag leaf area (cm²), total photosynthetic pigments (SPAD value) and RWC% of wheat as affected by the interaction between irrigation levels and seed treatments (combined data)

Seed treatments (S)	Irrigation levels (I)		
	50% ET _c	75% ET _c	100% ET _c
Flag leaf area (cm²)			
	A	A	A
Control	30.09a	34.45a	33.18b
	B	B	A
Soaking in SAA	30.59a	33.76a	42.11a
	B	AB	A
Soaking in ASA	34.88a	37.03a	43.39a
Total photosynthetic pigments (SPAD value)			
	C	B	A
Control	41.35a	47.35a	51.18a
	C	B	A
Soaking in SAA	43.06a	49.33a	53.35a
	C	B	A
Soaking in ASA	42.46a	48.98a	53.25a
RWC%			
	B	A	A
Control	58.04b	68.29a	73.93a
	A	A	A
Soaking in SAA	72.38a	74.72a	76.82a
	B	A	A
Soaking in ASA	65.64ab	74.16a	76.16a

Least significant difference at the 95% confidence level was used to compare means.

Capital and small letters were used to compare means in rows and columns, respectively.

with different letters were statistically significant. In the interaction tables, capital and small letters were used to compare between means in rows and columns, respectively.

Results

Combined analysis results presented in Table (4) revealed that reducing irrigation water requirements from 100% to 75% ET_c was not accompanied by a significant decrease in flag leaf area, RWC (%) and RE (%), but the total photosynthetic pigments (SPAD value) was significantly decreased with reducing irrigation water level.

Treating seeds with ASA or SAA significantly increased total photosynthetic pigments, RWC and RE compared with the control. However, treating seeds with ASA significantly enlarged flag leaf area compared to the control, with no significant difference between treating seeds with ASA or SAA and between treating seeds with SAA and the control treatment.

The interaction between the two studied factors had a significant effect on flag leaf area, total photosynthetic pigments and RWC as shown in Table (5). Reducing irrigation water requirements from 100% to 75% ET_c significantly decreased total photosynthetic pigments, but it had no significant influence on RWC and flag leaf area, except flag leaf area produced from seeds treated with SAA. Treating seeds with SAA or ASA significantly enlarged flag leaf area under full irrigation conditions by about 26.91 and 30.77%, respectively. Under severe water stress conditions, treating seeds with SAA significantly enhanced RWC compared to the control by about 24.71%, with no significant

Table 6: Spike length (cm), number of fertile spikelets spike⁻¹, grain number spike⁻¹ and grain weight spike⁻¹ (g) of wheat as affected by irrigation levels and seed treatments during (2016/2017) and (2017/2018) seasons and their combined data

Main effects and interaction	Spike length (cm)			Number of fertile Spikelets/spike			Grain number Spike ⁻¹			Grain weight Spike ⁻¹ (g)		
	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.	2016/2017	2017/2018	Com.
Irrigation levels (I)¹												
50% ET _c	9.84b	8.28b	9.06b	13.82	11.03b	12.42b	00.25c	26.22c	25.61c	1.01b	1.03c	1.02b
75% ET _c	12.69a	10.68a	11.68a	16.93	15.28a	16.11ab	39.26b	40.73b	40.00b	1.63a	1.63b	1.63a
100% ET _c	11.51ab	11.34a	11.42a	17.17	16.08a	16.63a	47.16a	45.08a	46.12a	1.68a	1.81a	1.74a
F. test ²	*	*	*	NS	*	*	*	*	*	*	*	*
Seed treatments (S)												
Control	10.96	10.04	10.50	14.95b	14.04	14.50b	33.17b	34.06b	33.62b	1.36	1.36b	1.36b
Soaking in SAA	11.28	10.28	10.78	17.10a	14.70	15.90a	39.32a	39.11a	39.22a	1.41	1.58a	1.49ab
Soaking in ASA	11.81	9.97	10.89	15.87ab	13.66	14.77b	38.93a	38.86a	38.90a	1.55	1.53a	1.54a
F. test	NS	NS	NS	*	NS	*	*	*	*	NS	*	*
Interaction												
I x S	*	*	*	*	*	*	*	*	*	*	*	*

¹Least significant difference at the 95% confidence level was used to compare means. Means of irrigation levels or seed treatments followed by the same letter are not significantly different. Columns that do not contain letters indicate no significance difference between treatments.

²* and NS indicate significance at 0.05 level of probability and non-significance of differences, respectively.

50% ET_c (230 mm), 75% ET_c (345 mm) and 100% ET_c (460 mm).



differences between treating seeds with SAA or ASA and between treating seeds with ASA and the control.

For the yield attributes, combined analysis in Table (6) showed that reducing irrigation water level from 100% to 75% ET_c produced at par statistical values for spike length, number of fertile spikelets spike⁻¹ and grain weight spike⁻¹, but grain number spike⁻¹ was significantly decreased with reducing irrigation water level by about 13.27%.

Spike length did not significantly change under seed treatments. Treating seeds with SAA or ASA produced at

Table 7: Spike length (cm), number of fertile spikelets spike⁻¹, grain number spike⁻¹ and grain weight spike⁻¹ (g) of wheat as affected by the interaction between irrigation levels and seed treatments (combined data)

Seed treatment (S)	Irrigation level (I)		
	50% ET _c	75% ET _c	100% ET _c
Spike length (cm)			
	B	A	A
Control	8.94a	11.39a	11.17a
	B	A	A
Soaking in SAA	9.34a	11.74a	11.25a
	B	A	A
Soaking in ASA	8.90a	11.92a	11.85a
Number of fertile spikelets spike⁻¹			
	A	A	A
Control	12.76a	15.16b	15.56b
	A	A	A
Soaking in SAA	13.68a	16.86a	17.15a
	B	A	A
Soaking in ASA	10.83b	16.30ab	17.18a
Grain number spike⁻¹			
	C	B	A
Control	23.66b	34.26c	42.93c
	B	A	A
Soaking in SAA	26.66a	44.93a	46.05b
	C	B	A
Soaking in ASA	26.50a	40.80b	49.40a
Grain weight spike⁻¹ (g)			
	B	A	A
Control	1.00a	1.53a	1.55b
	B	A	A
Soaking in SAA	1.05a	1.63a	1.80ab
	B	A	A
Soaking in ASA	1.02a	1.72a	1.88a

Least significant difference at the 95% confidence level was used to compare between means.

Capital and small letters were used to compare between means in rows and columns, respectively.

par significant increase in grain number spike⁻¹ and grain weight spike⁻¹. Treating seeds with SAA significantly increased the number of fertile spikelets spike⁻¹.

A significant interaction between the two studied factors was observed in both seasons and their combined analysis for the aforementioned traits. Results illustrated in Table (7) indicated that the reduction in irrigation water requirements from 100% to 75% ET_c had no significant impact on spike length, number of fertile spikelets spike⁻¹ and grain weight spike⁻¹; however, it significantly decreased grain number spike⁻¹ when the seeds were treated with water or ASA. Treating seeds with ASA produced the lowest significant number of fertile spikelets spike⁻¹ under severe water stress conditions. Treating seeds with SAA or ASA significantly increased the number of fertile spikelets spike⁻¹ under normal irrigation conditions. Under any irrigation level, treating seeds with SAA or ASA significantly increased grain number spike⁻¹ compared with the control. Regarding grain weight spike⁻¹, there were no significant differences among seed treatments in grain weight spike⁻¹ under severe and moderate water stress conditions. Under normal irrigation conditions seed soaking in ASA significantly increased grain weight spike⁻¹ compared to soaking in water, with no significant difference between treating seeds with ASA or SAA and between treating seeds with SAA and the control.

Table 8 showed that, reducing irrigation water level from 100% to 75% or 50% ET_c significantly decreased spike number m⁻², grain yield ha⁻¹ by about 5.17% and 9.41% for spike number m⁻² as well as 23.01% and 49.23% for grain yield ha⁻¹, respectively. The WUE was not significantly affected by reducing irrigation water level from 100% to 75% ET_c.

Seed treatments had a negligible influence on spike number m⁻². Treating seeds with SAA or ASA significantly produced high grain yield ha⁻¹ compared with the control, with no significant differences between treating seeds with SAA or ASA. Treating seeds with SAA significantly increased WUE compared with the two others seed treatments.

The interaction between the two studied factors had a significant impact on the aforementioned traits in the combined analysis as presented in Table (9). In most cases, reducing irrigation water levels significantly decreased spike number m⁻² and grain yield ha⁻¹. WUE was not affected significantly by reducing irrigation level under any seed treatment.



Table 8: Spike number m⁻², grain yield (kg ha⁻¹) and WUE (kg m⁻³) of wheat as affected by irrigation levels and seed treatments during (2016/2017) and (2017/2018) seasons and their combined data

Main effects and interaction	Spike number m ⁻²			Grain yield (kg ha ⁻¹)			WUE (kg m ⁻³)		
	2016/ 2017	2017/ 2018	Com.	2016/ 2017	2017/ 2018	Com.	2016/ 2017	2017/ 2018	Com.
Irrigation levels (I)¹									
50% ET _c	452.67b	447.56c	450.11c	4054.3c	4043.5c	4048.9c	2.13	2.11	2.12
75% ET _c	481.63ab	460.67b	471.15b	5945.8b	6334.5b	6140.1b	2.08	2.20	2.14
100% ET _c	501.31a	492.41a	496.86a	8118.2a	7832.8a	7975.5a	2.13	2.05	2.09
F ₁ test ²	*	*	*	*	*	*	NS	NS	NS
Seed treatments (S)									
Control	472.90	467.38	470.14	5283.5c	5456.9	5370.2b	1.84c	1.88b	1.86c
Soaking in SAA	483.25	464.99	474.12	6693.6a	6621.8	6657.7a	2.34a	2.34a	2.34a
Soaking in ASA	479.46	468.25	473.86	6141.3b	6132.1	*	2.15b	2.16ab	2.15b
F ₁ test	NS	NS	NS	*	NS	*	*	NS	*
Interaction									
I x S	*	*	*	*	*	*	*	*	*

¹Least significant difference at the 95% confidence level was used to compare means. Means of irrigation levels or seed treatments followed by the same letter are not significantly different. Columns that do not contain letters indicate no significance difference between treatments.

²* and NS indicate significance at 0.05 level of probability and non-significance of differences, respectively.

50% ET_c (230 mm), 75% ET_c (345 mm) and 100% ET_c (460 mm).

Table 9: Spike number m⁻², grain yield (kg ha⁻¹) and WUE (kg m⁻³) of wheat as affected by the interaction between irrigation levels and seed treatments (combined data)

Seed treatment (S)	Irrigation level (I)		
	50 % ET _c	75% ET _c	100 % ET _c
	Spike number m⁻²		
	B	A	A
Control	448.33ab	481.50a	480.59b
	B	B	A
Soaking in SAA	460.00a	459.00b	503.36a
	C	B	A
Soaking in ASA	442.00b	472.95ab	506.63a
	Grain yield (kg ha⁻¹)		
	C	B	A
Control	3388.9b	5412.2b	7309.4b
	C	B	A
Soaking in SAA	4696.6a	6487.8a	8788.8a
	C	B	A
Soaking in ASA	4061.3ab	6520.4a	7828.8ab
	WUE (kg m⁻³)		
	A	A	A
Control	1.78b	1.89b	1.92b
	A	A	A
Soaking in SAA	2.46a	2.27a	2.30a
	A	A	A
Soaking in ASA	2.13a	2.28a	2.05ab

Least significant difference at the 95% confidence level was used to compare means.

Capital and small letters were used to compare between means in rows and columns, respectively.

Such being the irrigation water level, spike number m⁻², grain yield ha⁻¹ and WUE obtained by treating seeds with SAA or ASA were statistically similar. Treating seeds with SAA significantly increased grain yield ha⁻¹ and WUE compared to the control under all irrigation levels.

Discussion

Drought is perhaps the major factor limiting crop production worldwide (Shangguan *et al.* 2000). The water shortage has motivated some researchers to study deficit irrigation that maybe a feasible method contributing in enhancing agricultural system in arid region (Zhang *et al.*, 2019). In the present study, subjecting wheat plants to deficit irrigation reducing irrigation water requirements from 100% to 75% ET_c did not cause any significant change in each of the flag leaf area, relative water content, recovery efficiency (Table 4), spike length, number of fertile spikelets spike⁻¹, grain weight spike⁻¹ (Table 6) and water use efficiency (Table 8). Contradictorily, each decrease in water level from 100% ET_c to 75% ET_c or 50% ET_c was accompanied by a significant decrease in total photosynthetic pigments (Table 4), grain number spike⁻¹ (Table 6), spike number m⁻² and grain yield ha⁻¹ (Table 8).

Deficit irrigation had a significant negative effect on the content of photosynthetic pigments. Lissner *et al.* (1999) and Farooq *et al.* (2013) reported that water stress causes directly or indirectly reduction in the total photosynthetic pigment content, leaf area and relative water content of wheat seedlings through molecular damage in plant cells due to the synthesis of reactive oxygen species. Results of the present research agree with previous finding that reported a significant decrease in photosynthetic pigment content and consequently the photosynthesis efficiency due to deficit irrigation such as (Kotb and Elhamahmy, 2013; Awad *et al.*, 2015). Others found a reduction in leaf area and RWC under water stress such as (Kotb and Elhamahmy, 2013; El-Shafey 2017), which contradicts the present findings.

Schonfeld *et al.* (1988) revealed that RWC is a promise selection criterion for drought resistance in wheat



and they attributed the differences in RWC values among wheat genotypes under the same drought stress level to genes variations, the genotype that are resistant to drought have more RWC. Also, the varietal differences in flag leaf area under the same water stress level were reported by Chipilski *et al.* (2012), which may explain the results contradiction between the present study results and the others.

Under moderate water stress and full irrigation requirements, no significant differences were observed in spike length, number of fertile spikelets spike⁻¹ and grain weight spike⁻¹, but reducing irrigation level from 100 ET_c to 75% ET_c significantly decreased grain number spike⁻¹ and spike number m⁻². These results are in harmony with those obtained by Said and Abd El-Moneem (2016). Water stress at anthesis stage reduces pollinations and thus a smaller number of grains is formed per spike (Ashraf 1998). Farhat (2015) found that the number of spikes m⁻² was the most affected trait by irrigation deficit. Under moderate water stress conditions, the compensatory capacity of the wheat plant plays an important role in the relationship between the abovementioned traits. Graziani *et al.* (2014) reported that, among yield components, number of grains m⁻² showed the strongest correlation with grain yield. Mwadzingeni *et al.* (2016) pronounced that there were a moderate to high positive and significant correlations of grain yield with number of spikes plant⁻¹, grain number spike⁻¹ under stressed and normal conditions. So, the grain yield ha⁻¹ significantly decreased with decreasing grain number spike⁻¹ and spike number m⁻² owing to reducing irrigation level from 100 ET_c to 75% ET_c in the present study. Kotb and Elhamahmy (2013) found that reducing irrigation water level from 100% ET_c to 80% ET_c significantly decreased grain number spike⁻¹ (15.09), spike number m⁻² (16.87%) and grain yield ha⁻¹ (14.35%) but significantly increased WUE (7.178%). Said (2016) also reported that decreasing irrigation water level from 100% ET_c to 75% ET_c significantly decreased spike number m⁻² and grain yield ha⁻¹. The significant reduction in WUE with reducing irrigation water level from 100% ET_c to 75% ET_c was confirmed by those obtained by Sun *et al.* (2006) who avouched that WUE increased with increasing irrigation water from zero to full irrigation in semi-arid regions. But many investigators have reported an increased WUE of bread wheat with decreasing water amount under Mediterranean environment such as (Kotb and Elhamahmy, 2013; Mansour *et al.* 2017). Varietal differences in WUE under the same level of water deficit were revealed by Said and Abd El-Moneem (2016), which may explain the results contradiction between the present study results and the others.

Salicylic acid (SAA) is an endogenous plant growth hormone that promotes growth and protects the plant cells against abiotic stresses like water stress. IAA has an important role in the expression of the growth-stimulating action of SAA (Hayat and Ahmad 2007). ASA plays an important role in protecting plant cells as non- enzymatic antioxidant and regulating plant growth owing to its effect on cell division and differentiation (Price 1966).

Our findings showed that, treating seeds with SAA or ASA increased plants tolerance to drought stress demonstrated by increased total photosynthetic pigments, relative water content, recovery efficiency (Table 4), grain number spike⁻¹ (Table 6) and grain yield ha⁻¹ (Table 8), compared with the control.

Treating seeds with ASA significantly increased flag leaf area compared with the control. Amin *et al.* (2008) reported that ascorbic acid was more effective than salicylic acid in increasing the different photosynthetic pigments in wheat. Moreover, El-Shafey (2017) reported that the foliar spray of salicylic or ascorbic acid significantly increased leaf area, LAI and chlorophyll content.

Treating seeds with SAA or ASA increased plants tolerance to drought stress demonstrated by increased relative water content and recovery efficiency. Relative water content represents the plant water status and reflects the metabolic activity in tissues (Flower and Ludlow, 1986). Ritchie *et al.*, (1990) noted that the high RWC is a drought resistant mechanism. Karimpour (2019) deduced that RWC can be used as screening tool for determining drought tolerance of genotypes in wheat. Recovery efficiency (RE%), a new trait proposed in the study, is the difference between the RWC% at sunrise of a day and the RWC% at the sunset of the previous day. The scientific basis of the trait depends on the fact that the air usually has an extremely low water potential compared with plant or soil and there is a steep energy gradient and continual movement of water from the soil cross the plant to the air. At night, the stomata close and the transpiration is reduced to near zero. However, water continues to flow in plants until ψ_{plant} would come close to equilibrium with the ψ_{soil} . Rates of water absorption by plants from the soil can be affected by many factors as the amount of soil moisture and ψ_{plant} (Gardner *et al.*, 1985). At night with closing the stomata and reducing the transpiration to near zero, dew is another water resource beside the soil water. Dew is one of the main water resources for plants which grow in arid and semi-arid environments due to its higher frequency and sustaining time comparing with the precipitation. It also helps the wilting plants to arrive a higher steady restoration state (Ye and Peng, 2011). Therefore, the amount of water absorbed



at night displays the plants ability to adapt with the water stress conditions. El-Shafey (2017) revealed that the foliar application of salicylic and ascorbic acids alone or in combination, significantly increased leaf proline concentration compared with the untreated plants. High cell proline content enabled the plant to lower the water potentials. By lowering water potentials, additional water would be taken from the environment, thus buffering the immediate effect of water shortages (Abdo and Anton, 2009). El-Shafey (2017) found that the foliar application of salicylic acid or ascorbic acid significantly increased RWC of soybean leaves.

Results illustrated that spike length did not significantly change under seed treatments (Table 6). Said and Abd El-Moneem (2016) studied the response of bread wheat to foliar spray by SAA and ASA under water stress conditions; they disclosed that the spike length was increased by foliar spray at 100ppm SAA.

Treating seeds with SAA or ASA produced at par significant increase in the number of fertile spikelets spike⁻¹ and grain number spike⁻¹ compared with the control. Seed soaking in ASA produced heavy grain weight spike⁻¹ compared to the control. Generally, the results of the number of fertile spikelets spike⁻¹, grain number spike⁻¹, grain weight spike⁻¹ and grain yield ha⁻¹ take the same trend of relative water content and recovery efficiency, however treating seeds with SAA significantly increased WUE compared with the other treatments. Kotb and Elhamahmy (2013) deduced that the foliar spraying with ASA significantly increased grain number spike⁻¹, spike number m⁻², grain yield ha⁻¹ and WUE under stress and normal irrigation conditions. Moreover, it saved approximately 852 m³ ha⁻¹ of irrigation water without yield reduction compared to the control. El Sayed and Mujahed (2015) stated that soaking wheat grains in SAA before planting can be used to improve wheat productivity and WUE. In the abovementioned study of Said and Abd El-Moneem (2016) they found that the highest values of spike number m⁻², grain yield ha⁻¹ and WUE were obtained from plants sprayed with 100 ppm of ASA. El-Shafey (2017) concluded that foliar application with SAA or ASA and their combinations increased WUE for soybean plants compared with untreated plants.

Treating seeds with SAA significantly increased grain number/spike, grain yield/ha and WUE under all irrigation levels as well as RWC under severe water stress. Öztürkci and Arpali (2019) deduced that salicylic acid could be utilized as an effective growth regulator for plants in enhancing drought tolerance. Sakhabutdinova *et al.* (2003) attributed the protective and growth promoting effects of

SAA to the increased content of indoleacetic acid and abscisic acid (ABA), which was induced by treating wheat plants with SAA. Moreover, exogenous application of SAA improved nitrogen assimilation in wheat (Khan *et al.*, 2013) and photosynthetic nitrogen use efficiency in mungbean (Nazar *et al.*, 2011).

Treating seeds with SAA or ASA significantly increased flag leaf area and number of fertile spikelets spike⁻¹ under full irrigation conditions. Kotb and Elhamahmy (2013) assured that foliar spray of ASA increased leaf area index and total chlorophyll content under full irrigation conditions. ASA induced 3-Bdioxgenase responsible for synthesis of plant growth promoting hormone, gibberellin (Coles *et al.*, 1999; Kotb and Elhamahmy, 2013)

These results reflect the influence of treating seeds with drought tolerance substances such as SAA or ASA, in the concentration of 2 mM for 8 h was more pronounced when plants were water stressed.

Conclusion

The impact of deficit irrigation and seed treatments on grain yield, some of its attributes and WUE of wheat cultivar "Shandaweel 1" was investigated under arid and semi-arid conditions of Egypt. Subjecting wheat plants to moderate water stress by reducing irrigation water requirements from 100% to 75% ET_c did not cause any significant change in each of the flag leaf area, relative water content, recovery efficiency, spike length, number of fertile spikelets spike⁻¹, grain weight spike⁻¹ and WUE, but significant decrease in total photosynthetic pigments, grain number spike⁻¹, spike number m⁻² and grain yield ha⁻¹ were observed by reducing irrigation water requirements. Treating seeds with SAA or ASA increased plants tolerance to drought stress demonstrated by increased total photosynthetic pigments, relative water content, recovery efficiency, grain number spike⁻¹, grain yield ha⁻¹ and WUE compared with the control. The results indicated that treating seeds with drought tolerance substances such as SAA or ASA is a promising technique to alleviate adverse effects of water stress.

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