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Grain-priming and foliar pretreatment enhanced stress defense in wheat (*Triticum aestivum* var. Gimaza 9) plants cultivated in drought land

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Abstract

Drought is a problem of water deficit in the soil and is the principal cause of the worldwide economic losses. Reduced water availability has seriously affected wheat growth, quality and production. The goal of the present study was analysis of drought stress defense triggers in wheat plants grown in dry sandy lands using methods of grain-priming and/or foliar pretreatments on the pre-anthesis stages. Grain-priming was induced using a low dose of salicylic acid (*SA*) while foliar pretreatments were performed using Thiourea (*Th*). We focussed our data description on the findings of headings and the anthesis stages. Morphological, biochemical and yield components data revealed that wheat originated from grain-priming combined with foliar applications had exhibited stronger anti-drought effects. A raised tolerance level was ascertained from the up-regulation of crop production and quality in drought cultivation compared to normally irrigated wheat. We recommend the utilities of natural products in low doses to assess wheat tolerance in drought environments.

Keywords: crop, foliar application, salicylic acid, Thiourea, wheat.
Abbreviations: SA_Salicylic acid; Th_Thiourea; TSS_Total soluble carbohydrates; NSS_Non-soluble sugar; T.C_Total carbohydrates

Introduction

Drought is the most prevailing problem and the factor known to be serious for its impacts on crop limitations (Souza et al., 2004). This kind of abiotic stress often occured as a consequence of the reduction of the water level that reaches earth due to extreme atmospheric conditions which frequently cause water loss via transpiration and evaporation (Kramer, 1980). Generally, water scarcity resulted from either drought or soil salinity influenced crop plant's morphology, physiology and could lead to cellular and organelles deformation (Abdelkader et al., 2007; Demirevska et al., 2009). Drought specific impacts on biochemical and molecular processes lead to stomatal closure with consecutive decrease in rates of transpiration, pigment content, photosynthesis, caused protein alterations and ended with growth inhibition (Lawlor and Cornic, 2002; Zhu, 2002). Wheat is one of the most important crops in the world. At present, wheat growth has been seriously influenced by drought in many regions (Abdelkader et al., 2010; Xiaoqin et al., 2009). Many techniques were invented to assess wheat tolerance; as such, seed priming and exogenous applications before and during cultivation were efficiently used as methods of plant mitigations under drought stress. Furthermore, glycinebetaine application to plants was effective with stabilizing the quaternary structures of enzymes and complex proteins, lipids of photosynthetic apparatus and in maintaining highly ordered state of membranes (Papageogiou and Murata, 1995; Xing and Rajashekar, 1999). Although physiological processes that stimulated these improvements are not yet discovered, the seed priming was achieved progressively in many plant species and was potent in improving yield quality and yield amounts (Harris et al., 2002). Root priming was performed in other plant species and participated in decreasing pathogen attacks (Alvarez et al., 1998) and other oxidative stresses (Morita et al., 1999). Salicylic acid (*SA*) is an endogenous growth regulator of phenolic nature, involved in the regulation of physiological processes in plants. SA played a role of natural inducer of thermogenesis in Arum lily, induces flowering in a range of plants, controlled ion uptake by roots and stomatal conductivity (Raskin, 1992). Salycilic acid is, for over 20 years, reputed for its ability to induce systemic acquired resistance in plants to diferent pathogens (Sakhabutdinova et al., 2003) and conferred a protective effect on plants under different abiotic stresses through diminishing alteration of phytohormones levels in wheat seedlings grown under water deficit conditions by preventing IAA decrease and maintaining of both ABA and proline accumulation (Sakhabutdinova et al., 2003). On the other hand, thiourea (*Th*), a sulfhydryl compound, was used for foliar treatments and enhanced an increase in ears number, grains/ear, weight/grain, biological yield, grain yield, and harvest index. Moreover, *'Th'* treatments lead to grain yield increase by 23.9% over control (Sahu and Singh, 1995). The experimental regime had covered five treatments: 1- for grain presoak; *SA* (1.0 mmol), 2- for foliar application, Th_1 (2.5 mmol), Th_2 (5 mmol) were sprayed in separate experiments, and 3- the two interactions; $SA+Th_1$ and $SA+Th_2$. The severity of water stress was determined by analysing changes in control and pretreated wheat of normally irrigated and drought stressed wheat on three levels: first: wheat plants morphology (e.g. shoot and root heights, fresh and dry weights of shoots and roots, flag leaf area), second: yield components of wheat (e.g. spike number and length, grain number and weight, biological yield, grain weight, crop and harvest indexes), and third: the biochemical changes in grain yield, including contents of carbohydrates, proteins, proline, flavonoids, total phenols and minerals. The purpose of this study was to evaluate both quality and quantity of wheat yielded from grain-priming using *SA* either separately or combined to a foliar application using *Th*, to track subsequent physiological and biochemical changes in pretreated wheat cultivation and finally, to save heavy consumption of fresh water used in crop agriculture, especially in arid and semiarid regions.

Results

In field studies with wheat grown in Nubariah dry lands, a progressive water stress was induced to 15-d old seedlings via withholding water irrigation for 10 days intervals (40% field water capacity) through an experimental span extended to 120 days, compared with control plants irrigated at intervals of five days (80% field water capacity). To underline effects of dehydration combined with *SA*, *Th* and *SA+ Th* pretreatments on wheat quality, some metabolic products synthesis, in addition to wheat morphology and yield component, were subjected to several analyses.

Morphological characters

Treatments using either *SA* or its interactions ($SA+Th_1$ or $SA+Th_2$) had induced an abrupt increase in shoots morphology (e.g. shoot height, shoot fresh and dry weights). In addition, the area of flag leaf had subsequently increased in the heading and anthesis stages (Table 1). Pretreatments with $SA+Th_1$ or $SA+Th_2$ resulted in higher improvements of the growth criteria compared to separate treatments, whereas, $SA+Th_1$ impact was pronounced. For example, maximum shoot height values with $SA+Th_1$ were 75 and 79 cm in heading and anthesis stages, respectively. Furthermore, the highest shoot fresh and dry weight values recorded with the same applications were 23.28 and 35.5 g/plant for the fresh weight in heading and anthesis, respectively, and 9.78, 13.49 g/plant for dry weight in heading and anthesis, respectively.
Root length has been affected by foliar treatments following the same trend as in the shoot morphology (Table 2). The best treatment triggered up-regulation in root morphological parameters was $SA+Th_1$. Root length values were 19.75 and 23.06 cm, root fresh weight values were 1.44 and 2.74 g/plant, whereas, root dry weight values detected 0.617 and 1.247 g/plant in heading and anthesis, respectively (Table 2).

Yield and yield components

Yield components were analysed in relation to wheat plants responses to drought effects. The spike length, spike number, spike weight per plant, grains number per plant, grain weight per plant and 100 grains weight per plant were up-regulated in response to grain priming using *SA* and with, particularly, the interaction '*SA+Th1*'. The values of the above traits were as follow: 7.91, 2.86, 5.62, 68.47, 3.3, and 3.45, respectively (Figure 1). Grain yields measured in tons per feddan (0.42 hectares) were estimated in wheat plants resulted from grain priming in *SA* and sprayed with Th_1 or Th_2 at the vegetative stage. Results showed that all treatments lead to an increase in the biological yield (straw+grains) in control as well as in drought-stressed wheat (Figure 1). Yield production was up-regulated upon applications of $SA+Th_1$ in drought-stressed wheat plants. As listed in Table 3B, the biological yield in drought-stressed wheat plants was 9.83 tons per feddan, crop index was 28.08 and harvest index was 39.04.

Biochemical characters

Carbohydrate content

Carbohydrate content was determined in the yield produced from normal and pretreated wheat. The values showed a significant decrease of total soluble sugars, which comprises sucrose and monosaccharide, under drought stress along with starch leading to a conspicuous drop in the level of total carbohydrate (Table 3). In control and stressed wheat, foliar applications with Th_1 and $SA+Th_1$ pretreatments had resumed soluble sugars to be 2.99 and 2.4 mg/g and 47.8 and 44.1 mg/g for total carbohydrate, respectively.

Protein content

Protein content (mg/g) has increased with *SA+Th1* pretreatment in control and drought-stressed wheat. The highest protein values were 110.6 and 74.7mg/g in control and stressed wheat, respectively (Table 3).

Proline, flavonoids and phenols content

A significant increase in proline, flavonoids and phenols values was detected in drought-stressed compared to control crop. Proline level was obviously up-regulated in drought-stressed grains pretreated with $SA+Th_1$ (0.443 mg/ml) compared to the rest of pretreatments (Table 4). The highest increase of phenols values in grains was in $SA+Th_1$ pretreated plants (12.02 mg/g). Similarly, flavonoids was significantly increased in grains of drought-stressed plants pretreated with $SA+Th_1$ (0.81 mg/g).

Nutritional value

Mineral content (*P, K, Ca* and *Mg*) in yielded grains of wheat grown under drought conditions was analysed and compared with those grown under normal conditions. As listed in Table 5, pretreatments using *SA* alone or combined to foliar spray using *Th* specially $SA+Th_1$, had induced overall accumulation of elements. Elements values per mg/g d.wt with $SA+Th_1$ under drought-stress pretreatment were, 0.152 for phosphorus, 0.45 for potassium, 0.28 for calcium and 0.146 for magnesium. These values were also significantly up-regulated in control values treated with $SA+Th_1$ as follow: 0.264, 0.9, 0.37, and 0.245 for P, K, Ca and Mg, respectively.

Table 1. Growth characters (shoot height, flag leaf area, fresh weight and dry weight) of wheat plants.

	Morphology	Shoot height (cm)		Flag leaf area (cm^2)		Shoot fresh wt (g/plant)		Shoot dry wt (g/plant)	
	Treatments	Headings (60d)	Anthesis (90 d)	Headings (60 d)	Anthesis (90 d)	Headings (60 d)	Anthesis (90 d)	Headings (60 d)	Anthesis (90 d)
Normal Condition	Control	71±2.45*	78±0.50*	17.59±2.30*	20.14±0.69*	11.33±1.20*	22.98±1.93*	3.64±0.60*	10.99±0.71*
	Th$_1$	73±3.69*	84.67±0.84*	18.78±2.31*	20.26±0.72*	13.66±0.77*	29.55±1.76*	4.64±0.51*	14.53±1.82*
	Th$_2$	72±5.34*	79.2±3.77*	20.00±4.77*	26.14±0.87*	16.81±0.51*	29.85±1.79*	4.99±0.64*	14.63±1.29*
	SA	74.5±4.54*	86.5±1.78*	20.57±3.73*	26.62±1.65*	18.47±1.27*	33.03±2.45*	5.14±0.61*	14. 78±1.32*
	SA Th$_1$	80±2.64*	89.5±1.65*	23.34±4.91*	28.83±0.47*	26.25±0.90*	49.00±0.81*	6.69±0.90*	19.52±0.34*
	SA Th$_2$	79±4.00*	86.8±5.11*	22.35±2.69*	28.17±0.40*	20.14±2.01*	39.69±3.39*	5.44±0.43*	15.88±0.26*
	L.S.D at 0.05	1.42	2.77	1.72	1.68	1.33	2.47	0.84	1.19
Drought Condition	Control	63.67±4.27*	67.08±2.16*	16.59±1.87*	17.20±1.91*	10.12±1.47*	18.40±0.54*	2.95±0.72*	8.63±0.33*
	Th$_1$	69±3.55*	68.11±0.83*	17.24±2.98*	18.15±0.19*	11.80±0.38*	18.80±0.47*	3.77±0.54*	9.07±0.32*
	Th$_2$	71±5.39*	72.82±1.430.83*	19.57±5.00*	21.24±1.21*	13.35±1.95*	21.70±1.02*	4.11±0.78*	9.4±0.55*
	SA	73.5±3.77*	74.65±4.88*	19.67±2.07*	21.99±0.43*	16.99±6.84*	22.53±0.37*	5.61±0.31*	10.65±0.71*
	SA Th$_1$	75±3.56*	79±2.94*	20.37±1.04*	26.47±0.32*	23.28±3.08*	35.50±1.47*	9.78±1.28*	13.49±0.31*
	SA Th$_2$	74.39±1.50*	76.97±2.99*	19.85±4.84*	23.61±0.53*	18.56±6.84*	24.05±1.37*	7.24±0.45*	11.31±0.40*
	L.S.D at 0.05	2.43	3.92	2.01	2.38	2.91	3.66	0.93	1.75

* Represents Mean ±SD of each value

Discussion

Drought is reputed as a major ecological factor limiting crop production and food quality. The key importance of this study was wheat anti-drought and biological-saving water in arid and semi-arid areas. It should be noted that the current investigation was an extension of a previous study in which wheat yield was produced from only grain priming applications using low concentrations of *SA*, *Th* and their interactions. The study covered physiological and biochemical evaluations of the produced wheat (Abdelkader et al., 2010). This study was performed in two successive growing seasons (2009/2010 and 2010/2011). Foliar application was implemented as a technique used for better improvements. We used *SA* (1 mmol) for grain presoak and *Th* (2.5, 5 mmol) separately for foliar applications on the vegetative stage. Drought is a non-uniform phenomenon, influencing plants differently, depending on the developmental stage on which it affects (Vijendra Das, 2000; Lopez et al., 2003). For example, dry conditions during emergence and early growth resulted in low yields because of the inability of plants to produce adequate dry matter (Regan et al., 1992), whereas, water deficit around anthesis caused yield loss by reducing spike and spikelet numbers and fertility. Plant's exposure to drought stress from anthesis to maturity triggered leaf senescence, reduced duration and rate of grain filling and subsequently reduced spikes weight (Giunta et al., 1993; Royo et al., 2000). As wheat is highly sensitive to drought on the pre-anthesis stage (Ehdaie et al. 2006) foliar application before this stage was mandatory. Foliar applications started on the vegetative stage and were two times affectingwheat plants on 15- d intervals. Different concentrations and diverse methods of applications had significantly improved growth and yield production (Tables 1-2 & Figure 1) where a correlation between wheat survival and foliar applications has been observed in all experimental studies. Physiological and biochemical parameters in plants included biological macro and small molecules were affected by drought stress (Apel and Hirt, 2004, Casati and Walbot 2004, Chaves et al. 2003, Chen and Gallie, 2004, Zhu et al., 2003). Subsequently, levels of carbohydrates, protein, proline, phenols, flavonoids and minerals were changed in yielded grains of non-treated as well as pretreated wheat under drought (Tables 3 & 4). In the literature, the role of carbohydrates had markedly regulated the osmotic pressure in plants, and were recorded as important defense substances alleviating protoplasm coagulation under various stress factors (Vassiliev and Vassiliev, 1936). Two decades of reports had revealed some significant effects of drought on altering the composition and ratio between water soluble and ethanol soluble carbohydrates, for example, a shift was obtained as a level of water soluble carbohydrates had decreased in the expense of increased ethanol soluble carbohydrates due to the hydrolysis of fructans (a water soluble carbohydrate, Virgona and Barlow, 1991). Based on the aforementioned, it seemed proper to consider first the carbohydrates. Total soluble carbohydrates (TSS) and the starch (NSS) were decreased significantly (Table 3). In most cases, the decreased carbohydrate content under stress conditions is related to the reduction of pigment and photosynthesis resulted from low expression of enzymes involved in photosynthesis under drought conditions (Bayramov et al., 2010). Simultaneously, the yield losses often occurred due to a reduction in the starch production (Fowler, 2003). Declines in yield protein were found dependent on the plant stage and the level of the stress. Many protein changes were detected if relative water content was less than 80% (Guliyev et al., 2008). Total protein was determined in mg per gram dry mass and showed decreased values in yielded grains harvested from untreated wheat under drought (Table 3). Drought effect accompanied with pretreatments had aggravated total protein accumulation when compared to the control. Total protein values were increased progressively by both *SA* treatments and foliar applications, particularly *SA+Th$_1$*. Under drought conditions, accumulations of proline are associated with drought tolerance in plants (Nayyar and Walia, 2003; Ben Ahmed et al., 2009; Liu et al., 2011). Proline amount had increased in

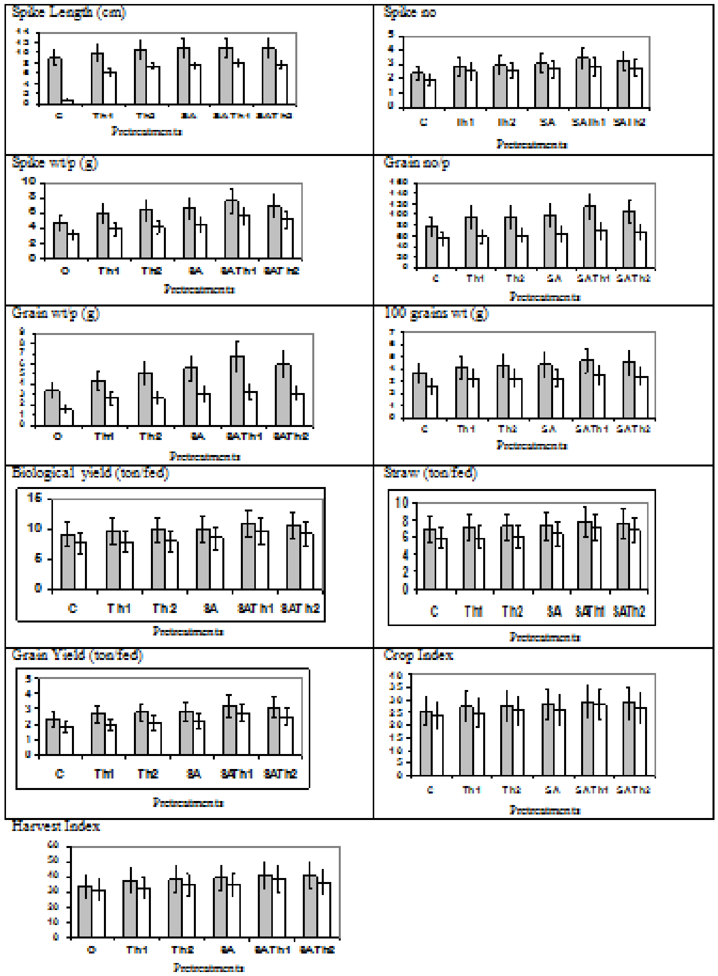

Fig 1. Yield components of wheat plants grown under normal and water deficit conditions as indicated in the headings, and actions of grain-priming using salycilic acid (SA), and foliar applications using two concentrations of thiourea. For 2.5 mmol (Th1), for 5 mmol (Th2) and their interactions (SA+Th). Error bars expressed ± SD of the means. Normal irrigation (dark columns) and water deficit conditions (white columns).

yielded grains under drought conditions. Interaction treatments using $SA+Th_2$ caused the high rise in proline accumulation (Table 4). Proline, generally, functions through counteracting the injury exerted by water stress by accumulation in the main plant organs (Heikal and Shaddad, 1982). Similar results were obtained by some other authors (Chen et al., 2001; Claussen, 2005; Hassanein et al., 2009). Flavonoids are members of the antioxidant family; they function on reducing potentials and accessibility of radicals under oxidative stress (Heim et al., 2002) and promoting plant protection (Grace and Logan 2000) through lipid peroxidation prevention (Caturla et al., 2003). The obtained data showed an increase level of flavonoids with drought stress in yielded wheat (Table 4). As similar to proline, flavonoids have protective role under stress condition. Therefore, we presumed that the induced flavonoid synthesis was enhanced first in plant and then in yield upon different foliar applications and, particularly, by using the interaction $SA+Th_1$. This might have led to total antioxidant activity of yielded grains in the present work (Adom and Liu, 2002). The total pool of phenolic compounds analysis as a photoprotector of the photosynthetic apparatus was carried out. The present data clarified the up-regulation of phenolic content in yielded crop under drought (Table 4). Participation of these substances in the mechanisms of adaptation of the photosynthetic apparatus to water stress in leaves was reported (Hura et al., 2009). Drought had negative effects on nutrient uptake and some nutrients translocation. Phosphorus is an essential element, participating in nucleic acids and ATP structures. The P uptake and translocation to shoots was reported as a drought-sensitive process (Pinkerton and Simpson, 1986; Rasnick, 1970) which was also found in this investigation from the decreased P representation in stressed wheat yield (Table 5). Improvements of P uptake were acheived via *SA* and *Th* treatments with their interactions. Application using $SA+Th_1$ resulted in the highest up regulation of P uptake and P presence in wheat grains (Table 5). Potassium is a famous element for protein and other enzymes syntheses; acts as osmoticum and maintains the turgor pressure of cell under water stress (Marschner, 1995). The level of K existence in wheat flag leaf was decreased as a consequence of water deficit (Table 5). The uptake had increased again after wheat plants were pretreated with low dilutions of *SA*, *Th* and their interactions. Magnesium uptake and level of existence in wheat plants is expected to be indirectly affected by drought conditions as it is influenced

Table 2. Growth characters (root length, root fresh weight, root dry weight) of wheat plants grown under drought stress on heading and anthesis and actions of salicylic acid (SA) and/or thiourea (Th). Grain priming (SA), foliar applications (Th).

Morphology / Treatments		Root length (cm) Headings (60 d)	Root length (cm) Anthesis (90 d)	Root fresh wt (g/plant) Headings (60d)	Root fresh wt (g/plant) Anthesis (90 d)	Root dry wt (g/plant) Headings (60 d)	Root dry wt (g/plant) Anthesis (90 d)
Normal condition	Control	18.00±9.00*	24.00±2.82*	1.01±0.18*	1.65±0.07*	0.391±0.11*	0.748±0.01*
	Th_1	19.00±9.27*	25.00±0.81*	1.07±0.21*	2.5±0.16*	0.444±0.04*	0.983±0.03*
	Th_2	21.38±10.44*	25.25±0.71*	1.42±0.25*	2.63±0.09*	0.549±0.11*	1.109±0.03*
	SA	22.40±11.18*	26.63±0.45*	1.81±0.96*	2.75±0.12*	0.757±0.13*	1.192±0.07*
	SA Th_1	25.25±12.24*	30.75±0.50*	2.34±0.50*	3.74±0.17*	0.959±0.02*	1.551±0.06*
	SA Th_2	24.83±1.15*	29.00±2.16*	1.95±0.17*	3.60±0.21*	0.768±0.16*	1.461±0.04*
L.S.D at 0.05		1.00	1.91	0.40	0.51	0.15	0.30
Drought condition	Control	15.40±8.43*	18.00±0.81*	0.82±0.13*	1.2±0.16*	0.306±0.03*	0.564±0.04*
	Th_1	17.50±8.42*	18.75±0.24*	0.84±0.17*	1.24±0.04*	0.353±0.03*	0.57±0.02*
	Th_2	17.63±8.59*	18.94±0.04*	1.07±0.03*	1.84±0.12*	0.421±0.03*	0.836±0.04*
	SA	18.00±8.87*	19.97±4.08*	1.08±0.10*	1.99±0.16*	0.449±0.03*	0.929±0.03*
	SA Th_1	19.75±9.91*	23.0±0.90*6	1.44±0.13*	2.74±0.09*	0.617±0.08*	1.247±0.07*
	SA Th_2	18.38±8.55*	21.75±0.86*	1.26±0.18*	2.06±0.08*	0.59±0.06*	1.009±0.08*
L.S.D at 0.05		1.41	2.71	0.56	0.72	0.29	0.42

* Represents Mean ±SD of each value

Table 3. Carbohydrate contents (mg/g) in yielded grains of wheat grown under drought stress and actions of salicylic acid (SA) and/or thiourea (Th). Total soluble sugars (T.S.S), total carbohydrates (T.C), Grain priming (SA), foliar applications (Th).

Metabolites (mg/g) / Treatments		T.S.S.	sucrose	Starch	T.C	Protein
Normal condition	Control	3.15±0.68*	1.36±0.29*	34.38±7.42*	37.53±4.42*	61.9±6.19*
	Th_1	2.99±0.64*	1.38±0.29*	34.7±7.5*	37.69±2.26*	74.7±7.47*
	Th_2	2.97±0.64*	1.77±0.38*	35.8±7.73*	38.76±1.55*	86.3±8.63*
	SA	2.79±0.60*	2.2±0.47*	37.31±8.05*	40.1±1.40*	92.9±9.29*
	SA Th_1	2.07±0.44*	2.7±0.58*	43.09±9.31*	45.16±2.25*	110.6±11.06*
	SA Th_2	2.47±0.53*	2.35±0.51*	42.75±9.23*	45.22±2.64*	97.3±9.73*
L.S.D at 0.05		0.13	0.045	0.045	1.02	1.02
Drought condition	Control	2.84±0.61*	0.99±0.21*	28.44±6.14*	31.28±0.85*	50.8±5.08*
	Th_1	2.4±0.52*	1.21±0.26*	32.08±6.93*	34.48±0.92*	66.4±6.64*
	Th_2	2.18±0.47*	1.51±0.32*	34.38±7.42*	36.56±1.30*	66.4±6.65*
	SA	2.11±0.45*	1.68±0.36*	36±7.77*	38.11±1.02*	69.1±6.91*
	SA Th_1	1.20±0.26*	2.16±0.46*	40.77±8.80*	41.97±0.77*	74.7±7.47*
	SA Th_2	1.95±0.42*	1.73±0.37*	39.53±8.54*	41.48±0.051*	71.9±7.19*
L.S.D at 0.05		0.18	0.063	1.45	1.82	1.82

* Represents Mean ±SD of each value.

by sulfur deficiency (Yuncai and Schmidhalter, 2005). Our data showed a decreased level of Mg upon drought stress, most probably due to chlorophylls reduction. The values of Mg had increased significantly following application using $SA+Th_1$ (Table 5). Calcium is involved in a number of physiological processes targeting plant growth and crop plants responses to different stresses (McLaughlin and Wimmer, 1999). Compared to other minerals, calcium values in flag leaf of wheat exposed to drought conditions were non-significantly decreased (Table 5). Our finding is in agreement with previous investigations reported the percent of Ca accumulation inside wheat grains which was not substantially depressed under water deficit (Jenne et al., 1958). For example, accumulation of Ca in yielded stressed wheat was detected as 78% without pretreatment and 155.5% with $SA+Th_1$ pre-protection (data not shown). This could be reasoned to the high pH value in the soil (8.2) which was preferred for best Ca uptake (Oertli, 1991).

Materials and methods

Plant materials and growth conditions

Field experiments were carried out at 'the Research and Production Station in Nubariah; the affiliate of National Research Center-Dokki-Cairo' during two successive seasons (2009/10 and 2010/11). A pure strain of wheat (*Triticum aestivum* var . Gimaza 9) grains were purchased from the

Table 4. Proline, phenols and flavonoids content in yielded grains of wheat grown under drought stress and actions of salicylic acid (SA) and/or thiourea (Th). Grain priming (SA), foliar applications (Th).

Treatment	Metabolite (mg/g)	Proline	Phenols	Flavonoids
Normal condition	Control	0.120±0.03*	4.00±1.06*	0.23±0.06*
	Th 1	0.157±0.04*	4.52±1.20*	0.25±0.07*
	Th_2	0.164±0.04*	5.37±1.41*	0.26±0.07*
	SA -	0.171±0.4*	5.95±1.57*	0.36±0.09*
	SA Th 1	0.178±0.04*	8.37±2.21*	0.61±0.16*
	SA Th_2	0.196±0.04*	7.17±1.90*	0.46±0.12*
L.S.D at 0.05		0.06	0.18	0.06
Drought condition	Control	0.158±0.04*	5.26±1.39*	0.34±0.98*
	Th 1	0.231±0.06*	5.60±1.48*	0.44±0.11*
	Th_2	0.244±0.06*	5.99±1.58*	0.52±0.13*
	SA -	0.283±0.07*	6.63±1.75*	0.57±0.15*
	SA Th_1	0.443±0.12*	12.02±3.18*	0.81±0.21*
	SA Th_2	0.350±0.10*	7.69±2.03*	0.67±0.17*
L.S.D at 0.05		0.08	0.25	0.17

*Represents Mean ±SD of each value

Table 5. Nutritional value (phosphorus, potassium, calcium and magnesium) of wheat grown under drought stress and actions of salicylic acid (SA) and/or thiourea (Th). Grain priming (SA), foliar applications (Th).

Treatments	Mineral (mg/g)	P	K	Ca	Mg
Normal condition	Control	0.163±0.04*	0.56±0.15*	0.23±0.06*	0.141±0.03*
	Th 1	0.21±0.05*	0.61±0.15*	0.26±0.07*	0.155±0.04*
	Th_2	0.213±0.05*	0.64±0.16*	0.29±0.08*	0.185±0.04*
	SA-	0.229±0.6*	0.66±0.17*	0.31±0.08*	0.19±0.05*
	SA Th 1	0.264±0.07*	0.9±0..23*	0.37±0.09*	0.245±0.07*
	SA Th_2	0.258±0.07*	0.66±0.16*	0.34±0.08*	0.235±0.8*
L.S.D at 0.05		0.009	0.04	0.03	0.006
Drought condition	Control	0.12±0.03*	0.33±0.17*	0.18±0.05*	0.11±0.06*
	Th 1	0.142±0.03*	0.35±0.09*	0.19±0.06*	0.12±0.02*
	Th_2	0.144±0.03*	0.36±0.16*	0.2±0.06*	0.12±0.03*
	SA	0.15±0.04*	0.42±0.11*	0.22±0.05*	0.12±0.03*
	SA Th 1	0.152±0.04*	0.45±0.12*	0.28±0.07*	0.15±0.03*
	SA Th_2	0.151±0.04*	0.43±0.11*	0.23±0.06*	0.130±0.03*
L.S.D at 0.05		0.012	0.06	0.05	0.01

** Represents Mean ±SD of each value

Agricultural Research Center, Egypt. The grains were cultivated in sandy-clay soil with the following soil components (%): sand (90.08), silt, (0.66), clay (9.26), moisture content (16.57), and water pressure (5.25). Other soil properties were as follows: pH (8.2), Electrical conductivity (1.7), Na^+ (0.982), K^+ (0.31) Ca^+ (7.02), Mg $^{++}$ (4.020_ Cl^- (0.566), and HCO_3 (1.3). The soils were fertilised with nitrogen/phosphorus/potassium at the rate of 80 kg N, 30 kg P_2O_5 and 30 kg K_2O/feddan and added in the form of ammonium nitrate (33.5 % N), calcium superphosphate (15.5 % P_2O_5) and potassium sulphate (48% K_2O), respectively. Superphosphate and potassium sulphate were added before planting; while, nitrogen was added at three equal intervals, the 1st before planting and the other two at three week intervals. After a complete emergence, wheat plants (15 d-old) were planted on November 29th and November 30th in the field for 120 d. The plants were irrigated daily with tap water for 15 days from the time of planting to allow the establishment of the plants. The applications in the pre-anthesis stages were processed by either grain priming using 1 mM salicylic acid (*SA*) or foliar applications using thiourea in one of the following concentrations, 2.5 mM (Th_1) or 5.0 mM (Th_2) or their interaction ($SA+Th_1$) and ($SA+Th_2$). Six groups of experiments were acheived and differed according to pretreatments: the 1st group was soaked in distilled water as 'control'. In the 2nd group; grains were soaked in 1 mM salicylic acid for 12 hrs. In the 3rd and 4th groups; plants were sprayed with the following concentrations of *Th*: 2.5 and 5 mM, respectively. For the 5th and 6th groups, grains were soaked in1 mM *SA* and the grown plants were sprayed with the following concentrations of *Th*: 2.5 and 5 mM, respectively. The first foliar application was carried out after 30 days from sowing and the second application was carried out after 40 days from sowing. Sampling of each group was achieved after 60 days (heading stage) and 90 days (anthesis stage) from sowing. On harvest, 30 plants from each group were collected to determine growth characters, yield and yield components as well as the biochemical changes in the yielded grains.

Growth Characters

Shoot Height

The heights of thirty replicates were taken at random from each treatment. Heights of plants from above soil surface until the uppermost growing tip were recorded in centimetres.

Flag Leaf Area

The leaf area (cm^2 $leaf^{-1}$) was determined by a method described by Quarrie and Jones (1979) using the proposed equation:

Leaf area= Length × Breadth × 0.75

Fresh and Dry Weight of Shoot and Root

Wheat plants were weighed immediately after harvest and estimations of fresh weight (F.wt) of both shoot and root were carried out. The fresh mass was dried at 80ºC to a constant dry weight. The fresh and dry weights of both shoot and root were expressed as 'g/plant'.

Root Length

The measurements were carried out from the above ground to the end of root tip and were recorded in centimetres.

Yield components

At harvest, all plants occupying a one metre squared cultivation area from each pretreatment were collected for yield component analyses including: spikes number/ plant, spike length/ plant (cm), spikes weight/ plant, grains number/ spike, grains weight/ plant, seed index, grain yield (kg/feddan), biological yield (kg/feddan), *harvest index* = economic yield /straw yield and the *crop index* = grain yield/ biological yield (Beadle1993).

Statistical analysis of data

Data of thirty measurements from two independent experiments were analysed through ± SD values using spss statistics data document for Windows, version 17.0. and Excel program, 2003. Each experiment was statistically analysed according to Snedecor and Cochran (1980). The least significant differences (LSD) at 5% level of probability were calculated to compare the means of different treatments.

Physiological analyses:

Biochemical analyses were carried out on fresh and dry materials of collected samples as indicated.

Estimation of carbohydrates

Extraction of plant tissues

Sugars were extracted by overnight submersion of dry tissue in 10 ml of 80 % (V/V) ethanol at 25^o C with periodic shaking. The extract was filtered and the filtrate was oven dried at 60 ^{o}C and then dissolved in a known volume of water to be ready for the determination of soluble sugars (Homme et al., 1992). Total soluble sugars and sucrose were determined using modifications of the procedures of Yemm and Willis (1954) and Handale (1968), respectively.

Estimation of polysaccharides

The method used for estimation of polysaccharides in the present study was that of Thayurmanavan and Sadasivam (1984).

Estimation of total protein

Total-N was determined by the conventional micro–Kjeldahl method, described by Peach and Tracy (1956). A sample of 0.05g of the dry powdered plant tissue was weighed into a digestion flask. Sulphate mixture followed by 1 ml ammonia-free water and 3 ml of ammonia-free H_2SO_4 were added. The sample was then incinerated, ammonia distilled off and nitrogen determined as aforementioned. The total protein was calculated by multiplying the value of total nitrogen by 6.25.

Estimation of proline

Proline accumulation in yielded wheat grains was determined according to Bates et al. (1973). The results were calculated in mg/g day wt of yielded grains.

Total phenolic contents

Total phenolic content in wheat flour was determined in a method described by Savitree et al. (2004) and Pourmorad et al. (2006).

Total flavonoid content

Total flavonoid content in the wheat plant was determined according to a colorimetric method described by Adom and Liu (2002).

Determination of mineral concentrations

The dried powder of plants was digested in a mixture of concentrated nitric acid, sulphuric acid and perchloric acid at the ratios 10: 1: 4, respectively. The volume was made up to a constant volume with distilled water according to the method of Chapman and Pratt (1978) with certain modifications. The acid digest of the plant matter was analysed for the determination of potassium (K), calcium (Ca), magnesium (Mg) and phosphorus (P), according to the following methods:

Phosphorus

Phosphorus content in the digested samples was determined colorimetrically by the ascorbic acid method described by Murphy and Riley (1958). Results were expressed as mg /g dry weight of yielded grains.

Potassium

Potassium content was determined using the flam photometer model (JENWAY Pf P7). The results were expressed as mg/g dry weight.

Magnesium and Calcium

Calcium and Magnesium contents were determined by using an Atomic Absorption Spectrophotometer; Perkin Elemer model 1100. The results were expressed as mg/g dry weight.

Conclusion

This study has made the following achievements: (1) Foliar applications and grain priming in wheat to avoid drought stress. (2) Characterisation of the morphology, physiology and the quality of wheat grains yielded from the field study

The obtained results highlighted marked effects of drought stress in decreasing growth parameters, yield component, total soluble sugars, total carbohydrates, protein and nutritional values of yielded grains including P, K, Ca and Mg. Alternatively, drought stress had increased proline, flavonoids and total phenol contents of the grains. It is generally accepted that grain priming using low substances of *SA* accompanied with foliar application using low concentrations of *Th* lead to regulations in wheat plant metabolism and, consequently, wheat performance under drought stress.

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