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Utilization Efficiency of Growth Regulators in Wheat under Drought Stress and Sandy Soil Conditions

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Abstract: Drought stress and nutrient status are highly important for plant growth and productivity. Two field experiments were conducted during two consecutive seasons (2017–2018 and 2018–2019) at El-Molak, Abo-Hammad, Sharkia, Egypt. This work was conducted under sandy soil conditions to evaluate the effects of foliar application with growth regulators (PGRs) such as cycocel (CCC), applied at 0, 500, or 1000 mg L⁻¹, and/or salicylic acid (SA), applied at 0, 0.05, or 0.1 mM on the productivity as well as improving drought tolerance of three wheat cultivars, i.e., Gemmeiza 11, Misr 1, and Giza 171 under three irrigation intervals, i.e., 10, 15, and 20 days. Foliar spray was given at 35 and 50 days after planting (DAP). The obtained results showed that mean squares as a result of the main effect and first- and second-order interactions were significant ($p \leq 0.01$) for all studied traits. The application of SA increased total chlorophyll content and flag leaf area (cm²) while the number of days to 50% heading was decreased; however, the number of spikes m⁻², protein and proline contents were increased with the application of CCC. The cultivar Misr 1 outperformed the other cultivars in the most studied traits. Estimates of heritability in the broad sense (h²b) were, on average, higher in five physiological traits than other agronomic traits, and the highest estimate of h²b (95.1%) was shown by the number of days to 50% heading followed by protein content (91.90%). Among the interactions between irrigation and growth regulators, the I₍₁₀₎ × SA_(0.1) recorded the highest flag leaf area (cm²), SPAD value, number of grains spike⁻¹, 1000-grain weight (g), and grain yield (t ha⁻¹). Among the interactions between irrigation and cultivars, the I₍₁₀₎ × Misr 1 recorded the highest flag leaf area (cm²), SPAD value, number of grains spike⁻¹, and grain yield (t ha⁻¹). Among the interactions among irrigation, growth regulators and cultivars, the I₍₁₀₎ × SA_(0.1) × Misr 1 recorded the highest flag leaf area (cm²), number of grains spike⁻¹, 1000-grain weight (g), and grain yield (t ha⁻¹). Correlation coefficient between grain yield (t ha⁻¹) and each of the number of days to 50% heading, flag leaf area, total chlorophyll content, number of spikes m⁻², number of grains spike⁻¹, and 1000-grain weight was positive and significant. Three main factors for the studied variables were created from the application of the factor analysis technique. Grain yield ha⁻¹ (Y) can be predicted by the method of forwarding stepwise through applying the automatic linear regression analysis. Besides, the best prediction equation of grain yield ha⁻¹ (Y) was formulated as: $\hat{Y} = -14.36 + 0.11$ number of grains spike⁻¹ (NGS) + 0.09 1000-grain weight (THW) + 0.04 number of spike m⁻² (NSm) + 0.03 days to 50% heading (DF) + 0.02 total chlorophyll content (TC) with adjusted-R² (87.33%).

Keywords: irrigation interval-prolonging; wheat cultivars; cycocel; salicylic acid; heritability; automatic linear regression

1. Introduction

Wheat (*Triticum aestivum* L.) is the most common crop in the world compared to other cereals and is of private prominence in Egypt because local production is not sufficient to meet the annual population requirements [1]. Recently, considerable attention has been directed to increasing the productivity of this imperative crop, so agricultural policies strategies should focus on increasing wheat production through using tolerant genotypes tolerant to biotic and abiotic stress circumstances and using optimal agricultural practices taking into account the limited water reserves available on a global scale [2]. The problem worsens when we only find sandy soil, with its many defects concerning its exploitation in agriculture, to expand the cultivation of such a food crop, where in Egypt, sandy soils are used in the horizontal amplification plain [3]. Such soils are described as suffering from a large loss of irrigation water as a result of leaching. As a finding, phenological development, physiological and biochemical processes—and thus plant productivity—are adversely affected by drought exposure [4–7]. Drought stress is one of the foremost affecting variables that seriously modify the plant physiology, definitely leading to the decline of the crop productivity. In plants, it causes a set of morpho-anatomical, physiological and biochemical changes. Drought stress adversely influences crop performance and weakens food security. It causes the activation of downstream pathways, basically through phytohormones homeostasis and their signaling networks [8,9].

If any crop is grown under adverse conditions such as the conditions of this study (irrigation interval-prolonging and sandy soil conditions), the plant stimulates the components of its endogenous antioxidant system to develop and/or adopt to protect it against these conditions, but it is often not enough to defend itself. Therefore, it is imperative to use one or more adjuvants such as growth regulators that they are used exogenously to increase the plant's ability to protect itself under such conditions. Among these growth regulators, cycocel (CCC) has been applied to many stressed crops such as cereals, including wheat [10]. This report indicated an enhancement in wheat morphology, physiology, biochemistry, and productivity under drought stress. It has also been reported that CCC improves the translocation of photosynthetic compounds to the seeds resulting in an increase in the protein content stored in the seeds and the content of plant proline for better tolerance to drought stress [11,12]. Cycocel foliar application increased cytokinin translocation from roots to shoots, leading to prolonged aboveground parts life-span and hence increased yield (Omidi et al., 2005) [13]. On the other hand, several reports also indicated an improvement in the morphological, physiological, biochemical, and productivity attributes of some crop plants grown under the negative impacts of some stressors when nourished with salicylic acid; SA [14–16]. Among the physiological processes regulated by SA are stomatal closure, ion uptake, inhibition of ethylene biosynthesis, transpiration, thus stimulating stress tolerance and promoting growth under drought stress [5,17,18]. Salicylic acid (SA) acts as an endogenous signal molecule responsible for inducing abiotic stress tolerance and regulating the physiological processes in plant [19].

What gives this research importance and a lot of novelty is the use of both CCC and SA to get our hands on the best wheat cultivar, among three cultivars used, which responds more to either of these two growth regulators and can withstand drought and adverse conditions of sandy soil, which are rarely addressed in any of the previous research or not addressed as far as we know.

Several investigators reported that wheat cultivars showed significant differences in yield and its attributes under drought stress due to differences in their genetic background [6,18,20]. Correlation coefficient analysis is one of the numerous tools that can be used to find the causes of an association. Factor analysis can be applied to minimize a considerable number of variables associated with main factors as a selection criterion. This information is advantageous in identifying selection criteria to promote crop yields under different environments, as [21,22] revealed.

Stepwise regression can be a way to appraise the value of a quantitative characteristic concerning one or some other quantitative characteristics. This strategy has been utilized by numerous researchers on wheat, such as in [23–25].

Hence, the issue of choosing which subset(s) of the expansive pool of capacity indicators to incorporate in a direct regression show is exceptionally common and seems to be the hardest portion of regression modeling [26]. Noteworthy, it seems that all possible subsets or the automatic linear model method are preferred by many researchers over the stepwise method. This could be due to the fact that researchers do not have the gist of defining one view, and the last one is based exclusively on an automatic variable determination strategy for insights.

In the stepwise method, the suggestion is to assess different, more promising subsets which best fit the optimal selection model [27–29]. The strategy of all possible subsets can supply the best subsets after assessing all conceivable regression models and the researcher at this point can select the last best offer from the foremost promising subsets after taking additional factors besides only statistical aspects.

Therefore, the objective of this study was to investigate the performance of three wheat cultivars (e.g., Giza 171, Misr 1, and Gemmieza 11) under different irrigation intervals and adverse conditions of sandy soil to select a cultivar that would be most appropriate and most responsive to foliar application with a growth regulator such as CCC or SA to expand its cultivation under either normal or mentioned stress conditions. Wheat plant morphology (the number of days to 50% heading and flag leaf area), physiology (chlorophyll content; SPAD index), biochemistry (protein and proline contents), and different yield components were estimated as indicators for selecting the best cultivar.

2. Materials and Methods

Two field trials were fulfilled in El-Molak, Abo-Hammad, and Sharkia, Egypt, during two consecutive seasons (2017–2018 and 2018–2019). Each experiment included three factors applied in combinations. The first factor was irrigation interval, i.e., 10, 15, and 20 days, and the second factor was foliar spraying with a growth regulator of cycocel (CCC), which was applied at 0, 500, 1000 mg L^{−1}, salicylic acid (SA) at 0.05 and 0.1 mM. The third factor was three cultivars of wheat, i.e., Giza 171, Misr 1, and Gemmieza 11. Growth regulators treatments were performed twice 35 days after sowing and 15 days later. All these combined treatments were applied using sandy soil, which had physicochemical properties displayed in Table 1.

Wheat plants were grown under the climatic conditions (e.g., temperatures and relative humidity) given in Table 2. In both seasons, the design of each experiment was a split-split plot with three replications, in which the main plots were filled with irrigation treatments, the sub-plots were assigned to growth regulator treatments, while wheat cultivars were distributed to the sub-sub-plots.

Wheat cultivars (Giza 171, Misr 1, and Gemmieza 11) were sown at a seeding rate of 168 kg ha^{−1} on 15 November. The plot area was 12 m² (3 m in width × 4 m in length) which included 20 rows 15 cm apart. Surface irrigation was applied. Nitrogen fertilizer in the form of urea (46.5%) was added at a rate of 216 kg N ha^{−1} in four equal doses. Calcium superphosphate (15.5% P₂O₅) was applied at a rate of 480 kg ha^{−1}, and potassium sulfate (50% K₂O) was added at a rate of 240 kg ha^{−1} during seedbed preparation. Weeds were controlled by hand hoeing (twice). Harvesting was practiced on 10th April for Gemmieza 11th and Giza 171 and 20th April for Misr 1 in both seasons. Other cultural practices were implemented as recommended by the Egyptian Ministry of Agriculture.

The number of days to 50% heading was recorded after 50% of spikes were emerged in each treatment including the replicates. Flag leaf area (cm²) was determined according to the following formula by Dodig et al. [30]:

$$\text{Flag leaf area (FLA)} = \text{max leaf length} \times \text{max leaf width} \times 0.75$$

Table 1. Some physical and chemical properties of the selected soil in the two seasons of investigation.

Soil Characteristics	Soil Location			
	0–15 cm		15–30 cm	
	1st Season	2nd Season	1st Season	2nd Season
Soil particles distribution				
Sand%	80.87	84.05	91.13	93.61
Silt%	12.03	10.23	7.83	4.23
Clay%	7.10	5.72	1.04	2.16
Texture Class	Sandy loam	Sandy loam	Sandy	Sandy
pH *	7.98	8.11	8.32	8.49
EC, (ds/m) *	0.40	0.36	0.14	0.13
Soluble cations and anions (mmole/L) *				
Ca ⁺⁺	1.4	1.3	0.42	0.22
Mg ⁺⁺	0.7	0.6	0.13	0.23
Na ⁺	1.55	1.38	0.64	0.55
K ⁺	0.35	0.32	0.21	0.30
CO ₃ [−]	-	-	-	-
HCO ₃ [−]	1.32	1.19	0.56	0.37
Cl [−]	1.29	1.16	0.43	0.51
SO ₄ ^{−2}	1.34	1.25	0.41	0.37
Available N, (mg kg ^{−1} soil)	40.33	53.91	36.72	31.49
Available P, (mg kg ^{−1} soil)	7.26	6.24	5.11	3.95
Available K, (mg kg ^{−1} soil)	60.40	58.09	53.95	49.81

* Soil-water suspension 1:2.5.

Table 2. Monthly mean minimum and maximum air temperatures (°C), relative humidity (%) and precipitation during the two wheat-growing seasons.

Month	Temperature (°C)			Relative Humidity (%)	Precipitation (Mean, mm)
	Min.	Max.	Mean		
2017–2018 Season					
November	13.3	24.33	18.81	73	4.5
December	12.83	21.0	16.91	88	9.1
January	8.16	14.83	11.49	85	14.2
February	14.83	25.16	19.99	65	4.0
March	15.0	26.50	20.75	60	0.3
April	16.83	32.0	24.41	54	0.1
2018–2019 Season					
November	13.0	24.33	19.66	74	4.2
December	11.83	20.50	18.08	80	9.0
January	7.66	14.00	10.83	73	13.5
February	13.66	24.83	19.24	68	4.2
March	14.33	26.16	20.24	70	0.5
April	14.50	29.00	21.75	62	0.0

A random twenty flag leaf sample was taken from each plot to determine the total chlorophyll content (SPAD reading), using a SPAD-502 [31]. The number of spikes m^{−2} was counted in an area of 0.45 m² at random in each plot. The number of grains spike^{−1} was calculated from twenty spikes and 1000-grain weight (g), as well as grain yield for each experimental unit (0.75 m²: 5 rows by long of one meter), was noted and converted into t ha^{−1} to estimate grain yield (t ha^{−1}). Nitrogen content in seeds was determined using micro-Kjeldahl and protein (%) was calculated by multiplying N content by 6.25 according to Paratt [32]. Proline content (μmol g^{−1} dw) was determined according to the procedure given by Bates et al. [33].

Data obtained from each trial were subjected to an analysis of variance of split-split plot design based on a randomized complete block design (RCBD) as described by Steel et al. [34] using the computer program MSTAT-C. The data were tested for normal distribution Shapiro and Wilk [35] Razali and Wah [36].

Bartlett's test was applied to determine the homogeneity of variance for the two years before a combined analysis was performed. The Bonferroni adjustment correction post-hoc test was applied to compare the differences among treatments, first-order and second-order interactions according to Abdi and Šidák [37]. The Bonferroni correction was recommended to avoid the problem that as the number of tests increases, the probability of a type I error increases, i.e., inferring a significant difference when it is not. So, Bonferroni's correction equals the alpha (α) or p -value ($p = 0.05$) divided by the comparison number in each factor or interaction. To estimate heritability in the broad sense, the expected mean squares were estimated from the ANOVA table according to Hallauer et al. [38].

Simple correlation coefficients were calculated between each pair of studied traits according to Singh and Narayanan [39]. Correlation coefficients were applied to calculate factor analysis according to Walton [40].

Automatic Linear Regression of the obtained data was also performed to test the significance of all independent variables influencing the dependent variable grain yield ha^{-1} according to the methods of IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA) Statistics Version 25 for Windows [41].

3. Results

3.1. Main Effects

Combined analysis of variance of randomized complete blocks design (RCBD) for studied traits of wheat as affected by irrigation intervals, growth regulators, and cultivars are shown in Table 3. Mean squares due to irrigation intervals, growth regulators, and cultivars were significant ($p \leq 0.01$) for all studied traits. Means of studied traits of wheat as affected by irrigation intervals, growth regulators and cultivars (combined of two successive winter seasons, 2017–2018 and 2018–2019) are tabulated (Table 3). The high means of all studied parameters were considered favorable, except earliness characters (Days to 50% heading), where high means were considered unfavorable. Regarding the effect of irrigation intervals, it was quite evident that increasing irrigation intervals was followed by a significant decrease in all studied characters except protein and proline contents.

Concerning the effect of growth regulators treatments, results presented in Table 3 show that both cycocel and salicylic acid treatments had a significant effect on all studied characters.

Respecting varietal differences, it is clear that Misr 1 cultivar gave the highest number of grains spike⁻¹ with a significant difference (Table 3).

Estimates of heritability in the broad sense (h^2_b) for studied wheat and traits overall factors under study are presented in Table 3.

Heritability estimates in the broad sense were, on average, higher in five physiology traits than other agronomic traits. On average, the highest h^2_b estimate (95.1%) was shown by days to 50% heading followed by protein content% (91.90%). On the contrary, the lowest h^2_b was shown for the number of spikes m^{-2} . Finally, post-hoc tests using the Bonferroni test indicated that there were statistically significant differences between three levels of irrigations ($p \leq 0.01$), five levels of growth regulators ($p \leq 0.05$), and three cultivars of wheat ($p \leq 0.01$) in all traits under study.

3.2. First-Order Interaction

Combined analysis of mean squares and means of each studied trait under three types of first-order interaction (irrigation $\times$ growth regulators, irrigation $\times$ cultivar, and growth regulators $\times$ cultivar) are presented in Table 4 and figures (from 1 to 3). Interaction between three types of first-order interaction (irrigation $\times$ growth regulators, irrigation $\times$ cultivar, and growth regulators $\times$ cultivar) had a significant ($p \leq 0.01$) effect on all studied traits.

Table 3. Main effect and heritability in broad sense of irrigation intervals, growth regulators and wheat cultivars on all traits under the study of wheat (combined analysis of two seasons).

Treatment	Flag Leaf Area (cm ²)	SPAD-Value	Days to 50% Heading	Protein Content (%)	Proline Content (μmol g ⁻¹)	Number of Spikes m ⁻²	No. of Grains Spike ⁻¹	1000 Grain Weight (g)	Grains Yield (t ha ⁻¹)
Irrigation (I)	**	**	**	**	**	**	**	**	**
I ₁₀	49.21 ^a	49.60 ^a	96.23 ^a	9.71 ^c	8.56 ^c	389.00 ^a	50.03 ^a	42.17 ^a	7.51 ^a
I ₁₅	48.14 ^b	45.65 ^b	94.01 ^b	10.44 ^b	10.42 ^b	367.99 ^b	43.02 ^b	39.24 ^b	5.74 ^b
I ₂₀	42.49 ^c	42.13 ^c	85.78 ^c	11.31 ^a	11.29 ^a	348.60 ^c	30.40 ^c	36.48 ^c	3.48 ^c
Growth regulators	**	**	**	**	**	**	**	**	**
Control	33.78 ^e	42.39 ^e	95.89 ^a	8.85 ^e	8.98 ^e	355.65 ^e	33.62 ^e	34.72 ^e	4.15 ^e
CCC ₅₀₀	41.79 ^d	45.28 ^d	93.54 ^b	9.79 ^d	10.07 ^c	369.61 ^c	36.47 ^d	38.32 ^d	5.01 ^d
CCC ₁₀₀₀	51.92 ^b	47.29 ^b	91.63 ^c	11.75 ^a	11.53 ^a	382.48 ^a	45.73 ^b	39.65 ^c	6.36 ^a
SA _{0.05}	49.27 ^c	45.99 ^c	90.81 ^d	10.71 ^c	9.31 ^d	364.02 ^d	46.00 ^a	42.34 ^a	6.03 ^c
SA _{0.1}	56.33 ^a	48.02 ^a	88.17 ^e	11.34 ^b	10.57 ^b	370.89 ^b	43.92 ^c	41.45 ^b	6.34 ^b
Cultivar	**	**	**	**	**	**	**	**	**
Giza 171	47.28 ^b	43.65 ^c	91.83 ^b	10.52 ^b	9.94 ^b	374.04 ^b	39.46 ^c	40.67 ^b	5.63 ^b
Misir 1	51.38 ^a	48.17 ^a	95.81 ^a	11.97 ^a	11.40 ^a	381.84 ^a	43.02 ^a	35.90 ^c	5.92 ^a
Gemmieza 11	41.19 ^c	45.56 ^b	88.38 ^c	8.97 ^c	8.93 ^c	349.70 ^c	40.96 ^b	41.32 ^a	5.19 ^c
Heritability in broad sense	82.10 (%)	83.4 (%)	95.1 (%)	91.9 (%)	89.12 (%)	29.7 (%)	76.32 (%)	89.66 (%)	70.22 (%)

** $p \leq 0.01$. Means within the same column in each studied factor followed by the same letter are not significantly different at $p \leq 0.01$ according to Bonferroni test. CCC₅₀₀ = cycocel (500 mg L⁻¹), CCC₁₀₀₀ = cycocel (1000 mg L⁻¹), SA_{0.05} = salicylic acid (0.05 mmol L⁻¹), SA_{0.1} = salicylic acid (0.1 mmol L⁻¹), and I₁₀, I₁₅, I₂₀ refer to irrigation every 10, 15, and 20 d, respectively.

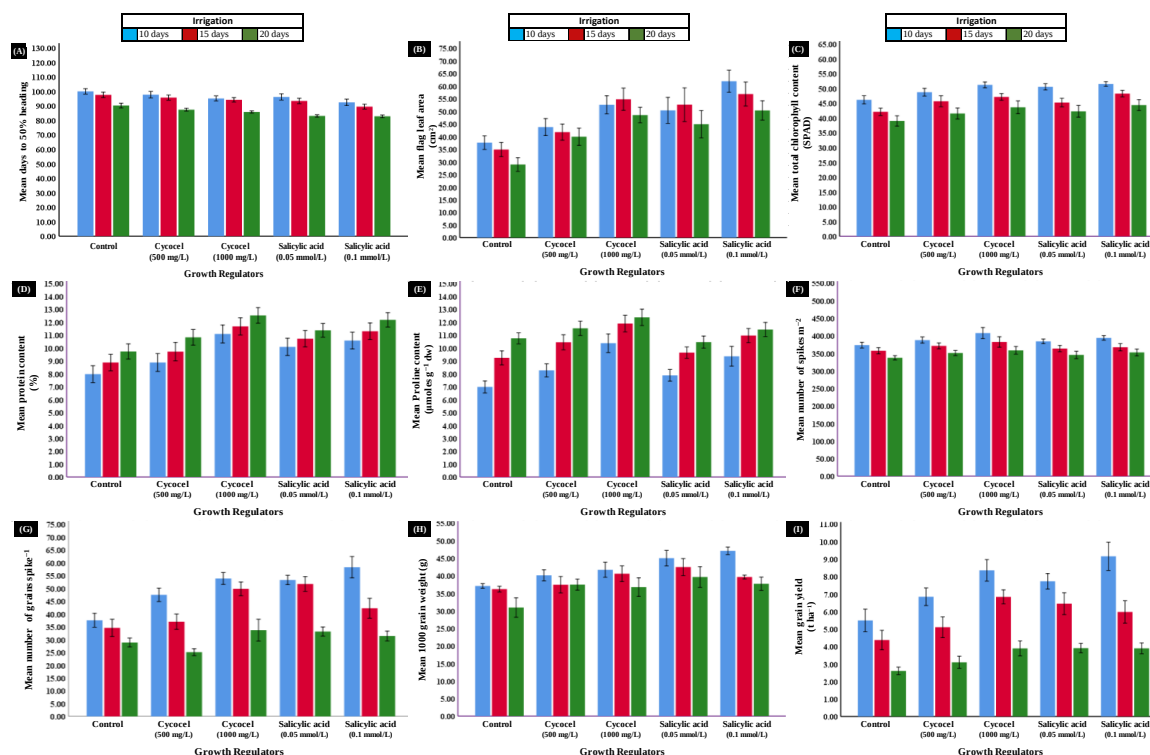
Table 4. Significant of three first-order interactions of combinations between irrigation intervals, growth regulators and wheat cultivars on physiological and agronomic traits of wheat in (combined two seasons).

Physiological Traits					
Interactions	Flag Leaf Area (cm ²)	SPAD-Value	Days to 50% Heading	Protein Content (%)	Proline Content (μmol g ⁻¹ dw)
Irrigation × growth regulators	**	**	**	**	**
Irrigation × Cultivar	**	**	**	**	**
Growth regulators × Cultivar	**	**	**	**	**
Agronomic Traits					
	Number of Spikes (m ⁻²)	Number of Grains Spike ⁻¹	1000-Grain Weight (g)	Grains Yield (t ha ⁻¹)	
Irrigation × growth regulators	**	**	**	**	
Irrigation × Cultivar	**	**	**	**	
Growth regulators × Cultivar	**	**	**	**	

** significant at 0.05 and 0.01 significant levels.

The mean squares of three first-order interactions of combinations between irrigation intervals, growth regulators and wheat cultivars on physiological and agronomical traits of wheat in (combined two seasons) were significant ($p \leq 0.01$) for all studied traits (Table 4).

The $I_{10} \times SA_{0.1}$ combination of interaction between irrigation and growth regulators recorded the highest flag leaf area (cm²), SPAD-value, number of grains spike⁻¹, 1000-grain weight (g), and grain yield (t ha⁻¹). While the $I_{10} \times CCC_{1000}$ combination recorded the highest protein content (%) and proline content (μmol g⁻¹ dw). However, the lowest value of days to 50% heading was recorded under $I_{20} \times SA_{0.1}$ combination (Figure 1).

**Figure 1.** Error bar chart showing the effect of the interaction between irrigation and growth regulators of (A) mean days to 50% heading, (B) mean flag leaf area (cm²), (C) mean total chlorophyll content (SPAD), (D) mean protein content (%), (E) mean proline content (moles g⁻¹ dw), (F) mean number of spikes m⁻², (G) number on grains spike⁻¹, (H) mean 1000 grain weight (g), (I) mean grain yield (t ha⁻¹).

The $I_{10} \times \text{Misr 1}$ combination of interaction between irrigation and cultivars recorded the highest flag leaf area (cm^2), SPAD-value, number of grains spike⁻¹, and grain yield (t ha^{-1}). While $I_{20} \times \text{Misr 1}$ combination recorded the highest protein content (%) and proline content ($\mu\text{mol g}^{-1} \text{dw}$). In this respect [7] found a significant interaction between wheat genotypes and irrigation treatments for 1000-grain weight. However, the lowest value of days to 50% heading was recorded under $I_{20} \times \text{Gemmieza 11}$ combination (Figure 2).

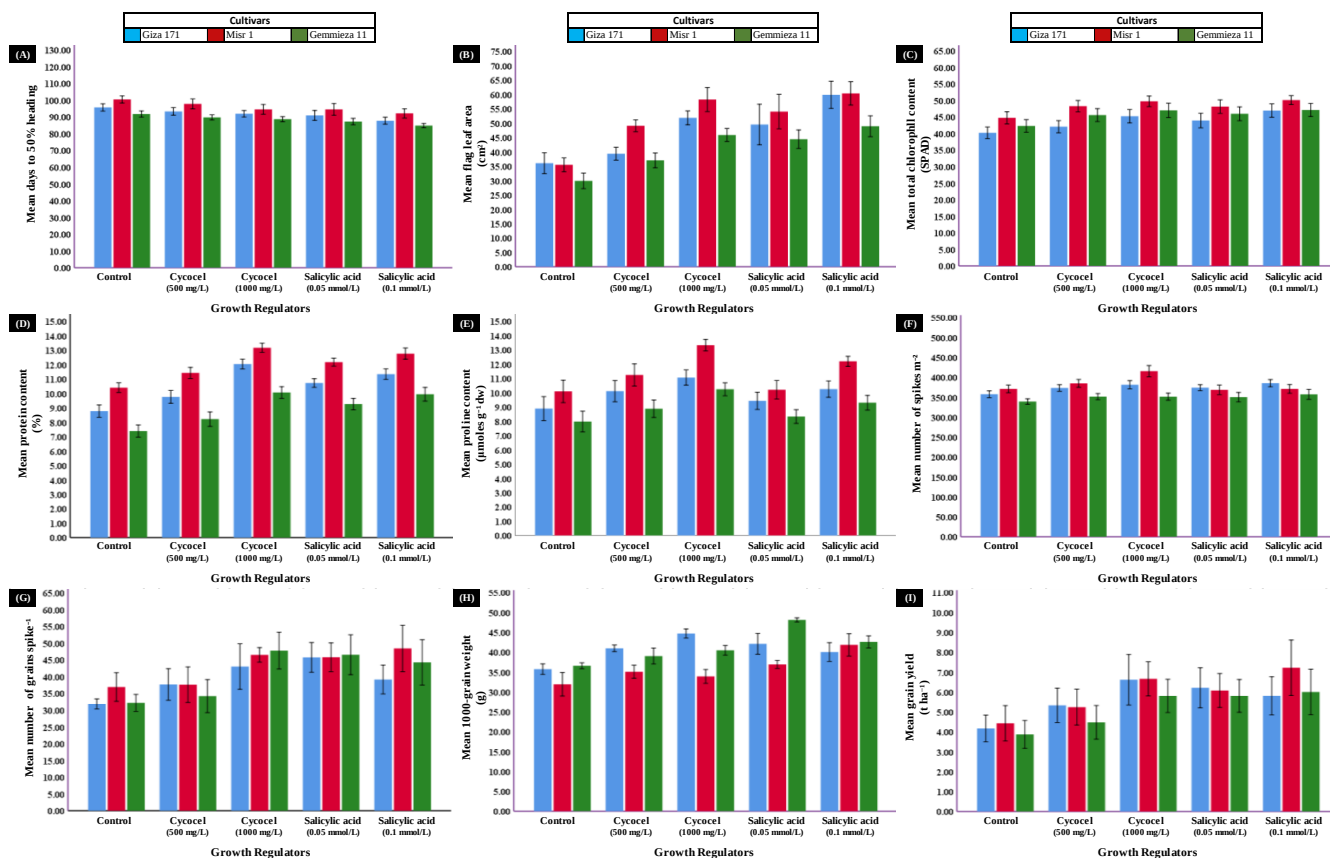


Figure 2. Error bar chart showing the effect of the interaction between cultivars and growth regulators on (A) mean days to 50% heading, (B) mean flag leaf area (cm^2), (C) mean total chlorophyll content (SPAD), (D) mean protein content (%), (E) mean proline content ($\mu\text{mol g}^{-1} \text{dw}$), (F) mean number of spikes m^{-2} , (G) number on grains spike⁻¹, (H) mean 1000 grain weight (g), (I) mean grain yield (t ha^{-1}).

The $\text{SA}_{0.1} \times \text{Misr 1}$ combination of interaction between growth regulators and cultivars recorded the highest flag leaf area (cm^2), SPAD-value, number of grains spike⁻¹ and grain yield (t ha^{-1}). While $\text{CCC}_{1000} \times \text{Misr 1}$ combination recorded the highest protein content (%), proline content ($\mu\text{mol g}^{-1} \text{DW}$), and the number of spikes m^{-2} . However, the lower value of days to 50% heading was recorded under $\text{SA}_{0.1} \times \text{Gemmieza 11}$ combination (Figure 3).

3.3. Second-Order Interaction

Combined analysis of second-order interaction between irrigation, growth regulators, and cultivars (irrigation $\times$ growth regulators $\times$ cultivar) are presented in (Tables 5 and 6). The mean square of second-order interaction had a significant effect on all studied traits. The high means of all studied traits were considered favorable, except days to 50% heading trait, where high means were considered unfavorable.

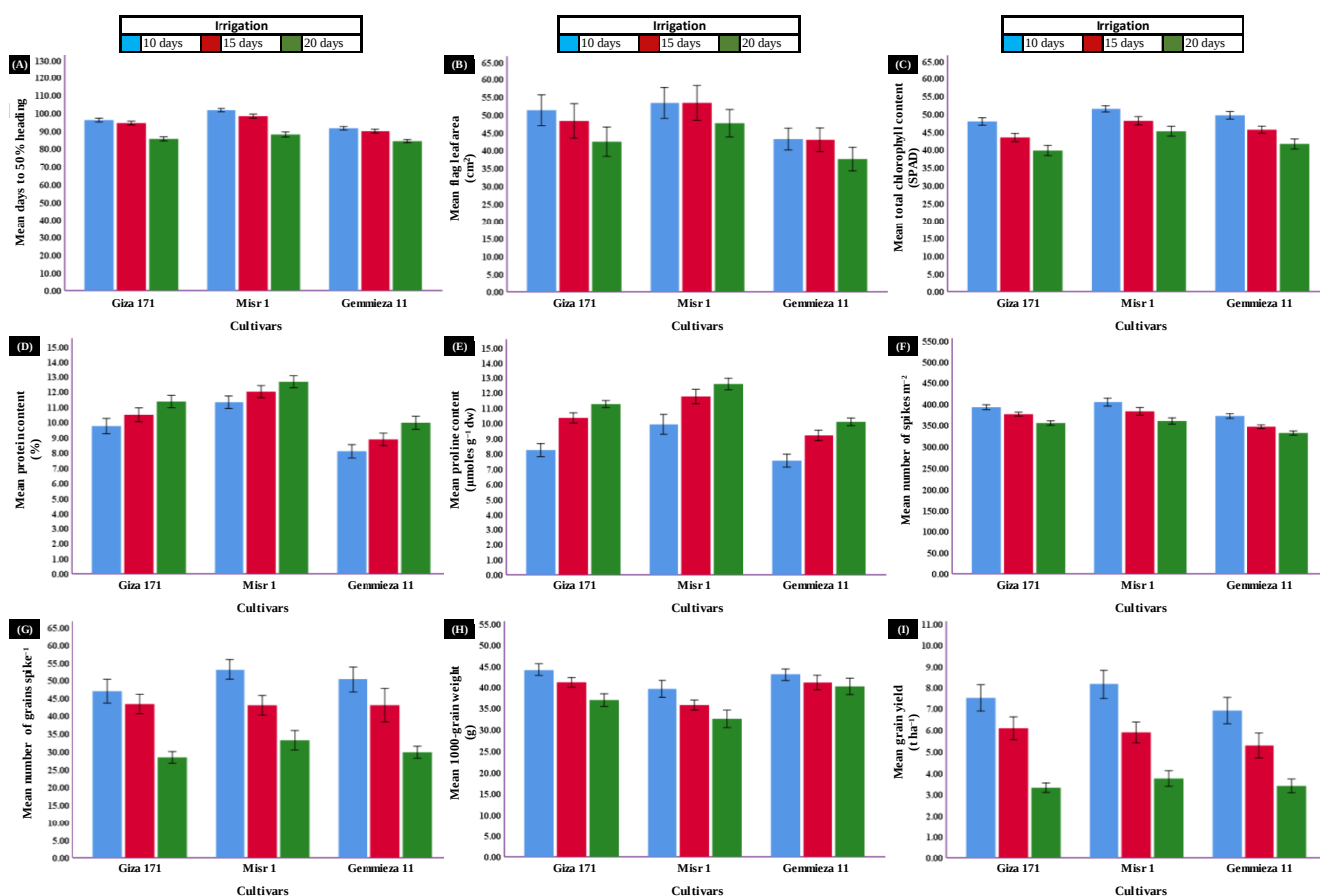


Figure 3. Error bar chart showing the effect of the interaction between irrigation and cultivars on (A) mean days to 50% heading, (B) mean flag leaf area (cm^2), (C) mean total chlorophyll content (SPAD), (D) mean protein content (%), (E) mean proline content ($\mu\text{moles g}^{-1} \text{dw}$), (F) mean number of spikes m^{-2} , (G) number on grains spike $^{-1}$, (H) mean 1000 grain weight (g), (I) mean grain yield (t ha^{-1}).

The $I_{10} \times SA_{0.1} \times \text{Misr1}$ combination of interaction between irrigation, growth regulators, and cultivars recorded the highest flag leaf area (cm^2), number of grains spike $^{-1}$, 1000-grain weight (g), and Grain yield (t ha^{-1}). Flag leaf area (cm^2), SPAD-value, number of grains spike $^{-1}$, and grain yield (t ha^{-1}). While $I_{20} \times CCC_{1000} \times \text{Misr1}$ combination recorded the highest protein content (%) and proline content ($\mu\text{mol g}^{-1} \text{dw}$). However, the lowest value of days to 50% heading was recorded under $I_{20} \times SA_{0.1} \times \text{Gemmeiza 11}$ combination (Table 5). The highest value of SPAD was recorded by $I_{10} \times SA_{0.05} \times \text{Misr1}$ interaction.

3.4. Automatic Linear Regression

The data obtained from automatic linear regression analysis for predicting grain yield ha^{-1} are presented in (Figure 4) for combined of two successive seasons. The results showed that the best method for predicting grain yield ha^{-1} was forward stepwise. Among eight independent variables, five variables (1000-grain weight (THW), number of grains spike $^{-1}$ (NGS), number of spike m^{-2} (NSm), number of days to 50% heading (DF), and total chlorophyll content (TC)) were the best combination for predicting grain yield ha^{-1} . All five independent variables had a positive and highly significant regression coefficient associated with a high value of adjusted- R^2 (87.33%), this means 87.33% of the total variation in grain yield ha^{-1} could be explained by the variation of five variables and low value of the standard error of estimate, SEE (0.78). The best prediction equation of grain yield ha^{-1} (Y) was formulated as: $\hat{Y} = -14.36 + 0.11 \text{ NGS} + 0.09 \text{ THW} + 0.04 \text{ NSm} + 0.03 \text{ DF} + 0.02 \text{ TP}$.

Table 5. Second-order interaction between irrigation intervals, growth regulators and wheat cultivars on flag leaf area (cm²), SPAD-value, days to 50% heading, protein content (%) and proline content (μmol g^{−1}dw) of wheat in (combined two seasons) (mean ± S.E.).

Treatment		Flag Leaf Area (cm ²)	SPAD-Value	Days to 50% Heading	Protein Content (%)	Proline Content (μmol g ⁻¹ dw)	
Irrigation × growth regulators × Cultivar		**	**	**	**	**	
I ₁₀	Control	Giza 171	42.41 ^{d-j} ± 1.86	43.98 ^{c-h} ± 0.79	100.00 ^{rst} ± 0.26	7.75 ^{bcd} ± 0.13	6.80 ^{ab} ± 0.32
		Misir 1	36.68 ^{b-g} ± 1.76	48.53 ^{h-p} ± 0.56	104.50 ^w ± 0.56	9.65 ^{ijkl} ± 0.12	7.98 ^{cde} ± 0.25
		Gemmieza 11	33.62 ^{abcde} ± 1.94	45.82 ^{d-k} ± 1.37	95.33 ^{mno} ± 0.33	6.48 ^a ± 0.16	6.14 ^a ± 0.20
	CCC ₅₀₀	Giza 171	42.03 ^{d-j} ± 1.71	46.25 ^{d-l} ± 0.92	97.33 ^{opq} ± 0.33	8.80 ^{efgh} ± 0.16	8.12 ^{cdef} ± 0.27
		Misir 1	50.79 ^{i-p} ± 1.98	51.15 ^{lmnop} ± 0.87	103.50 ^{uw} ± 0.22	10.57 ^{mnpq} ± 0.13	9.27 ^{g-l} ± 0.28
		Gemmieza 11	38.35 ^{b-i} ± 2.44	48.70 ^{h-p} ± 0.58	92.17 ^{ijkl} ± 0.48	7.22 ^{ab} ± 0.22	7.38 ^{bc} ± 0.37
	CCC ₁₀₀₀	Giza 171	53.47 ^{mnpq} ± 2.11	49.37 ^{i-p} ± 0.26	94.00 ^{klmn} ± 0.26	11.38 ^{rstu} ± 0.16	9.65 ^{h-m} ± 0.24
		Misir 1	58.08 ^{nopqr} ± 3.17	52.40 ^p ± 0.85	99.83 ^{qrst} ± 0.04	12.57 ^{xyz} ± 0.17	12.30 ^{tuwx} ± 0.21
		Gemmieza 11	46.16 ^{g-m} ± 1.94	51.77 ^{nop} ± 0.78	91.33 ^{ghij} ± 0.33	9.27 ^{hij} ± 0.24	9.12 ^{f-k} ± 0.26
	SA _{0.05}	Giza 171	53.04 ^{l-q} ± 6.53	49.10 ^{i-p} ± 0.73	96.50 ^{nop} ± 0.22	10.13 ^{klmno} ± 0.19	7.85 ^{bcd} ± 0.35
		Misir 1	53.32 ^{mnpq} ± 3.35	52.45 ^p ± 0.88	101.33 ^{tu} ± 0.33	11.65 ^{tuw} ± 0.19	8.62 ^{defgh} ± 0.29
		Gemmieza 11	44.63 ^{f-m} ± 1.97	50.00 ^{k-p} ± 0.53	90.50 ^{ghi} ± 0.22	8.43 ^{defg} ± 0.14	7.13 ^{abc} ± 0.29
	SA _{0.1}	Giza 171	65.24 ^r ± 2.99	50.58 ^{k-p} ± 0.52	91.67 ^{hijk} ± 0.33	10.60 ^{m-r} ± 0.22	8.73 ^{d-i} ± 0.29
		Misir 1	67.50 ^r ± 2.77	52.32 ^{op} ± 0.82	98.17 ^{pqrs} ± 0.48	12.05 ^{uwxy} ± 0.18	11.40 ^{qrstu} ± 0.24
		Gemmieza 11	52.86 ^{k-q} ± 2.64	51.57 ^{mnp} ± 0.62	87.33 ^{def} ± 0.33	9.03 ^{fghi} ± 0.27	7.90 ^{cd} ± 0.13
I ₁₅	Control	Giza 171	35.93 ^{bcdef} ± 2.88	39.92 ^{abc} ± 0.77	97.33 ^{opq} ± 0.33	8.80 ^{efgh} ± 0.21	9.02 ^{e-j} ± 0.20
		Misir 1	36.87 ^{b-g} ± 2.94	43.85 ^{c-h} ± 1.04	102.17 ^{tuw} ± 0.48	10.42 ^{lmnop} ± 0.17	10.55 ^{mnpq} ± 0.23
		Gemmieza 11	31.73 ^{abc} ± 1.89	42.43 ^{b-g} ± 0.87	93.17 ^{ijklm} ± 0.48	7.37 ^{bc} ± 0.19	8.10 ^{cdef} ± 0.20
	CCC ₅₀₀	Giza 171	38.35 ^{b-i} ± 1.77	41.35 ^{abcd} ± 0.38	95.50 ^{mno} ± 0.22	9.65 ^{ijkl} ± 0.22	10.52 ^{mnpq} ± 0.18
		Misir 1	48.70 ^{klmn} ± 1.75	49.08 ^{i-p} ± 0.53	100.17 st ± 0.31	11.42 ^{stu} ± 0.19	11.68 ^{rstu} ± 0.34
		Gemmieza 11	38.13 ^{b-h} ± 2.22	46.50 ^{e-m} ± 1.42	91.33 ^{ghij} ± 0.33	8.05 ^{cde} ± 0.28	9.08 ^{f-k} ± 0.18
	CCC ₁₀₀₀	Giza 171	53.44 ^{mnpq} ± 2.02	45.68 ^{d-k} ± 0.69	95.17 ^{mno} ± 0.17	11.92 ^{uw} ± 0.22	11.53 ^{qrstu} ± 0.14
		Misir 1	62.41 ^{qr} ± 4.56	49.73 ^{i-p} ± 0.60	97.33 ^{opq} ± 0.33	13.10 ^{zab} ± 0.18	13.60 ^{yz} ± 0.11
		Gemmieza 11	48.36 ⁱ⁻ⁿ ± 2.02	45.90 ^{d-k} ± 0.55	89.83 ^{fghi} ± 0.31	9.97 ^{jklm} ± 0.22	10.50 ^{mnpq} ± 0.16
	SA _{0.05}	Giza 171	52.56 ^{k-q} ± 6.75	42.64 ^{b-g} ± 0.73	93.67 ^{ijklm} ± 0.33	10.65 ^{m-s} ± 0.16	9.90 ^{j-o} ± 0.12
		Misir 1	58.02 ^{nopqr} ± 6.82	46.98 ^{g-n} ± 1.34	97.50 ^{opqr} ± 0.5	12.25 ^{wxy} ± 0.22	10.48 ^{mnpq} ± 0.24
		Gemmieza 11	47.22 ^{h-m} ± 3.13	46.00 ^{d-k} ± 0.95	88.83 ^{efg} ± 0.91	9.22 ^{ghij} ± 0.19	8.50 ^{defg} ± 0.07
	SA _{0.1}	Giza 171	60.78 ^{pqr} ± 4.41	47.27 ^{g-o} ± 0.79	89.50 ^{fgh} ± 0.5	11.37 ^{qrstu} ± 0.23	10.72 ^{nopqr} ± 0.12
		Misir 1	60.46 ^{opqr} ± 2.82	50.50 ^{k-p} ± 0.74	93.33 ^{ijklm} ± 0.49	12.77 ^{yza} ± 0.21	12.37 ^{uw} ± 0.19
		Gemmieza 11	49.17 ^{klmn} ± 3.47	46.92 ^{f-n} ± 0.59	85.33 ^{cd} ± 0.49	9.72 ^{ijkl} ± 0.18	9.77 ^{i-o} ± 0.14
I ₂₀	Control	Giza 171	29.69 ^{ab} ± 2.37	36.64 ^a ± 1.10	89.50 ^{fgh} ± 0.43	9.75 ^{ijkl} ± 0.10	10.82 ^{opqr} ± 0.14
		Misir 1	32.79 ^{abcd} ± 2.05	41.77 ^{bcde} ± 1.59	94.50 ^{lmn} ± 0.43	11.10 ^{pqrst} ± 0.18	11.72 ^{rstuw} ± 0.07
		Gemmieza 11	24.25 ^a ± 1.27	38.53 ^{ab} ± 1.18	86.50 ^{cde} ± 0.43	8.30 ^{def} ± 0.25	9.67 ^{h-n} ± 0.12
	CCC ₅₀₀	Giza 171	37.57 ^{b-h} ± 2.12	38.53 ^{ab} ± 1.26	86.83 ^{cde} ± 0.54	10.80 ^{n-s} ± 0.16	11.65 ^{rstu} ± 0.08
		Misir 1	47.61 ^{h-m} ± 1.63	44.52 ^{c-i} ± 1.33	89.50 ^{fgh} ± 0.43	12.27 ^{wxy} ± 0.17	12.75 ^{wxy} ± 0.29
		Gemmieza 11	34.56 ^{bcdef} ± 2.04	41.43 ^{a-e} ± 1.37	85.50 ^{cd} ± 0.56	9.37 ^{hijk} ± 0.21	10.13 ^{k-p} ± 0.08
	CCC ₁₀₀₀	Giza 171	48.44 ⁱ⁻ⁿ ± 1.76	40.55 ^{abc} ± 1.40	86.33 ^{cde} ± 0.61	12.78 ^{yza} ± 0.12	11.97 ^{stuw} ± 0.21
		Misir 1	53.98 ^{mnpq} ± 2.58	46.98 ^{g-n} ± 1.57	86.17 ^{cd} ± 0.54	13.80 ^b ± 0.19	14.05 ^z ± 0.17
		Gemmieza 11	42.98 ^{e-l} ± 1.55	43.25 ^{b-g} ± 1.84	84.67 ^{bc} ± 0.81	10.93 ^{o-t} ± 0.18	11.07 ^{pqrs} ± 0.18
	SA _{0.05}	Giza 171	42.83 ^{d-k} ± 5.15	39.97 ^{abc} ± 1.54	82.33 ^{ab} ± 0.49	11.37 ^{qrstu} ± 0.13	10.50 ^{mnpq} ± 0.11
		Misir 1	50.57 ^{j-o} ± 5.35	44.88 ^{c-j} ± 1.44	84.50 ^{bc} ± 0.43	12.58 ^{xyz} ± 0.13	11.48 ^{qrstu} ± 0.28
		Gemmieza 11	41.21 ^{c-j} ± 3.05	41.85 ^{bcdef} ± 1.79	82.17 ^{ab} ± 0.75	10.12 ^{klmn} ± 0.25	9.33 ^{g-l} ± 0.08
	SA _{0.1}	Giza 171	53.39 ^{mnpq} ± 3.74	42.87 ^{b-g} ± 1.88	81.83 ^a ± 0.31	12.02 ^{uwxy} ± 0.21	11.27 ^{qrst} ± 0.16
		Misir 1	52.94 ^{k-q} ± 2.40	47.40 ^{g-p} ± 0.93	84.67 ^{bc} ± 0.49	13.43 ^{ab} ± 0.34	12.78 ^{xy} ± 0.14
		Gemmieza 11	44.58 ^{f-m} ± 2.79	42.78 ^{b-g} ± 1.28	81.67 ^a ± 0.8	11.05 ^{pqrst} ± 0.25	10.20 ^{lmnop} ± 0.21

** $p \leq 0.01$. Means within the same column followed by the same letter are not significantly different at $p \leq 0.01$ according to Bonferroni test. CCC₅₀₀ = cycocel (500 mg L^{−1}), CCC₁₀₀₀ = cycocel (1000 mg L^{−1}), SA_{0.05} = salicylic acid (0.05 mmol L^{−1}), SA_{0.1} = Salicylic acid (0.1 mmol L^{−1}), and I₁₀, I₁₅, I₂₀ refer to irrigation every 10, 15, and 20 d, respectively.

Table 6. Second-order interaction between irrigation intervals, growth regulators and wheat cultivars on number of spikes m^{-2} , number of grains spike $^{-1}$, 1000-grain weight (g), and grain yield (t ha^{-1}) of wheat in (combined two seasons) (mean $\pm$ S.E.).

			Agronomic Traits			
Treatment			Number of Spikes m^{-2}	Number of Grains Spike $^{-1}$	1000-Grain Weight (g)	Grain Yield (t ha^{-1})
Irrigation $\times$ growth regulators $\times$ Cultivar			**	**	**	**
I ₁₀	Control	Giza 171	375.67 ^{g-o} $\pm$ 3.33	33.30 ^{a-g} $\pm$ 0.97	37.65 ^{f-n} $\pm$ 0.64	5.40 ^{ghijk} $\pm$ 0.64
		Misir 1	389.50 ^{mnop} $\pm$ 3.68	44.55 ^{ijkl} $\pm$ 1.17	36.17 ^{e-j} $\pm$ 0.37	6.10 ^{h-m} $\pm$ 0.34
		Gemmieza 11	353.67 ^{a-j} $\pm$ 4.17	34.67 ^{defgh} $\pm$ 1.21	37.37 ^{f-m} $\pm$ 0.54	4.97 ^{efghi} $\pm$ 0.63
	CCC ₅₀₀	Giza 171	389.83 ^{mnop} $\pm$ 4.71	43.90 ^{hijkl} $\pm$ 2.88	42.13 ^{pqrst} $\pm$ 0.77	6.92 ^{k-p} $\pm$ 0.55
		Misir 1	405.17 ^{Pq} $\pm$ 3.43	51.10 ^{klmno} $\pm$ 0.99	36.03 ^{d-i} $\pm$ 0.78	7.25 ^{lmnop} $\pm$ 0.37
		Gemmieza 11	367.00 ^{f-n} $\pm$ 3.75	47.27 ^{klmn} $\pm$ 1.68	42.13 ^{pqrst} $\pm$ 0.51	6.35 ^{ijklm} $\pm$ 0.34
	CCC ₁₀₀₀	Giza 171	404.67 ^{Pq} $\pm$ 6.00	56.20 ^{nopq} $\pm$ 1.06	47.10 ^{wx} $\pm$ 0.43	9.28 ^{rs} $\pm$ 0.37
		Misir 1	445.50 ^r $\pm$ 5.44	49.02 ^{klmn} $\pm$ 1.71	36.98 ^{e-k} $\pm$ 0.91	8.48 ^{pqr} $\pm$ 0.55
		Gemmieza 11	371.83 ^{f-n} $\pm$ 4.69	56.18 ^{nopq} $\pm$ 1.64	40.92 ^{l-r} $\pm$ 0.51	7.29 ^{l-q} $\pm$ 0.35
	SA _{0.05}	Giza 171	387.00 ^{k-p} $\pm$ 4.73	53.20 ^{lmnop} $\pm$ 1.74	47.92 ^{wx} $\pm$ 0.61	8.08 ^{nopqr} $\pm$ 0.32
		Misir 1	387.50 ^{lmnop} $\pm$ 7.27	55.95 ^{nopq} $\pm$ 1.17	38.93 ^{g-p} $\pm$ 0.86	8.18 ^{opqr} $\pm$ 0.29
		Gemmieza 11	377.00 ^{h-p} $\pm$ 4.72	50.55 ^{klmno} $\pm$ 1.03	48.10 ^{wx} $\pm$ 0.66	6.93 ^{k-p} $\pm$ 0.35
	SA _{0.1}	Giza 171	402.00 ^{opq} $\pm$ 4.62	47.55 ^{klmn} $\pm$ 1.49	45.76 ^{tuwx} $\pm$ 0.39	7.77 ^{m-r} $\pm$ 0.34
		Misir 1	391.67 ^{nopq} $\pm$ 6.00	64.70 ^q $\pm$ 2.56	49.32 ^x $\pm$ 1.01	10.71 ^s $\pm$ 0.62
		Gemmieza 11	387.00 ^{k-p} $\pm$ 5.28	62.37 ^{Pq} $\pm$ 1.07	46.10 ^{uwv} $\pm$ 0.41	8.97 ^{qr} $\pm$ 0.53
I ₁₅	Control	Giza 171	358.83 ^{c-k} $\pm$ 3.62	31.65 ^{a-f} $\pm$ 1.78	37.12 ^{e-l} $\pm$ 0.65	4.10 ^{b-g} $\pm$ 0.37
		Misir 1	375.00 ^{g-o} $\pm$ 4.28	37.07 ^{ghij} $\pm$ 4.18	36.07 ^{d-i} $\pm$ 0.68	4.88 ^{d-i} $\pm$ 0.60
		Gemmieza 11	337.33 ^{abcde} $\pm$ 4.52	34.92 ^{efgh} $\pm$ 2.23	35.31 ^{defgh} $\pm$ 0.66	4.13 ^{b-g} $\pm$ 0.46
	CCC ₅₀₀	Giza 171	374.17 ^{f-o} $\pm$ 3.75	43.60 ^{hijk} $\pm$ 1.05	39.58 ^{i-r} $\pm$ 0.66	5.70 ^{g-l} $\pm$ 0.39
		Misir 1	386.67 ^{k-p} $\pm$ 4.01	36.38 ^{ghij} $\pm$ 1.48	31.15 ^{bc} $\pm$ 1.12	5.10 ^{ghij} $\pm$ 0.62
		Gemmieza 11	351.67 ^{a-i} $\pm$ 4.22	30.82 ^{a-f} $\pm$ 1.69	41.50 ^{opqrs} $\pm$ 0.59	4.50 ^{c-h} $\pm$ 0.47
	CCC ₁₀₀₀	Giza 171	379.17 ^{i-p} $\pm$ 3.75	48.75 ^{klmn} $\pm$ 1.56	45.08 ^{stuv} $\pm$ 0.34	7.32 ^{l-q} $\pm$ 0.31
		Misir 1	419.17 ^{qr} $\pm$ 3.75	46.57 ^{klm} $\pm$ 1.15	35.30 ^{defgh} $\pm$ 0.48	6.75 ^{j-o} $\pm$ 0.31
		Gemmieza 11	347.50 ^{a-g} $\pm$ 4.43	53.97 ^{mnop} $\pm$ 2.95	41.28 ^{n-s} $\pm$ 1.61	6.44 ⁱ⁻ⁿ $\pm$ 0.38
	SA _{0.05}	Giza 171	377.00 ^{h-p} $\pm$ 3.06	50.32 ^{klmno} $\pm$ 1.19	43.12 ^{rstu} $\pm$ 0.38	7.07 ^{k-p} $\pm$ 0.33
		Misir 1	366.67 ^{f-n} $\pm$ 8.33	45.95 ^{ijklm} $\pm$ 1.26	36.12 ^{d-j} $\pm$ 0.41	5.90 ^{hijkl} $\pm$ 0.33
		Gemmieza 11	345.83 ^{a-f} $\pm$ 4.9	58.72 ^{opq} $\pm$ 1.18	48.08 ^{wx} $\pm$ 0.44	6.38 ⁱ⁻ⁿ $\pm$ 0.79
	SA _{0.1}	Giza 171	388.33 ^{mnop} $\pm$ 4.01	41.87 ^{ghijk} $\pm$ 1.54	40.22 ^{k-r} $\pm$ 0.33	6.20 ^{h-m} $\pm$ 0.48
		Misir 1	363.33 ^{d-n} $\pm$ 8.03	48.48 ^{klmn} $\pm$ 2.44	39.92 ^{j-r} $\pm$ 0.49	6.80 ^{k-p} $\pm$ 0.36
		Gemmieza 11	349.17 ^{a-h} $\pm$ 5.54	36.20 ^{efghi} $\pm$ 3.87	38.70 ^{g-p} $\pm$ 0.39	4.92 ^{d-i} $\pm$ 0.56
I ₂₀	Control	Giza 171	337.50 ^{abcde} $\pm$ 4.42	30.55 ^{a-f} $\pm$ 0.98	32.33 ^{bcd} $\pm$ 0.39	3.00 ^{abc} $\pm$ 0.13
		Misir 1	347.50 ^{A-G} $\pm$ 4.42	29.05 ^{a-f} $\pm$ 1.99	23.43 ^a $\pm$ 0.54	2.30 ^a $\pm$ 0.19
		Gemmieza 11	325.83 ^a $\pm$ 3.27	26.87 ^{abcde} $\pm$ 1.19	37.00 ^{e-k} $\pm$ 0.46	2.51 ^{ab} $\pm$ 0.12
	CCC ₅₀₀	Giza 171	355.00 ^{b-j} $\pm$ 4.28	25.43 ^{abcd} $\pm$ 1.51	41.07 ^{m-r} $\pm$ 0.29	3.36 ^{abcde} $\pm$ 0.32
		Misir 1	361.67 ^{c-m} $\pm$ 5.58	25.27 ^{abc} $\pm$ 1.12	37.93 ^{g-o} $\pm$ 0.43	3.36 ^{abcde} $\pm$ 0.23
		Gemmieza 11	335.33 ^{abcd} $\pm$ 4.05	24.45 ^{ab} $\pm$ 0.97	33.33 ^{cde} $\pm$ 0.34	2.57 ^{ab} $\pm$ 0.25
	CCC ₁₀₀₀	Giza 171	359.50 ^{c-l} $\pm$ 4.64	24.00 ^a $\pm$ 0.69	41.78 ^{pqrs} $\pm$ 0.45	3.25 ^{abcd} $\pm$ 0.27
		Misir 1	380.83 ^{j-p} $\pm$ 6.25	43.82 ^{hijk} $\pm$ 2.27	29.32 ^b $\pm$ 0.41	4.75 ^{d-i} $\pm$ 0.27
		Gemmieza 11	334.17 ^{abc} $\pm$ 4.55	33.08 ^{a-g} $\pm$ 1.02	39.10 ^{h-q} $\pm$ 0.62	3.68 ^{a-f} $\pm$ 0.28
	SA _{0.05}	Giza 171	357.33 ^{c-j} $\pm$ 4.52	33.65 ^{b-g} $\pm$ 1.14	35.17 ^{defg} $\pm$ 0.63	3.48 ^{a-f} $\pm$ 0.18
		Misir 1	350.67 ^{a-i} $\pm$ 10.41	35.42 ^{efghi} $\pm$ 1.37	35.60 ^{defgh} $\pm$ 0.59	4.15 ^{b-g} $\pm$ 0.18
		Gemmieza 11	327.17 ^{ab} $\pm$ 7.39	30.25 ^{a-f} $\pm$ 1.43	48.07 ^{wx} $\pm$ 0.31	4.09 ^{b-g} $\pm$ 0.24
	SA _{0.1}	Giza 171	364.67 ^{e-n} $\pm$ 5.42	27.97 ^{a-f} $\pm$ 1.40	34.03 ^{cdef} $\pm$ 0.29	3.45 ^{a-f} $\pm$ 0.30
		Misir 1	356.83 ^{c-j} $\pm$ 8.64	31.98 ^{a-f} $\pm$ 1.37	36.17 ^{e-j} $\pm$ 0.66	4.13 ^{b-g} $\pm$ 0.26
		Gemmieza 11	335.00 ^{abcd} $\pm$ 7.30	34.15 ^{cdefg} $\pm$ 1.32	42.87 ^{qrstu} $\pm$ 0.29	4.10 ^{b-g} $\pm$ 0.16

** $p \leq 0.01$. Means within the same column followed by the same letter are not significantly different at $p \leq 0.05$ according to Bonferroni test. CCC500 = cycocel (500 mg L^{-1}), CCC1000 = cycocel (1000 mg L^{-1}), SA0.05 = Salicylic acid (0.05 mmol L^{-1}), SA0.1 = salicylic acid (0.1 mmol L^{-1}), and I₁₀, I₁₅, I₂₀ refer to irrigation every 10, 15, and 20 d, respectively.

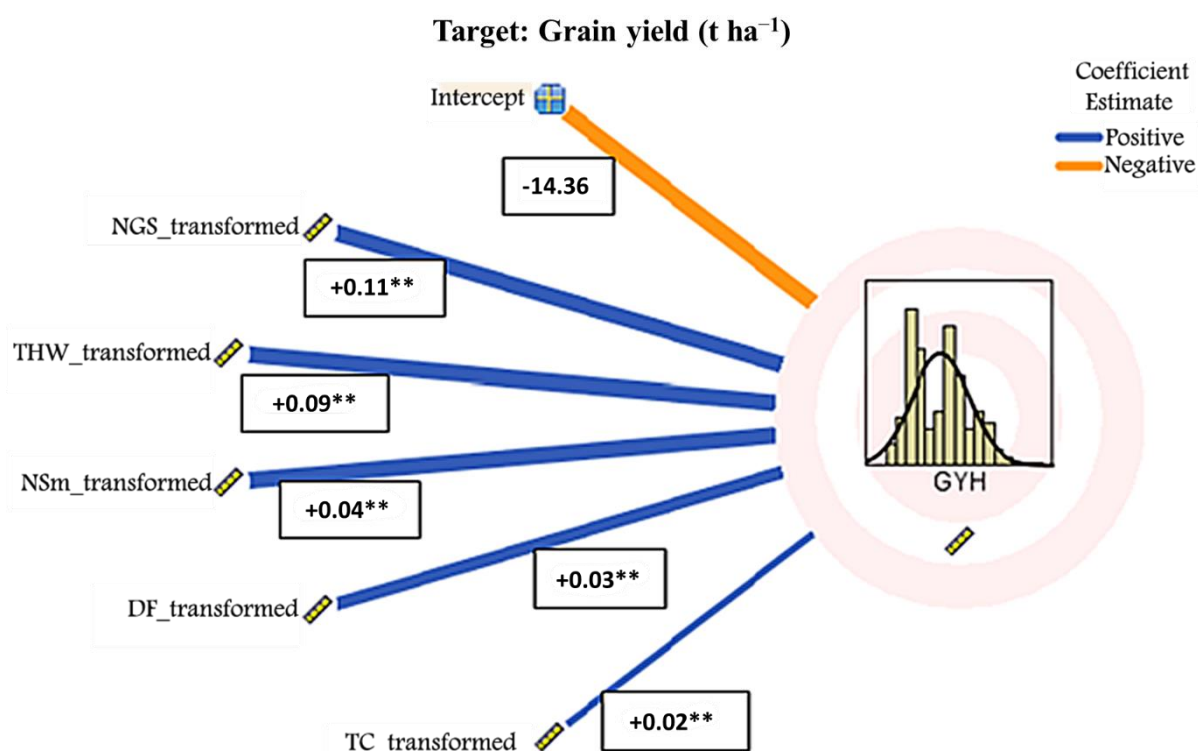


Figure 4. Automatic linear regression for predicting grain yield ha^{-1} and its attributes overall factors (combined of two successive seasons, 2017–2018 and 2018–2019). Where: GYH = grain yield ha^{-1} ; THW = 1000-grain weight; NGS = number of grains/spike; NT = number of fertile tillers; NSm = number of spike m^{-2} ; DF = days to 50 heading; TC = total chlorophyll content (SPAD) and ** indicate significant at 0.01.

3.5. Correlation and Factor Analysis

The correlation coefficients between the studied traits (combined data) are presented in (Table 7). The results indicated that positive and significant correlation coefficient values were recorded between most of each other of the studied traits. However, negative and significant correlations were detected between proline content and each of days to 50% heading, 1000-grain weight, and grain yield (t ha^{-1}). Similar results of a positive association of grain yield plant^{-1} with number of spikes plant^{-1} , thousand grains weight and number of grains spike $^{-1}$ were observed by Ebrahimnejad and Rameeh [42], Munjal and Dhanda [43] and Rahman [44].

The principal factor matrix after orthogonal rotations and summary of factor loading for some studied characters of wheat in the combined analysis under the first irrigation level are presented in (Table 5). The factor analysis technique divided the studied variables into three main factors. These three factors accounted for about 81.652% of the total variability in the dependence structure of wheat grain yield. The first factor included five variables that accounted for 41.118%. These variables were number of grains spike $^{-1}$ (22.58%), total chlorophyll content (22.23%), flag leaf area (20.84%), number of spikes m^{-2} (20.60%), and 1000-grain weight (13.75%). It is clear that these variables had high loading coefficients and participate much more in the dependence structure. All of these variables exhibited positive and significant correlation values with wheat grain yield as previously mentioned. The second factor consists of two variables and accounted for 25.991% of the total variability of wheat grain yield. These two variables were proline content (51.79%) and protein content (48.21%). One variable was loaded in the third factor included one variable and accounted for 14.544% of the total variance. This variable was number of days to 50% heading.

Table 7. Simple correlation between grain yield (t ha^{-1}) and the other important physiological and agronomic characters (combined data over two seasons).

Variables	Days to 50% Heading	Flag Leaf Area (cm^2)	Total Pigments (SPAD)	Number of Spikes m^{-2}	Number of Grains Spike $^{-1}$	1000-Grain Weight (g)	Protein Content (%)	Proline Content ($\mu\text{mol g}^{-1}\text{dw}$)	Grain Yield (t ha^{-1})
Days to 50% heading	1								
Flag leaf area (cm^2)	0.096	1							
Total chlorophyll (SPAD)	0.387 **	0.560 **	1						
Number of spikes m^{-2}	0.570 **	0.444 **	0.569 **	1					
Number of grains spike $^{-1}$	0.351 **	0.550 **	0.700 **	0.509 **	1				
1000-grain weight g^{-1}	0.007	0.355 **	0.381 **	0.240 **	0.553 **	1			
Protein content (%)	−0.100	0.564 **	0.170 **	0.269 **	0.208 **	−0.092	1		
Proline content ($\mu\text{mol g}^{-1}\text{dw}$)	−0.211 **	0.296 **	−0.087	0.082	−0.047	−0.233 **	0.830 **	1	
Grain yield (t ha^{-1})	0.467 **	0.500 **	0.681 **	0.642 **	0.861 **	0.625 **	0.081	−0.180 **	1

** indicate significant at 0.01.

4. Discussion

4.1. Main Effects

Mean squares due to irrigation intervals, growth regulators, and cultivars were significant ($p \leq 0.01$) for all studied parameters, indicating significant differences among the studied wheat cultivars. High means of all characters studied were considered favorable, except for early ones (number of days to 50% heading), where high means were considered unfavorable. Regarding the effect of irrigation intervals, the increase in the irrigation interval was followed by a significant decrease in all studied characters except for protein and proline contents. Increasing the irrigation interval, especially in sandy soils characterized by rapid loss of water and nutrients, means exposing plants to drought, which stimulates an increase in protein and proline contents of plants as osmotic-resistant components to protect them from the negative effects of drought stress through osmoregulation. These results are in agreement with those detected by Yavas and Unay [5] and Harb et al. [6].

Although the application of salicylic acid (SA) increased the total chlorophyll content (SPAD index) and flag leaf area (cm^2) and decreased the number of days to 50% heading, the application of cycocel (CCC) increased the number of spikes m^{-2} , and the contents of protein and proline. As the chlorophyll and proline contents are indicators of stress tolerance, the results obtained indicate that SA or CCC increased the plant's tolerance to stress conditions for increased irrigation intervals and sandy soil as those of Pirasteh Anosheh et al. [10]. While there were no significant differences between the treatment with SA or CCC for the number of grains spike $^{-1}$, 1000-grain weight (g), and grains yield (t ha^{-1}).

Misir 1 outperformed the other two cultivars in preserving the studied characters. It can be concluded that the varietal differences among wheat cultivars may be due to genetic makeup. Thus, Misir 1 is considered to be the most drought-resistant cultivar to drought stress collecting the best results, especially for protein and proline contents (for osmoregulation under drought stress), while displaying the highest response to foliar spraying with SA or CCC under the conditions of lack of irrigation water. These results are in harmony with those obtained by Harb et al. [6] and Maghsoudi et al. [18].

Pramoda [45] categorized H^2b estimates as low (<40%), medium (40–59%), moderately high (60–79%), and very high (≥ 80). Estimates of heritability in the broad sense were, on average, higher in five physiological and biochemical traits than for other agronomic traits. On average, the highest h^2b estimate (95.1%) was shown by the number of days to 50% heading followed by protein content (91.90%). On the contrary, the lowest h^2b appeared in the number of spikes m^{-2} . The results obtained are in agreement with the previously reported results of Rajput [46], Berhanu et al. [47] and Tesfaye et al. [48]. As the efficiency of selection will depend on the magnitude of heritable variability, the higher heritability of the studied characters should be of great value.

4.2. First-Order Interaction

The mean squares resulting from irrigation intervals $\times$ cultivars were significant ($p \leq 0.01$) for all the studied traits, indicating that cultivars rank differently from one irrigation interval to another, and selection can be made under a specific level of irrigation for the best cultivar. Moreover, mean squares due to growth regulators $\times$ cultivars were significant ($p \leq 0.01$) for all the studied traits, indicating that cultivars rank differently from one growth regulator to another.

The significant irrigation $\times$ cultivar and growth regulator $\times$ cultivar interactions for flag leaf area (cm^2), SPAD-value, number of days to 50% heading, protein and proline contents were also good evidence for the differential responses of the tested wheat cultivars at various irrigation intervals and any of the growth regulators (SA or CCC). Finally, mean squares resulting from irrigation $\times$ growth regulator were significant ($p \leq 0.01$) for all the studied traits, indicating that the activity of growth regulators differs from one irrigation interval to another.

Our findings displayed that the $I_{(20)} \times$ Misr 1 combination recorded the highest protein and proline contents. This positive result enables the plants of the Misr 1 cultivar to conserve more water under drought conditions due to these increased protein and proline contents that stimulate osmoregulation in the plants. In this respect, EL Hag [7] found a significant interaction between wheat genotypes and irrigation treatments for 1000-grain weight.

Among the interaction between growth regulators and cultivars, the $SA_{0.1} \times$ Misr 1 combination recorded the highest flag leaf area (cm^2), SPAD-value, number of grains spike $^{-1}$, and grain yield ($t\ ha^{-1}$). These positive findings were obtained due to the finding that Misr 1 was the most-tolerant cultivar, which also benefited more when sprayed with SA as an efficient growth regulator and antioxidant, which enabled the plants of Misr 1 cultivar to efficiently tolerate drought stress conditions and achieve optimum results. These results are in harmony with those obtained by Zamaninejad [15] who reported that foliar spraying with SA produced the highest values of grain yield.

4.3. Second-Order Interaction

Among the interaction between irrigation, growth regulators, and cultivars, the $I_{10} \times SA_{0.1} \times$ Misr 1 combination recorded the highest flag leaf area (cm^2), SPAD-value, number of grains spike $^{-1}$, 1000-grain weight (g), and grain yield ($t\ ha^{-1}$). In the case of this combination treatment, there was no drought stress, thus Misr 1 plants did not achieve any increase in protein and proline content, but rather achieved the highest yield. While $I_{20} \times CCC_{1000} \times$ Misr 1 combination recorded the highest protein and proline contents. In the case of this combination treatment, drought stress was created by increasing the irrigation interval from 10 to 20 days, thus the highest protein and proline contents were obtained to help the plants regulate osmosis to withstand the effects of drought stress. However, the lower number of days to 50% heading was recorded under $I_{20} \times SA_{0.1} \times$ Gemmieza 11 combination (Table 5). In this case (increasing irrigation interval), the plants tend to speed up heading, helped by the use of SA at a concentration of 0.1 mM. The highest value of SPAD was recorded by $I_{10} \times SA_{0.05} \times$ Misr1 interaction.

4.4. Automatic Linear Regression

The data obtained from automatic linear regression analysis to predict grain yield ha^{-1} are presented in Figure 4 for the combination of two consecutive seasons. The results showed that the best method to predict grain yield ha^{-1} was forward stepwise. Among eight independent variables, five variables (1000-grain weight (THW), number of grains spike $^{-1}$ (NGS), number of fertile tillers (NT), number of spike m^{-2} (NSm), number of days to 50% heading (DF), and total chlorophyll content (TC)) were the best combination to predict grain yield ha^{-1} . All five independent variables had a positive, highly significant regression coefficient associated with a high value of adjusted-R² (87.33%), meaning that 87.33% of the total variation in grain yield ha^{-1} could be explained by the variation of five variables and a low-value estimate of standard error, SEE (0.78). The best prediction equation of grain yield ha^{-1} (Y) was formulated as: $\hat{Y} = -14.36 + 0.11 \text{ NGS} + 0.09 \text{ THW} + 0.04 \text{ NSm} + 0.03 \text{ DF} + 0.02 \text{ TP}$. The existence of a significant positive regression coefficient by automatic regression indicates the effectiveness of these traits in increasing the grain yield. Therefore, these traits were considered as the main grain yield components. Our findings are in line with those illustrated by Nasri et al. [49].

4.5. Correlation and Factor Analysis

Correlation coefficients between grain yield (t ha^{-1}) and number of days to 50% heading, flag leaf area, total pigments content, number of spikes m^{-2} , number of grains spike $^{-1}$, 1000-grain weight, protein and proline contents (combined data) are shown in Table 6. The results indicated that positive and significant correlation coefficient values were recorded between grain yield (t ha^{-1}) and each of number of days to 50% heading (0.467 **), flag leaf area (0.500 **), total pigments content (0.681 **), number of spikes m^{-2} (0.642 **), number of grains spike $^{-1}$ (0.861 **), and 1000-grain weight (0.625 **), number of days to 50% heading and each of total chlorophyll content (0.387 **), number of spikes m^{-2} (0.570 **), and number of grains spike $^{-1}$ (0.351 **), flag leaf area and each of total chlorophyll content (0.560 **), number of spikes m^{-2} (0.444 **), number of grains spike $^{-1}$ (0.550 **), 1000-grain weight (0.355), protein content (0.564 **), and proline content (0.296 **). Likewise, the association was positive and significant between total pigments content and each of number of spikes m^{-2} (0.569 **), number of grains spike $^{-1}$ (0.700 **), 1000-grain weight (0.381 **), and protein content (0.170 **), number of spikes m^{-2} , number of grains spike $^{-1}$ (0.509 **), 1000-grain weight (0.240 **), and protein content (0.269 **), number of grains spike $^{-1}$ and each of 1000-grain weight (0.553) and protein content (0.208 **), as well as protein and proline contents (0.830 **). On the other hand, negative and significant correlations were detected between proline content and each of the number of days to 50% heading (−0.211 **), 1000-grain weight (−0.233 *), and grain yield (t ha^{-1}) (−0.180 **). Similar results of a positive association of grain yield plant^{-1} with number of spikes plant^{-1} , thousand grains weight, and number of grains spike $^{-1}$ were observed by Ebrahimnejad and Rameeh [42], Munjal and Dhanda [43] and Rahman [44].

The principal factor matrix after orthogonal rotations and summary of factor loading for some of the studied characters of wheat in the combined analysis under the first irrigation level are presented in Table 5. The factor analysis technique divided the studied variables into three main factors. These three factors accounted for about 81.652% of the total variability in the dependence structure on wheat grain yield. The first factor included five variables representing 41.118%. These variables were number of grains spike $^{-1}$ (22.58%), total chlorophyll content (22.23%), flag leaf area (20.84%), number of spikes m^{-2} (20.60%), and 1000-grain weight (13.75%). These variables had high loading coefficients and were much more participated in the dependence structure. All of these variables exhibited positive and significant correlation values with wheat grain yield as previously mentioned. The second factor consisted of two variables and accounted for 25.991% of the total variability of wheat grain yield. These two variables were proline content (51.79%) and protein content (48.21%). One variable was loaded into the third

factor including one variable representing 14.544% of the total variance. This variable was the number of days to 50% heading.

5. Conclusions

Finally, it could be concluded that the selection of the most drought-tolerant cultivar, which has the most important yield traits particularly the number of spikes m^{-2} , number of grains spike $^{-1}$, and 1000-grain weight is imperative for the expansion of the cultivation of such drought-tolerant cultivars under harsh conditions that affected the arid and semi-arid regions. The cultivar Misr 1 was selected based on that it had the highest yield traits along with physio-biochemical characters such as chlorophyll, protein, and proline contents that would maximize the total grain yield and improve drought tolerance in this wheat genotype with the help of SA or CCC applied to the plant as foliar spraying

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