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Bread Wheat Productivity in Response to Humic Acid Supply and Supplementary Irrigation Mode in Three Northwestern Coastal Sites of Egypt

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Abstract: Drought stress is a major factor limiting wheat crop production worldwide. The application of humic acid (HA) and the selection of the appropriate genotype in the suitable site is one of the most important methods of tolerance of wheat plants to drought-stress conditions. The aim of this study was achieved using a three-way ANOVA, the stress tolerance index (STI), the Pearson correlation coefficient (r_p), and principal component analysis (PCA). Three field experiments in three sites (Al-Qasr, El-Neguilla, and Abo Kwela) during the 2019/21 and 2020/21 seasons were conducted, entailing one Egyptian bread wheat variety (Sakha 94) with three HA rates (0, 30, and 60 kg ha^{-1}) under normal and drought-stress conditions (supplemental irrigation). According to the ANOVA, the sites, supplemental irrigation, HA rates, and their first- and second-order interactions the grain yield and most traits evaluated ($p \leq 0.05$ or 0.01) were significantly influenced in both seasons. Drought stress drastically reduced all traits registered in all factors studied compared with normal conditions. The wheat plants at the Al-Qasr site in both seasons showed significantly increased grain yield and most traits compared with that of the other sites under normal and drought-stress conditions. HA significantly promoted all studied traits under drought stress, and was highest when applying 60 kg HA ha^{-1}, regardless of the site. The greatest grain yield and most traits monitored were observed in wheat plants fertilized with 60 kg HA ha^{-1} at the Al-Qasr site in both seasons under both conditions. Grain yield significantly ($p \leq 0.05$ or 0.01) correlated with water and precipitation use efficiency as well as the most studied traits under normal and drought-stress conditions. The results of STI, r_p, and PCA from the current study could be useful and could be used as a suitable method for studying drought-tolerance mechanisms to improve wheat productivity. Based on the results of statistical methods used in this study, we recommend the application of 60 kg HA ha^{-1} to improve wheat productivity under drought conditions along the north-western coast of Egypt.

Keywords: correlation; environment; drought stress; humic acid; PCA analysis; rain-fed; wheat varieties

1. Introduction

Cereal crops are a major staple food worldwide, which directly contribute more than 50% of the total human calorie input. Among them, wheat (*Triticum aestivum* L.) occupies a prominent position as a source of dietary protein and calories for the ever-burgeoning population of the world [1]. Bread wheat is widely cultivated over the world because of its great demand and cultivars that are adaptable to various environmental conditions [2]. Wheat is the most significant cereal grain and a staple diet for millions of people in Egypt, where 1.40 million hectares were planted in 2021/2022, yielding 9.0 million tons [3]. Egypt is the world's largest wheat importer [4], and by expanding its output, it hopes to reduce its reliance on imports. Due to water constraints, inefficient irrigation systems, poor conservation, and low agricultural water efficiency, water availability per unit of irrigated area is decreasing in the Mediterranean regions [5,6].

Irrigation water scarcity is one of the most significant constraints on agricultural production [7], given that irrigated agriculture is the largest user of freshwater, accounting for approximately 79% of all water withdrawal in Egypt and 69% worldwide [8]. Increased water use efficiency (WUE) in both irrigated and rain-fed agriculture is required to meet the demand for food production while preserving freshwater resources [9]. Drought is the most serious issue affecting wheat output. As a result, improving drought resistance is of particular significance for long-term wheat production. Egypt's rain belt is confined to the coast, particularly in the north, which is categorized as semi-arid and has poor sandy or saline soil. Rain-fed agriculture is practiced in Egypt's North Sinai and Marsa Matrouh [10]. A substantial amount of the Egyptian North Coast's present economic activities is based on rain-fed agriculture. Rainfall in this area ranges from 130 to 150 mm on the northwest coast to 80 mm (west of Al-Arish) to 280 mm (near Rafah) in the northeast [11]. Drought-tolerant crops such as wheat, barley, fig, olive, and tiny patches of faba bean and lentils are the most widely grown crops in the area. Due to the lack of rain throughout the winter wheat-growing seasons, only 30% of the crop's water requirements are met, and over 70% of irrigation water is required to sustain winter wheat's potential output [10]. Long dry spells are common during important growth stages, such as flowering and grain filling, and have a significant impact on eventual production [12].

Rain-fed areas, where most of the land is farmed utilizing old, traditional, and rudimentary soil and agricultural practices, are facing several critical problems [13]. Because of their small canopy and low evaporative demands in the winter, all winter-sown crops are more vulnerable to drought in the spring or early summer when evaporative demand is high, especially during flowering and grain-filling stages, and are largely reliant on stored soil moisture to complete their growth cycles [14]. Supplemental irrigation (SI) with a limited amount of water can improve crop output while also increasing WUE [15]. Previous researchers found that increasing the soil water content at a depth of 40 cm to 65% of the field capacity after jointing and 70% of the field capacity after anthesis using SI boosted grain output and WUE by almost 40% and 15%, respectively. Many studies have found that varying quantities of SI at different stages of wheat growth considerably and significantly increased grain yield [16–20].

Under rain-fed conditions, fertilizer rates should be regulated because when excessive amounts of fertilizer are provided, the vegetative growth of the plants is stimulated much more in the early periods, and water stress may arise at later times, affecting the effective grain-filling period [21]. Fertilizer application improves the usage of stored water as well as boosts wheat yields by correcting nutritional deficiencies [22]. Therefore, increasing crop productivity under water scarcity is deliberated as the main purpose via hybridizing or genetic engineering plans [23]. To challenge this problem conventionally, chemical treatment and agronomical crop management practices have been applied to decrease the detrimental effects of water deficiency [24]. Alternatively, humic acid (HA) as organic fertilization plays an essential role in diminishing the utilization of chemical fertilizers and reducing its harmful impact on soil, the environment, and sustainable agriculture [25]. HA is the active ingredient in organic fertilizers, and its use could be a viable alternative to traditional soil fertilization and a quick source of nitrogen, especially in semi-arid areas [26].

HA is a naturally occurring polymeric-heterocyclic organic molecule with carboxylic (COOH), phenolic (OH), alcoholic, and carbonyl fractions, and is used as an organic fertilizer [27]. HA has been shown to improve nutrient transport and availability [28,29]. Due to their effective components, humic compounds can alter biochemical processes in plants, resulting in higher photosynthesis and respiration rates, as well as increased hormone and protein production [28]. In general, the beneficial effects of HA on plant physiology are discussed in terms of root growth and nutrient uptake [30]. HA can be used as a low-cost organic fertilizer to boost plant growth and productivity, improve stress tolerance, and improve soil physical characteristics and complex metal ions, among other things [31]. Effect of HA on wheat seedling growth in the presence and absence of nitrogen (N) was also investigated. Small amounts of HA (54 mg L^{-1}) in the water medium resulted in a 500% increase in root length [32]. HA enhanced the fresh and dry weight of roots considerably. In the presence of 54 mg HA L^{-1}, the wheat dry matter yield of shoots rose by 22%. In addition to the improvement in the soil's physical structure, humic compounds in the soil boost nutrient absorption by increasing the availability of nutrients [32].

The main purpose of the current work was to evaluate the possible use of HA as a soil application to alleviate the harmful effects of water stress on wheat plants, explaining the role of HA in improving the growth and yield of water-stressed wheat plants and maximizing WUE for optimal crop production.

2. Materials and Methods

2.1. Geographic and Climatic Data of the Studied Sites

Field experiments (2019/2020 and 2020/2021 winter seasons) were carried out at three different sites along the north-western coast of Egypt: The Al-Qasr site, (latitude: 31°35′ and longitude: 27°16′), the El-Neguilla site (latitude: 31°43′ and longitude: 26°50′), and the Abo Kwela site (latitude: 31°57′ and longitude: 25°99′), located in Marsa Matrouh, approximately 300 km west of Alexandria city, on the north-western coast of Egypt. Geographic coordinates for the three cultivated sites are presented in Figure 1. Climatic data of the three cultivated sites, such as the monthly average precipitation (mm), minimum and maximum temperature (°C), solar radiation (Mj m^{-2} d^{-1}), wind speed (m s^{-1}), and relative humidity (%) for the experimental duration (December–April) during both growing winter seasons (2019/2020 and 2020/2021), are presented in Table 1.

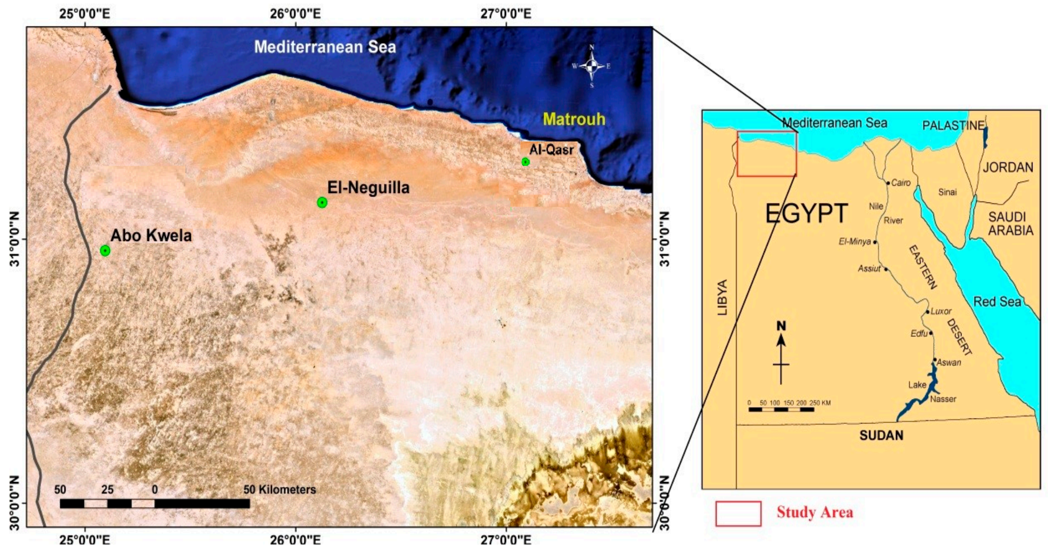

Figure 1. Geographic coordinates for Al-Qasr, El-Neguilla, and Abo Kwela sites, Marsa Matrouh, Egypt.

Table 1. Climatic data at Al-Qasr, El-Neguilla, and Abo Kwela sites, Egypt, during the 2019/2020 and 2020/2021 growing seasons.

Season		Al-Qasr					El-Neguilla					Abo Kwela				
		Temperature (°C)		RH (%)	WS (m s^{-1})	Solar Radiation (MJ m^{-2} d^{-1})	Temperature (°C)		RH (%)	WS (m s^{-1})	Solar Radiation (MJ m^{-2} d^{-1})	Temperature (°C)		RH (%)	WS (m s^{-1})	Solar Radiation (MJ m^{-2} d^{-1})
		Min	Max				Min	Max				Min	Max			
2019/2020	November	9.65	28.3	66.1	2.40	13.2	10.01	28.9	62.6	5.23	15.3	9.16	29.9	56.2	2.45	8.6
	December	3.39	22.2	71.9	3.78	10.2	3.96	22.7	71.5	6.98	12.4	4.42	23.3	71.1	3.37	6.6
	January	3.37	17.8	74.0	3.98	11.3	3.49	17.7	74.3	5.74	11.1	3.83	17.9	75.9	3.21	6.8
	February	4.37	22.1	74.3	3.58	14.7	4.50	22.1	74.1	6.96	14.8	4.19	21.9	73.7	3.25	9.1
	March	4.91	25.7	67.4	3.98	20.8	4.99	27.3	64.6	6.38	20.6	4.97	29.1	61.6	3.73	12.0
	April	8.00	29.1	65.2	3.16	25.2	8.13	30.1	62.1	8.21	28.5	7.65	31.8	57.9	3.25	15.5
	May	9.89	39.9	56.7	3.43	27.1	10.26	40.4	54.1	9.79	30.2	9.63	41.6	47.3	3.52	18.5
2020/2021	November	7.22	24.0	79.6	2.88	12.3	7.33	23.9	77.8	12.01	29.8	6.37	24.8	76.4	2.61	7.9
	December	8.32	25.1	62.0	3.32	14.7	5.50	20.3	76.9	8.68	15.7	5.11	22.2	73.9	2.53	7.1
	January	5.08	19.7	79.3	2.51	10.8	10.8	17.1	63.0	4.89	7.12	6.87	25.8	68.2	2.87	7.8
	February	10.76	18.6	58.0	4.90	20.7	10.65	18.5	58.0	5.32	15.2	4.11	24.1	72.2	3.20	10.5
	March	10.92	26.8	57.0	4.88	25.9	12.91	22.2	57.0	4.94	22.1	6.12	15.6	74.3	3.98	8.0
	April	11.66	30.5	55.0	3.85	34.5	15.72	25.4	56.0	4.89	26.4	8.24	31.0	77.2	3.91	16.3
	May	17.80	33.1	55.0	4.99	33.1	18.03	30.7	60.0	4.82	30.0	8.55	43.0	66.5	2.56	17.8

RH = relative humidity and WS = wind speed.

The agriculture in the studied regions is mainly rain-fed, and these regions are characterized by a Mediterranean-type climate with cold wet winters and hot dry summers. The highest percentage of precipitation usually occurs in December and January in the three cultivated sites. The highest seasonal rainfall rates during the studied period (Figure 2) were recorded at the Al-Qasr site (4224 m^3), followed by the El-Neguilla site (3115 m^3), then the Abo Kwela site (2342 m^3).

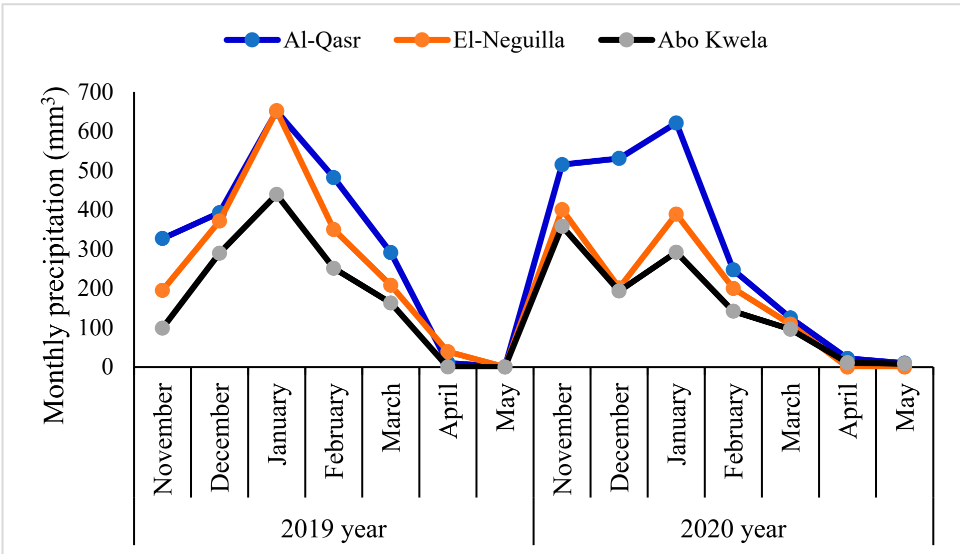

Figure 2. Monthly precipitation at each site during the two growing seasons.

2.2. Soil Characteristics of the Studied Field Sites

The soils of the studied area could be classified at the family level as Typic Torripsamments, siliceous, hyperthermic, and moderately deep. In addition, the suitability of the studied soils ranged between not suitable and marginally suitable [33]. The soil of the three sites where the experiments were carried out for the two seasons had topsoil (0–100 cm depth) characterized as sandy loam in texture. Table 2 shows the results of the soil analysis at the three study sites at a 0.0–0.50 cm depth before planting in both winter seasons (2019/2020 and 2020/2021) using [34,35] standard methods.

Table 2. Soil analysis of the studied experimental sites (0.0–0.5 m depth) before sowing during the 2019/2020 and 2020/2021 growing seasons.

Soil Property	Al-Qasr		El-Neguilla		Abo Kwela	
	2019/2020	2020/2021	2019/2020	2020/2021	2019/2020	2020/2021
Physical Characteristics						
Coarse sand (%)	45.78	36.97	38.76	35.22	42.87	37.11
Fine sand (%)	38.20	44.60	40.80	47.16	34.11	45.32
Silt (%)	14.30	16.32	19.46	15.74	21.04	15.21
Clay (%)	1.72	2.11	0.98	1.88	1.98	2.36
Texture class	SL	SL	SL	SL	SL	SL
Chemical properties:						
pH	8.35	8.27	8.50	8.11	8.40	7.25
EC_e (dS m^{-1})	2.40	6.00	4.50	9.30	3.10	8.80
Soluble Cations (meq 100^{-1} g)						
Mg^{2+}	0.70	1.60	1.00	2.50	0.69	2.60
Ca^{2+}	0.81	2.60	1.50	3.16	1.30	3.90
Na^+	0.74	1.04	1.46	2.81	1.35	1.70
K^+	0.27	0.96	0.67	0.84	0.19	0.66
Soluble Anions (meq 100^{-1} g)						
HCO_3^-	1.0	2.06	1.03	3.60	0.83	3.50
Cl^-	0.38	1.25	0.6	1.70	1.0	2.24
SO_4^{2-}	1.14	2.89	3.00	4.01	1.7	3.12

SL: Sandy loam; EC_e: Electrical conductivity of soil past extract (1:2.5 soil:H_2O, *w*/*v*).

2.3. Experimental Design and Treatment Details

The bread wheat Sakha 94 variety was bought from the central administration of seeds production of the Egyptian Ministry of Agriculture and Land Reclamation and was sown in different environments at three sites along the north-western coast of Egypt. The pedigree of the studied cultivar is OPATA/RAYON//KAUZ (CMBW90Y3180-0TOPM-3Y-010Y-10M-015Y-0Y-0AP-0S, the year of release was (2004). At each site, wheat grains were sown in a split-plot design in a randomized complete block design (RCBD) with three replicates. Each plot (3.5 × 4 m) included 13 rows 3.5 m long and 30 cm apart. Irrigation treatments were allocated to the main plots as rain-fed (drought) and SI (normal) (Table 3), and the water used for SI was groundwater (with EC_e = 1.2 ± 0.3 dS m^{-1}) pumped from a local well and provided via a sprinkler irrigation system. HA treatments were allocated in subplots and applied at three doses of 0 (HA_0), 30 (HA_{30}), and 60 (HA_{60}) kg ha^{-1}. The main constituents of the water-dissolvable HA compound used in this experiment (Alpha Chemika, Mumbai, Maharashtra, India) are listed in Table 4. Each HA dose was applied once during planting after being well mixed with fine sand (200 kg), then equally spread throughout the topsoil layer and blended in the rhizosphere zone where the root is active.

2.4. Agronomical Management Practices

After one chisel plow, grains of the Sakha 94 variety were sown at the rate of 167 kg ha^{-1} in rows after the first effective rainfall precipitation on 10, 12, and 13 December in the first season and 15, 16, and 17 November in the second season for Al-Qasr, El-Neguilla, and Abo Kwela sites, respectively. The experimental field of each cultivated site was basally supplied with 52.5 kg of P_2O_5 ha^{-1} (169.4 kg of calcium super monophosphate containing 15.5% P_2O_5) during the preparation of the field. Furthermore, nitrogen was applied with 180.4 kg of N ha^{-1} (284.2 kg of ammonium nitrate 33.5% N), which was supplied in two or three equal doses with SI times. Meanwhile, the other recommended agricultural practices were applied as usual in bread wheat fields under Egyptian rain-fed conditions.

Table 3. Description of irrigation mode and humic acid treatments applied in the three research sites.

A. Supplemental Irrigation (SI)													
Treatment	**Description**	**Total Amount of Supplemental and Rain Irrigation Water (m^3 ha^{-1})**											
		2019/2020						**2020/2021**					
		Al-Qasr		**El-Neguilla**		**Abo Kwela**		**Al-Qasr**		**El-Neguilla**		**Abo Kwela**	
		Rain	**SI**	**Rain**	**SI**	**Rain**	**SI**	**Rain**	**SI**	**Rain**	**SI**	**Rain**	**SI**
Normal	Wheat plants were irrigated with three supplemental irrigations at stages of stem elongation, flowering, and grain filling.	2154	1751	1815	2090	1242	2663	2070	1751	1300	2521	1100	2721
Drought	Wheat plants were irrigated with three supplemental irrigations (60% of water amount applied at normal level) at stages of stem elongation, flowering, and grain filling.	2154	189	1815	528	1242	1101	2070	223	1300	993	1100	1193
B. Humic Acid (HA)													
HA_0	0 kg ha^{-1} HA addition												
HA_{30}	30 kg ha^{-1} of HA mixed well with 200 kg of fine sand was added once at planting for each site												
HA_{60}	60 kg ha^{-1} of HA mixed well with 200 kg of fine sand was added once at planting for each site												

Table 4. The main components of humic acid (HA) substance applied in the three research sites on a dry weight basis.

Component	**Concentration (%)**	**Component**	**Concentration (%)**
Pure HA content	90.3	Iron (Fe)	0.61
Nitrogen (N)	0.94	Manganese (Mn)	0.09
Phosphorus (P)	1.04	Zinc (Zn)	0.32
Potassium (K)	1.46	Copper (Cu)	0.55
Calcium (Ca)	2.81	Sodium (Na)	0.04
Magnesium (Mg)	0.92	Others	0.44
Sulfur (S)	0.48		

2.5. Agronomic Traits, Grain Yield, and Its Components

At full maturity, wheat plants were manually harvested on 20, 21, and 27 April in the 2019/2020 season, and 9, 13, and 15 April in the 2020/2021 season for Al-Qasr, El-Neguilla, and Abo Kwela sites, respectively. Ten wheat plants were randomly collected from each plot to measure the plant height (PH; cm), spike length (SL; cm), and spikelet number per spike (SNS). The spikelet density was calculated by dividing SNS by SL. However, all wheat plants in one square meter area were manually harvested from each plot to measure the number of spike per m^2 (NSm^2). The tillering index (%) was calculated by dividing the NSm^2/tiller number per m^2 and the thousand-grain weight (T-GW; g). Meanwhile, the remaining wheat plants in each plot were harvested to determine the grain (GY), straw (SY), and biological (BY) yields and converted into t ha^{-1}. WUE was calculated by dividing GY (kg ha^{-1}) by growing season irrigation (m^3 ha^{-1}). The precipitation use efficiency (PUE) was obtained by dividing GY (kg ha^{-1}) by growing season precipitation (m^3 ha^{-1}) [36].

2.6. Statistical Analysis

Upon pre-running the variance analysis, Shapiro-Wilk's normality and Levene's homogeneity for all variables were verified using the normality and homogeneity tests according to [37,38]. The outputs of the normality and homogeneity tests showed all variables to be statistically acceptable for further analysis of variance. Pooled data of all variables for both seasons were subjected to a three-way ANOVA using GenStat statistical software (12th edition, VSN International Ltd., Harpenden, UK) according to [39]. The coefficient of variation (C.V. %) was estimated and categorized as very high (C.V. % $\geq$ 21), high (15 $\leq$ C.V. % < 21), moderate (10 $\leq$ C.V. % < 15), and low (C.V. % < 10) according to [40]. The obtained data were expressed as the mean $\pm$ standard error (SE), and multiple comparisons were determined using the least-significant-difference test (LSD) at the 0.05 level of probability [39]. The stress tolerance index was calculated according to [41]. Pearson's correlation coefficient and principal component analysis (PCA) were applied to assess the association among the studied traits using the Origin Pro 2021 version b 9.5.0.193 computer software program.

3. Results

3.1. Analysis of Variance (ANOVA) Results

Table 5 outlines the detailed results of the three-way ANOVA for the studied wheat traits. The results showed that the environment (E), SI, and HA treatments, as well as the first-order interactions (E × SI, E × HA, and SI × HA), had a statistically significant effect ($p \leq 0.05$ or 0.01) on all studied traits. The second-order interaction (E × SI × HA) had statistically significant effects ($p \leq 0.05$ or 0.01) for most studied traits, while non-significant differences were observed between second-order interactions for the SNS trait. In Table 5, the C.V. % values registered for all evaluated traits across experimental factors are low (C.V. $\leq$ 10%), indicating the high precision and reliability of the field experiments carried out.

Table 5. Three-way ANOVA (*p*-values) for the impact of environment (E), supplemental irrigation (SI), humic acid (HA) treatment, and their interactions on the studied bread wheat traits.

S. O. V.	PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2	SY	BY	GY	T-GW (g)	WUE	PUE
							(t ha^{-1})				(kg m^{-3})	
E	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **
SI	0.00 **	0.00 **	0.00 **	0.00 **	0.02 *	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.03 *	0.00 **
HA	0.00 **	0.00 **	0.00 **	0.00 **	0.06 *	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **
E × SI	0.00 **	0.00 **	0.07 *	0.00 **	0.00 **	0.00 **	0.02 *	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **
E × HA	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.04 *	0.02 *	0.00 **	0.00 **	0.00 **	0.00 **
SI × HA	0.00 **	0.00 **	0.00 **	0.00 **	0.02 *	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **
E × SI × HA	0.00 **	0.00 **	0.00 **	0.32 ^{ns}	0.05 *	0.03 *	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **	0.00 **
C.V. %	4.39	5.14	4.39	6.14	6.11	8.11	7.80	5.93	6.38	4.45	6.48	7.18

(*) and (**) significant for $p \leq 0.05$ and $p \leq 0.01$, respectively; ns: Indicates a non-significant difference. S.O.V.: Source of variance, PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. C.V. %: Coefficient of variation (%).

3.2. Experimental Factors Effects on Wheat Traits

The results in Table 6 shows significant differences in the effects of the environment (site × year), SI, and HA treatments on all studied wheat traits. PH, SNS, and SD were significantly higher at the El-Neguilla site in both seasons than at the Al-Qasr and Abo Kwela sites. Meanwhile, SL, SY, BY, GY, T-GW, WUE, and PUE increased significantly at the Al-Qasr site in both seasons compared with the Abo Kwela and El-Neguilla sites. Regarding the irrigation mode, all studied wheat traits were markedly higher under normal conditions compared to drought-stress conditions, except WUE, which was higher in drought conditions compared to normal conditions. Regarding HA treatments, all studied wheat traits in the current study were significantly higher in plants supplied with 60 kg HA ha^{-1}, moderate in plants fertilized with 30 kg HA ha^{-1}, and lower in non-fertilized wheat plants (0 kg HA ha^{-1}).

Table 6. Effects of the environment (E; location and year), supplemental irrigation (SI), and humic acid (HA) on the studied bread wheat traits.

Factor	PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2
E						
Abo Kwela 2019/20	44.4 ± 3.9c	1.37 ± 0.07b	6.06 ± 0.37c	12.23 ± 0.53e	2.06 ± 0.06c	113.6 ± 5.40c
Abo Kwela 2020/21	44.0 ± 3.6d	1.39 ± 0.06a	6.22 ± 0.38b	12.55 ± 0.54d	2.07 ± 0.05c	116.4 ± 5.10b
El-Neguilla 2019/20	58.7 ± 2.2a	0.77 ± 0.01f	5.99 ± 0.29d	15.31 ± 1.01b	2.52 ± 0.07b	63.1 ± 2.29d
El-Neguilla 2020/21	58.4 ± 2.0a	0.89 ± 0.05e	5.95 ± 0.32d	15.67 ± 1.15a	2.57 ± 0.04a	57.5 ± 4.60e
AL-Qasr 2019/20	44.3 ± 0.8c	1.14 ± 0.03c	6.26 ± 0.19b	10.92 ± 0.38f	1.75 ± 0.03e	136.8 ± 8.28a
AL-Qasr 2020/21	45.6 ± 0.7b	1.06 ± 0.02d	6.79 ± 0.23a	13.20 ± 0.65c	1.94 ± 0.05d	137.6 ± 8.00a
SI						
Normal	54.3 ± 3.1a	1.14 ± 0.10a	7.01 ± 0.10a	15.25 ± 1.20a	2.18 ± 0.18a	117.8 ± 16.90a
Drought	44.2 ± 3.4b	1.08 ± 0.11b	5.42 ± 0.16b	11.37 ± 0.35b	2.12 ± 0.10b	90.5 ± 12.47b
HA						
0 kg ha^{-1} (HA_0)	41.1 ± 3.5c	0.95 ± 0.08c	5.17 ± 0.30c	10.97 ± 0.35c	2.15 ± 0.13c	85.4 ± 10.72c
30 kg ha^{-1} (HA_{30})	49.8 ± 3.1b	1.11 ± 0.10b	6.30 ± 0.09b	13.28 ± 0.85b	2.12 ± 0.14b	102.8 ± 15.52b
60 kg ha^{-1} (HA_{60})	56.9 ± 3.4a	1.26 ± 0.14a	7.17 ± 0.21a	15.69 ± 1.08a	2.19 ± 0.16a	124.3 ± 17.23a
Factor	**SY**	**BY**	**GY**	**T-GW (g)**	**WUE**	**PUE**
		(t ha^{-1})			**(kg m^{-3})**	
E						
Abo Kwela 2019/20	4.04 ± 0.25d	5.44 ± 0.42c	1.41 ± 0.20c	31.3 ± 2.5c	0.42 ± 0.10c	1.13 ± 0.30b
Abo Kwela 2020/21	4.49 ± 0.28b	5.90 ± 0.44b	1.43 ± 0.21c	32.3 ± 2.6b	0.43 ± 0.09c	1.28 ± 0.41a
El-Neguilla 2019/20	2.92 ± 0.27e	3.87 ± 0.39d	0.96 ± 0.12e	31.6 ± 1.1c	0.29 ± 0.07e	0.53 ± 0.06f
El-Neguilla 2020/21	2.93 ± 0.28e	3.89 ± 0.40d	0.98 ± 0.13d	32.4 ± 1.2b	0.30 ± 0.07d	0.75 ± 0.06e
AL-Qasr 2019/20	4.24 ± 0.31c	5.91 ± 0.50b	1.66 ± 0.20b	35.0 ± 2.9a	0.51 ± 0.16b	0.77 ± 0.34d
AL-Qasr 2020/21	4.67 ± 0.27a	6.45 ± 0.47a	1.78 ± 0.25a	35.1 ± 2.7a	0.54 ± 0.11a	0.86 ± 0.17c
SI						
Normal	4.64 ± 0.31a	6.63 ± 0.51a	1.99 ± 0.21a	38.5 ± 1.8a	0.52 ± 0.17a	1.30 ± 0.27a
Drought	3.12 ± 0.33b	3.86 ± 0.39b	0.74 ± 0.08b	27.4 ± 1.0b	0.32 ± 0.18b	0.48 ± 0.22b
HA						
HA_0	2.88 ± 0.31c	3.85 ± 0.41c	0.97 ± 0.10c	25.6 ± 0.6c	0.30 ± 0.01c	0.63 ± 0.01c
HA_{30}	4.09 ± 0.37b	5.40 ± 0.50b	1.30 ± 0.14b	32.4 ± 0.6b	0.40 ± 0.06b	0.85 ± 0.07b
HA_{60}	4.66 ± 0.28a	6.49 ± 0.45a	1.83 ± 0.18a	40.8 ± 1.4a	0.55 ± 0.03a	1.19 ± 0.14a

Each value represents means ± standard error. Means sharing different letters in the same column indicate statistically significant ($p \leq 0.05$) differences according to the LSD test. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

3.3. The First-Order Interaction Effect on Wheat Traits

With respect to the E × SI interaction (Table 7), all studied wheat traits under normal conditions were higher than in drought conditions except for the TI trait at Abo Kwela and El-Neguilla sites in the 2019/2020 season and the SD trait at Abo Kwela in both seasons and AL-Qasr in the 2019/2020 season. The interaction effect between environments and normal conditions showed significant differences for all studied traits compared with the environments × drought stress interactions, except for WUE at the El-Neguilla site in both seasons and the AL-QASR site in the 2019/2020 season. The highest values of GY and most studied traits were registered by the Al-Qasr × SI interaction in the 2020/2021 season compared with their values in other E × SI interactions. A significant decrease was found in the El-Neguilla site × SI interaction than other E × SI interactions for GY and most studied traits under both conditions. Generally, the Al-Qasr site in both seasons showed more WUE, thus more GY and most traits comparatively than other sites under drought-stress conditions.

Table 7. The first-order interaction of environment (E) and supplemental irrigation (SI) for the studied bread wheat traits.

Factor		PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2
E	SI						
Abo Kwela 2019/2020	Normal	53.7 ± 12.5b	1.37 ± 0.14b	6.86 ± 1.11c	13.37 ± 1.7d	1.98 ± 0.10e	122.0 ± 16.4b
	Drought	35.1 ± 2.8ab	1.38 ± 0.22b	5.27 ± 0.63h	11.09 ± 0.7g	2.14 ± 0.15d	105.1 ± 9.6e
Abo Kwela 2020/2021	Normal	52.6 ± 11.3d	1.41 ± 0.16a	7.06 ± 1.14b	13.55 ± 1.7d	1.94 ± 0.09e	124.5 ± 14.4b
	Drought	35.3 ± 3.0b	1.38 ± 0.21b	5.38 ± 0.63g	11.55 ± 0.8f	2.18 ± 0.12d	108.3 ± 11.3d
El-Neguilla 2019/2020	Normal	63.3 ± 6.5f	0.76 ± 0.02j	6.76 ± 0.57d	18.33 ± 2.1b	2.70 ± 0.08b	68.8 ± 5.0f
	Drought	54.1 ± 3.5d	0.79 ± 0.05i	5.21 ± 0.66h	12.29 ± 1.7e	2.35 ± 0.04c	57.4 ± 5.5g
El-Neguilla 2020/2021	Normal	63.2 ± 5.4f	0.96 ± 0.17g	6.91 ± 0.67c	19.33 ± 2.3a	2.77 ± 0.09a	69.2 ± 5.6f
	Drought	53.7 ± 3.9e	0.82 ± 0.09h	5.00 ± 0.54i	12.00 ± 1.7e	2.38 ± 0.13c	45.8 ± 10.0h
AL-Qasr 2019/2020	Normal	46.4 ± 1.3i	1.20 ± 0.03c	6.98 ± 0.12bd	12.02 ± 0.7e	1.72 ± 0.08h	161.5 ± 19.9a
	Drought	42.3 ± 1.8f	1.09 ± 0.05e	5.53 ± 0.15f	9.82 ± 0.5h	1.78 ± 0.06g	112.1 ± 11.0c
AL-Qasr 2020/2021	Normal	46.6 ± 1.2i	1.12 ± 0.03d	7.48 ± 0.34a	14.91 ± 1.9c	1.98 ± 0.16e	160.6 ± 20.3a
	Drought	44.7 ± 1.9h	1.01 ± 0.02f	6.11 ± 0.49e	11.50 ± 0.8f	1.89 ± 0.04f	114.5 ± 10.4c

E	SI	SY	BY	GY	T-GW (g)	WUE	PUE
		(t ha^{-1})				(kg m^{-3})	
Abo Kwela 2019/2020	Normal	4.59 ± 0.49c	6.69 ± 0.91d	2.10 ± 0.48c	37.8 ± 7.3d	0.54 ± 0.03b	1.69 ± 0.6b
	Drought	3.49 ± 0.67e	4.20 ± 0.71i	0.71 ± 0.04h	24.8 ± 2.3j	0.31 ± 0.09f	0.58 ± 0.09g
Abo Kwela 2020/2021	Normal	5.21 ± 0.26b	7.31 ± 0.73c	2.10 ± 0.47c	39.6 ± 7.2c	0.55 ± 0.04b	1.91 ± 0.2a
	Drought	3.76 ± 0.81f	4.48 ± 0.86g	0.72 ± 0.05h	25.1 ± 3.0j	0.31 ± 0.09f	0.65 ± 0.03f
El-Neguilla 2019/2020	Normal	3.74 ± 0.57f	5.10 ± 0.85e	1.36 ± 0.29e	32.9 ± 3.3f	0.35 ± 0.02e	0.75 ± 0.1e
	Drought	2.10 ± 0.47h	2.65 ± 0.54j	0.55 ± 0.07i	30.2 ± 2.6g	0.24 ± 0.01g	0.30 ± 0.05j
El-Neguilla 2020/2021	Normal	3.74 ± 0.59f	5.14 ± 0.88e	1.40 ± 0.29d	34.0 ± 3.7e	0.37 ± 0.03d	1.08 ± 0.5d
	Drought	2.09 ± 0.48h	2.64 ± 0.55j	0.55 ± 0.07i	30.8 ± 2.7g	0.24 ± 0.01g	0.43 ± 0.073i
AL-Qasr 2019/2020	Normal	5.13 ± 0.57b	7.43 ± 1.06b	2.30 ± 0.51a	43.7 ± 7.3a	0.59 ± 0.0b	1.07 ± 0.09d
	Drought	3.36 ± 0.61g	4.38 ± 0.75h	1.03 ± 0.18f	26.2 ± 3.4i	0.44 ± 0.02c	0.48 ± 0.02h
AL-Qasr 2020/2021	Normal	5.43 ± 0.09a	8.11 ± 0.58a	2.68 ± 0.50a	42.8 ± 6.7b	0.70 ± 0.10a	1.30 ± 0.60c
	Drought	3.92 ± 0.78d	4.80 ± 0.83f	0.88 ± 0.06g	27.3 ± 3.7h	0.38 ± 0.03d	0.43 ± 0.05i

Each value represents means ± standard error. Means sharing different letters in the same column indicate statistically significant ($p \leq 0.05$) differences according to the LSD test. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency.

In Table 8, compared with 0 and 30 kg of HA ha^{-1}, crops fertilized with 60 kg HA ha^{-1} showed significantly increased interactions of E × HA for all studied traits under normal and drought-stress conditions. On the other hand, SD was significantly decreased with the 60 kg HA ha^{-1} treatment at the Abo Kwela site in both seasons. Compared with sites and years in E × HA interactions, the Al-Qasr site across both years reached the maximum values of GY and most studied traits. Meanwhile, the highest PH, SNS, and SD were found at the El-Neguilla site in both seasons. Generally, the application of 60 kg HA ha^{-1} at the Al-Qasr site during the 2020/2021 season comparatively produced more GY and most other traits than other applications of HA at other sites in both seasons under normal and drought-stress conditions.

Table 8. The first-order interaction of environment (E) and humic acid (HA) treatment for the studied bread wheat traits.

Factor		PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2
E	HA						
Abo Kwela 2019/2020	HA$_0$	30.8 ± 0.4k	1.07 ± 0.03g	4.54 ± 0.52g	10.36 ± 0.58j	2.30 ± 0.13e	91.7 ± 3.7d
	HA$_{30}$	45.2 ± 10.4h	1.39 ± 0.10c	6.15 ± 0.49e	11.91 ± 0.67h	1.94 ± 0.04g	112.6 ± 6.3c
	HA$_{60}$	57.2 ± 17.2c	1.66 ± 0.13b	7.49 ± 1.38a	14.42 ± 2.17f	1.94 ± 0.07g	136.5 ± 15.5b
Abo Kwela 2020/2021	HA$_0$	31.1 ± 1.2k	1.08 ± 0.02g	4.67 ± 0.52g	10.50 ± 0.50j	2.27 ± 0.15e	95.4 ± 6.4d
	HA$_{30}$	44.9 ± 9.1h	1.39 ± 0.11c	6.25 ± 0.65e	12.33 ± 0.50h	1.99 ± 0.13fg	114.3 ± 6.3c
	HA$_{60}$	55.9 ± 15.5d	1.71 ± 0.08a	7.76 ± 1.35a	14.82 ± 2.01e	1.93 ± 0.08g	139.7 ± 11.7b
El-Neguilla 2019/2020	HA$_0$	49.7 ± 2.4e	0.72 ± 0.02k	4.81 ± 0.87f	11.75 ± 2.75h	2.42 ± 0.14d	54.1 ± 6.9g
	HA$_{30}$	59.7 ± 3.8b	0.80 ± 0.05i	6.26 ± 0.72e	16.00 ± 3.00c	2.54 ± 0.18c	63.3 ± 4.3f
	HA$_{60}$	66.8 ± 7.8a	0.80 ± 0.01i	6.89 ± 0.72b	18.18 ± 3.32b	2.62 ± 0.21b	72.0 ± 6.0e
El-Neguilla 2020/2021	HA$_0$	50.0 ± 3.5e	0.67 ± 0.02l	4.81 ± 0.86f	12.25 ± 3.25h	2.41 ± 0.26d	51.8 ± 7.8gf
	HA$_{30}$	59.3 ± 7.8b	0.87 ± 0.04j	6.18 ± 0.88e	15.50 ± 3.50d	2.55 ± 0.15c	49.3 ± 19.8f
	HA$_{60}$	66.00 ± 6.0a	1.12 ± 0.15e	6.88 ± 1.13a	19.25 ± 4.25a	2.77 ± 0.16a	71.5 ± 7.5e
AL-Qasr 2019/2020	HA$_0$	41.75 ± 2.3j	1.12 ± 0.12efi	6.09 ± 0.86e	10.05 ± 0.74j	1.67 ± 0.11i	109.2 ± 16.9c
	HA$_{30}$	44.15 ± 2.4h	1.14 ± 0.00efi	6.23 ± 0.57e	10.69 ± 1.26ij	1.71 ± 0.04hi	138.8 ± 24.8b
	HA$_{60}$	47.0 ± 1.5g	1.18 ± 0.05d	6.45 ± 0.75d	12.02 ± 1.30h	1.86 ± 0.02h	162.5 ± 32.4a
AL-Qasr 2020/2021	HA$_0$	43.0 ± 1.5i	1.03 ± 0.02h	6.12 ± 0.83e	10.91 ± 0.81i	1.81 ± 0.11h	110.5 ± 14.3c
	HA$_{30}$	45.5 ± 1.0h	1.07 ± 0.09g	6.72 ± 0.66c	13.28 ± 1.55g	1.97 ± 0.03fg	138.5 ± 23.5b
	HA$_{60}$	48.4 ± 0.4f	1.09 ± 0.06fg	7.55 ± 0.56a	15.42 ± 2.75d	2.03 ± 0.21fh	163.6 ± 31.4a
E	HA	SY	BY	GY	T-GW (g)	WUE	PUE
			(t ha^{-1})			(kg m^{-3})	
Abo Kwela 2019/2020	HA$_0$	2.90 ± 0.71h	3.89 ± 1.07j	0.99 ± 0.36i	23.4 ± 2.2k	0.31 ± 0.01h	0.80 ± 0.04l
	HA$_{30}$	4.46 ± 0.59d	5.81 ± 1.21f	1.35 ± 0.62f	30.6 ± 6.5h	0.41 ± 0.02e	1.08 ± 0.06i
	HA$_{60}$	4.75 ± 0.34c	6.63 ± 1.44c	1.88 ± 1.10c	39.9 ± 10.9c	0.55 ± 0.03c	1.51 ± 0.07e
Abo Kwela 2020/2021	HA$_0$	3.48 ± 1.26f	4.47 ± 1.62h	0.99 ± 0.36i	24.4 ± 2.9j	0.31 ± 0.09i	0.90 ± 0.01o
	HA$_{30}$	4.69 ± 0.58c	6.04 ± 1.19e	1.35 ± 0.61f	30.9 ± 8.1h	0.42 ± 0.04f	1.23 ± 0.50n
	HA$_{60}$	5.30 ± 0.34a	7.18 ± 1.43b	1.89 ± 1.09c	41.7 ± 10.7b	0.56 ± 0.03d	1.71 ± 0.08m
El-Neguilla 2019/2020	HA$_0$	2.00 ± 0.71i	2.68 ± 0.97k	0.68 ± 0.26l	26.3 ± 0.7i	0.21 ± 0.01j	0.38 ± 0.01m
	HA$_{30}$	2.95 ± 0.88h	3.84 ± 1.21j	0.89 ± 0.33k	31.8 ± 1.5g	0.28 ± 0.14i	0.49 ± 0.03k
	HA$_{60}$	3.80 ± 0.87e	5.10 ± 1.50g	1.30 ± 0.63g	36.5 ± 2.00e	0.39 ± 0.02g	0.72 ± 0.09g
El-Neguilla 2020/2021	HA$_0$	1.99 ± 0.72i	2.67 ± 0.98k	0.69 ± 0.26l	26.5 ± 2.50i	0.22 ± 0.11j	0.53 ± 0.28m
	HA$_{30}$	2.91 ± 0.85h	3.85 ± 1.25j	0.94 ± 0.39j	33.2 ± 2.33f	0.29 ± 0.08i	0.72 ± 0.05j
	HA$_{60}$	3.85 ± 0.91e	5.15 ± 1.54g	1.30 ± 0.63g	37.5 ± 2.0d	0.40 ± 0.01eg	1.00 ± 0.04f
AL-Qasr 2019/2020	HA$_0$	3.09 ± 0.95g	4.23 ± 1.31i	1.14 ± 0.36h	26.4 ± 5.7i	0.36 ± 0.02eg	0.53 ± 0.06fk
	HA$_{30}$	4.66 ± 0.74c	6.19 ± 1.36d	1.53 ± 0.62e	33.8 ± 8.3f	0.47 ± 0.08d	0.71 ± 0.04c
	HA$_{60}$	4.98 ± 0.97b	7.30 ± 1.90b	2.32 ± 0.93a	44.75 ± 12.3a	0.71 ± 0.08a	1.08 ± 0.04a
AL-Qasr 2020/2021	HA$_0$	3.84 ± 1.43e	5.15 ± 1.95g	1.31 ± 0.52f	26.68 ± 5.3i	0.41 ± 0.01e	0.63 ± 0.06h
	HA$_{30}$	4.89 ± 0.55c	6.65 ± 1.45c	1.76 ± 0.90d	34.0 ± 7.5f	0.54 ± 0.01c	0.85 ± 0.15d
	HA$_{60}$	5.29 ± 0.28a	7.56 ± 1.56a	2.27 ± 1.28b	44.5 ± 10.5a	0.68 ± 0.02b	1.10 ± 0.29b

Each value represents means ± standard error. Means sharing different letters in the same column indicate statistically significant ($p \leq 0.05$) differences according to the LSD test. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. HA$_0$, HA$_{30}$, and HA$_{60}$ indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

Regarding the SI × HA interaction (Table 9), all studied wheat traits were increased with 60 kg HA ha^{-1} applied, followed by a decrease with 30 and 0 kg HA ha^{-1} treatments applied under the normal and drought conditions. All studied wheat traits with the three HA treatments were observed to be higher under normal conditions than drought conditions, although 0 kg HA ha^{-1} had a higher value of SD in drought-stress conditions as compared to normal conditions. The SI × HA interaction recorded the highest GY and other studied traits of wheat plants fertilized with 60 kg HA ha^{-1} and the lowest values in wheat plants fertilized with 0 kg HA ha^{-1} of HA under normal and drought-stress conditions, which was opposite to the SD trait. In all the first-order interactions, different tendencies were observed, but based on statistical evaluation, the highest values of GY, WUE, PUE, and other important traits were found in wheat plants fertilized with 60 kg HA ha^{-1} at the Al-Qasr site in both seasons under normal and drought conditions.

Table 9. The first-order interaction of supplemental irrigation (SI) and humic acid (HA) treatment for the studied bread wheat traits.

Factor SI	Factor HA	PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2
Normal	HA_0	42.9 ± 3.9e	0.99 ± 0.09e	5.91 ± 0.34d	12.41 ± 0.84d	2.13 ± 0.18c	94.8 ± 12.0d
	HA_{30}	55.0 ± 3.2b	1.16 ± 0.12c	6.96 ± 0.10b	15.03 ± 1.32b	2.16 ± 0.18b	116.9 ± 17.3b
	HA_{60}	64.9 ± 5.2a	1.26 ± 0.12a	8.15 ± 0.30a	18.32 ± 1.50a	2.26 ± 0.21a	141.7 ± 21.5a
Drought	HA_0	39.2 ± 3.1f	0.91 ± 0.08f	4.43 ± 0.26f	9.53 ± 0.20f	2.16 ± 0.11b	76.1 ± 9.7f
	HA_{30}	44.5 ± 3.7d	1.06 ± 0.08d	5.64 ± 0.10e	11.54 ± 0.48e	2.08 ± 0.11d	88.6 ± 14.6e
	HA_{60}	48.8 ± 3.6c	1.25 ± 0.18b	6.18 ± 0.19c	13.05 ± 0.67c	2.12 ± 0.13c	106.9 ± 13.3c
SI	**HA**	**SY (t ha^{-1})**	**BY (t ha^{-1})**	**GY (t ha^{-1})**	**T-GW (g)**	**WUE (kg m^{-3})**	**PUE (kg m^{-3})**
Normal	HA_0	3.85 ± 0.43d	5.16 ± 0.56c	1.32 ± 0.14c	28.5 ± 1.1d	0.34 ± 0.01f	0.86 ± 0.82c
	HA_{30}	4.79 ± 0.32b	6.67 ± 0.53b	1.88 ± 0.22b	38.1 ± 1.4b	0.49 ± 0.01d	1.22 ± 0.09b
	HA_{60}	5.28 ± 0.21a	8.05 ± 0.47a	2.77 ± 0.28a	48.9 ± 3.2a	0.72 ± 0.02a	1.81 ± 0.15a
Drought	HA_0	1.92 ± 0.21f	2.53 ± 0.27f	0.61 ± 0.07f	22.7 ± 1.0f	0.27 ± 0.05e	0.40 ± 0.03f
	HA_{30}	3.39 ± 0.43e	4.12 ± 0.48e	0.72 ± 0.06e	26.7 ± 1.4e	0.31 ± 0.06c	0.47 ± 0.04e
	HA_{60}	4.04 ± 0.38c	4.92 ± 0.43d	0.88 ± 0.11d	32.8 ± 1.0 c	0.38 ± 0.02b	0.56 ± 0.06d

Each value represents means ± standard error. Means sharing different letters in the same column indicate statistically significant ($p \leq 0.05$) differences according to the LSD test. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

3.4. The Second-Order Interaction Effect on Wheat Traits

Table 10 depicts the effect of the second-order interactions of experimental factors on GY and other investigated wheat traits under normal and drought conditions. The interaction of E × SI × HA revealed significant differences between the single variations in experimental factors on GY and most studied traits under normal and drought conditions. The GY and some studied traits were increased in the studied environments and HA treatments in normal conditions compared to in drought-stress conditions. Compared with other interactions of E × SI × HA, the highest PH, SNS, and SD values under normal and drought conditions, as well as T-GW under drought conditions, were found in wheat plants fertilized with 60 kg HA ha^{-1} at the El-Neguilla site in both seasons. Meanwhile, the highest SL, SN, SY, BY, GY, WUE, and PUE values under normal and drought conditions, as well as T-GW under normal conditions, were observed in wheat plants treated with 60 kg of HA ha^{-1} at the Al-Qasr site in both seasons.

Generally, from the results of the effect of experimental factors and the first- and second-order interactions, the wheat plants fertilized with 60 kg HA ha^{-1} showed increased GY and most measured traits, while this decreased in the plants fertilized with 30 and

0 kg HA ha^{-1}. Furthermore, the highest GY, WUE, PUE, and other studied traits were obtained in wheat plants treated with 60 kg HA ha^{-1} at the Al-Qasr site in both seasons under drought conditions.

Table 10. The second-order interaction of environment, supplemental irrigation (SI), and humic acid (HA) treatment for the studied bread wheat traits.

E	SI	HA	PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2
Abo Kwela 2019/2020	Normal	HA_0	31.2 ± 0.4i	1.10 ± 0.01e	5.06 ± 0.18h	10.94 ± 0.40a	2.17 ± 0.15c	95.4 ± 2.7g
		HA_{30}	55.6 ± 0.3e	1.49 ± 0.02c	6.65 ± 0.19e	12.58 ± 0.01a	1.90 ± 0.06d	118.8 ± 4.2e
		HA_{60}	74.4 ± 3.1a	1.52 ± 0.03c	8.87 ± 0.06a	16.60 ± 0.55a	1.87 ± 0.05de	151.9 ± 11.5c
	Drought	HA_0	30.5 ± 0.3j	1.05 ± 0.01ef	4.03 ± 0.10i	9.78 ± 0.33a	2.44 ± 0.14b	87.9 ± 2.8g
		HA_{30}	34.8 ± 0.01i	1.29 ± 0.06d	5.66 ± 0.03g	11.24 ± 0.14a	1.99 ± 0.04d	106.3 ± 5.0fg
		HA_{60}	40.0 ± 0.04h	1.79 ± 0.02a	6.11 ± 0.12f	12.25 ± 0.20a	2.01 ± 0.01d	121.0 ± 0.4e
Abo Kwela 2020/2021	Normal	HA_0	32.3 ± 0.4i	1.10 ± 0.00ef	5.18 ± 0.10h	11.00 ± 0.00a	2.13 ± 0.04c	101.8 ± 1.0fg
		HA_{30}	54.0 ± 1.2e	1.50 ± 0.01c	6.90 ± 0.06de	12.83 ± 0.04a	1.86 ± 0.02d	120.5 ± 3.2e
		HA_{60}	71.4 ± 3.8b	1.62 ± 0.01b	9.11 ± 0.12a	16.83 ± 0.48a	1.85 ± 0.03d	151.3 ± 9.5c
	Drought	HA_0	29.9 ± 0.6i	1.07 ± 0.00ef	4.15 ± 0.09i	10.00 ± 0.58a	2.42 ± 0.19b	89.0 ± 0.6g
		HA_{30}	35.8 ± 0.1i	1.28 ± 0.05d	5.60 ± 0.06g	11.83 ± 0.10a	2.11 ± 0.00c	108.0 ± 4.6f
		HA_{60}	40.4 ± 0.2h	1.79 ± 0.01a	6.40 ± 0.23e	12.82 ± 0.10a	2.01 ± 0.06d	128.0 ± 1.2e
El-Neguilla 2019/2020	Normal	HA_0	52.0 ± 1.2e	0.74 ± 0.01k	5.68 ± 0.01g	14.50 ± 0.29a	2.55 ± 0.04b	61.0 ± 0.6i
		HA_{30}	63.5 ± 2.0c	0.75 ± 0.00k	6.99 ± 0.00d	19.00 ± 0.00a	2.72 ± 0.00a	67.5 ± 0.3i
		HA_{60}	74.5 ± 2.6a	0.79 ± 0.00jk	7.62 ± 0.29c	21.50 ± 0.87a	2.82 ± 0.01a	78.0 ± 0.6h
	Drought	HA_0	47.3 ± 0.2f	0.70 ± 0.00k	3.94 ± 0.04i	9.00 ± 0.58a	2.28 ± 0.12c	47.2 ± 0.5j
		HA_{30}	55.9 ± 0.3e	0.85 ± 0.01ij	5.54 ± 0.06g	13.00 ± 0.58a	2.35 ± 0.13b	59.0 ± 0.6i
		HA_{60}	59.0 ± 0.6d	0.81 ± 0.03ij	6.17 ± 0.04f	14.87 ± 1.08a	2.41 ± 0.16b	66.0 ± 1.7i
El-Neguilla 2020/2021	Normal	HA_0	53.5 ± 0.9e	0.69 ± 0.03k	5.68 ± 0.01g	15.50 ± 0.29a	2.67 ± 0.01a	59.5 ± 1.4i
		HA_{30}	64.0 ± 0.6c	0.92 ± 0.09h	7.05 ± 0.03d	19.00 ± 0.00a	2.70 ± 0.01a	69.0 ± 0.6i
		HA_{60}	72.0 ± 2.3b	1.27 ± 0.02d	8.00 ± 0.23b	23.50 ± 0.87a	2.94 ± 0.02	79.0 ± 0.6h
	Drought	HA_0	46.5 ± 0.3f	0.66 ± 0.01k	3.95 ± 0.03i	9.00 ± 0.58a	2.15 ± 0.05c	44.0 ± 0.6j
		HA_{30}	54.5 ± 0.9e	0.83 ± 0.02ij	5.30 ± 0.29h	12.00 ± 0.58a	2.40 ± 0.06b	29.5 ± 16.5k
		HA_{60}	60.0 ± 0.01d	0.97 ± 0.01h	5.75 ± 0.03g	15.00 ± 0.58a	2.61 ± 0.09a	64.0 ± 1.7i
AL-Qasr 2019/2020	Normal	HA_0	44.0 ± 0.6g	1.24 ± 0.09d	6.95 ± 0.39d	10.78 ± 0.10a	1.56 ± 0.07g	126.1 ± 7.8e
		HA_{30}	46.6 ± 0.6f	1.14 ± 0.02e	6.80 ± 0.03de	11.95 ± 0.53a	1.76 ± 0.09e	163.6 ± 4.0b
		HA_{60}	48.5 ± 0.3f	1.23 ± 0.01d	7.20 ± 0.26d	13.33 ± 0.96a	1.85 ± 0.07de	194.8 ± 2.8a
	Drought	HA_0	39.5 ± 0.3h	1.00 ± 0.03gh	5.23 ± 0.04h	9.31 ± 0.33a	1.78 ± 0.08de	92.3 ± 1.3g
		HA_{30}	41.8 ± 0.2h	1.14 ± 0.03e	5.66 ± 0.03g	9.44 ± 0.14a	1.67 ± 0.03g	114.0 ± 2.9ef
		HA_{60}	45.5 ± 1.4f	1.13 ± 0.06e	5.70 ± 0.02ig	10.72 ± 0.03a	1.88 ± 0.00d	130.1 ± 5.4d
AL-Qasr 2020/2021	Normal	HA_0	44.5 ± 0.9g	1.06 ± 0.06efg	6.95 ± 0.39d	11.73 ± 0.16a	1.70 ± 0.07ef	124.8 ± 8.6de
		HA_{30}	46.6 ± 0.6f	1.16 ± 0.00e	7.38 ± 0.22c	14.83 ± 0.68a	2.01 ± 0.03d	162.0 ± 1.7b
		HA_{60}	48.7 ± 0.2f	1.15 ± 0.02ef	8.11 ± 0.13b	18.17 ± 0.48a	2.24 ± 0.02c	195.0 ± 2.9a
	Drought	HA_0	41.5 ± 0.9h	1.01 ± 0.01fg	5.28 ± 0.03h	10.10 ± 0.06a	1.91 ± 0.00d	96.3 ± 1.0g
		HA_{30}	44.5 ± 1.4g	0.98 ± 0.02fh	6.06 ± 0.03f	11.74 ± 0.04a	1.94 ± 0.00d	115.0 ± 2.9e
		HA_{60}	48.0 ± 1.2f	1.03 ± 0.01fgh	6.99 ± 0.00d	12.67 ± 0.19a	1.81 ± 0.03def	132.3 ± 4.2d

E	SI	HA	SY (t ha^{-1})	BY (t ha^{-1})	GY (t ha^{-1})	T-GW (g)	WUE (kg m^{-3})	PUE (kg m^{-3})
Abo Kwela 2019/2020	Normal	HA_0	3.61 ± 0.29h	4.96 ± 0.30j	1.35 ± 0.01i	25.6 ± 1.2m	0.35 ± 0.01l	1.09 ± 0.15l
		HA_{30}	5.06 ± 0.04c	7.02 ± 0.03e	1.96 ± 0.02f	37.1 ± 2.1g	0.50 ± 0.01j	1.58 ± 0.28i
		HA_{60}	5.10 ± 0.30c	8.08 ± 0.32c	2.98 ± 0.02c	50.9 ± 0.6d	0.76 ± 0.02d	2.40 ± 0.46d
	Drought	HA_0	2.18 ± 0.04k	2.82 ± 0.01m	0.64 ± 0.03m	21.3 ± 0.1o	0.27 ± 0.06j	0.52 ± 0.52q
		HA_{30}	3.87 ± 0.18hi	4.60 ± 0.17j	0.73 ± 0.01l	24.1 ± 0.4n	0.31 ± 0.02j	0.59 ± 0.20pq
		HA_{60}	4.41 ± 0.16f	5.19 ± 0.16i	0.78 ± 0.00l	29.0 ± 0.01j	0.33 ± 0.00i	0.63 ± 0.00op

Table 10. *Cont.*

E	SI	HA	SY	BY	GY	T-GW (g)	WUE	PUE
			(t ha^{-1})				(kg m^{-3})	
Abo Kwela 2020/2021	Normal	HA_0	4.73 ± 0.29e	6.08 ± 0.29g	1.35 ± 0.00i	27.4 ± 0.8l	0.35 ± 0.00l	1.23 ± 0.00q
		HA_{30}	5.26 ± 0.01cd	7.23 ± 0.00e	1.97 ± 0.01f	39.0 ± 2.3f	0.52 ± 0.01j	1.79 ± 0.08o
		HA_{60}	5.64 ± 0.15b	8.62 ± 0.18b	2.98 ± 0.03c	52.4 ± 0.9c	0.78 ± 0.03e	2.71 ± 0.27lm
	Drought	HA_0	2.22 ± 0.17k	2.85 ± 0.14m	0.63 ± 0.02m	21.5 ± 0.9o	0.27 ± 0.04k	0.57 ± 0.19r
		HA_{30}	4.11 ± 0.15hi	4.85 ± 0.14j	0.74 ± 0.01l	22.8 ± 0.4no	0.32 ± 0.02j	0.67 ± 0.07r
		HA_{60}	4.96 ± 0.02ce	5.75 ± 0.03h	0.79 ± 0.01l	31.1 ± 0.6i	0.34 ± 0.02j	0.72 ± 0.09r
El-Neguilla 2019/2020	Normal	HA_0	2.71 ± 0.03j	3.65 ± 0.00k	0.94 ± 0.03k	27.0 ± 0.01l	0.24 ± 0.02n	0.52 ± 0.67m
		HA_{30}	3.83 ± 0.10h	5.05 ± 0.04ij	1.22 ± 0.06j	33.3 ± 0.8i	0.31 ± 0.05m	0.67 ± 1.34k
		HA_{60}	4.67 ± 0.13ef	6.60 ± 0.16f	1.93 ± 0.03f	38.5 ± 0.3f	0.49 ± 0.03j	1.06 ± 0.74f
	Drought	HA_0	1.29 ± 0.03l	1.71 ± 0.03n	0.43 ± 0.00o	25.7 ± 0.4m	0.18 ± 0.01m	0.24 ± 0.07q
		HA_{30}	2.08 ± 0.08k	2.63 ± 0.08m	0.56 ± 0.01n	30.4 ± 1.0ij	0.24 ± 0.02k	0.31 ± 0.20pq
		HA_{60}	2.93 ± 0.08j	3.60 ± 0.10k	0.67 ± 0.01lm	34.5 ± 0.3i	0.29 ± 0.03j	0.37 ± 0.27opq
El-Neguilla 2020/2021	Normal	HA_0	2.71 ± 0.00j	3.65 ± 0.03k	0.95 ± 0.03k	27.0 ± 0.01l	0.25 ± 0.02n	0.73 ± 0.63m
		HA_{30}	3.76 ± 0.08h	5.09 ± 0.06ij	1.33 ± 0.02i	35.5 ± 0.3h	0.35 ± 0.01lm	1.02 ± 0.42j
		HA_{60}	4.77 ± 0.15e	6.69 ± 0.17f	1.93 ± 0.01f	39.5 ± 0.3f	0.51 ± 0.02j	1.48 ± 0.35e
	Drought	HA_0	1.27 ± 0.04l	1.70 ± 0.04n	0.43 ± 0.01o	26.0 ± 0.6lm	0.19 ± 0.01m	0.33 ± 0.14q
		HA_{30}	2.06 ± 0.07k	2.60 ± 0.06m	0.55 ± 0.01n	30.9 ± 0.2i	0.24 ± 0.03k	0.42 ± 0.35opq
		HA_{60}	2.94 ± 0.09j	3.62 ± 0.11k	0.68 ± 0.01lm	35.5 ± 0.3h	0.30 ± 0.03j	0.52 ± 0.35o
AL-Qasr 2019/2020	Normal	HA_0	4.04 ± 0.54g	5.54 ± 0.54h	1.50 ± 0.00h	32.00 ± 0.01ik	0.38 ± 0.00k	0.70 ± 0.00g
		HA_{30}	5.40 ± 0.06bd	7.55 ± 0.03d	2.15 ± 0.03e	42.00 ± 1.7e	0.55 ± 0.02h	1.00 ± 0.82c
		HA_{60}	5.95 ± 0.24a	9.20 ± 0.39a	3.25 ± 0.14b	57.00 ± 0.6a	0.83 ± 0.12c	1.51 ± 4.12a
	Drought	HA_0	2.15 ± 0.03k	2.92 ± 0.05m	0.78 ± 0.01l	20.7 ± 0.01o	0.33 ± 0.03h	0.36 ± 0.41m
		HA_{30}	3.91 ± 0.09g	4.83 ± 0.07j	0.92 ± 0.01k	25.5 ± 0.3m	0.39 ± 0.03f	0.43 ± 0.41l
		HA_{60}	4.01 ± 0.24g	5.40 ± 0.23i	1.39 ± 0.01i	32.5 ± 0.3i	0.59 ± 0.02a	0.65 ± 0.25h
AL-Qasr 2020/2021	Normal	HA_0	5.27 ± 0.08cd	7.10 ± 0.12e	1.83 ± 0.04g	32.0 ± 0.6ik	0.48 ± 0.03j	0.88 ± 0.86hi
		HA_{30}	5.44 ± 0.00bd	8.10 ± 0.06c	2.66 ± 0.06d	41.5 ± 1.4e	0.70 ± 0.05f	1.29 ± 1.23d
		HA_{60}	5.57 ± 0.07b	9.12 ± 0.13a	3.56 ± 0.19a	55.0 ± 0.6b	0.93 ± 0.16b	1.72 ± 4.12b
	Drought	HA_0	2.41 ± 0.28k	3.20 ± 0.23l	0.79 ± 0.05l	21.4 ± 0.4o	0.34 ± 0.12h	0.38 ± 1.11no
		HA_{30}	4.34 ± 0.25f	5.20 ± 0.17ij	0.86 ± 0.08k	26.5 ± 0.3lm	0.38 ± 0.18g	0.42 ± 1.72n
		HA_{60}	5.01 ± 0.06de	6.00 ± 0.00gh	0.99 ± 0.06k	34.0 ± 0.6i	0.43 ± 0.14ef	0.48 ± 1.35m

Each value represents means ± standard error. Means sharing different letters in the same column indicate statistically significant ($p \leq 0.05$) differences according to the LSD test. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

3.5. Stress Tolerance Index (STI)

The STI of wheat plants fertilized with HA under different environmental conditions is presented in Table 11. The wheat plants fertilized with 60 kg HA ha^{-1} for all studied traits had the highest STI values at the three sites in both seasons, except the Abo Kwela site in the 2020/2021 season for the SD trait. Compared with that of the Abo Kwela and El-Neguilla sites, the STI increased for GY and most traits at the Al-Qasr site in both seasons. For GY and most traits, the wheat plants treated with 60 kg HA ha^{-1} at the Al-Qasr site in both seasons recorded the highest STI.

3.6. Pearson's Correlation Coefficient

Pearson's correlation coefficient was employed to understand the relationships between the studied wheat traits across normal and drought-stress conditions (Figure 3). The statistical evaluation showed 25 and 31 positive and significant ($p \leq 0.05$ or 0.01) correlation coefficients among the traits under the normal and drought-stress conditions, respectively. Meanwhile, the other correlation coefficients were positive and non-significant as well as negative and non-significant or significant under the two conditions.

Table 11. Stress tolerance index for the studied bread wheat traits as affected by the environment (E) and humic acid (HA) treatment.

Factor E	Factor HA	PH (cm)	TI (%)	SL (cm)	SNS	SD	NSm^2	SY ($t\ ha^{-1}$)	BY ($t\ ha^{-1}$)	GY ($t\ ha^{-1}$)	T-GW (g)	WUE ($kg\ m^{-3}$)	PUE ($kg\ m^{-3}$)
Abo Kwela 2019/2020	HA_0	0.32	0.89	0.41	0.46	1.11	0.60	0.37	0.32	0.22	0.37	0.61	0.85
	HA_{30}	0.66	1.49	0.77	0.61	0.79	0.91	0.91	0.74	0.36	0.60	1.01	1.02
	HA_{60}	1.01	2.10	1.10	0.87	0.79	1.33	1.04	0.95	0.59	1.00	1.64	1.19
Abo Kwela 2020/2021	HA_0	0.33	0.91	0.44	0.47	1.08	0.65	0.49	0.39	0.21	0.40	0.49	0.86
	HA_{30}	0.66	1.48	0.79	0.65	0.82	0.94	1.00	0.80	0.37	0.60	0.83	1.01
	HA_{60}	0.98	2.24	1.19	0.93	0.78	1.40	1.30	1.13	0.59	1.10	1.36	1.19
El-Neguilla 2019/2020	HA_0	0.83	0.40	0.46	0.56	1.22	0.21	0.16	0.14	0.10	0.47	0.29	0.89
	HA_{30}	1.20	0.49	0.79	1.06	1.34	0.29	0.37	0.30	0.17	0.68	0.49	0.88
	HA_{60}	1.49	0.49	0.96	1.37	1.43	0.37	0.64	0.54	0.33	0.90	0.93	1.05
El-Neguilla 2020/2021	HA_0	0.84	0.35	0.46	0.60	1.20	0.19	0.16	0.14	0.10	0.47	0.30	0.88
	HA_{30}	1.18	0.59	0.76	0.98	1.36	0.15	0.36	0.30	0.18	0.74	0.53	0.95
	HA_{60}	1.47	0.95	0.94	1.51	1.61	0.36	0.65	0.55	0.33	0.95	0.95	1.05
Al-Qasr 2019/2020	HA_0	0.59	0.96	0.74	0.43	0.58	0.84	0.40	0.37	0.30	0.45	0.86	0.78
	HA_{30}	0.66	1.00	0.78	0.48	0.62	1.34	0.98	0.83	0.50	0.72	1.46	0.93
	HA_{60}	0.75	1.07	0.84	0.61	0.73	1.83	1.11	1.13	1.14	1.25	2.34	0.93
Al-Qasr 2020/2021	HA_0	0.63	0.83	0.75	0.51	0.68	0.87	0.59	0.52	0.36	0.46	1.04	0.92
	HA_{30}	0.70	0.88	0.91	0.75	0.82	1.34	1.10	0.96	0.58	0.74	1.63	1.09
	HA_{60}	0.79	0.92	1.15	0.99	0.85	1.86	1.30	1.25	0.89	1.26	2.52	1.17

PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

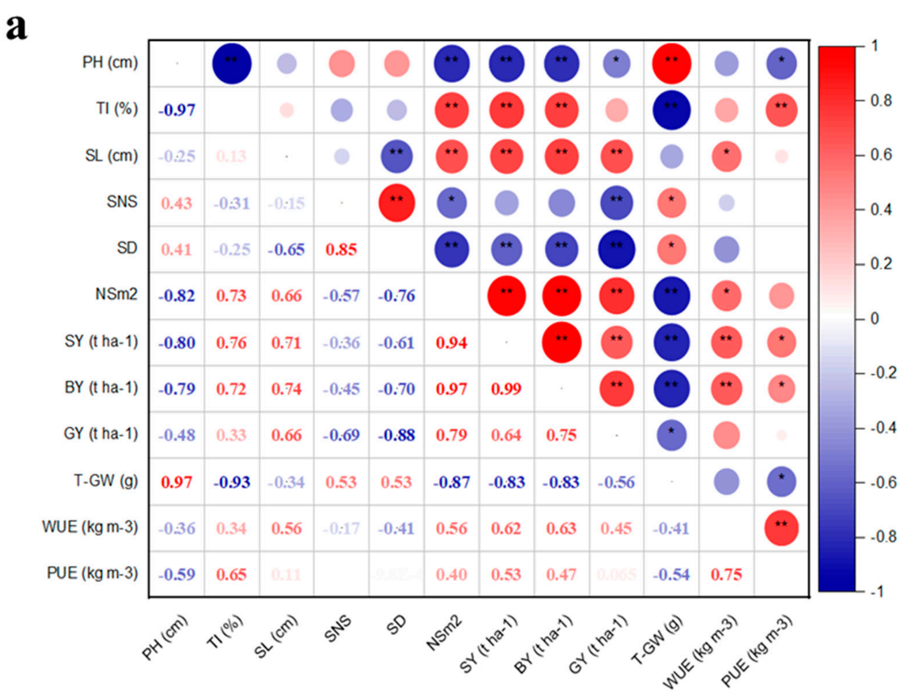

Figure 3. *Cont.*

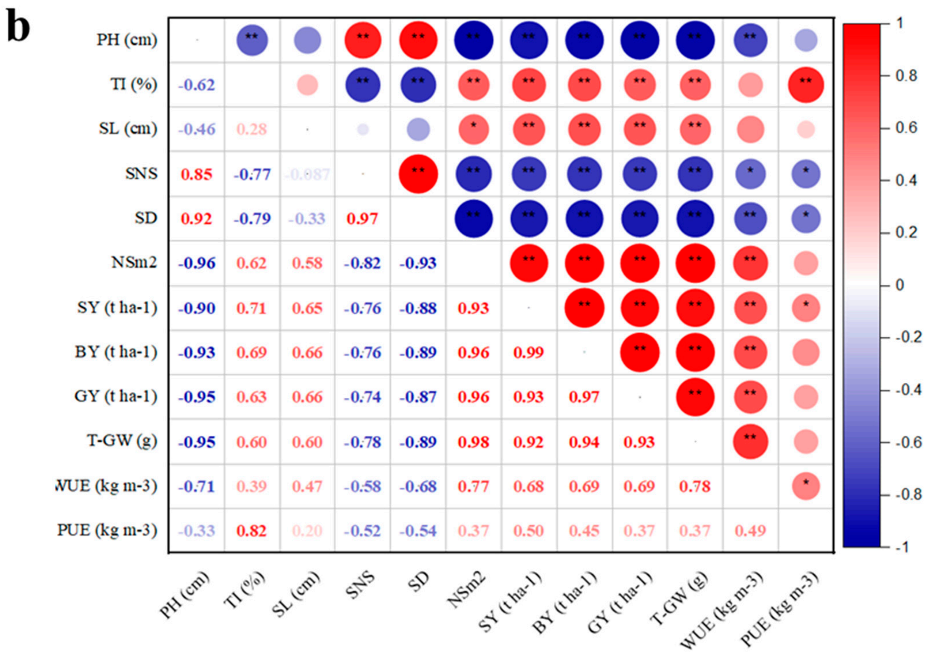

Figure 3. Plot describing Pearson's correlation between studied traits in the normal (**a**,**b**) drought-stress conditions. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency. The large and medium blue (positive) and red (negative) circles indicate a significant (* $p \leq 0.05$) or highly significant (** $p \leq 0.01$) correlation, while the small blue (positive) and red (negative) circles indicate a non-significant correlation.

Under the normal conditions (Figure 3a), SL, SN, SY, BY, GY, and WUE, as well as SNS, SD, and T-GW, had positive and significant correlations ($p \leq 0.05$ or 0.01) across all factors studied. PH was significantly positively correlated with T-GW ($p \leq 0.01$). TI showed significant positive correlations ($p \leq 0.01$) with NS, SY, BY, and PUE. In this respect, PUW showed significant positive correlations ($p \leq 0.01$) with SY and BY ($p \leq 0.05$) and WUE ($p \leq 0.01$).

Regarding drought-stress conditions (Figure 3b), a high, significant, positive correlation ($p \leq 0.01$) was observed among all possible pairs for NS, SY, BY, GY, T-GW, and WUE, as well as for PH, SNS, and SD. TI and SL showed high, significant, positive correlations ($p \leq 0.01$) with NS, SY, BY, GY, and T-GW. PUE was significantly positively correlated with TI ($p \leq 0.01$), SY, and WUE ($p \leq 0.05$). Generally, the highest positive correlation was observed among the traits of SN, SY, BY, GY, and WUE under normal and drought conditions.

3.7. Principal Component Analysis (PCA)

The seven PCs for all bread wheat traits based on E, SI, and HA treatments are shown in Table 12. Out of all PCs, the two first main PCs (PC1 and PC2) extracted had eigenvalues larger than one (Eigenvalue > 1) with values of 7.57 and 3.39, respectively. Meanwhile, the rest of the other PCs had eigenvalues less than one (Eigenvalue < 1). Therefore, PC1 and PC2 were retained for the final analysis, in which these two PCs explain more variance than an individual attribute [42] and express more variability and support to select the trait with a positive loading factor. The first two PCs contributed 91.35% of the total variation existing among studied traits regarding E, SI, and HA variables. The contributions of PC1 to the total variance were higher than that of PC2 (28.27%), with PC1 describing approximately only 63.07% of the measured data total variability. The results of PC1 and PC2 may be used to summarize the original variables in any further analysis of the data, as well as to explain the total variance and the collection of the PCs.

Table 12. Results of principal component analysis (PCA) in the first seven principal components (PCs) for the studied bread wheat traits as affected by the three experimental factors (i.e., environment, supplemental irrigation, and humic acid).

Trait	PC1	PC2	PC3	PC4	PC5	PC6	PC7
PH (cm)	−0.01	0.53	−0.05	0.34	−0.23	−0.42	0.32
TI (%)	0.25	−0.22	0.63	0.56	−0.04	0.14	0.29
SL (cm)	0.32	0.25	−0.13	0.08	0.34	−0.01	0.25
SNS	0.05	0.53	0.08	−0.04	0.29	0.31	0.05
SD	−0.21	0.42	0.28	−0.16	0.16	0.39	−0.06
NSm^2	0.32	−0.23	−0.19	0.10	0.08	0.29	0.17
SY (t ha^{-1})	0.36	−0.03	0.03	0.00	0.52	−0.36	−0.28
BY (t ha^{-1})	0.36	0.00	−0.04	−0.16	0.20	−0.24	0.02
GY (t ha^{-1})	0.35	0.06	−0.14	−0.45	−0.38	0.02	0.49
T-GW (g)	0.30	0.28	−0.16	0.32	−0.43	−0.02	−0.56
WUE (kg m^{-3})	0.35	−0.01	−0.23	0.07	−0.11	0.52	−0.17
PUE (kg m^{-3})	0.30	0.07	0.60	−0.43	−0.24	−0.12	−0.23
Eigenvalues	7.57	3.39	0.78	0.15	0.07	0.03	0.01
Variance (%)	63.07	28.27	6.50	1.26	0.61	0.22	0.05
Cumulative (%)	63.07	91.35	97.85	99.11	99.72	99.93	99.99

PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: Number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency.

Based on the data of E, SI, and HA variables (Table 12), PC1 had a high positive correlation with all studied traits, except PH and SD traits, while it was related to wheat GY, WUE, and PUE under both conditions in the present study. These variables of the wheat GY and its components contributed to PC1. PC2 identified all studied traits possessing positive loading factors and contributes to the variables except TI, SN, SY, and WUE traits, while the most variables studied had the highest positive loadings on PC3 and other PCs under experimental factors. Based on the studied traits (Table 13), the Al-Qasr and Abo Kwela sites in both years with 60 kg HA ha^{-1} influenced PC1, while PC2 was affected by the El-Neguilla site and 60 kg HA ha^{-1} in both seasons under normal conditions. During normal irrigation conditions, PC1 included 30 and 60 kg HA ha^{-1} applications in the Al-Qasr and Abo Kwela sites in both seasons, while PC2 consisted of 60 kg HA ha^{-1} application at the El-Neguilla site in both seasons.

Based on all measured data, PC1 and PC2 mainly distributed and distinguished the experimental factors and studied traits in different groups. Therefore, the first two PCs were employed to draw a biplot (Figure 4). The data of variables studied displayed a positive correlation between most studied traits, but they differed in their degree and consistency in quantity. The biplot diagram depicted the contribution of E, SI, and HA in creating variability of all traits measured.

In PC1 (Figure 4), GY and other investigated traits, excluding PH, SNS, and SD, were highly and positively associated with the Al-Qasr and Abo Kwela sites in both seasons, with 30 and 60 kg HA ha^{-1} under normal irrigation conditions, which was located in the first and fourth quarters. Regarding PC2, PH, SD, and SNS traits had a positive correlation with the El-Neguilla site in both seasons with 0 kg HA ha^{-1} under drought-stress conditions, which occupied the second and third quadrants. The 60 kg HA ha^{-1} treatment at the Al-Qasr site in the 2020/21 season was located near GY and its components traits, as well as WUE and PUE parameters under the normal and drought-stress conditions. Regarding the relationships between all studied traits by PCA, WUE and PUE are strongly correlated with GY and its component traits under normal and drought-stress conditions. The PCA scree plot for E, SI, and HA on GY and other traits evaluated showed that the PC1 and PC2 eigenvalues correspond to the whole percentage of the variance in the dataset (Figure 5).

Table 13. Results of principal components (PCs) for the studied bread wheat traits as affected by the environment (E) and humic acid (HA) treatments under supplemental irrigation (SI) mode (i.e., normal and drought) conditions.

Factors	PC1	PC2	PC3	PC4	PC5	PC6	PC7
E							
Abo Kwela 2019/2020	0.76	−1.35	1.25	0.08	−0.11	0.08	0.17
Abo Kwela 2020/2021	1.53	−1.17	1.54	−0.09	0.19	−0.10	−0.13
El-Neguilla 2019/2020	−3.45	2.45	−0.57	0.01	0.09	−0.10	0.07
El-Neguilla 2020/2021	−3.07	2.62	0.34	0.00	−0.15	0.05	−0.08
Al-Qasr 2019/2020	1.73	−1.98	−1.31	0.27	−0.46	−0.17	−0.03
Al-Qasr 2020/2021	2.47	−0.55	−1.30	−0.32	0.46	0.19	0.00
SI							
Normal	3.11	1.69	0.11	−0.55	−0.17	−0.07	0.02
Drought	−3.06	−1.71	−0.09	0.59	0.16	0.11	−0.02
HA							
HA_0	−3.43	−1.96	−0.06	−0.63	−0.21	0.12	−0.01
HA_{30}	0.02	−0.04	−0.03	0.13	0.33	−0.31	0.04
HA_{60}	3.41	2.01	0.12	0.51	−0.13	0.20	−0.02

HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively.

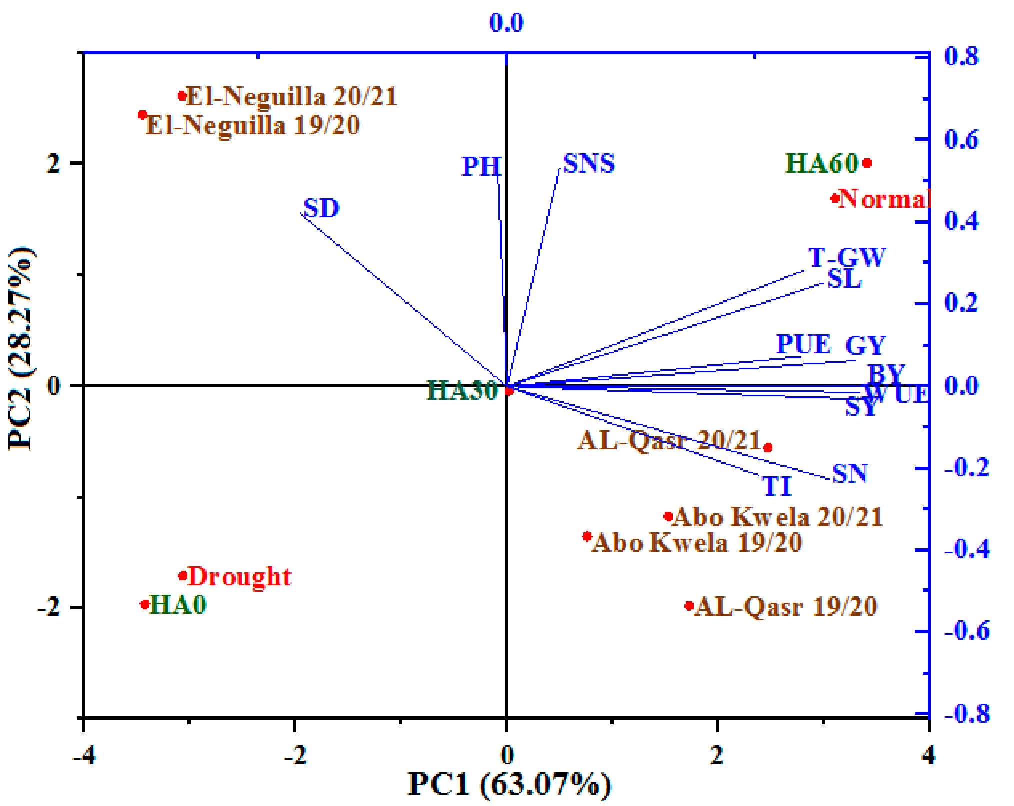

Figure 4. Biplot diagram of PC1 and PC2 shows similarities and dissimilarities in relationships between the studied traits for the studied factors under normal and drought conditions. HA_0, HA_{30}, and HA_{60} indicate the addition of 0, 30, and 60 kg ha^{-1} humic acid, respectively. PH: Plant height, TI: Tillering index, SL: Spike length, SNS: Spikelet number per spike, SD: Spikelet density, NSm^2: number of spike per m^2, SY: Straw yield, BY: Biological yield, GY: Grain yield, T-GW: Thousand-grain weight, WUE: Water use efficiency, and PUE: Precipitation use efficiency.

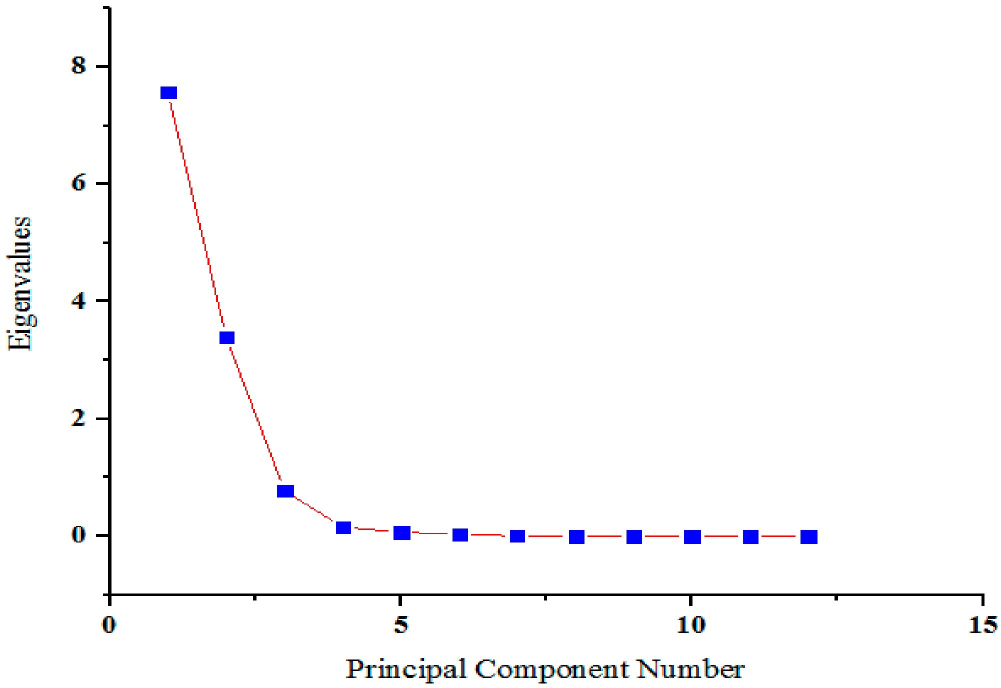

Figure 5. Scree plot of PCA between respective eigenvalues % and component number.

4. Discussion

The current study evaluated GY and other quantitative traits of the cultivar Sakha 94 fertilized with HA in different environments (three sites over two years) under normal and drought-stress conditions. Statistically, GY and most traits were significantly affected by E, SI, and HA, as well as first- and second-order interactions. These results indicated the existence of variability between our experimental factors for drought tolerance; thus, improvement can be achieved for wheat GY in Egypt. Some previous studies reported conclusions similar to our results; for example, [43–46] mentioned that HA and years had highly significant effects on all production components in wheat. Pačuta et al. [46] confirmed significant differences in the first- and second-order interactions for GY in wheat. The differences between years were oftentimes weather-related [43]. Thus, we can assume that weather conditions, HA, and SI were the causes of significant differences for all studied traits of bread wheat. Cultivar-specific differences can play an important role in helping wheat breeders to develop more climate-change-resistant wheat [47].

Based on C.V. % values, the environmental influence was low (<10%) for all studied traits, so this trial would be considered to have high precision. The SN, SY, and PUE traits showed that the C.V. % values (10 > C.V. % > 7%) were greater than that of the other traits measured. Thus, the environmental influence was high for these traits in the normal and drought-stress conditions when compared to the other traits. This would suggest the existence of substantial differences among experimental factors for the studied traits in their drought response. The magnitude of C.V. % indicated that the wheat plants fertilized with HA had exploitable variability during the selection of GY and other traits under the various environments. These findings were consistent with [48] and different from [49–51] in wheat. The values of C.V. % confirmed the existence of high diversity and it is a useful resource in providing the fundamentals for future breeding under stress conditions [51,52].

Mean values indicated that the interactions among experimental factors revealed that there was different behavior for studied traits in normal and drought-stress conditions. Thus, it is possible to use these data in the future to increase wheat GY in Egypt. Generally, the drought-stress conditions during critical stages of growth reduced all studied traits compared to normal conditions, with decreased values ranging from 1% for SD to 46% for GY. Our results are also in agreement with [47,48,50,53–55]. The decrease in GY and its related traits under drought-stress conditions is a popular phenomenon and can be controlled by many complex morphological, physiological, and molecular factors during plant growth stages [56]. The largest impact of drought on the grain yield of wheat may be partially due to the accumulative effects that it exerts on grain yield-related characteristics [57], pre-anthesis, post-anthesis, anthesis, and booting stages [58], and the grain-filling duration [48].

Our study revealed that GY and most studied traits were significantly higher at the Al-Qasr site in both seasons than those at the Abo Kwela and El-Neguilla sites under normal and drought-stress conditions, regardless of HA rates. Wheat productivity and other traits increased at the Al-Qasr site due to the high seasonal rainfall rates during the studied seasons, and the extent of the increase was 10% and 20% in the 2019/2020 season, as well as 50% and 45% in the 2020/2021 season, compared to the El-Neguilla and Abo Kwela sites, respectively. Applying 60 kg HA ha^{-1} led to a significant increase in wheat GY and its traits compared to 0 and 30 kg HA ha^{-1} under the two conditions, regardless of the other factors studied. We also found that all studied traits of normal conditions were higher than that of drought-stress conditions, regardless of the other two factors studied. In the study by [45], the growing season affected the GY and T-GW of durum wheat differently; also, the behavior of the genotypes changed in relation to growing years. Wheat production varies greatly from year to year. Lower GY may be due to rainfall variability in the wheat-growing season [46]. As reported in [59], wheat plants respond to drought stress through changes in various metabolic and physiological processes. The significant increase in GY and other traits due to HA application compared to the control treatment was also reported previously by [27,46,60,61].

Regarding the first-order interactions, the highest GY and most traits were found in the interaction of E $\times$ SI (Al-Qasr in both seasons $\times$ normal conditions), the interaction of E $\times$ HA (Al-Qasr in both seasons $\times$ 60 kg HA ha^{-1}), and the interaction of SI $\times$ HA (normal conditions $\times$ 60 kg HA ha^{-1}). As for the second-order interaction, the highest GY and most studied traits were found for the interaction of Al-Qasr $\times$ normal conditions $\times$ 60 kg HA ha^{-1} in both seasons under the two conditions. These results may be due to enabling the plants to adapt to drought conditions. The GY and other studied traits have been observed to increase via the combination of factors in an experiment that evaluated and recorded the highest values of every single factor, as already reported by [45,46].

STI is used for the identification of high-tolerance genotypes based on the ratio of means under normal and drought-stress conditions [41]. Compared with all experimental factors in our study, the wheat plants fertilized with 60 kg HA ha^{-1} at the Al-Qasr site in both seasons recorded the highest STI for GY and most studied traits under normal and drought-stress conditions. The application of 60 kg HA ha^{-1} differed from other HA rates by showing higher performance under drought conditions, hence having higher STI values. Thus, wheat plants under the 60 kg HA ha^{-1} application had the lowest susceptibility to drought stress. STI was most useful to identify genotypes differing in their response to drought in wheat [50] and barley [62].

The reciprocal correlations among most studied traits were positive and insignificant or significant ($p \leq 0.05$ or 0.01) under normal and drought-stress conditions. Generally, the GY was positively and significantly correlated with the most studied traits under both conditions. Positive correlations for studied traits indicated that selection for the increased value of one trait will result in an increase in the value of the other [63], where the contrasting GY change is a consequence of the changes in yield components [64]. Statistically, a significant correlation was noted for GY and other traits under drought-stress conditions by [49,65]. Significant correlations between most of the traits were found under rainfed and water-stress conditions in different years, which also explained why an increase in these traits would further enhance GY under both conditions [50].

Principal component analysis (PC) has been used to estimate the similarities and dissimilarities in the relationships between the studied traits across environments, supplemental irrigation, and HA variables. Similarly, Koua et al. [51] reported that the first two PCs explain the total variance under drought-stress conditions better than in rainfed conditions. In agreement with [66], PC1 and PC2 explain more than 90% of the total variance of all variables studied in both conditions. Meanwhile, both PCs explained lower values in our results than those in [44,49,50,67,68]. PC1 explained approximately <63% of the measured data total variability in the original variables under normal and drought-stress conditions in our study, similar to other studies [66–68]. It is evident that PC1 and PC2 can be interpreted as a response related to WUE and PUE, as well as GY and its components traits, which possess positive and negative contributions to the experimental factors. PC1 is considered very important to increase wheat GY under drought-stress conditions. Likewise, PC1 characterized GY and other agronomic traits under drought stress in winter wheat in both seasons [50], while PC2 seems to represent humic substances [67]. The biplot showed the degree of correlation amongst most studied wheat traits under E, SI, and HA variables. In other studies, the statistical analysis of PCA exhibited a strong correlation among the studied traits of wheat in both seasons under drought stress [49,50]. PC1 obtained higher loading values for all traits measured, except PH, SNS, and SD, and it also included wheat plants under the 60 kg HA ha^{-1} application at the Al-Qasr site in both seasons under normal irrigation conditions. The results of the scree plot were harmonic with [69] who reported that there is a break in the plot that separates the meaningful components from the trivial components. Thus, most researchers would agree that PC1 and PC2 are likely meaningful.

The biplot analysis of the relationship between the variables studied revealed that wheat plants under 60 kg HA ha^{-1} treatment at the Al-Qasr site in both seasons gave the highest wheat GY under normal and drought-stress conditions. In line with this study, Hegab et al. [70] have already stated that wheat GY and its components increased with an increasing the application of HA rates. It is worth noting that HA application in wheat promoted plant growth, yields (grain, straw, and biological), nutrient uptake in the soil, and resistance to biotic and abiotic stress. Furthermore, previous authors [59,71–73] mentioned that HA increased the levels of 40 compounds that are associated with the stress response. HA molecules promote the osmotic adjustment ability, increase leaf water retention, as well the photosynthetic and antioxidant metabolism of plants under drought stress [74,75]. The integration of HA application and a water deficit makes it possible to assess the precision and efficiency of the system in researching the effect of HA on drought tolerance [45,76]. Moreover, the traits may respond differently across genotypes, showing different types of drought tolerance [77]. Generally, our results showed that there is a divergence between environments (sites and seasons) and HA rates under normal irrigation and drought-stress conditions, and thus, these diversities can be used to improve wheat GY under drought-stress conditions.

5. Conclusions

Significant divergences between different environments (sites and seasons) and HA rates under normal irrigation and drought-stress conditions, as well as their interactions for wheat GY and most traits evaluated, were observed via a three-way ANOVA. Drought stress markedly decreased wheat GY and its components compared to normal conditions under the studied factors. The Al-Qasr site had the highest positive impact on GY and most studied traits in both seasons. The application of HA at a rate of 60 kg ha^{-1} markedly increased all studied traits compared with 0 and 30 kg ha^{-1}. The highest level of GY and most of its traits was recorded when fertilizing wheat plants with 60 kg HA ha^{-1} under normal and drought-stress conditions at the Al-Qasr site. The results of STI, Pearson's correlation coefficients, and PCA in our study could be useful and used as a suitable method for studying drought tolerance mechanisms and wheat GY improvement. Finally, the application of the 60 kg HA ha^{-1} dose is recommended to obtain the maximum wheat productivity under drought-stress conditions in Egypt.

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References

1. FAO. 2019. Available online: http://www.fao.org/3/cb1329en/CB1329EN.pdf (accessed on 21 July 2021).
2. Ghasemi-Mobtaker, H.; Kaab, A.; Rafiee, S. Application of life cycle analysis to assess environmental sustainability of wheat cultivation in the west of Iran. *Energy* **2020**, *193*, 116768. [CrossRef]
3. USDA. United States Department of Agriculture. World Agricultural Production. March 2022. Available online: https://apps.fas.usda.gov/psdonline/circulars/production.pdf (accessed on 8 April 2022).
4. FAO. FAOSTAT Wheat Production Statistics 2016. Available online: www.fao.org/faostat/en/#data/TP (accessed on 20 June 2020).
5. Abd El-Mageed, T.A.; El-Sherif, A.M.; Abd El-Mageed, S.A.; Abdou, N.M. A novel compost alleviate drought stress for sugar beet production grown in Cd-contaminated saline soil. *Agric. Water Manag.* **2019**, *226*, 105831. [CrossRef]
6. Rady, M.O.A.; Semida, W.M.; Howladar, S.M.; Abd El-Mageed, T.A. Raised beds modulate physiological responses, yield and water use efficiency of wheat (*Triticum aestivu* L.) under deficit irrigation. *Agric. Water Manag.* **2021**, *245*, 106629. [CrossRef]
7. Rady, M.O.A.; Semida, W.M.; Abd El-Mageed, T.A.; Howladar, S.M.; Shaaban, A. Foliage applied selenium improves photosynthetic efficiency, antioxidant potential and wheat productivity under drought stress. *Int. J. Agric. Biol.* **2020**, *24*, 1293–1300.
8. Food and Agriculture Organization of the UN (FAO). AQUASTAT-FAO's Global Information System on Water and Agriculture. Available online: http://www.fao.org/aquastat/en/ (accessed on 20 December 2019).
9. Shaaban, A.; Al-Elwany, O.A.; Abdou, N.M.; Hemida, K.A.; El-Sherif, A.; Abdel-Razek, M.A.; Semida, W.M.; Mohamed, G.F.; Abd El-Mageed, T.A. Filter mud enhanced yield and soil properties of water-stressed *Lupinus termis* L. in saline calcareous soil. *J. Soil Sci. Plant Nutr.* **2022**, *22*, 1572–1588. [CrossRef]
10. Ouda, S.; Noreldin, T.; Alarcón, J.J.; Ragab, R.; Caruso, G.; Sekara, A.; Abdelhamid, M.T. Response of spring wheat (*Triticum aestivum*) to deficit irrigation management under the semi-arid environment of Egypt: Field and modeling study. *Agriculture* **2021**, *11*, 90. [CrossRef]
11. Ouda, S.A.H.; Noreldin, T.; Amer, A. Rain fed areas in Egypt: Obstacles and opportunities. In *Management of Climate Induced Drought and Water Scarcity in Egypt*; Springer: Cham, Switzerland, 2016; pp. 27–46.
12. Agami, R.A.; Alamri, S.A.M.; Abd El-Mageed, T.A.; Abousekken, M.S.M.; Hashem, M. Salicylic acid and proline enhance water use efficiency, antioxidant defense system and tissues anatomy of wheat plants under field deficit irrigation stress. *J. Appl. Bot. Food Qual.* **2019**, *92*, 360–370. [CrossRef]
13. Kumar, A.; Verma, R.P.; Singh, A.; Sharma, H.K.; Devi, G. Barley landraces: Ecological heritage for edaphic stress adaptations and sustainable production. *Environ. Sustain. Indic.* **2020**, *6*, 100035. [CrossRef]
14. Cooper, P.J.M.; Gregory, P.J.; Keating, J.D.H.; Brown, S.C. Effects of fertilizer, variety and site on barley production under rainfed conditions in Northern Syria 2. Soil water dynamics and crop water use. *Field Crops Res.* **1987**, *16*, 67–84. [CrossRef]
15. Man, J.; Shi, Y.; Yu, Z.; Zhang, Y. Root growth, soil water variation, and grain yield response of winter wheat to supplemental irrigation. *Plant Prod. Sci.* **2016**, *19*, 193–205. [CrossRef]
16. Ilbeyi, A.; Ustun, H.; Oweis, T.; Pala, M.; Benli, B. Wheat water productivity and yield in a cool highland environment: Effect of early sowing with supplemental irrigation. *Agric. Water Manag.* **2006**, *82*, 399–410. [CrossRef]
17. Benli, B.; Pala, M.; Stockle, C.; Oweis, T. Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model. *Agric. Water Manag.* **2007**, *93*, 45–53. [CrossRef]
18. Xiao, G.; Zhang, Q.; Xiong, Y.; Lin, M.; Wang, J. Integrating rainwater harvesting with supplemental irrigation into rain-fed spring wheat farming. *Soil Till. Res.* **2007**, *93*, 429–437. [CrossRef]
19. Erekul, O.; Gotz, K.P.; Gurbuz, T. Effect of supplemental irrigation on yield and bread-making quality of wheat (*Triticum aestivum* L.) varieties under the Mediterranean climatical conditions. *Turk. J. Field Crops* **2012**, *17*, 78–86.

20. Tadayon, M.R.; Ebrahimi, R.; Tadayyon, A. Increased water productivity of wheat under supplemental irrigation and nitrogen application in a semi-arid region. *J. Agric. Sci. Technol.* **2012**, *14*, 995–1003.
21. Keatinge, J.D.H.; Neate, P.J.; Shepherd, K.D. The role of fertilizer management in the development and expression of crop drought stress in cereals under mediterranean environmental conditions. *Exp. Agric.* **1985**, *21*, 209–222. [CrossRef]
22. Singh, R.S.; Prihar, Y.S.S.; Singh, P. Effects of N fertilization on yield and water use efficiency of dryland wheat as affected by stored water and rainfall. *Agron. J.* **1975**, *67*, 599–603. [CrossRef]
23. Cattivelli, F.S.; Sayed, A.H.; Hu, X.; Lee, D.; Vespa, P. Mathematical models of cerebral hemodynamics for detection of vasospasm in major cerebral arteries. In *Acta Neurochirurgica Supplements*; Springer: Vienna, Austria, 2008; pp. 63–69.
24. Qiao, J.; Wang, J.; Zhao, D.; Zhou, W.; Schwenke, G.; Yan, T.; Li Liu, D. Optimizing N fertilizer rates sustained rice yields, improved N use efficiency, and decreased N losses via runoff from rice-wheat cropping systems. *Agric. Ecosys Environ.* **2022**, *324*, 107724. [CrossRef]
25. Mekdad, A.A.; El-Sherif, A.; Rady, M.M.; Shaaban, A. Culture management and application of humic acid in favor of *Helianthus annuus* L. oil yield and nutritional homeostasis in a dry environment. *J. Soil Sci. Plant Nutr.* **2021**, *22*, 71–86. [CrossRef]
26. Semida, W.M.; Abd El-Mageed, T.A.; Howladar, S.M.; Mohamed, G.F.; Rady, M.M. Response of *Solanum melongena* l. seedlings grown under saline calcareous soil conditions to a new organo-mineral fertilizer. *J. Anim. Plant Sci.* **2015**, *25*, 485–493.
27. Khan, R.U.; Khan, M.Z.; Khan, A.; Saba, S.; Hussain, F.; Jan, I.U. Effect of humic acid on growth and crop nutrient status of wheat on two different soils. *J. Plant Nutr.* **2018**, *41*, 453–460. [CrossRef]
28. Olk, D.C.; Dinnes, D.L.; Scoresby, J.R.; Callaway, C.R.; Darlington, J.W. Humic products in agriculture: Potential benefits and research challenges a review. *J. Soils Sediment* **2018**, *18*, 2881–2891. [CrossRef]
29. Rady, M.M.; Boriek, S.H.K.; Abd El-Mageed, T.A.; El-Yazal, M.A.S.; Ali, E.F.; Hassan, F.A.S.; Abdelkhalik, A. Exogenous gibberellic acid or dilute bee honey boosts drought stress tolerance in *Vicia faba* by rebalancing osmoprotectants, antioxidants, nutrients, and phytohormones. *Plants* **2021**, *10*, 748. [CrossRef] [PubMed]
30. Dinçsoy, M.; Sönmez, F. The effect of potassium and humic acid applications on yield and nutrient contents of wheat (*Triticum aestivum* L. var. Delfii) with same soil properties. *J. Plant Nutr.* **2019**, *42*, 2757–2772. [CrossRef]
31. Piccolo, A.; Nardi, S.; Concheri, G. Structural characteristics of humic substances as regulated to nitrate uptake and growth regulation in plant systems. *Soil Biol. Biochem.* **1992**, *24*, 373–380. [CrossRef]
32. Abdelrasheed, K.G.; Mazrou, Y.; Omara, A.E.; Osman, H.S.; Nehela, Y.; Hafez, E.M.; Rady, A.; El-Moneim, D.A.; Alowaiesh, B.F.; Gowayed, S.M. Soil amendment using biochar and application of K-humate enhance the growth, productivity, and nutritional value of onion (*Allium cepa* L.) under deficit irrigation conditions. *Plants* **2021**, *10*, 2598. [CrossRef]
33. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports No. 106; FAO: Rome, Italy, 2015.
34. Page, A.I.; Miller, R.H.; Keeny, D.R. *Methods of Soil Analysis. Part II. Chemical and Microbiological Methods*, 2nd ed; American Society of Agronomy: Madison, WI, USA, 1982; pp. 225–246.
35. Klute, A. Water retention: Laboratory methods. *Methods Soil Anal. Part 1 Phys. Mineral. Methods* **1986**, *5*, 635–662. [CrossRef]
36. Sun, H.; Shen, Y.; Yu, Q.; Flerchinger, G.N.; Zhang, Y.; Liu, C.; Zhang, X. Effect of precipitation change on water balance and WUE of the winter wheat-summer maize rotation in the North China Plain. *Agric. Water Manag.* **2010**, *97*, 1139–1145. [CrossRef]
37. Razali, N.; Wah, Y.B. Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. *J. Stat. Modeling Anal.* **2011**, *2*, 21–33.
38. Levene, H. Robust tests of equality of variances. In *Contributions to Probability and Statistics, Essays in Honor of Harold Hoteling*; Olkin, I., Ghurye, S.G., Hoeffding, W., Madow, W.G., Mann, H.B., Eds.; Stanford University Press: Stanford, CA, USA, 1960; pp. 278–292.
39. Steel, R.G.D.; Torrie, J.H. *Dickey DA Principles and Procedures of Statistics: A Biometrical Approach*, 3rd ed.; McGraw Hill: New York, NY, USA, 1997.
40. Gomes, F.P. *Curso de Estatística Experimental*, 15th ed.; Esalq: Piracicaba, Brazil, 2009; p. 477.
41. Fernandez, G.C. Effective selection criteria for assessing plant stress tolerance. In Proceedings of the International Symposium on Adaptation of Food Crops to Temperature and Water Stress, Taiwan, China, 13–16 August 1992; pp. 257–270.
42. Sharma, S. *Applied Multivariate Techniques*; Wiley: New York, NY, USA, 1996.
43. Delfine, S.; Tognetti, R.; Desiderio, E.; Alvino, A. Effect of foliar application of N and humic acids on growth and yield of durum wheat. *Agron. Sustain. Dev.* **2005**, *25*, 183–191. [CrossRef]
44. Vergara-Diaz, O.; Kefauver, S.C.; Elazab, A.; Nieto-Taladriz, M.T.; Araus, J.L. Grain yield losses in yellow-rusted durum wheat estimated using digital and conventional parameters under field conditions. *Crop J.* **2015**, *3*, 200–210. [CrossRef]
45. Gagliardi, A.; Carucci, F.; Masci, S.; Flagella, Z.; Gatta, G.; Giuliani, M.M. Effects of genotype, growing season and nitrogen level on gluten protein assembly of durum wheat grown under mediterranean conditions. *Agronomy* **2020**, *10*, 755. [CrossRef]
46. Pačuta, V.; Rašovský, M.; Michalska-Klimczak, B.; Wyszyňski, Z. Grain yield and quality traits of durum wheat (*Triticum durum* Desf.) treated with seaweed- and humic acid-based biostimulants. *Agronomy* **2021**, *11*, 1270. [CrossRef]
47. Shew, A.M.; Tack, J.B.; Nalley, L.L.; Petronella, C. Yield reduction under climate warming varies among wheat cultivars in South Africa. *Nat. Commun.* **2020**, *11*, 4408. [CrossRef]

48. Chowdhury, M.K.; Hasan, M.A.; Bahadur, M.M.; Islam, M.R.; Hakim, M.A.; Iqbal, M.A.; Javed, T.; Raza, A.; Shabbir, R.; Sorour, S.; et al. Evaluation of drought tolerance of some wheat (*Triticum aestivum* L.) genotypes through phenology, growth, and physiological indices. *Agronomy* **2021**, *11*, 1792. [CrossRef]
49. Taheri, S.; Jalal, S.; Farid, S.; Thohirah, L.A. Effects of drought stress condition on the yield of spring wheat (*Triticum aestivum*) lines. *Afr. J. Biotech.* **2011**, *10*, 18339–18348. [CrossRef]
50. Grzesiak, S.; Natalia, H.; Piotr, S.; Maciej, T.; Angelika, N.; Magdalena, S. Variation among wheat (*Triticum easativum* L.) genotypes in response to the drought stress: I—Selection approaches. *J. Plant Interact.* **2019**, *14*, 30–44. [CrossRef]
51. Koua, A.P.; Oyiga, B.C.; Baig, M.M.; Léon, J.; Ballvora, A. Breeding driven enrichment of genetic variation for key yield components and grain starch content under drought stress in winter wheat. *Front. Plant Sci.* **2012**, *12*, 684205. [CrossRef]
52. Oyiga, B.C.; Sharma, R.; Shen, J.; Baum, M.; Ogbonnaya, F.; Léon, J. Identification and characterization of salt tolerance of wheat germplasm using a multivariable screening approach. *J. Agron. Crop Sci.* **2016**, *202*, 472–485. [CrossRef]
53. Beltrano, J.; Ronco, M.G. Improved tolerance of wheat plants (*Triticum aestivum* L.) to drought stress and rewatering by the arbuscular mycorrhizal fungus *Glomus claroideum*: Effect on growth and cell membrane stability. *Braz. J. Plant Physiol.* **2009**, *20*, 29–37. [CrossRef]
54. Farooq, M.; Mubshar, H.; Kadambot, H.; Siddique, M. Drought stress in wheat during flowering and grain-filling periods. *Crit. Rev. Plant Sci.* **2014**, *33*, 331–349. [CrossRef]
55. Daryanto, S.; Wang, L.; Jacinthe, P.A. Global synthesis of drought effects on maize and wheat production. *PLoS ONE* **2016**, *11*, e0156362. [CrossRef] [PubMed]
56. Kadam, N.N.; Struik, P.C.; Rebolledo, M.C.; Yin, X.; Jagadish, S.K. Genome-wide association reveals novel genomic loci controlling rice grain yield and its component traits under water-deficit stress during the reproductive stage. *J. Exp. Bot.* **2018**, *69*, 4017–4032. [CrossRef] [PubMed]
57. Mohammadi, R. Breeding for increased drought tolerance in wheat: A review. *Crop Pasture Sci.* **2018**, *69*, 223–241. [CrossRef]
58. Mehraban, A.; Tobe, A.; Gholipouri, A.; Amiri, E.; Ghafari, A.; Rostaii, M. The effects of drought stress on yield, yield components, and yield stability at different growth stages in bread wheat cultivar (*Triticum aestivum* L.). *Pol. J. Environ. Stud.* **2019**, *28*, 739–746. [CrossRef]
59. Chandrasekar, V.; Sairam, R.K.; Srivastava, G.C. Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. *J. Agron. Crop Sci.* **2000**, *185*, 219–227. [CrossRef]
60. Tahir, M.M.; Khurshid, M.; Khan, M.Z.; Abbasi, M.K.; Kazmi, M.H. Lignite-derived humic acid effect on growth of wheat plants in different soils. *Pedosphere* **2011**, *21*, 124–131. [CrossRef]
61. Manzoor, A.; Riaz, A.K.; Dost, M. Humic acid and micronutrient effects on wheat yield and nutrients uptake in salt affected soils. *Int. J. Agric. Biol.* **2014**, *16*, 991–995.
62. El-Hashash, E.F.; Agwa, A.M. Genetic parameters and stress tolerance index for quantitative traits in barley under different drought stress severities. *Asian J. Res. Crop Sci.* **2018**, *1*, 1–16. [CrossRef]
63. Yehia, W.M.B.; El-Hashash, E.F. Correlation and multivariate analysis across non-segregation and segregation generations in two cotton crosses. *Egypt. J. Agric. Res.* **2012**, *99*, 354–364. [CrossRef]
64. He, D.; Shibo, F.; Hanyue, L.; Enli, W.; Dong, W. Contrasting yield responses of winter and spring wheat to temperature rise in China. *Environ. Res. Lett.* **2020**, *15*, 124038. [CrossRef]
65. Zhang, Y.; Qiu, X.; Yin, T.; Liao, Z.; Liu, B.; Liu, L. The impact of global warming on the winter wheat production of China. *Agronomy* **2021**, *11*, 1845. [CrossRef]
66. Chen, X.; Wu, J.; Opoku-Kwanowaa, Y. Effects of returning granular corn straw on soil humus composition and humic acid structure characteristics in saline-alkali soil. *Sustainability* **2020**, *12*, 1005. [CrossRef]
67. Kotzé, E.; Loke, P.F.; Akhosi-Setaka, M.C.; Du Preez, C.C. Land use change affecting soil humic substances in three semi-arid agro ecosystems in South Africa. *Agric. Ecosys. Environ.* **2016**, *216*, 194–202. [CrossRef]
68. Júnior, G.A.; Pereira, R.A.; Sodré, G.A.; Gross, E. Humic acids from vermicompost positively infl uence the nutrient uptake in mangosteen seedlings. *Pesqui. Agropecuária Trop.* **2019**, *49*, 1–8. [CrossRef]
69. El-Hashash, E.F. Genetic diversity of soybean yield based on cluster and principal component analyses. *J. Adv. Biol. Biotech.* **2016**, *10*, 1–9. [CrossRef]
70. Hegab, R.H.; Fawy, H.A.; Habib, A.A.M. Evaluates effect of amino acids, humic acid and antioxidants as foliar application on the biochemical content and productivity of wheat under North Sinai soils conditions. *Am. J. Agric. Forest.* **2020**, *8*, 167–174. [CrossRef]
71. Elshabrawi, H.M.; Bakry, B.A.; Ahmed, M.A.; Abouellail, M. Humic and oxalic acid stimulates grain yield and induces accumulation of plastidial carbohydrate metabolism enzymes in wheat grown under sandy soil conditions. *Agric. Sci.* **2015**, *6*, 175–185. [CrossRef]
72. Van Oosten, M.J.; Pepe, O.; De Pascale, S.; Silletti, S.; Maggio, A. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem. Biol. Technol. Agric.* **2017**, *4*, 5. [CrossRef]
73. Roomi, S.; Masi, A.; Conselvan, G.B.; Trevisan, S.; Quaggiotti, S.; Pivato, M. Protein profiling of arabidopsis roots treated with humic substances: Insights into the metabolic and interactome networks. *Front. Plant Sci.* **2018**, *871*, 1812. [CrossRef]

74. Abou Tahoun, A.M.; El-Enin, M.M.A.; Mancy, A.G.; Sheta, M.H.; Shaaban, A. Integrative soil application of humic acid and foliar plant growth stimulants improves soil properties and wheat yield and quality in nutrient-poor sandy soil of a semiarid region. *J. Soil Sci. Plant Nutr.* **2022**, *22*, 851–858. [CrossRef]
75. Shen, J.; Guo, M.J.; Wang, Y.G.; Yuan, X.Y.; Wen, Y.Y.; Song, X.; Dong, S.Q.; Guo, P.Y. Humic acid improves the physiological and photosynthetic characteristics of millet seedlings under drought stress. *Plant Signal. Behav.* **2020**, *15*, 8. [CrossRef] [PubMed]
76. Dalal, A.; Bourstein, R.; Haish, N.; Shenhar, I.; Wallach, R.; Moshelion, M. Dynamic physiological phenotyping of drought-stressed pepper plants treated with productivity-enhancing and survivability-enhancing biostimulants. *Front. Plant Sci.* **2019**, *10*, 905. [CrossRef] [PubMed]
77. Negin, B.; Moshelion, M. The advantages of functional phenotyping in pre-field screening for drought-tolerant crops. *Funct. Plant Biol.* **2016**, *44*, 107–118. [CrossRef]