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Efficacy Comparison of Stearic Acid, Glutathione and Salicylic Acid on Wheat (*Triticum aestivum* L.) Cultivars Productivity in Sandy Soil

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Authors' contributions

This work was carried out in collaboration between both authors. Author MSAAEW designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author HFA managed the analyses of the study and managed the literature searches. Two authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out at Salhia District, Sharkia Governorate, Egypt, to study the growth and productivity of wheat cultivars (Gemmeiza 9, Sakha 93, Giza 168 and Sakha 94) to three bioregulators *i.e.* stearic acid (StA), glutathione (Gl) and salicylic acid (SA) at 50 and 100 ppm concentration. The results indicated that there was a significant difference in the accumulation of photosynthetic pigment in flag leaf among the wheat cultivars as well as between the bioregulator treatments. Gemmeiza 9 produced significantly higher grain yield than Sakha 93, Giza 168 and Sakha 94 cultivars by 26.0, 32.6 and 22.9%, respectively. The response of wheat plants to the three bioregulators was varied according to the wheat cultivar and bioregulator as well as bioregulator concentration used. Application of StA at 100 ppm gave the highest increment in grain yield (26.2%) followed by SA at 100 ppm (23.4%) with insignificant difference between the two superior treatments. The maximum grain yield was obtained by spraying Gemmeiza 9 and Sakha 94 with 100 ppm of stearic acid and salicylic acid, respectively. Application of SA (50 ppm) gave the lowest grain yieldha^{-1}, compared to rest bio-regulators treatments, however this treatment increased grain yield per ha by 9.4%. Insignificant differences were noticed among the wheat cultivars in the free amino acids, total phenols and total

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sugars, while Sakha 94 recorded the highest sucrose content in grains. Exogenous application of Gl (50 and 100 ppm) gave the highest value of the free amino acids and sucrose percent, respectively, while highest total phenols and total sugars were recorded with application SA at 100 ppm. Generally, it could be concluded that growing wheat plants Gemmeiza 9 and spraying the plants with stearic acid at 100 ppm increase the wheat productivity in the sandy soil.

Keywords: Concentrations; chemical constituents; glutathione; pigments; salicylic acid; stearic acid.

1. INTRODUCTION

Wheat crop is considered the most important cereal crop inEgypt and in the world. There is a gap between the production (7.3 Million tons) and consumption (19.7 Million tons) of wheat in Egypt [1]; therefore the efforts towards increasing the wheat productivity, particularly in the sandy soil, are very necessary.

Managing balance between vegetative and reproductive growth is a very important part of crop productivity [2]. Plant growth regulators can help to manage this balance [3]. Plant growth regulators are natural compounds that have shown farreaching effects on the growth and development of plants even at low concentration [4]. In addition, plant growth regulators are known to affect growth, flowering and assimilate translocation in plants [5]. Salicylic acid, glutathione and stearic acid are bioregulators substances using for improving crop productivity.

Salicylic acid (SA) is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in plant, such as stomatal closure, ion uptake, inhibition of ethylene biosynthesis, transpiration and stress tolerance [6,7]. Salicylic acid has been reported to cause amultitude of effects on the morphology and physiology of plants [8] and to induce a protective mechanism enhancing resistance to biotic and abiotic stresses [9]. Foliar application of SA exerted a significant effect on plant growth metabolism when applied at physiological concentration and thus acted as one of the plant growth regulating substances [10]. Salicylic acid enhanced wheat growth [6] and maize growth [11]. Gharib and Hegazi [12] reported that SA stimulated various growth aspects of bean seedlings perhaps through interference with the enzymatic activities responsible for biosynthesis and/or catabolism of growth promoting and inhibiting substances. Thus, it might be concluded that salicylic acid could eliminate the adverse effects of cold stress in common bean. Salicylic acid foliar application caused a partial improvement in number of plant pods in DPX and Gorgan 3 soybean varieties [13]. They added that increasing salicylic acid concentration caused the plant height and sub-branch length to decrease. At the beginning of the growth season, chlorophyll content was higher in salicylic acid sprayed plants with 0.4 mM concentration. While sprayed plants with 0.8 mM of salicylic acid concentration had more leaf area duration at the end of the growth season [13].

Glutathione (L- cysteine, L-glutamine and L-glycine) could be improvising the economic plants through build blocks of protein synthesis, which could be enzyme, hormones and antioxidants important for metabolic activities [14]. Low molecular weight antioxidants, such as ascorbate, glutathione and tocopherol, are information-rich redox buffers that interact with numerous cellular components. In addition to crucial roles in defence and as enzyme cofactors, cellular antioxidants influence plant growth and development by modulating processes from mitosis and cell elongation to senescence and death [15,16]. Localized activity of glutathione could also help elucidate the mechanism of stress resistance. This effect indicates that glutathione may be involved in protection against DNA damage [17]. Whereas ascorbate and glutathione are major redox metabolites in plant callus with specific roles in cellular redox homeostasisand the regulation of cell cycle [18]. All redox regulators influenced on the hydrolytic activity with H+ translocating enzymes, although sensitivity of proton pumps to redox regulators was found to depend from stage of plant development [19].

Stearic acid is one of long-chain fatty acids occurring in the cells of plants and animals. It occurs very extensively in nature, most often being incorporated into triglycerides. It is also known to promote the growth of some soil organisms, such as bacteria. Higher plants contain two galactolipids, monogalactosyldiacylglycerol (MGD) and digalactosyldiacylglycerol (DGD), which constitute about 75 mol % of the thylakoid lipids in chloroplasts [20]. MGD and DGD are synthesized from UDP-Gal and diacylglycerol by MGD and DGD synthases in the chloroplast envelope membranes. While MGD is mostly produced from diacylglycerol originating from the plastid (“prokaryotic lipid”), DGD is largely derived from endoplasmic reticulum (ER) lipid precursors “eukaryotic lipid” [21]. Recent results suggest that an ATP-binding cassette-type transport complex is involved in the transfer of eukaryotic lipids from the ER to the chloroplast [22]. Galactolipids do not only establish the lipid bilayer into which the photosynthetic complexes are embedded. Structural analysis of crystallized protein complexes revealed that galactolipids are also found within the structures of PSI and PSII, light-harvesting complex II (LHCII) and cytochrome b_6/f [23,24]. The strong extent of *Arabidopsis* growth retardation of the DGD-deficient lines *dgd1* and *dgd1dgd2* can be primarily attributed to a decreased capacity for chloroplast membrane assembly and proliferation and to a smaller extent, to photosynthetic deficiency. During phosphate limitation, GGD increases in plastidial and extraplastidial membranes of the transgenic lines to an extent similar to that of DGD in the wild type, indicating that synthesis and transport of the bacterial lipid (GGD) and of the authentic plant lipid (DGD) are subject to the same mechanisms of regulation [25]. Therefore, using StA on plant led to an increase plant growth and yield as follow bean, marigold and squash (twice), carrots (30 %) and Red beets (60 %). The mechanism of stimulation in an enzyme system by stearic acid, then, is proposed to be involved in the Calvin cycle of photosynthetic reactions. Specifically, the rate-limiting step of carbon dioxide fixation, in which ribulose-1,5-diphosphate is converted into 3-phosphoglyceric acid; a reaction catalyzed by ribulose-1,5-bisphosphate carboxylase, is proposed to be the affected system. It is thus proposed that that stimulating effect of stearic acid observed is due to its hormone-like effects on plants [26].

Therefore, the objective of this study was to investigate the effect of three bioregulators *i.e.* stearic acid, glutathione and salicylic acid at 50 and 100 ppm concentration on thegrowth and productivity of wheat cultivars (Gemmeiza 9, Sakha 93, Giza 168 and Sakha 94) in sandy soil.

2. MATERIALS AND METHODS

The study was carried out in a private farm at Salheia District, Sharkia Governorate, Egypt during winter season of 2010-2011 and 2011-2012. The average temperature was 19.9ºC and relative humidity was 65.2% during the two season's growth. The experiments were conducted to investigate the effect of three bioregulators at two concentrations on the productivity of four wheat cultivars grown in sandy soil. The texture of the experimental soil was sandy with pH 7.8, organic matter 1.65%, electrical conductivity 1.14 mmohs cm^{-1}, $CaCO_3$ 1.56%, total N 0.05%, total P 0.028% and total K 0.02%.

The variants were 4 cultivars of common wheat, *i.e.*, Gemmeiza 9, Giza 168, Sakha 93 and Sakha 94, while the three bioregulators were glutathione (L-gammaglutamyl-L-cysteinylglycine), stearic acid ($CH_3(CH_2)_{16}CO_2H$) and salicylic acid at 50 and 100 ppm concentrations beside the control (untreated) treatment.

The seeds of four wheat (*Triticum aestivum* L.) cultivars were obtained from Agricultural Research Centre, Giza, Egypt and were sown in the second week of November in both seasons.

The plot area was 10.5 m^2 (3.0 m width by 3.5 m length), containing five ridges spaced 60 cm apart. Wheat seeds were sown in constant spaced hills (20 cm apart) on the both sides of ridge according to [27]. The experiment was established with a split-plot design having three replicates. The main plots included four wheat cultivars and subplots were assigned to seven bioregulators treatments. The irrigation system was surface and the crop received 214, 54 and 60 of N, P_2O_5 and K_2O kg ha^{-1}. The normal cultural practices for growing wheat in sandy soil were applied as recommended, except for the bioregulators treatment. After one month from sowing, the wheat plants were sprayed with the bioregulators.

Salicylic acid was dissolved in distilled water and the pH was adjusted at 6.5 with NaOH.

After 70 days (Heading stage) from sowing, 5 holes from each plot were taken to determine plant height, Number of tillers m^{-2}, flag leaf area (cm^2), flag leaf weight, fresh and dry weight of plant (gm^{-2}).

At harvest, a plant sample of one square meter from each plot was taken to determine the plant height (cm), spikes number (number of spike-bearing tillers) per total tillers number (%), spike weight (g), spike length (cm) and grain index (1000 grains weight) and harvest index (percentage of grain yield to biological yield). Biological and grain yields per hectare were determined by harvesting the whole plot area.

2.1 Chlorophyll Extraction and Measurement

Chlorophyll concentration was determined from fully expanded flag leaf at heading stage. A leaf sample of 0.1 g was ground and extracted with 5 mL of 80% (v/v) acetone in the dark [28]. The mixture was filtered and absorbancies (Jenway 6105 UV/VIS, Spectrophotometer) were determined at 645, 663 and 450 nm. Concentration of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoids were estimated [29].

2.2 Biochemical constituent's determination

Photosynthetic pigments (chl. *a*, *b* and carotenoids) were determined in the flag leaf [30]. Wheat grains were dried in oven at 70ºC and then finally ground for determination free amino acid [31] and total phenols [32], total sugars [33] and sucrose [34].

2.3 Statistical Analysis

The obtained results were subjected to the statistical analysis by MSTAT-C statistical analysis program [35]. Since the trend was similar in both seasons, Bartlett's test and the combined analysis of the two growing seasons were applied. Means were compared using least significant difference test at 5% probability level.

3. RESULTS AND DISCUSSIONS

3.1 Vegetative Growth

3.1.1 Effect of wheat cultivars

Wheat cultivars significantly differed in all growth parameters studied. Giza 168 variety recorded the highest values of plant height and number of tillers m^2, while Gemmeiza 9 recorded the highest values of flag leaf area, flag leaf fresh weight and fresh and dry weights of plant than the other cultivars (Table 1).

The highest flag leaf area and weight were showed with Gemmeiza 9 variety which more than Sakha 93, Giza 168 and Sakha 94 varieties by 74.3, 66.0 and 47.9% and 28.6, 80.0 and 28.6% respectively (Table 1). McMaster et al. [36] did not find differences in the phyllochron among 10 cultivars of winter wheat or between maturity classes. However, others have reported that growth criteria for wheat cultivars were differed according to the agronomic practices [37].

Gemmeiza 9 *var.* produced a significant more plant dry weight than Sakha 93, Giza 168 and Sakha 94 varieties by 45.5, 33.5 and 21.5%, respectively. Insignificant differences in the dry weight were noticed among Sakha 93, Giza 168 and Sakha 94 cultivars. Hangarter [38] reported that plants have evolved highly sensitive and selective mechanisms that detected and respond to various aspects of their environment. As a plant develops, it integrates the environmental information perceived by all of its sensory systems and adapts its growth to the prevailing environmental conditions.

3.1.2 Effect of bioregulators treatments

Application of StA and SA at 100 ppm gave the tallest plants (Table 1), compared to the unsprayed plants. Both treatments were significantly surpassed the others. Stearic acid (50 ppm) treatment caused a significant increase in the number of tillers, whereas application of StA (50ppm), GI (100 ppm) and SA (100 ppm) treatments increased the tillers number by 25.3, 16.1 and 3.1%, respectively, compared to untreated treatment. This might be due to StA and SA had a regulatory effect on activating biochemical pathways associated with tolerance mechanisms in plants [26,39].

Table 1. Effect of some bio-regulators at two concentrations on growth criteria at heading stage of four wheat cultivars grown in sandy soil (pooled analysis in terms of statistics analysis of the two seasons)

Treatments		Gem 9	Sakha 93	Giza 168	Sakha 94	Mean	Gem 9	Sakha 93	Giza 168	Sakha 94	Mean
Growth regulators	Conc ppm	Plant height (cm)					Number of tillers/m^2				
Control	-	90	95	105	96	97	192	126	178	152	162
StA	50	85	100	90	90	91	215	185	174	237	203
StA	100	88	100	106	105	100	152	155	181	137	156
Gl	50	87	100	100	95	96	115	141	144	137	134
Gl	100	95	95	100	95	96	189	196	204	163	188
SA	50	94	100	103	91	97	237	152	181	96	167
SA	100	96	102	101	99	100	207	133	170	159	167
Mean		91	99	101	96		187	155	176	154	
LSD for varieties		7					23				
LSD for bioregulators		6					22				
LSD for interaction		NS					46				
		Flag leaf area (cm^2)					Flag leaf fresh weight (g)				
Control	-	19.2	16.8	7.6	9.8	13.4	0.8	0.7	0.4	0.5	0.6
StA	50	19.4	8.8	8.6	16.7	13.3	1.1	0.4	0.4	0.9	0.7
StA	100	5.0	6.3	10.6	8.9	7.7	0.6	0.4	0.7	0.8	0.6
Gl	50	16.1	8.3	10.8	1.9	11.5	0.6	0.7	0.5	0.6	0.6
Gl	100	11.1	8.8	5.6	5.6	7.8	0.5	0.8	0.4	0.5	0.6
SA	50	21.0	13.8	12.2	12.2	14.8	0.9	0.8	0.6	0.7	0.8
SA	100	31.4	8.1	19.0	19.0	19.4	1.7	0.9	0.6	1.O	1.1
Mean		17.6	10.1	10.6	11.9		0.9	0.7	0.5	0.7	
LSD for varieties		3.2					0.3				
LSD for bioregulators		2.9					0.2				

LSD for interaction		5.7					0.4				
		Fresh weight of plants (kg m^{-2})					**Dry weight of plant (g m^{-2})**				
Control	-	3.80	2.40	2.40	2.99	3.90	1292	816	816	1017	985
StA	50	3.64	2.68	3.64	3.65	3.02	1238	911	1238	1241	1157
StA	100	4.20	2.44	2.57	2.87	3.50	1428	830	874	976	1027
Gl	50	3.64	3.06	3.64	3.66	2.89	1238	1040	1238	1244	1190
Gl	100	4.12	1.98	2.57	2.87	4.04	1401	673	874	976	981
SA acid	50	4.62	3.82	4.12	3.60	3.66	1571	1299	1401	1224	1374
SA acid	100	4.7	3.37	2.57	4.00	3.40	1598	1146	874	1360	1244
Mean		4.10	2.82	3.07	3.38		1395	959	1045	1148	
LSD for varieties		0.76					240				
LSD for bioregulators		0.52					231				
LSD for interaction		1.04					469				

Conc: concentration, Gem: Gemmeiza, StA: stearic acid SA: salicylic acid, Gl: glutathione

Increasing the StA concentration from 50 to 100 ppm resulted in decreasing the number of tillers by 30.1% (Table 1). Increased the application rate of Gl from 50 to 100 ppm increased the number of tillers. The results indicated that spraying the wheat plants by bioregulators significantly increased both flag leaf area and weight compared with control treatment as shown in Table (1). Salicylic acid (100 ppm) gave the highest values of the leaf flag leaf characters. Glutathione (100 ppm) and SA at 50 ppm gave the maximum fresh and dry weights of wheat plants which increased than that of unsprayed plants by 3.6 and 39.5%, respectively. Therefore the application of Gl and SA ameliorated the wheat growth parameters (Table1). In the same trend low molecular weight antioxidants, such as ascorbate, glutathione and tocopherol are information-rich redox buffers that interact with numerous cellular components. In addition to crucial roles in defence and as enzyme cofactors, cellular antioxidants influence plant growth and development by modulating processes from mitosis and cell elongation to senescence and death [15,16].

Hormones play a critical role in regulating branching [40,41]. Salicylic acid is an endogenous growth regulator of phenolic nature and acts as potential non-enzymatic antioxidant which participates in the regulation of many physiological processes in plants, such as stomatal closure, photosynthesis, ion uptake, inhibition of ethylene biosynthesis, transpiration and stress tolerance [6,42]. Salicylic acid is a tool to increase plant tolerance against the adverse effect of biotic and abiotic stresses [43] either by foliar application or seed treatment. Since, it has a regulatory effect on activating biochemical pathways associated with tolerance mechanisms in plants [39]. Salicylic acid stimulated various growth aspects of bean seedlings perhaps through interference with the enzymatic activities responsible for biosynthesis and/or catabolism of growth promoting and inhibiting substances [12].

Using StA at 50 and 100 ppm improved the dry weight of plants by 17.5and 4.3% compared to the unsprayed plants as shown in Table (1). This effect might due to bioregulators influence plant growth and development by modulating processes from mitosis and cell elongation to senescence and their protection to these processes.

3.1.3 Effect of the interaction between wheat cultivars and bioregulators treatments

Number of tillersm^{-2}, flag leaf area and weight fresh and dry weight of plant were significantly improved with bioregulators application. Salicylic acid at 100 ppm treatment in Gemmeiza 9 cultivar gave the highest values of plant characters, if compared to untreated plants (Table 1). Similar finding was reported [44] on onion. Salicylic acid ameliorates seedling growth, phytohormones and enzymes activity in bean (*Phaseolus vulgaris* L.) under abiotic stress [12,45]. Khodary [46] reported that SA and related compounds have been reported to induce significant effects on various biological aspects in plants. These compounds influence in a variable manner; inhibiting certain processes and enhancing others [47].

3.2 Photosynthetic Pigments

3.2.1 Effect of wheat cultivars

There was insignificant difference between Gemmeiza 9, Sakha 93 and Giza 164 in the chlorophyll *a* as well as among Gemmeiza 9, Sakha 93 and Giza 168 cultivars in chlorophyll *b* and carotene (Table 2). Giza 168 recorded the highest chlorophyll *a* and total chlorophyll compared to the three cultivars studied. While Sakha 94 was gave the best values of the chlorophyll *b* and carotene content. The differences between all cultivars content of photosynthetic pigments might be due to gene expression of all cultivars.

Table 2. Effect of some bio-regulators at two concentrations on photosynthetic pigments (mg100g^{-1} fresh wt) at 75 days after planting of four wheat cultivars grown in sandy soil (Pooled analysis in terms of statistics analysis of the two seasons)

Treatments		Gem 9	Sakha 93	Giza 168	Sakha 94	Mean	Gem 9	Sakha 93	Giza 168	Sakha 94	Mean
Growth regulators	**Conc ppm**										
		chll. *a* (mg g^{-1})					**chll. *b* (mg g^{-1})**				
Control	-	1.245	0.839	0.779	0.754	0.904	0.725	0.427	0.376	0.420	0.487
StA	50	0.849	0.756	1.116	0.883	0.901	0.442	0.423	0.639	0.560	0.516
StA	100	0.954	0.390	0.900	1.018	0.816	0.511	0.434	0.490	0.582	0.504
Gl	50	0.970	0.911	0.838	0.914	0.908	0.503	0.489	0.489	0.470	0.488
Gl	100	0.617	1.006	1.069	0.643	0.834	0.586	0.562	0.458	0.329	0.484
SA	50	0.648	0.852	1.012	0.894	0.852	0.352	0.494	0.566	0.514	0.482
SA	100	0.716	0.618	0.740	0.815	0.722	0.377	0.374	0.353	0.635	0.435
Mean		0.857	0.768	0.922	0.846		0.499	0.458	0.482	0.501	
LSD at 5% for Var.		0.085					NS				
LSD at 5% for Bior.		0.083					NS				
LSD at 5% for Inter.		0.171					0.143				
		Carotene (mg g^{-1})					**Total Chlorophyll (*a+b*) (mg g^{-1})**				
Control	-	0.458	0.297	0.459	0.457	0.418	1.970	1.266	1.155	1.174	1.391
StA	50	0.338	0.227	0.353	0.400	0.330	1.291	1.179	1.755	1.443	1.417
StA	100	0.318	0.333	0.272	0.379	0.326	1.466	0.824	1.390	1.600	1.320
Gl	50	0.383	0.380	0.464	0.276	0.376	1.473	1.400	1.327	1.384	1.396
Gl	100	0.291	0.303	0.429	0.350	0.343	1.203	1.568	1.527	0.972	1.318
SA	50	0.242	0.219	0.304	0.281	0.262	1.000	1.346	1.578	1.408	1.333
SA	100	0.281	0.307	0.279	0.457	0.331	1.092	0.992	1.094	1.450	1.157
Mean		0.330	0.295	0.366	0.371		1.356	1.225	1.404	1.347	
LSD at 5% for Var.		0.55					0.061				
LSD at 5% for Bior.		0.48					0.060				
LSD at 5% for Inter.		0.98					0.127				

Abbreviations: Conc: concentration, Gem: Gemmeiza, Var: varieties, SA: salicylic acid, Bior: bioregulators, Inter: interaction

3.2.2 Effect of bioregulators treatments

Spraying stearic acid at 50 ppm recorded the highest accumulation of chlorophyll *b* and total chlorophyll content compared with the other treatments, while application of SA at 100 ppm significantly exhibited chlorophyll *a*, *b* and total chlorophyll pigments content as shown in Table (2) compared to the control. Treatment maize with salicylic acid [45,47] increased pigments content in the leaves as well as the rate of photosynthesis. Stearic acid at 50 ppm recorded the highest chlorophyll *b* and total chlorophyll accumulations and increased its content by 6.0 and 1.9% over the unsprayed plants, respectively (Table 2). Spraying Gl at 50 ppm increased the accumulation of chlorophyll *a* by 0.04% than unsprayed plants. Glutathione system plays critical roles in the coordination of cellular processes with photosynthetic activity [48]. Photosynthetic organisms have developed robust antioxidant and redox buffering systems composed of enzymatic and small molecule components [49]. In addition, Galactolipids do not only establish the lipid bilayer into which the photosynthetic complexes are embedded. Structural analysis of crystallized protein complexes revealed that galactolipids are also found within the structures of PSI and PSII, light-harvesting complex II (LHCII) and cytochrome b_6/f [23,24].

3.3 Effect of the Interaction between Wheat Cultivars and Bioregulators Treatments

The interaction between wheat cultivars and bioregulators treatments had a significant effect on chlorophyll *a,* chlorophyll *b* carotene and total chlorophyll pigments content (Table 2). Application of StA at 50 ppm on Giza 168 gave the highest value of chlorophyll *a*, *b* and total chlorophyll, while the highest carotene content was recorded with the application of Gl at 50 ppm on Giza 168. This effect might be due to the differences in wheat genotype that reflected on their response to the different bioregulators.

3.4 Yield Attributes and Yield

3.4.1 Effect of wheat cultivars

Data in Table 3 showed that there are significant differences among wheat cultivars in the plant height, spike number per tillers number %, spike weight, grain index and harvest characters; however Sakha 94 cultivar recorded the tallest plants, Giza 168 recorded the highest value of spikes number and Gemmeiza 9 recorded the highest value of grain index, biological yield and harvest index. This result means that Gemmeiza 9 cultivar contribute relatively more resources to the grain than to the vegetative plant parts. This effect is related to increase spike weight and grain index as shown in Table 3. Insignificant in grain index were recorded among Gemmeiza 9 and the two Sakha cultivars, while Giza 168 recorded the lowest grain index if compared to the three cultivars.

Gemmeiza 9 significantly surpassed the three cultivars in the biological and grain yield criteria. In the same direction, the highest grain yield per unit area was recorded with Gemmeiza 9 while the lowest was recorded with Giza 168. Gemmeiza 9 significantly gave more grain yield than Sakha 93, Giza 168 and Sakha 94 cultivars by 43.2, 51.8 and 22.0%, respectively (Table 3). This result was expected where Gemmeiza 9 recorded the tallest plant, spike weight and grain index.

Table 3. Effect of some bio-regulators at two concentrations on yield and its related characters of four wheat cultivars grown in sandy soil (Pooled analysis in terms of statistics analysis of the two seasons)

Treatments		**Gem 9**	**Sakha 93**	**Giza 168**	**Sakha 94**	**Mean**	**Gem 9**	**Sakha 93**	**Giza 168**	**Sakha 94**	**Mean**
Growth regulators	**Conc ppm**	**Plant height (cm)**					**Spikes number/tillers number (%)**				
Control	-	108	104	102	114	107	89.0	96.3	86.8	96.1	92.0
StA	50	114	104	109	115	111	95.8	90.7	99.0	92.7	94.5
StA	100	112	100	116	117	111	96.8	100.0	100.0	98.5	98.8
Gl	50	108	108	117	113	111	84.3	97.9	92.2	98.9	91.4
Gl	100	119	106	105	116	112	99.0	100.0	92.2	100.0	97.8
SA	50	119	106	118	111	114	99.1	95.9	83.8	96.1	92.9
SA	100	116	116	114	116	116	100.0	100.0	89.3	98.7	97.0
Mean		114	106	112	115		94.9	97.2	91.9	97.3	
LSD at 5% for Var.		7					2.7				
LSD at 5% for Bior.		6					1.9				
LSD at 5% for Inter.		12					3.8				
		Spike weight g^{-1}					**Spike length (cm)**				
Control	-	2.2	1.9	2	2.3	2.1	10.0	10.5	10.0	10.0	10.1
StA	50	2.6	2.5	2.3	2.8	2.6	10.0	10.0	10.5	10.5	10.3
StA	100	2.7	2.4	2.3	2.3	2.4	11.5	10.0	10.5	10.5	10.6
Gl	50	2.2	2.4	2.5	3.0	2.5	10.0	10.5	11.0	09.5	10.3
Gl	100	3.0	2.9	2.8	2.2	2.7	10.0	10.5	10.0	10.5	10.3
SA	50	2.5	2.4	2.4	2.3	2.4	10.5	10.5	10.5	10.5	10.5
SA	100	2.8	2.6	2.4	2.4	2.6	10.5	10.0	10.0	11.5	10.5
Mean		2.6	2.4	2.4	2.5		10.4	10.3	10.4	10.4	
LSD at 5% for Var.		0.2					NS				

LSD at 5% for Bior.		0.2					NS				
LSD at 5% for Inter.		0.4					0.8				
		Grain index g-[1]					**Harvest index%**				
Control	-	5.3	4.5	4.7	4.4	4.7	35.3	44.5	45.9	42.2	41.9
StA	50	4.7	5.6	5.7	3.8	5.0	33.5	48.4	44.5	43.2	42.4
StA	100	5.0	4.9	4.7	4.4	4.8	34.7	44.4	47.3	45.0	42.8
Gl	50	5.0	5.1	4.9	4.4	4.9	34.7	47.8	43.2	43.1	42.2
Gl	100	4.7	4.7	5.0	4.2	4.7	31.9	47.3	45.2	43.4	41.9
SA	50	5.3	4.8	5.0	4.0	4.8	33.1	43.4	42.4	41.6	40.1
SA	100	4.7	4.8	5.0	4.6	4.8	32.7	46.5	39.3	43.5	40.5
Mean		5.0	4.9	5.0	4.3		33.7	46.0	43.9	43.1	
LSD at 5% for Var.		0.2					1.4				
LSD at 5% for Bior.		0.3					1.8				
LSD at 5% for Inter.		0.5					3.6				

Abbreviations: Conc: concentration, Gem: Gemmeiza Var: varieties, Bio: bioregulators, Inter: interaction

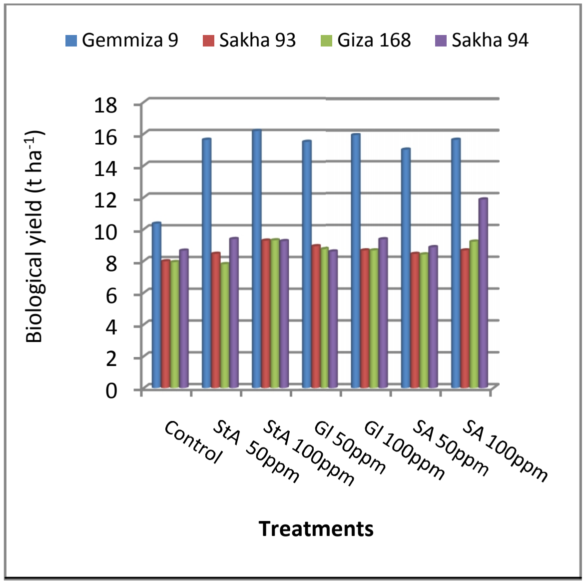
The differences yield among cultivars in grain and biological yields might be due to the genetically differences among cultivars and different genotypes concerning dry matter partitioning where wheat cultivars might differ in carbon equivalent, yield energy per plant and per hectare [50].

3.4.2 Effect of bioregulators treatments

Bioregulators varied of their effect on the yield and its attributes of wheat plant. Salicylic acid was more effective on plant height weight and biological yield, while stearic acid at 50 and 100 ppm were more effective on grain index, grain yield and harvest index. The stimulatory effect of salicylic acid on the biological yield of wheat plants may be attributed to the effect of SA on many biochemical and physiological processes that were reflected on improving vegetative growth and active translocation of the photosynthesis products from source to sink. Similar findings were recorded on sunflower [51]. Exogenous application of SA increased antioxidant enzyme activities and proline content. The greatest responses were obtained in plants sprayed with 10^{-5} M SA, with significant increases observed in activity of catalase (20.1%), guaiacol peroxidase (45.2%), superoxide dismutases (44.1%) and proline content (43.1%) [52]. Stearic acid (100 ppm) recorded the greatest grain yield ha^{-1} followed by SA (100 ppm) and Gl(50 and 100 ppm) with insignificant differences among the three superiorities treatments (Table 3). The three superior treatments increased the grain yield per ha by 29.8, 25.1 and 22.4%, respectively, if compared to untreated treatment. The mechanism of stimulation in an enzyme system by StA, then, is proposed to be in the Calvin cycle of photosynthetic reactions. Specifically, the rate-limiting step of carbon dioxide fixation, in which ribulose-1,5-diphosphate is converted into 3-phosphoglyceric acid; a reaction catalyzed by ribulose-1,5-bisphosphate carboxylase, is proposed to be the affected system. It is thus proposed that that stimulating effect of stearic acid observed is due to its hormone-like effects on plants [26].

Gemmeiza 9 significantly surpassed the three cultivars in the biological and grain yield criteria, while the lowest was recorded with Giza 168. Gemmeiza 9 produced significantly higher grain yield than Sakha 93, Giza 168 and Sakha 94 cultivars by 26.0, 32.6 and 22.9 %, respectively (Table 3). This result was expected whereas Gemmeiza 9 recorded the tallest plant, biological yield and grain index. According to [53] the better productivity of the Gemmeiza 9 were due to the higher flag leaf area and weight (Table 1), total photosynthetic pigments (Table 2), spikes number per tillers number (%), spike weight and length and 100 grain weight (Table 3), but other characteristics were intermediate. Similar findings were reported by Pandey et al. [54].

The response of wheat plants productivity to the three bioregulators was varied according to the wheat cultivar, bioregulators as well as bioregulator concentration used (Fig. 1). The maximum grain yield was obtained by the application of StA at 100 ppm, followed by SA at 100 ppm with insignificant difference between the two superior treatments. The two superior treatments significantly increased the grain yield by 26.2 and 23.4%, respectively compared to unsprayed plants. Insignificant differences were recorded among StA (50 ppm), Gl (50 ppm) and Gl (100 ppm). Application of SA at 50 ppm gave the lowest grain yield per ha, compared to the other bioregulators treatments, however this treatment increased the grain yield per ha by 9.7%.



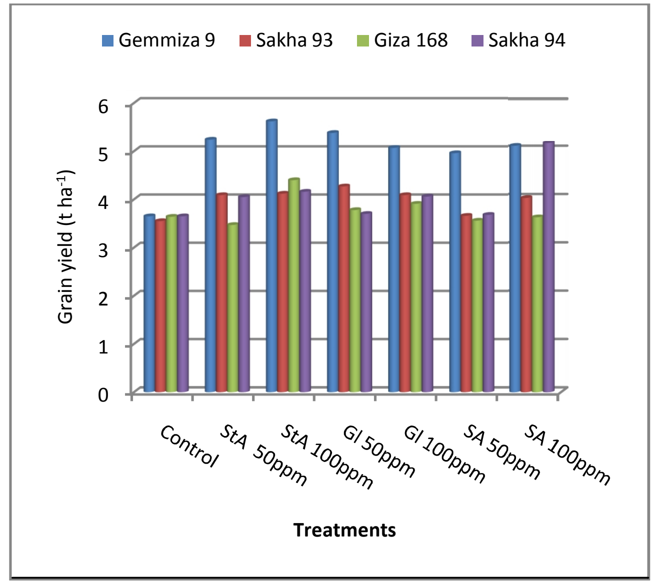


Fig. 1. Grain and biological yields as affected by the interaction between wheat cultivars and bioregulators treatments grown in sandy soil. (Pooled analysis in terms of statistics analysis of the two seasons).Abbreviations: StA: stearic acid; Gl. glutathione; SA: salicylic acid.

Increasing the bioregulator concentration resulted in increasing the grain yield, except with Gl treatment, where both concentration treatments gave typically grain yield. Increasing StA concentration from 50 to 100 ppm caused significant increase of the grain yield by 8.6 %, while with SA the increase amounted by 12.8%.

Devi et al. [55] reported that the increase in the soybean seed yield could be a reflection of the effect of bioregulators on growth and development, it might be due to (a) marked increase in the number of branches per plant which gave a chance to the plant to carry more seeds (b) marked increase in the photosynthetic pigments content, which could lead to increase in photosynthesis, resulting in greater transfer of assimilates to the seeds and causing increase in their weight. The increments in wheat grain yield due to Gl at 50 ppm, StA (100 ppm) and SA (100 ppm) may be attributed to that Gl is as an antioxidant protecting the cell from damage caused by free radical hydrogen. Glutathione also help the other antioxidation in the cells stay in their active form. The externally supplied glutathione similarly increased the enzyme activities, particularly peroxides [56]. In addition, it could be through improve wheat growth physiology that reflect in build blocks of protein synthesis which could be enzymes, and hormones important for metabolic activates [14]. Khan [6] and [7] reported that salicylic acid is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in plant, such as stomatal closure, ion uptake, inhibition of ethylene biosynthesis, transpiration and stress tolerance.

3.4.3 Effect of the interaction between wheat cultivars and bioregulators treatments

Data presented in Table 3 indicated that the interaction among wheat cultivars and bioregulators treatments had significant effect on the plant height, spike weight and length, grain index, spikes number per tillers number (%), harvest index, biological and grain yields per ha**.**

The highest biological yield was recorded with Gemmeiza 9 sprayed with stearic acid at 100 ppm, while the lowest one was recorded with Giza 168 sprayed with stearic acid at 50 ppm.

The role of glutathione in increasing Gemmeiza 9 cultivar productivity may be attributed to that Gl is as an antioxidant protecting the cell from damage caused by free radical hydrogen. Glutathione also help the other antioxidation in the cells stay in their active form. Localized activity of glutathione could also help elucidate the mechanism of stress resistance. This effect indicates that glutathione may be involved in protection against DNA damage [16]. The externally supplied glutathione similarly increased the enzyme activities, particularly peroxides [56]. In addition, it could be through improve wheat growth physiology that reflect in build blocks of protein synthesis which could be enzymes and hormones important for metabolic activates [14]. The extremely supplied glutathione increased the enzyme activity, particularly peroxidase. Alla [56] reported the relationship of glutathione with corn growth and its importance for corn tolerance to herbicides effects. Besides the implication of ascorbate and glutathione in the defence against oxidative stress, these two compounds are involved in plant growth and cell cycle control [15].

Table 4. Effect of some bio-regulators at two concentrations on biochemical constituents in grains of four wheat cultivars grown in sandy soil (Pooled analysis in terms of statistics analysis of the two seasons)

Treatments		Gem 9	Sakha 93	Giza 168	Sakha 94	Mean	Gem 9	Sakha 93	Giza 168	Sakha 94	Mean
Growth regulators	**Conc ppm**										
		Free amino acids mg g^{-1}					Total phenols mg g^{-1}				
Control	-	3.7	3.4	3.3	3.5	3.5	7.7	3.6	4.5	4.3	5.0
StA	50	4.2	4.9	3.9	5.2	4.6	3.7	7.7	3.5	5.2	5.0
StA	100	4.5	3.5	4.8	4.4	4.3	7.4	4.7	6.9	4.5	5.9
Gl	50	6.0	7.4	5.9	6.0	6.3	5.8	5.6	5.3	7.2	6.0
Gl	100	4.9	4.2	4.6	4.2	4.5	5.6	3.4	4.2	6.0	4.8
SA	50	4.6	5.3	5.6	5.7	5.3	5.4	5.4	7.7	5.8	6.1
SA	100	4.3	5.5	6.6	4.9	5.3	5.7	8.2	6.2	5.4	6.4
Mean		4.6	4.9	5.0	4.8		5.7	5.5	5.4	5.3	
LSD for varieties		NS					NS				
LSD for		0.5					0.7				
LSD for interaction		1.1					1.4				
		Sucrose %					**Total sugars %**				
Control	-	3.5	4.5	3.6	5.0	4.2	74.8	77.7	83.7	86.1	79.3
StA	50	3.8	4.0	5.7	5.2	4.7	83.3	79.2	79.2	82.7	81.1
StA	100	9.1	8.1	8.0	9.7	8.7	82.6	77.0	80.9	75.9	79.1
Gl	50	8.4	10.5	6.3	8.8	8.5	82.6	79.2	75.9	76.4	78.5
Gl	100	9.6	8.0	9.0	12.7	9.8	78.2	79.9	73.6	70.8	75.6
SA	50	6.7	7.4	8.3	7.7	7.5	77.1	75.7	81.8	79.7	78.6
SA	100	8.2	9.3	7.7	8.7	8.5	84.7	84.0	78.3	77.9	81.2
Mean		7.0	7.4	6.9	8.3		80.5	78.2	79.1	78.5	
LSD for varieties		1.1					NS				
LSD for bioregulators		0.8					NS				
LSD for interaction		1.7					NS				

Abbreviations: Conc: concentration, Gem: Gemmeiza

3.5 Chemical Constituents of Wheat Grains

3.5.1 Effect of wheat cultivars

Insignificant differences were noticed among the four wheat cultivars in the free amino acids, total phenols and total sugars in grains as shown in above Table (4). On the other hand, Sakha 94 cultivar surpassed the other cultivars in the sucrose concentration, with insignificant difference with Sakha 93 cultivar whereas sucrose content is related to resistance the environmental stress. This result might due to genotype differences expression response in its effect on plant characters.

3.5.2 Effect of bioregulators treatments

Application of the three growth regulators in two concentrations caused a significant increases, in most cases, in the concentration of the free amino acids, total phenols and sucrose while, total sugars was unaffected by the three bioregulators, compared to unsprayed plants (Table 4). Exogenous application of Glutathione (50 and 100 ppm) gave the highest values of the free amino acids and sucrose percent, respectively, while total phenols and total sugars were recorded with using SA at 100 ppm. Application of Gl (50 ppm), SA (100 ppm) and Gl (100 ppm) caused significant increase in free amino acids, total phenols, Sucrose and total sugar by 80.0, 28.0 and 133.3%, respectively, compared to untreated plants. El-Awadi and Abd El-Wahed [44] reported that application of Gl on onion plants significant increase the biochemical constituents; fixed oil percentage, total protein, phenols and free amino acids, flavonoids and indoles, of green onion content at sprout and vegetative growth stages compared with control treatment.

3.5.3 Effect of the interaction between wheat cultivars and bioregulators treatments

The interaction between wheat cultivars and bioregulators treatments had significant effects on the 4 chemical constituents of wheat grains, except on total sugars content (Table 4).

Spraying Giza Sakha 93 cultivars with Gl (50 ppm) and SA (100 ppm) produced the highest concentration of total free amino acids and total phenols in the grains, respectively, while the highest value of sucrose percent was recorded in the grains of Sakha 94 cultivar sprayed with Gl at 100 ppm (Table 4).

4. CONCLUSION

The results suggest that maximum productivity of wheat plants grown in the sandy soil could be obtained with growing Gemmiza 9 *cv*. and spraying the plants with stearic acid at 100 ppm or glutathione at 50 ppm after one month from wheat sowing.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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