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CHARACTERIZATION OF BREAD WHEAT SEGREGATING POPULATIONS UNDER OPTIMUM IRRIGATION AND WATER STRESS CONDITIONS

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SUMMARY

Water scarcity is currently threatening almost every country in the arid regions. Using advanced generations, breeding can help in the development of improved bread wheat genotypes for adaptation to abiotic and biotic stresses. The pedigree selection was practiced on two bread wheat crosses (Sids 12 × Line 44) and (Line 20 × Sakha 93) during two seasons (2017−2018 and 2018–2019) under full irrigation (optimal conditions) and limited irrigation (drought-stressed) conditions at Kafer El-Hamam Agriculture Station, Agricultural Research Center, Giza, Egypt. The results indicated significant differences in two crosses of F_2 and F_3 families for all the studied traits under optimal irrigation and water stress. The estimates of phenotypic coefficients of variability (PCV) were slightly higher than those of genotypic coefficients of variability (GCV) for all the traits in two crosses of both water regimes. Broad-sense heritability (h^2_{Bs}) estimates, accompanied with high magnitudes of the genetic advance (GA), were higher under optimal irrigation than water stress in F_2 and F_3 generations of two crosses. A positive correlation was recorded between spikes per plant and grain yield in both water treatments of two crosses. A positive correlation (r) was revealed between offsprings (F_3) and their parents (F_2) in yield and its components under optimal irrigation and water stress conditions. Hence, the hybridization followed by selection under optimal and drought stress conditions have been a demand to accelerate the genetic gain of wheat grain yield.

Keywords: Wheat, selection parameters, heritability, genetic advance, water stress

Key findings: Climate change is the main threat to the wheat crop; thus, breeding strategies for drought consist of a large number of segregating wheat crosses to derive new pure lines under optimal and drought stress conditions.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal field crop feeding one-fifth of the world's population, and the wheat production should be doubled by 2050 to fulfill the demand for an increasing population and decreasing land for cultivation; hence, the need to increase the yield per unit area (Alotaibi *et al*., 2021; IPCC, 2013). Present water shortages impair nearly every country in the arid Mediterranean regions. Most significantly, water shortages in the world's arid regions continue to worsen due to sudden climatic changes, rising incomes,

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and continuous population growth (El-Hendawy *et al*., 2017; Swailam *et al.*, 2021). Most of the current water-limited countries will become warmer and drier due to climate change (Darzi-Ramandi *et al*., 2016; Ali *et al*., 2021). Moreover, climate change is expected to increase the temperature by 3 °C–5 °C. reducing rainfalls by 4%–27% during the cropping season (IPCC, 2013), which will drastically affect crop production (Shauka *et al.* 2021). Thus, under climate changes, the demand for irrigation water in the future is generally expected to increase over time (Kamruzzaman *et al*., 2020). Climate change is the main threat to most crops; therefore, scientific and political contexts have gained increasing importance for this event (Sallam *et al*., 2019; Tembo, 2021). The drought stress effect is one of the consequences of climate change that harms field crop growth and yield (Ali, 2017; Sallam *et al*., 2019).

Drought reduced the wheat grain yield by 62% (Aberkane *et al*., 2020), and gene introgression from wild relatives pays off and can increase wheat genotype's resilience to climate change effects. Drought tolerance is a polygenic character, and genetic studies can help control drought tolerance (Gazal *et al*., 2016; Sallam *et al*., 2019). In 2030, wheat demand is expected to reach up to 40% with the continuous growth in human population (Ahmed *et al*., 2019a). Breeding for drought tolerance is important to know the mechanism and behavior of plants under water stress environments. The drought tolerance mechanism is complex, for reasons considering intensity, period of stress, plant growth stage, and crop species (Ahmed *et al*., 2019b). In that respect, there are three fundamental mechanisms, i.e., escape avoidance (tolerance) and resistance mechanisms, which a plant can acclimatize to manage drought stress (Ali *et al*., 2021). The selection of early flowering genotypes has been recognized as enhancing drought stress tolerance through escape (Barakat *et al*., 2020).

Breeding strategies for drought consist of many segregating wheat crosses to derive new pure lines, which are evaluated and compared with commercial cultivars for high yield and tolerance to biotic and/or abiotic stresses (Al-Ashkar *et al*., 2021). Morphological and physiological plant characters can significantly influence the productivity of wheat yield in direct and indirect pathways. Productivity is affected by environmental fluctuations when there are a high genetic environment interaction and low heritability that make the selection of genotypes more difficult (Sallam *et al*., 2019; Mansour *et al*., 2020; Al-Ashkar *et al*., 2021).

Stability analysis studies revealed a differential response of wheat genotypes to various drought stress environments, and significant differences found among the bread wheat genotypes for yield components (Ali, 2017; Putri *et al*., 2020; Al-Ashkar *et al*., 2021). These studies reported the significance of genetic relationships, such as, selection efficiencies, genetic gain, heritability and co-heritability for evaluating trait stability under stress levels and their interactions.

The selection of genetically superior wheat genotypes amongst the huge amount of segregating and recombinant progenies is an essential but complex process in plant breeding. The development of new cultivars demands long periods that involve cyclic hybridization and selection techniques (Ali *et al*., 2020). During the last two decades, crossing and selection have played an important role in wheat improvement, as well as, the transgressive segregation crossing technique using superior characters to genotype by environment interaction (GEI), where an example of this tremendous improvement in the wheat genome was the green revolution, in which the progress was slow but consistent (Alotaibi *et al*., 2021).

The study of heritability, genetic advance, and genotypic and phenotypic coefficient of variation helps find the magnitude and nature of variation in germplasm. Thus, crop improvement depends on genetic variability in breeding material (Sohail *et al*., 2018; Ahmed *et al*., 2019a; Arifuzzaman *et al*., 2020). Selection of the superior phenotype type is possible only when the genotype (G) and phenotype (Ph) are strongly correlated. A selection program can be predicted when data on heritability are available. Additionally, a high heritability estimate coupled with a high selection response value, is desired for selection (Merida-Garcia *et al*., 2019; Ali *et al*., 2020).

Based on the major points stated earlier, the study was conducted to explore more information on genetic variability, heritability, and selection response in bread wheat for its superior genotype development under both full irrigation and water stress conditions, by identifying characteristics having a significant direct effect on grain yield as selection criteria.

MATERIALS AND METHODS

Plant material

Two bread wheat crosses, i.e., (Sids 12 × Line 44) and (Line 20 × Sakha 93), were selected from 15 F_1's diallel crosses of previous work (Swelam, 2015). These crosses had the best values for yield components under full irrigation and water stress environments. These crosses were derived from four diverse parental bread wheat genotypes, i.e., two commercially adopted cultivars and two exotic genotypes (Table 1).

Experimental site

The experiment was carried out during the two successive growing seasons, 2017/2018 and 2018/2019 at the experimental farm at the Kafer El-Hamam Agriculture Station, at Kafer El-Hamam Agriculture Station, Agricultural Research Center, Giza, Egypt (30°37'03.3"N, 31°31'03.6"E). The soil mechanical and chemical analyses of the experimental sites are given in Table 2. The monthly weather data during two field trial seasons are shown in Figure 1.

Table 1. Pedigree and origin of the parental genotypes used in two bread wheat crosses.

Genotypes	Parental name	Pedigree	Origin
Cross I	Sids 12 (P1)	BUC//7C/ALD/5/MAYA74/ON//1160-147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SX.SD7096-4SD-1SD1SD-0SD.KS82142/2*WBLL1.	ARC, Egypt
	Line 44 (P2)	CROC_1/AE.SQUARROSA(224)///OPATA/3/SOKOLL	CIMMYT, Mexico
Cross II	Line 20 (P1)	KS82142/2*WBLL1.	CIMMYT, Mexico
	Sakha 93 (P2)	SAKA92/TR810328.	ARC, Egypt

Table 2. Soil mechanical and chemical analyses of the experimental sites.

Properties	Sand (%)	Silt (%)	Clay (%)	Texture class	Organic matter (%)	Available (N) (ppm)	Available (P) (ppm)	Available (K) (ppm)	pH
2017/2018	18.7	34.5	46.8	Clay	1.72	44.6	9.8	378.6	8.31
2018/2019	17.5	33.6	48.9	Clay	1.59	36.71	8.4	405.5	8.22

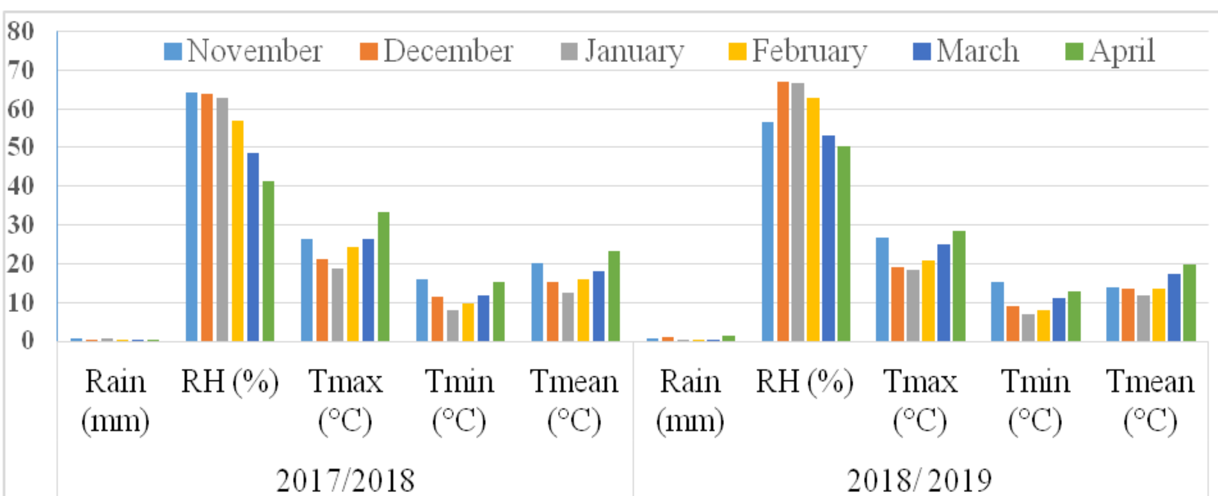

Figure 1. Monthly weather data during the field trial at Kafer El-Hamam, Sharkia Governorate, Rain is precipitation (mm day-1), RH: average relative humidity at 2 meters, Tmax: average maximum temperature, Tmin: average minimum temperature, Tmean: temperature average.

Experimental design

In the first season, the seeds of F_2 for two wheat crosses and their parents were sown under field water experiments—optimal irrigation and water stress conditions—in anon-replicated plots. Each plot had 20 rows of F_2 population alongside eight rows for their parents (P_1 and P_2). The rows' lengths were 3 m, with row to row at 30 cm apart, and the distance between any two plants within a row was 10 cm, presenting 600 plants for each population and 120 plants for each parent. Data for earliness characters were collected on about 30 and 40 plants, and then these plants were harvested for each population under optimal irrigation and drought stress, respectively. Grain yield and its components were recorded on each plant. The height of 10 plants was selected based on their desired results for earliness, yield, and components to demonstrate the F_3 generation seeds (10 families for each population under both water treatments). Also, data were recorded on10 plants for each parent for studied characters under the two environments.

In the second season, the field experiment was conducted to evaluate 10 families under optimal irrigation and another 10 families under water stress conditions, and compared with their parents in strip design, with a randomized complete block design (RCBD) in two replicates. Each plot consisted of 24 rows of 10 families and their parents (P_1 and P_2), two rows of each population. The row length was 3 m, with row to row at 30 cm apart, and the distance between any two plants within a row was 10 cm, presenting 600 plants for each population (60 plants for each family × 10 families) and 60 plants for each parent. In each replicate, data were collected for days to heading (DH), plant height (PH), and days to maturity (DM) characters on 10 guarded and competitive plants for parents (P_1 and P_2) and 100 plants for each F_3 population (10 plants for each family) under the two water treatments. These plants were harvested and measured with the following traits, i.e., spikes per plant (S/P), grains per spike (G/S), 1000-grain weight (TGW), and grain yield per plant (GY/P), recorded for individual plants. The means of the 10 plants were subjected to statistical and genetic analysis.

The best three families (selection intensity 30%) were selected, and the best five plants from each selected family were chosen to represent 15 families of the F_4 generation, including 15 families from each cross that will be completed in the subsequent feature work of obtaining improved yielded lines of wheat under two ways, the optimal and water stress conditions.

Statistical procedures

Means and variances for the parents and F_2 generation studied under the two irrigation conditions were statistically estimated, while data of the tested families in F_3 were statistically analyzed in RCBD as described by Snedecor and Cochran (1967). Genotypic and phenotypic mean squares (σ^2g and σ^2Ph) were estimated by the method of Singh and Choudhary (1987) and Wricke and Weber (1986) as $\sigma^2g = (MSg - MSI) / r$ and $\sigma^2Ph = Vg + MSI$. The genotypic and phenotypic coefficient of variations (GCV % and PCV %) were estimated according to Johnson *et al.* (1955) as follows:

$$\text{GCV \%} = \left(\frac{\sqrt{\sigma^2 \mathbf{g}}}{\bar{\bar{\mathbf{X}}}}\right) \times 100$$

and

$$\text{PCV \%} = \left(\frac{\sqrt{\sigma^2 \mathbf{Ph}}}{\bar{\bar{\mathbf{X}}}}\right) \times 100$$

Where, $\bar{\bar{\mathbf{X}}}$ is grand mean. GCV and PCV values were classified according to Deshmukh *et al.* (1986) as follows: 0% – 10%, low; 10 % – 20%, moderate, and >20%, high. Broad sense heritability (h^2_b) was described by Allard (1960) as $h^2_b = (\sigma^2g / \sigma^2P) \times 100$. According to Singh (2001), broad-sense heritability was categorized as 0% – 40%, low; 40% – 59%, medium; 60% – 79%, moderately high, and >80%, very high. Genetic advance (GA) was estimated according to the method (Johnson *et al.*, 1955) as $GA = h^2_b \times K \times \sqrt{\mathbf{VP}}$ where K is 2.67 and 1.14 at 5% and 30% selection intensities. Realized selection differential (observed response) = $\bar{X}_p - \bar{X}_0$ (this relates to the same generation), where, $\bar{\mathbf{X}}_p$ = mean of selected genotypes (families) for next-generation and $\bar{\mathbf{X}}_o$ = mean of bulk population. Realized response in F_3 = mean F_3 - mean F_2. Correlation (r) between offspring (F_3) and parents (F_2) = $SP_{xy}/\sqrt{SS_x \times SS_y}$. Regression (b) of offspring (F_3) on parents (F_2) = SP_{xy}/SS_x.

Table 3. Analysis of variance of earliness, plant height, and grain yield components for F_3 families under optimal irrigation and water stress conditions for two crosses.

Cross	Sources of variation	d.f	Optimal irrigation						
			DH	DM	PH	NS/P	NG/S	TGW	GY/P
Cross I	Replications	1	0.72^{*}	2.89^{*}	160.18^{*}	0.29	33.8	5.21^{*}	26.68
	Families	9	0.56^{**}	12.27^{**}	239.70^{**}	5.65^{**}	63.01^{**}	14.93^{**}	28.49^{**}
	Error	9	0.1	1.28	22.38	0.58	11.28	1.96	6.92
Cross II	Replications	1	0	1.06	1.68	0.29	20.69	22.35	1.1
	Families	9	3.90^{**}	3.58^{**}	92.60^{**}	7.03^{**}	34.91^{**}	126.59^{**}	4.98^{*}
	Error	9	0.3	0.41	8.34	0.26	4.56	12.49	1.07
			Water stress						
Cross I	Replications	1	2.24	0.11	1.8	0.18	25.54	7.42	8.1
	Families	9	2.02^{**}	1.75^{**}	178.31^{**}	3.23^{**}	52.62^{**}	16.19^{**}	10.29^{*}
	Error	9	0.48	0.32	29.24	0.69	11.62	2.95	3.08
Cross II	Replications	1	0.34	0.22	8.19	0.05	12.77	0.04	0.04
	Families	9	3.02^{**}	2.80^{**}	57.45^{*}	2.93^{**}	30.24^{*}	6.88^{*}	9.14^{*}
	Error	9	0.27	0.42	13.82	0.51	5.88	1.32	2.28

DH: days to heading, DM: days to maturity, PH: plant height, S/P: spikes per plant, G/S: grains per spike, TGW: 1000-grain weight, and GY/P: grain yield per plant. Cross I is (Sids 12 × Line 44) and Cross II is (Line 20 × Sakha 93).* $P < 0.05$ and ** $P < 0.01$.

Coefficient of the determinant (R) of selection response = $r^2 \times 100$. Microsoft Excel and SAS 9.2 (2008) computer programs for Windows were used for the statistical analysis.

RESULTS

Mean squares and mean performance

The analysis of variance showed that mean squares from DH, DM, PH, NS/P, NG/S, TGW, and GY/P of F_3 generation families for two wheat crosses were significant to highly significant in both the optimal irrigation and water stress conditions (Table 3). The average earliness, plant height, and grain yield components in the F_2 (selected on the bias of the high grain yield per plant) and F_3 generations under optimal irrigation and water stress treatments for the two crosses are shown in Tables 4 and 5.

In general, wheat plants for F_2 and F_3 generations respond to moisture water stress with the changes in various traits for two crosses. In other words, water deficit reduced the means of two generations compared with optimal irrigation of all studied traits for two wheat crosses. Days to heading and days to maturity increased in F_3 generation compared with F_2 generation for all crosses under both environments. In contrast, in most families of cross II under the two water treatments, the F_2 plants were taller than their offspring. In comparison, the mean behavior of the plant height fluctuated between the families in the second and third generations in cross I under optimal irrigation and water stress.

The spikes plant fluctuated among families of offspring (F_3) and their parents (F_2) in cross I under optimal irrigation and water stress, and cross II under water stress. In contrast, most F_2 families had more spikes per plant than F_3 in cross II under optimal irrigation. The grains per spike decreased in most F_3 families compared with their F_2 families for two crosses under both environments. On the other hand, most F_3 families were greater than F_2 in all crosses for 1000-grain yield under optimal irrigation and water stress. For grain yield per plant, most of the selected F_2 families had higher values than F_3 generation for two crosses in both water environments. Therefore, direct selection for grain yield is not practical in early generations for developing drought-tolerant and high-yielding varieties.

Genetic and selection parameters

Populations of the cross I (Sids 12 × Line 44)

F_2 Generation

Results showed that under optimal irrigation, days to heading varied from 88.0 to 92.0 with an average of 89.7 days. Days to maturity ranged from 143.0 to 147.0 with an average of 145.0 days. Plant height ranged between 90.0 and 143.0 cm with an average of 121.5 cm. Spikes per plant diverse from 2.0 to 25.0 with

Table 4. The average earliness, plant height, and grain yield components in the F_2 (selected) and F_3 generations under optimal irrigation and water stress conditions for the cross I (Sids 12 × Line 44).

Traits	Days to heading (days)		Days to maturity (days)		Plant height (cm)		Spikes/ plant		Gains/ spike		1000-grain weight (g)		Grain yield /plant(g)	
Generations	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
Families	Optimal irrigation													
1	90	90.8	147	153.2	135	126.4	15	14.8	60	71.8	51.7	47.25	38.1	34.17
3	89	91.6	145	150.2	143	144.9	25	15.6	84	78.5	52.4	44.96	80.5	29.84
4	88	91.3	147	155.1	101	119.6	15	14.3	86	67.1	43	46.49	43.7	32.09
5	90	92.1	145	150.5	111	130.6	6	15.8	108	80.8	47.2	51.79	36.1	28.11
6	91	91.1	146	154.1	141	143	11	15.8	73	63.6	57.5	48.03	30.5	27.27
10	89	91.8	145	157	133	148.4	16	16.8	63	68.5	57.1	52.91	42.6	25.8
17	89	91.8	145	154.9	110	145.5	20	15.3	63	74.5	44.4	46.14	44.1	28.94
19	91	90.7	145	153.2	129	146.5	23	17.6	57	70.8	43.9	48.32	46	34.08
24	89	91.4	143	156.5	110	121.7	15	16	62	66.3	53.2	44.94	38.5	27.23
30	88	92.3	145	150.5	121	137.7	17	20.2	86	66.5	45.3	45.82	49.2	37.4
Mean	89.4	91.5	145.3	153.5	123.4	136.4	16.3	16.2	74.2	70.8	49.57	47.67	44.93	30.49
SE	0.32	0.16	0.35	0.74	4.44	3.28	1.66	0.5	4.91	1.68	1.65	0.82	4.08	1.13
Sids 12 (P_1)	91.8		155.4		120.4		14		86.6		57.7		29.2	
Line 44 (P_2)	92.5		156.8		110.2		18		81		55		31	
Families	Water stress													
5	88	90.8	131	144	137	126.5	10	14.5	74	55.5	52.7	47.19	29.3	25.76
6	85	91.6	133	142.9	110	126.3	14	15.7	73	55.3	50.7	46.05	32.6	29.93
8	87	91.3	134	142.9	135	133	18	18.3	74	55.4	50	47.85	37	30.6
9	85	92.1	130	142.9	145	114.7	18	16.7	87	61.7	56.3	55.34	28.6	27.23
15	85	91.1	131	143.3	135	122.5	19	17.9	45	65.1	66.7	48.82	37.1	27.76
16	87	91.8	133	143.2	105	136	13	15.4	30	54.9	53.3	52.62	33.8	23.29
18	85	91.8	141	142.9	95	128.3	17	15.4	78	51.1	51.3	48.74	53.3	28.55
28	94	90.7	135	142.6	102	137.4	18	14.8	54	53.3	57.4	46.73	38.2	28.14
34	93	91.4	136	145.8	115	118.5	14	15.3	56	65.5	57.1	49.15	40.3	29.77
37	92	92.3	136	143.2	110	146.2	11	15.8	86	62.1	51.2	47.96	31.5	30.15
Mean	88.1	91.5	134	143.4	118.9	128.9	15.2	16	65.7	58	54.67	49.04	36.17	28.12
SE	1.07	0.16	0.97	0.28	5.24	2.83	0.97	0.38	5.61	1.54	1.51	0.85	2.15	0.68
Sids 12 (P_1)	87.4		145.1		117.9		12.7		59.1		52.1		25.7	
Line 44 (P_2)	85.8		135		107.2		14.6		72.7		47.1		28.1	

Table 5. The average of earliness, plant height, and grain yield components in the F_2 (selected) and F_3 generations under optimal irrigation and water stress conditions for the cross II (Line 20 × Sakha 93).

Traits	Days to heading (days)		Days to maturity (days)		Plant height (cm)		Spikes/ plant		Grains/ spike		1000-grain weight (g)		Grain yield /plant (g)	
Generations	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
Families	Optimal irrigation													
1	86.0	87.5	147.0	156.3	130.0	122.8	10.0	14.6	71.0	71.2	56.3	70.27	44.90	27.73
2	87.0	89.4	146.0	157.7	145.0	124.2	17.0	17.6	68.0	68.1	51.5	64.24	40.50	26.94
3	85.0	88.6	146.0	158.1	125.0	122.5	16.0	12.5	73.0	66.8	50.7	45.40	37.80	28.30
4	88.0	90.0	144.0	159.7	131.0	130.8	11.0	15.1	69.0	69.8	50.7	58.68	54.10	30.06
13	85.0	91.5	147.0	158.2	135.0	137.6	22.0	16.1	69.0	64.5	47.8	54.97	62.80	30.96
19	94.0	90.8	146.0	158.7	129.0	120.0	17.0	15.0	64.0	68.8	48.4	56.12	37.80	29.05
20	95.0	87.7	145.0	155.2	125.0	117.4	20.0	11.6	70.0	75.2	40.0	50.08	76.60	29.01
26	93.0	87.9	146.0	158.0	140.0	135.8	17.0	11.9	55.0	64.2	69.1	64.05	46.00	27.05
27	92.0	88.2	146.0	158.8	110.0	122.7	16.0	14.4	92.0	74.7	43.5	50.18	42.70	31.57
28	95.0	87.9	147.0	156.6	127.0	121.7	22.0	14.4	69.0	63.2	46.4	49.30	48.00	29.82
Mean	90.0	88.9	146.0	157.7	129.7	125.6	16.8	14.3	70.0	68.6	50.44	56.33	49.12	29.05
SE	1.3	0.4	0.3	0.4	2.9	2.0	1.2	0.6	2.8	1.3	2.38	2.39	3.70	0.47
Line 20 (P_1)	89.0		157.6		117.0		15.8		61.4		62.6		29.5	
Sakha 93 (P_2)	87.2		150.6		110.2		16.2		63.6		61.4		28.1	
Families	Water stress													
1	82.0	87.3	140.0	150.2	115.0	119.7	18.0	17.2	79.0	50.8	33.7	54.03	32.80	26.37
5	83.0	87.0	139.0	148.2	125.0	126.2	18.0	17.5	66.0	48.6	31.8	53.96	30.00	23.53
9	82.0	86.0	139.0	150.3	120.0	127.0	17.0	18.9	50.0	56.7	42.0	48.85	22.50	21.82
11	81.0	88.1	141.0	148.0	125.0	110.6	17.0	16.0	59.0	56.9	28.8	50.60	29.20	22.76
17	83.0	85.7	140.0	147.9	115.0	120.7	15.0	16.9	66.0	55.3	46.3	53.95	32.90	24.51
19	86.0	85.2	139.0	146.8	125.0	128.5	13.0	17.0	64.0	48.5	40.6	51.92	31.50	18.34
28	83.0	87.7	140.0	148.4	115.0	121.1	18.0	15.8	55.0	56.8	45.5	50.65	24.20	21.47
33	83.0	85.4	140.0	146.7	130.0	121.3	17.0	16.9	68.0	50.4	36.8	53.01	29.60	22.40
34	84.0	85.3	138.0	148.3	125.0	127.7	15.0	15.2	77.0	48.8	23.4	50.61	26.40	21.22
37	83.0	88.4	142.0	148.0	120.0	125.0	19.0	18.9	67.0	47.8	26.3	50.26	32.70	23.24
Mean	83.0	86.6	139.8	148.3	121.5	122.8	16.7	17.0	65.1	52.1	35.52	51.78	29.18	22.56
SE	0.4	0.4	0.3	0.4	1.6	1.6	0.6	0.4	2.7	1.2	2.41	0.56	1.11	0.64
Line 20 (P_1)	86.0		147.6		101.0		15.1		58.6		54.4		23.5	
Sakha 93 (P_2)	82.8		147.3		109.8		14.7		51.1		57.8		21.7	

an average of 11.9 spikes. Grains per spike varied between 51.0 and 108.0 with an average of 71.3 grains. Thousand-grain yield ranged from 38.8 to 116.5 g with an average of 53.7 g and grain yield per plant varied from 12.8 to 60.5 g with an average yield of 31.2 g (Table 6).

On the other side, under water stress, the traits ranged as follows: from 84.0 to 94.0 with an average of 88.7 days for days to heading; days to maturity - from 130.0 to 142.0 with an average of 134.8 days; plant height - from 99.0 to 140.0 cm with an average of 117.0 cm; spikes per plant - from 3.0 to 19.0 with an average of 10.6; grains per spike - from 30.0 to 87.0 with an average of 61.6 grains; 1000-grain weight - from 35.0 to 66.7 g with an average of 52.9 g, and grain yield per plant from 5.2 to 45.3 g with an average of 23.2 g.

The values of genotypic coefficients of variability (GCV) in F_2 under optimal irrigation and water stress were 1.01% and 2.51% for days to heading, 0.63% and 1.49% for days to maturity, 8.25% and 7.19% for plant height, 40.65% and 34.55% for spikes per plant, 15.91% and 19.82% for grains per spike, 21.85% and 9.34% for 1000-grain weight, and 23.88% and 17.70% for grain yield per plant, respectively. As for the values of phenotypic coefficient of variability (PCV), these were 1.28% and 3.25% for days to heading, 0.71% and 1.91% for days to maturity, 9.51% and 8.58% for plant height, 45.32% and 38.88% for spikes per plant, 20.53% and 22.25% for grains per spike, 26.35% and 13.74% for 1000-grain weight, and 34.93% and 36.79% for grain yield per plant under optimal irrigation and water stress, respectively.

Estimates of broad-sense heritability (h^2_{Bs}) in F_2 were 62.14% and 59.87% for days to heading, 78.15% and 60.78% for days to maturity, 75.27% and 70.39% for plant height, 80.45% and 79.0% for spikes per plant, 60.07% and 79.35% for grains per spike, 68.73% and 46.22% for 1000-grain weight, and 46.73% and 23.15% for grain yield per plant for optimal irrigation and water stress conditions, respectively.

The magnitudes of the genetic advance (GA) in F_2 were 0.80% and 2.19% for days to heading, 0.90% and 1.99% for days to maturity, 9.74% and 8.97% for plant height, 4.89% and 4.14% for spikes per plant, 9.85% and 13.82% for grains per spike, 10.90% and 4.27% for 1000-grain weight, and 5.71% and 2.51% for grain yield per plant under optimal irrigation and water stress, respectively.

F_3 Generation

Results for F_3 generation in Table 6 showed the following data under optimal irrigation. Days to heading varied from 90.7 to 92.3 with an average of 91.5 days. Days to maturity ranged from 150.2 to 157.0 with an average of 153.5 days. Plant height ranged between 119.6 and 148.5 cm with an average of 136.4 cm. Spikes per plant diverse from 14.3 to 20.2 with an average of 16.2 spikes. Grains per spike varied between 63.6 and 80.8 with an average of 70.8 grains. Thousand-grain weight ranged from 44.9 to 52.9 with an average of 47.7 g. Grain yield per plant varied from 25.8 to 37.4 with an average of 30.5 g.

With water stress condition, the studied traits varied as follows: Days to heading from 84.6 to 87.2 with an average of 85.9 days; Days to maturity varied from 142.6 to 145.8 with an average of 143.4 days; Plant height ranged from 114.7 to 146.2 cm with an average of 128.9 cm; Spikes per plant varied from 14.5 to 18.3 with an average of 15.9 spikes; Grains per spike varied from 51.1 to 65.5 with an average of 57.9 grains; 1000-grain weight varied from 46.1 to 55.3 g with an average of 49.0 g; and Grain yield per plant varied from 23.3 to 30.6 g with an average of 28.1 g.

The GCV values in F_3 under both optimal irrigation and water stress for all the traits were 0.53% and 1.02% for days to heading, 1.53% and 0.59% for days to maturity, 7.64% and 6.70% for plant height, 9.82% and 7.05% for spikes per plant, 7.18% and 7.81% for grains per spike, 5.34% and 5.25% for 1000-grain weight, and 10.77% and 6.70% for grain yield per plant, respectively. The PCV values, on the other hand, were 0.63% and 1.30% for days to heading, 1.70% and 0.71% for days to maturity, 8.39% and 7.90% for plant height, 10.88% and 8.77 % for spikes per plant, 8.60% and 9.77% for grains per spike, 6.10% and 6.31% for 1000-grain weight, and 13.80% and 9.23% for grain yield per plant, for optimal irrigation and water stress, respectively.

Estimates of broad-sense heritability (h^2_{Bs}) in F_3 under optimal irrigation and water stress treatments were 69.85% and 61.68% for days to heading, 81.05% and 69.38% for days to maturity, 82.92% and 71.83% for plant height, 81.47% and 64.73% for spikes per plant, 69.63% and 63.83% for grains per spike, 76.76% and 69.20% for 1000-grain weight and 60.93% and 57.77% for grain yield per plant, respectively.

Table 6. Genetic and selection parameters for the cross I (Sids 12 × Line 44) of studied traits in the F_2 and F_3 generations under optimal irrigation and water stress conditions.

Environments	Optimal irrigation							Water stress						
Traits	DH	DM	PH	NS/P	NG/S	TGW	GY/P	DH	DM	PH	NS/P	NG/S	TGW	GY/P
F_2	Genetic parameters													
Range	(88.0 - 92.0)	(143.0 - 147.0)	(90.0 - 143.0)	(2.0 - 25.0)	(51.0 - 108.0)	(38.8 - 116.5)	(12.8 - 60.5)	(84.0 - 94.0)	(130.0 - 142.0)	(99.0 - 140.0)	(3.0 - 19.0)	(30.0 - 87.0)	(35.0 - 66.7)	(5.2 - 45.3)
Mean	89.7	145	121.5	11.9	71.3	53.7	31.2	88.7	134.8	117	10.6	61.6	52.9	23.20
VE	0.5	0.23	33.03	5.75	85.6	62.69	63.44	3.33	2.61	29.81	3.58	38.83	28.42	56.20
VG	0.82	0.83	100.53	23.66	128.77	137.77	55.65	4.97	4.04	70.86	13.48	149.25	24.42	16.93
G.C.V.%	1.01	0.63	8.25	40.65	15.91	21.85	23.88	2.51	1.49	7.19	34.55	19.82	9.34	17.70
P.C.V.%	1.28	0.71	9.51	45.32	20.53	26.35	34.93	3.25	1.91	8.58	38.88	22.25	13.74	36.79
h^2_{Bs}	62.14	78.15	75.27	80.45	60.07	68.73	46.73	59.87	60.78	70.39	79	79.35	46.22	23.15
GA	1.47	1.66	17.92	8.99	18.12	20.05	10.5	3.55	3.23	14.55	6.72	22.42	6.92	4.08
Realized selection differential	-0.3	0.27	1.87	4.33	2.87	-4.16	11.69	-0.63	-1.35	2.4	4.58	4.05	1.77	12.13
F_3	I. Genetic parameters													
Range	(90.7-92.3)	(150.2-157.0)	(119.6 - 148.5)	(14.3 - 20.2)	(63.6-80.8)	(44.9-52.9)	(25.8-37.4)	(84.6-87.2)	(142.6-145.8)	(114.7 - 146.2)	(14.5 - 18.3)	(51.1-65.5)	(42.1-55.3)	(23.3 - 30.6)
Mean	91.50	153.50	136.40	16.20	70.80	47.70	30.50	85.90	143.40	128.90	15.90	57.90	46.00	28.10
VE	0.10	1.28	22.38	0.58	11.28	1.96	6.92	0.48	0.32	29.24	0.69	11.62	2.95	3.18
VG	0.23	5.49	108.66	2.54	25.86	6.48	10.79	0.77	0.72	74.54	1.27	20.50	6.62	3.55
VP	0.33	6.77	131.04	3.11	37.14	8.44	17.70	1.25	1.04	103.77	1.96	32.12	9.57	6.73
V F3	0.56	12.27	239.70	5.65	63.01	14.93	28.49	2.02	1.75	178.31	3.23	52.62	16.19	10.29
G.C.V.%	0.53	1.53	7.64	9.82	7.18	5.34	10.77	1.02	0.59	6.70	7.05	7.81	5.25	6.70
P.C.V.%	0.63	1.70	8.39	10.88	8.60	6.10	13.80	1.30	0.71	7.90	8.77	9.77	6.31	9.23
h^2_{Bs}	69.85	81.05	82.92	81.47	69.63	76.76	60.93	61.68	69.38	71.83	64.73	63.83	69.20	52.77
Realized selection differential	-0.22	-0.52	-3.88	0.51	-1.79	-0.69	3.94	0.87	0.32	2.06	0.30	1.59	-1.29	2.00
	II. Selection parameters													
Realized response in F3 (rR)	1.64	8.62	17.67	6.42	1.94	-8.14	6.08	-2.98	8.23	13.17	6.88	-2.31	-3.25	9.52
Percentage rR of F3 (rR %)	1.79	5.61	12.95	39.58	2.74	-17.09	19.95	-3.46	5.74	10.22	43.04	-3.98	-6.63	33.85
GA	0.51	2.75	12.45	1.88	5.36	2.88	3.16	0.85	0.89	9.30	1.13	4.49	2.70	1.64
Predicted selection differential	0.84	3.92	17.34	2.66	8.89	4.33	5.98	1.80	1.68	16.96	2.28	9.21	5.11	4.07
Predicted generalized in F4	2.19	2.46	1.14	2.70	0.24	-2.11	1.14	-2.10	6.22	0.99	3.83	-0.32	-0.81	2.97
R	-0.60	-0.11	0.59	0.17	0.43	0.25	0.18	-0.23	0.05	-0.52	0.60	-0.05	0.17	0.24
B	-0.29	-0.05	0.79	0.56	1.24	0.50	0.65	-0.03	0.16	-0.96	1.53	-0.16	0.31	0.74
R	35.60	1.22	34.54	2.91	18.17	6.32	3.29	5.48	0.23	26.82	36.22	0.20	3.06	5.56

DH: days to heading, DM: days to maturity, PH: plant height, S/P: spikes per plant, G/S: grains per spike, TGW: 1000-grain weight, and GY/P: grain yield per plant. GA: genetic advance, h^2_{Bs}: heritability in the broad sense, r: correlation between offspring (F_3) and parents (F_2), b: the regression of offspring (F_3) on parents (F_2), and R: coefficient of the determinant of selection response.

The realized (actual) response to selection in F_3 (rR) values were 1.64 and -2.98 days to heading, 8.62 and 8.23 days to maturity, 17.67 and 13.17 cm for plant height, 6.42 and 6.88 spikes per plant, 1.94 and -2.31 grain for grains per spike, -8.14 and -3.25 g for 1000-grain weight, and 6.08 and 9.52 g for grain yield per plant under optimal irrigation and water stress, respectively.

On the other hand, the predicted selection differential in F_3 values were 0.84 and 1.80 days to heading, 3.92 and 1.68 days to maturity, 17.34 and 16.96 cm for plant height, 2.66 and 2.28 spikes per plant, 8.89 and 9.21 grain for grains per spike, 4.33 and 5.11 g for 1000-grain weight, and 5.98 and 4.07 g for grain yield per plant under optimal irrigation and water stress, respectively. Meanwhile, the magnitudes of the GA in F_3 under optimal irrigation and water stress conditions were 0.51% and 0.85% for days to heading, 2.75% and 0.89% for days to maturity, 12.45% and 9.30% for plant height, 1.88% and 1.13% for spikes per plant, 5.36% and 4.49% for grains per spike, 2.88% and 2.70% for 1000-grain weight, and 3.16% and 1.64% for grain yield per plant, respectively (Table 6).

Moreover, the predicted generalized in F_4 was 2.19 and -2.10 days to heading, 2.46 and 6.22 days to maturity, 1.14 and 0.99 cm for plant height, 2.70 and 3.83 spikes per plant, 0.24 and -0.32 grain for grains per spike, -2.11 and -0.81 g for 1000-grain weight, and 1.14 and 2.97 g for grain yield per plant under optimal irrigation and water stress, respectively.

Correlation (r) between offspring (F_3) and parents (F_2) showed positive values for plant height (0.59), spikes per plant (0.17), grains per spike (0.43), 1000-grain weight (0.25), and grain yield per plant (0.18) under optimal irrigation. Likewise, under water stress condition, positive values were noted for days to maturity (0.05), spikes per plant (0.60), 1000-grain weight (0.17), and grain yield per plant (0.24). Conversely, negative correlation values were recorded for days to heading (-0.6) and days to maturity (-0.11) under optimal irrigation, while under water stress, these were also for days to heading (-0.23), as well as, for plant height (-0.52), and grains per spike (-0.05).

Regression (b) of offspring (F_3) on parents (F_2) estimates were positive for plant height (0.79), spikes per plant (0.56), grains per spike (1.24), 1000-grain weight (0.5), and grain yield per plant (0.65) under optimal irrigation, as well as, for days to maturity (0.16), spikes per plant (1.53), 1000-grain weight (0.31), and grain yield per plant (0.74) under water stress. The negative regression values recorded under optimal irrigation were for days to heading (-0.29) and days to maturity (-0.05), while days to heading (-0.03), plant height (-0.96), and grains per spike (-0.16) were noted for the water stress conditon.

Populations of cross II (Line 20 × Sakha 93)

Genetic and selection parameters for the cross II (Line 20 × Sakha 93) on days to heading, days to maturity, plant height, spikes per plant, grains per spike, 1000-grain weight, and grain yield per plant in the F_2 and F_3 generations under optimal irrigation and water stress conditions are shown in Table 7.

F_2 Generation

Under optimal irrigation, the following were the results. Days to heading varied from 85.0 to 95.0 with an average of 89.6 days. Days to maturity ranged from 143.0 to 149.0 with an average of 146.2 days. Plant height ranged between 108.0 and 145.0 cm with an average of 128.1 cm. Spikes per plant diverse from 9.0 to 22.0 with an average of 14.5 spikes. Grains per spike varied between 44.0 and 92.0 with an average of 66.1 grains. The 1000-grain weight ranged from 24.2 to 69.1 with an average of 47.0 g. Lastly, grain yield per plant varied from 10.6 to 62.8 with an average of 34.5 g.

Under water stress, the following were the results. Days to heading ranged from 81.0 to 87.0 with an average of 84.4 days. Days to maturity varied from 136.0 to 144.0 with an average of 139.6 days. Plant height ranged from 105.0 to 135.0 cm with an average of 118.8 cm. Spikes per plant varied from 5.0 to 19.0 with an average of 12.3 spikes. Grains per spike ranged between 50.0 and 79.0 with an average of 65.0 grain. The 1000-grain weight varied from 17.1 to 47.8 g with an average of 33.6 g, and grain yield per plant varied from 10.1 to 37.2 g with an average of 21.3 g.

The values of GCV in F_2 of cross II were 3.37% and 1.55% for days to heading, 0.72% and 0.80% for days to maturity, 6.61% and 4.32% for plant height, 17.53% and 24.93% for spikes per plant, 10.08% and 6.36% for grains per spike, 17.36% and 18.47% for 1000-grain weight, and 24.17% and 19.23% for grain yield per plant under optimal irrigation and water stress,

Table 7. Genetic and selection parameters for the cross II (Line 20 × Sakha 93) of studied traits in the F_2 and F_3 generations under optimal irrigation and water stress conditions.

Environments	Optimal irrigation							Water stress						
Traits	DH	DM	PH	NS/P	NG/S	TGW	GY/P	DH	DM	PH	NS/P	NG/S	TGW	GY/P
F_2	Genetic parameters													
Range	(85.0-95.0)	(143.0-149.0)	(108.0-145.0)	(9.0 - 22.0)	(44.0-92.0)	(24.2 - 69.1)	(10.6 - 62.8)	(81.0 - 87.0)	(136.0 - 144.0)	(105.0 - 135.0)	(5.0 - 19.0)	(50.0-79.0)	(17.1 - 47.80)	(10.1 - 37.20)
Mean	89.6	146.17	128.07	14.53	66.13	47	34.51	84.38	139.6	118.83	12.38	65.05	33.64	21.33
VE	3.35	0.55	20.85	7.7	39.55	32.88	78.74	0.64	0.81	20.64	5.06	33.74	21.03	30.47
VG	9.11	1.11	71.56	6.49	44.43	66.6	69.57	1.71	1.24	26.32	9.52	17.1	38.59	16.82
G.C.V.%	3.37	0.72	6.61	17.53	10.08	17.36	24.17	1.55	0.8	4.32	24.93	6.36	18.47	19.23
P.C.V.%	3.94	0.88	7.51	25.92	13.86	21.22	35.29	1.82	1.02	5.77	30.85	10.96	22.95	32.24
h^2_{Bs}	73.1	66.89	77.44	45.73	52.91	66.95	46.91	72.62	60.63	56.04	65.3	33.64	64.73	35.58
GA	5.31	1.78	15.33	3.55	9.99	13.76	11.77	2.29	1.79	7.91	5.14	4.94	10.3	5.04
Realized selection differential	0.4	-0.17	1.63	2.27	3.87	3.44	13.03	-1.38	0.2	2.68	4.33	0.05	1.88	7.85
F_3	I. Genetic parameters													
Range	(87.5-91.45)	(155.2-159.70)	(117.4-137.60)	(11.6-17.60)	(63.2-75.20)	(45.4-70.27)	(26.94 - 31.57)	(85.2 - 88.4)	(146.7 - 150.3)	(110.6 - 128.5)	(10.20 - 18.9)	(47.84 - 56.9)	(48.85 - 54.03)	(18.34 - 26.37)
Mean	88.95	157.73	125.55	14.32	68.64	56.33	29.05	86.61	148.28	122.78	13.03	52.05	51.78	22.56
VE	0.3	0.41	8.34	0.26	4.56	12.49	1.07	0.27	0.42	13.82	0.51	5.88	1.32	2.28
VG	1.8	1.59	42.13	3.39	15.18	57.05	1.96	1.38	1.19	21.81	1.21	12.18	2.78	3.43
VP	2.1	2	50.47	3.65	19.73	69.54	3.02	1.65	1.61	35.64	1.72	18.06	4.1	5.71
V F3	3.9	3.58	92.6	7.03	34.91	126.59	4.98	3.02	2.8	57.45	2.93	30.24	6.88	9.14
G.C.V.%	1.51	0.8	5.17	12.85	5.68	13. 69	4.82	1.36	0.73	3.8	6.46	6.7	3.22	8.2
P.C.V.%	1.63	0.9	5.66	13.34	6.47	14.8	5.98	1.48	0.86	4.86	7.71	8.16	3.91	10.59
h^2_{Bs}	85.88	79.5	83.47	92.84	76.91	82.05	64.74	83.78	73.62	61.21	70.27	67.44	67.85	59.99
Realized selection differential	1.04	0.22	0.9	1.06	0.28	-0.73	0.72	0.49	0.29	0.12	0.6	-1.06	1.27	1.85
	II. Selection parameters													
Realized response in F3 (rR)	-0.45	11.48	-1.7	0.92	4.44	11.05	1.09	1.78	8.74	4.85	6.1	-12.98	18.77	3.85
Percentage rR of F3 (rR %)	-0.51	7.28	-1.35	6.42	6.47	19.61	3.74	2.05	5.9	3.95	35.8	-24.94	36.24	17.05
GA	1.64	1.46	7.79	2.39	4.41	8.95	1.4	1.41	1.19	4.5	1.17	3.6	1.73	1.76
Predicted selection differential	2.21	2.12	10.78	2.97	6.62	12.6	2.5	2.21	2.12	9.63	2.18	6.98	3.33	3.84
Predicted generalized in F4	-0.23	6.07	-0.18	0.35	0.75	0.98	0.49	1.02	5.23	0.64	3.56	-2.36	7.15	1.27
R	-0.33	-0.31	0.48	-0.06	0.59	0.65*	0.29	-0.58	-0.11	0.11	0.36	-0.68*	0.14	0.4
B	-0.11	-0.22	0.67	-0.12	1.3	0.65*	2.3	-0.54	-0.11	0.11	0.54	-1.57*	0.62	0.69
R	10.62	9.5	22.87	0.31	34.92	42.79	8.67	33.97	1.25	1.27	13.01	46.81	2.07	16.07

DH: days to heading, DM: days to maturity, PH: plant height, S/P: spikes per plant, G/S: grains per spike, TGW: 1000-grain weight, and GY/P: grain yield per plant. GA: genetic advance, h^2_{Bs}: heritability in the broad sense, r: correlation between offspring (F_3) and parents (F_2), b: regression of offspring (F_3) on parents (F_2), and R: coefficient of the determinant of selection response.

respectively. For the PCV values, results were 3.94% and 1.82% for days to heading, 0.88% and 1.02% for days to maturity, 7.51% and 5.77% for plant height, 25.92% and 30.85% for spikes per plant, 13.86% and 10.96% for grains per spike, 21.22% and 22.95% for 1000-grain weight, and 35.29% and 32.24% for grain yield per plant under optimal irrigation and water stress, respectively.

Estimates of h^2_{Bs} in F_2 were 73.10% and 72.62% for days to heading, 66.89% and 60.63% for days to maturity, 77.44% and 56.04% for plant height, 45.73% and 65.30% for spikes per plant, 52.91% and 33.64% for grains per spike, 66.95% and 64.73% for 1000-grain weight, and 46.91% and 35.58% for grain yield per plant under optimal irrigation and water stress, respectively. The GA estimates in F_2 were 2.89% and 1.41% for days to heading, 0.97% and 1.10% for days to maturity, 8.34% and 4.88% for plant height, 1.93% and 3.17% for spikes per plant, 5.43% and 3.05% for grains per spike, 7.48% and 6.35% for 1000-grain weight, and 6.40% and 3.11% for grain yield per plant under optimal irrigation and water stress, respectively.

F_3 Generation

Mean performance under optimal irrigation of F_3 generation for cross Line 20 × Sakha 93 in Table 7 showed that days to heading varied from 87.5 to 91.5. Days to maturity ranged from 155.2 to 159.7. Plant height ranged between 117.4 and 137.6 cm. Spikes per plant ranged from 11.6 to 17.6. Grains per spike varied between 63.2 and 75.2. The 1000-grain weight diverse from 45.4 to 27.3. Grain yield per plant varied from 26.9 to 31.6 with an average of 29.0 g. Moreover, under water stress, these traits ranged between 85.2–88.4 (days to heading), 146.7–150.3 (days to maturity), 110.6–128.5 cm (plant height), 15.2–18.9 (spikes per plant), 47.8–56.9 (grains per spike), 48.8–54.0 g (1000-grain weight), and 18.3–26.4 g (grain yield per plant).

The magnitude of GCV values in F_3 of cross II were 1.51%, 0.80%, 5.17%, 12.8%, 5.68%, 13.0%, and 4.82% under optimal irrigation, and 1.36%, 0.73%, 3.80%, 6.46%, 6.70%, 3.22%, and 8.20% under water stress, for days to heading, days to maturity, plant height, spikes per plant, grains per spike, 1000-grain weight, and grain yield per plant traits, respectively. The values of PCV were 1.63%, 0.90%, 5.66%, 13.34%, 6.47%, 14.80%, and 5.98% under optimal irrigation, and 1.48%, 0.86%, 4.86%, 7.71%, 8.16%, 3.91%, and 10.59% under water stress for enumerated traits, respectively.

Estimates of h^2_{Bs} in F_3 were 85.88%, 79.50%, 83.47%, 92.84%, 76.91%, 82.05%, and 64.74% under optimal irrigation, and 83.78%, 73.62%, 61.21%, 70.27%, 67.44%, 67.85%, and 59.99% under water stress for days to heading, days to maturity, plant height, spikes per plant, grains per spike, 1000-grain weight and grain yield per plant traits, respectively.

Selection parameters

The realized (actual) response to selection in F_3 (rR) values of cross II were -0.45 day, 11.48 day, -1.70 cm, 0.92 spike, 4.44 grains, 11.05 g, and 1.09 g under optimal irrigation, and 1.78 days, 8.74 days, 4.85 cm, 6.10 spikes, -12.98 grain, 18.77 g, and 3.85 g under water stress for days to heading, days to maturity, plant height, spikes per plant, grains per spike, 1000-grain weight, and grain yield per plant traits, respectively. On the other hand, the predicted selection differential in F_3 values were 2.21 days, 2.12 days, 10.78 cm, 2.97 spikes, 2.62 grains, 12.60 g, and 2.50 g under optimal irrigation, and 2.21 days, 2.12 days, 9.63 cm, 2.18 spikes, 6.98 grains, 3.33 g, and 3.84 g under water stress, for enumerated traits, respectively (Table 7).

Meanwhile, the GA values in F_3 of cross II were 1.64%, 1.46%, 7.79%, 2.39%, 4.41%, 8.95%, and 1.40% under optimal irrigation, and 1.41%, 1.19%, 4.50%, 1.17%, 3.60%, 1.73%, and 1.76% under water stress, for days to heading, days to maturity, plant height, spikes per plant, grains per spike, 1000-grain weight, and grain yield per plant traits, respectively (Table 7). Moreover, the predicted generalized in F_4 was -0.23 and 1.02 days to heading, 6.07 and 5.23 days to maturity, -0.18 and 0.64 cm for plant height, 0.35 and 3.56 spikes per plant, 0.75 and -2.36 grain for grains per spike, 0.98 and 7.15 g for 1000-grain weight, and 0.49 and 1.27 g for grain yield per plant under optimal irrigation and water stress, respectively.

Positive correlation (r) values were recorded between offsprings (F_3) and parents (F_2) under optimal irrigation (0.48, 0.59, 0.65, and 0.29) and drought stress (0.11, 0.36, 0.14, and 0.40) for plant height, grains per spike, 1000-grain weight, and grain yield per plant, respectively. However, days to heading and days to maturity showed negative correlation values under optimal irrigation (-0.33 and -0.31) and water stress (-0.58 and -0.11), as well as, in spikes per plant (-0.06) under optimal irrigation and grains per spike (-0.68) under water stress condition.

Positive regression (b) estimates of offspring (F_3) on parents (F_2) were observed for plant height, grains per spike, 1000-grain weight, and grain yield per plant under optimal irrigation (0.67, 1.30, 0.65, and 2.30) and water stress (0.11, 0.54, 0.62, and 0.69). But for negative regression, values were recorded for days to heading and days to maturity under optimal irrigation at -0.11 and -0.22 and water stress at -0.54 and -0.11, as well as, for spikes per plant and grains per spike under optimal irrigation and water stress (-.12 and -1.57), respectively.

DISCUSSION

All studied traits of F_2 and F_3 families had significant differences in the two crosses under two water regimes. These confirm considerable genetic variation between F_2 plants and F_3 families and the measured traits and possibility of selection for drought tolerance and optimal irrigation. Genetic variation was found in wheat for earliness traits and yield components (Mahdy *et al*., 2015; Aziz *et al*., 2018; Darwish *et al*., 2018), where the efficiency of selection and heterosis are mainly dependent upon the magnitude of genetic variability existing in the wheat populations (Al-Naggar *et al*., 2020).

Water shortage stress reduced the means of F_2 and F_3 generations for all studied traits for two wheat crosses compared with the optimal irrigation. Wheat traits of cross I (Sids12 × Line 44) were reduced in F_2 generation by 1.11%, 7.03%, 3.7%, 10.92%, 13.6%, 1.49%, and 25.64%, as well as, in F_3 by 6.12%, 6.58%, 5.5%, 1.85%, 18.22%, 3.56%, and 7.87% for DH, DM, PH, S/P, G/S, TGW, and GY/P, respectively. Likewise, traits of cross II (Line 20 × Sakha 93) were reduced in F_2 by 5.83%, 4.49%, 7.21%, 14.8%, 1.63%, 28.43%, and 38.19%, and in F_3 by 2.63%, 5.99%, 2.21%, 9.01%, 24.17%, 8.08%, and 22.34% for DH, DM, PH, S/P, G/S, TGW, and GY/P, respectively. The different behaviors of genotypes under drought stress and full irrigation conditions reflect the effect of genetic influences and the impact of environments, similar to results observed by wheat scientists (Ahmed *et al*., 2019a). Furthermore, grain yield losses under water stress were associated with an insufficient supply of assimilates to support the wheat reproductive stages and grain growth. Aberkane *et al*. (2020) reported that the wheat grain yield was reduced by 62% under drought and found high variation for phenology and agronomic traits, with days to heading explaining 16% of GY under drought.

In addition, drought decreased wheat grain yield by 47% in Australia in 2006 (Rauf *et al*., 2016). Forward-looking, grain yield losses by 2050 are predicted to reach 10%–30% associated with the expected increase in drought and heat stresses (Kumar *et al*., 2013). Thus, for each 1 °C increase in earth temperature, the wheat grain yields worldwide are expected to reduce by 6% (Asseng *et al*., 2015). Therefore, breeding programs for drought tolerance in the arid and semi-arid area are very useful for developing elite wheat germplasm that will respond to the requirements of farmers and consumers and adapt to climate change effects. It is worthy to note that transgressive segregants were observed for GY/P and its related traits occurred in many selected recombination in F_2 and F_3; these recombinants exceeded the highest or lesser parent, suggesting that all selected parents had associated alleles with high values of these traits. Moreover, the high-yielding segregants plants would be used as a germplasm source to improve wheat productivity under optimal irrigation and water stress conditions, as explained by Jan *et al*. (2015); Saleem *et al*. (2016); and Channa (2022). Breeding for water deficit environments is challenging because drought tolerance is a complex trait; its mechanism is generally environment-specific, and intense in interaction of genotype × environment, which reduces the efficiency of selection (Mickelbart *et al*., 2015). Consequently, breeding for drought stress requires methodologies in plant science and the integration of multiple disciplines (Mwadzingeni *et al*., 2016).

Under optimal irrigation for the cross I in F_2 and F_3 generations, family three was early with high NS/P and GY/P, making it a potential family for earliness and high grain yield. In addition, family 19 had high NS/P, NG/S, TGW, and GY/P. As for the water stress condition, the family 16 was early with high TGW, making it a potential family for earliness and high grain-filling rate. Family 34 exhibited high NG/S, TGW, and GY/P and short PH, as well as, families six, eight, 18, and 37 showing high GY/P under drought. Family four was early with high TGW and GY/P for cross II under optimal irrigation, where family 27 had high NG/S, TGW, and GY/P, and family 13 showed high NS/P and GY/P. On the other side, under water stress for cross II, family 17 was early with high NG/S, TGW, and GY/P, while family one had high NS/P, TGW, and GY/P and short PH.

Table 8. Correlation between grain yield per plant and other studied traits under optimal irrigation (OI) and water stress (WS).

Crosses	Cross I (Sids 12 × Line 44)				Cross II (Line 20 × Sakha 93)			
Generations	F_2		F_3		F_2		F_3	
Environments	OI	WS	OI	WS	OI	WS	OI	WS
Days to heading	-0.35	-0.02	-0.11	0.10	0.18	0.16	0.33	0.42
Days to maturity	-0.12	0.84**	-0.49*	0.06	-0.28	0.43	0.31	0.48*
Plant height (cm)	0.32	-0.57	-0.14	0.05	-0.02	-0.03	0.07	-0.44
Spikes plant^{-1}	0.75**	0.39	0.46*	0.33	0.36	-0.08	0.13	0.19
Grains spike^{-1}	0.15	-0.10	-0.09	0.20	-0.06	0.60*	0.20	0.10
1000-grain weight (g)	-0.09	0.00	-0.39	-0.50*	-0.39	-0.18	-0.56*	0.49*

This finding highlights the ability to include such families in the selective breeding programs to obtain new pure-lines and improve specific adaptive characters to drought stresses. Therefore, these bread wheat genotypes should be selected for the following breeding programs to improve yield under well irrigation and water stress environments. Similar findings have also been reported by Aberkane *et al*. (2020) and Ali *et al.* (2021) for yield related traits in bread and durum wheat.

Selecting early wheat lines with a long grain filling period (GFP) might lead to selecting genotypes with good levels of drought tolerance (Aberkane *et al*., 2020). Li *et al.* (2021) reported that under severe water shortages, the old hexaploid genotypes with drought evading characteristics exhibited lower reduction for grain yield and aboveground biomass than modern wheat genotypes, whereas under moderate and mild water deficits modern genotypes had higher aboveground biomass and yields.

The correlation among studied traits and grain yield showed a positive correlation between NS/P and GY/P at two water regimes in two crosses (Table 8). In two generations, days to maturity correlated positively with TGW and GY/P under drought. The grains per spike positively correlated with GY/P under water stress in two generations for cross II. Thousand-grain weight was positively valued with GY/P under water stress in F_3 for cross II. Several studies reported the contribution of NG/S to higher yields under drought stress (Sardouei-Nasab *et al.,* 2019; Arifuzzaman *et al*., 2020; Ali *et al.,* 2021). Wheat breeders strongly associated TGW and GY/P during drought (Aberkane *et al.,* 2020).

The selection of superior genetic genotypes between the enormous amount of recombinant and segregating offspring is a necessary but complex process in plant breeding**.** The development of wheat cultivars implicates cyclic crossing and selection trials over long times (Ali *et al.,* 2020). Usually, wheat scientists relied on phenotypic selection to define the genetic potential of families or individuals in the field and select the best one that simultaneously displayed multiple desirable characters. Phenotypic selection serves as a well-organized strategy to improve complex characters by continuously increasing the number of favorable alleles (Li *et al.,* 2018; Al-Naggar *et al*., 2020)**.** Conventional breeding and modern techniques had pushed the yearly genetic gain for wheat grain yield from ~0.7% to ~1.2%, but the current annual genetic yield of yield in main food crops counting wheat is not enough to meet future demands (Li *et al.,* 2018). Hence, the hybridization followed by selection under optimal and drought stress conditions has been a demand to accelerate the genetic gain of wheat grain yield (Ali *et al.,* 2021).

The estimates of phenotypic coefficients of variability (PCV) were a little higher than those of genotypic coefficients of variability (GCV) for all traits in two crosses under both water regimes, indicating the low effect of the environment on the studied characters. The ranges, means, genetic variances, PCV, and GCV estimates for most studied traits were higher under optimal irrigation than corresponding estimates under water stress condition in two crosses for F_2 and F_3 populations. These present results agree with the findings of investigators Mahdy *et al*. (2015) and Al-Naggar *et al*. (2020), who reported higher GCV and PCV under full irrigation conditions than under water stress environments. On the opposite, the GCV and PCV values were higher under water stress than corresponding estimates under optimal irrigation conditions for DH and DM in cross I, and DM and TGW in cross II. Wheat scientists reported similar results for DM and TGW (Al-Naggar *et al*., 2020), where they recorded higher values for GCV and PCV under drought stress.

The study's results showed that the genotypic variances, GCV, and PCV values were higher in the F_2 generation than corresponding estimates in the F_3 generation under the two water treatments for all studied traits, except DM in two crosses, indicating the higher genetic variations between the plants of F_2. The highest estimates of GCV and PCV were exhibited by NG/S, GY/P, and TGW, whereas DH and DM showed the lowest ones.

The coefficients of heritability (h^2_{Bs}) for all studied traits were higher under optimal irrigation than corresponding estimates under water stress conditions in the F_2 and F_3 generations for two wheat crosses, except NG/S for the cross I and NS/P for cross II in the F_2 population. Moreover, it is higher in F_3 than F_2 generations for all studied traits under two water regimes in two crosses. The h^2_{Bs} estimates were more than 50% for all traits in F_3 generation for all cases. Significant estimates of h^2_{Bs} are associated with higher genetic variability, higher selective accuracy, and better possibilities for achievement in selecting wheat genotypes with greater grain yield productivity (Attri *et al*., 2021; Channa, 2022). Al-Naggar *et al*. (2020) investigated heritability estimates are higher under full watering than those under drought for DH, S/P, G/S, and GY/P.

In the same trend, the genetic advance (GA) estimates were higher under optimal irrigation than corresponding estimates under water stress condition for most studied traits in the F_2 and F_3 generations for the two wheat crosses. In comparison, GA values in the F_2 generation showed higher corresponding estimates than in the F_3 generation for all studied traits under both water conditions for the two wheat crosses. Therefore, in general, estimates of heritability (h^2_{Bs}) and genetic advance (GA) were higher under optimal irrigation than under water stress conditions for the most of studied traits (Al-Naggar *et al*., 2020), indicating the effects of genotype × environment interaction. Also, high heritability coupled with high to moderate genetic advance is a percent of the mean for DH, NS/P, PH, SL, GY/P, and 1000-grain weight (Attri *et al*., 2021; Channa, 2022). The genetic advance was the highest for GY/P followed by the number of productive tillers per plant and 1000-grain weight (Al-Naggar *et al*., 2020).

The maximum values of response to selection in the first cross were 17.67 and 13.17 cm for plant height and 11.05 and 18.77 g for 1000-grain weight under optimal irrigation and water stress, respectively. Positive values of correlation (r) between offsprings (F_3) and parents (F_2) in yield and its components were noted under optimal irrigation and water stress conditions in the two crosses. The regression results showed a high positive estimation in grains per spike under optimal irrigation and spikes per plant under water stress in the first cross, and grain yield per plant in both the optimal irrigation and water stress conditions in the second cross. Similar results have also been reported by Aziz *et al.* (2018), Attri *et al*. (2021), and Channa (2022).

CONCLUSIONS

The outperforming wheat genotypes under drought stress and optimal irrigation conditions can be helpful in future wheat breeding programs. The Cross-I families three and 19, and Cross-II families one, four, 13, and 27 showed the best desirable values under optimal irrigation for yield traits. Cross-I families six, eight, 18, and 37, and Cross-II families one and 17 exhibited high GY/P under drought stress. Early selection for the earliness and yield component characters will effectively develop drought-tolerant and high-yielding wheat varieties. At the same time, direct selection for grain yield is not effective in early generations for developing drought-tolerant and high-yielding varieties. This information could help future wheat breeders' selection for improve water stress tolerance in bread wheat.

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REFERENCES

Aberkane H, Amri A, Belkadi B, Filali-Maltouf A, Kehel Z, Tahir ISA, Meheesi S, Tsivelikas A (2020). Evaluation of durum wheat lines derived from interspecific crosses under drought and heat stress. *Crop Sci.* 61: 119-136. doi:10.1002/csc2.20319.

Ahmed H, Sajjad M, Li M, Azmat M, Rizwan M, Maqsood R, Khan S (2019a). Selection criteria for drought-tolerant bread wheat genotypes at the seedling stage. *Sustainability* 11. doi.org/10.3390/su11092584

Ahmed HGM, Khan AS, Li Mj., Khan SH, Kashif M (2019b). Early selection of bread wheat genotypes using morphological and photosynthetic attributes conferring drought tolerance. *J. Integr. Agric.* 18: 2483-2491. doi:10.1016/s2095-3119(18)62083-0.

Al-Ashkar I, Ibrahim A, Ghazy A, Attia K, Al-Ghamdi AA, Al-Dosary MA (2021). Assessing the correlations and selection criteria between different traits in wheat salt-tolerant genotypes. *Saudi J. Biol. Sci.* 15(8): e0236351. doi:10.1016/j.sjbs.2021.05.076.

Ali M, Zhang L, DeLacy I, Arief V, Dieters M, Pfeiffer WH, Wang J, Li H (2020). Modeling and simulation of recurrent phenotypic and genomic selections in plant breeding under the presence of epistasis. *The Crop J.* 8: 866-877. doi:10.1016/j.cj.2020.04.002.

Ali MMA, Abdulhamid MLE (2017). Yield stability of wheat under some drought and sowing dates environments in different irrigation systems. *Zagazig J. Agric. Res.* 44: 865-886. doi.org/10.21608/zjar.2017.52284

Ali MMA, Mansour E, Awaad HA (2021). Drought tolerance in some field crops: State of the art review. In: Mitigating Environmental Stresses for Agricultural Sustainability in Egypt. pp. 17-62.

Allard RW (1960). Principles of Plant Breeding. 1st ed/Ed. John Wiley and Sons. Inc, New York, USA.

Al-Naggar AMM, El-Shafi MAE, El-Shal MH, Anany AH (2020). Selection criteria and selection environment for drought tolerance of Egyptian wheat (*Triticum aestivum* L.) landraces. *Annu. Res. and Rev. in Biol.* 25-40. doi:10.9734/arrb/2020/v35i230186.

Alotaibi F, Alharbi S, Alotaibi M, Al Mosallam M, Motawei M, Alrajhi A (2021). Wheat omics: Classical breeding to new breeding technologies. *Saudi J. Biol. Sci.* 28: 1433-1444. doi:10.1016/j.sjbs.2020.11.083.

Arifuzzaman M, Barman S, Hayder S, Azad MAK, Turin MTS, Amzad MA, Masuda MS (2020). Screening of bread wheat (*Triticum aestivum* L.) genotypes under drought stress conditions using multivariate analysis. *Cereal Res. Commun.* 48: 301-308. doi:10.1007/s42976-020-00039-8. doi:10.1007/s42976-020-00039-8.

Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, Kimball BA, Ottman MJ, Wall GW, White JW, Reynolds MP, Alderman PD, Prasad PVV, Aggarwal PK, Anothai J, Basso B, Biernath C, Challinor AJ, de-Sanctis G, Doltra J, Fereres E, Garcia-Vila M, Gayler S, Hoogenboom G, Hunt LA, Izaurralde RC, Jabloun M, Jones CD, Kersebaum KC, Koehl AK, Müller C, Kumar SN, Nendel C, O'Leary G, Olesen JE, Palosuo T, Priesack E, Rezaei EE, Ruane AC, Semenov MA, Shcherbak I, Stoöckle C, Stratonovitch P. Streck T, Supit I, Tao F, Thorburn PJ, Waha K, Wang E, Wallach D, Wolf I, Zhao Z, Zhu Y (2015). Rising temperatures reduce global wheat production. *Nature Climate Change* 5: 143-147. doi.org/10.1038/nclimate2470.

Attri H, Dey T, Singh B, Kour A (2021). Genetic estimation of grain yield and its attributes in three wheat (*Triticum aestivum* L.) crosses using six parameter model. *J. Genet.* 100. doi.org/10.1007/s12041-021-01298-y.

Aziz T, Khalil IH, Hussain Q, Shah T, Ahmad N, Sohail A (2018). Heritability and selection response for grain yield and associated traits in F_3 wheat populations. *Sarhad J. Agric.* 34. doi:10.17582/journal.sja/2018/34.4.767.774.

Barakat MN, Al-Doss AA, Moustafa KA, Motawei MI, Al-Ashkar IM, Al-Otayk SM, Alamri MS, Mergoum M (2020). Mapping wheat QTLs for grain yield-related traits under high-temperature stress. *Genetika* 52: 1107-1125. doi.org/10.2298/GENSR20107B.

Channa QA (2022). Estimation of genetic variability and heritability in F_2 populations of wheat (*Triticum aestivum* L.) genotypes under drought stress conditions. *Pure Appl. Biol*. doi:10.19045/bspab.2022.110025.

Darwish MAH, Abd El-Kreem THA, Farhat WZE (2018). Selection studies in some bread wheat F_3 crosses at Sakha and Nubaria locations *J. Plant Production, Mansoura Univ.,* 9: 81-89.

Darzi-Ramandi H, Najafi-Zarini H, Shariati V, Razavi K, Kazemitabar SK (2016). Screening Iranian bread wheat lines under different water regimes using yield based drought tolerance indices. *SABRAO J. Breed. Genet*. 48(4): 491-503.

Deshmukh SNN, Basu MS, Reddy PS (1986). Genetic variability, character association, and path coefficients of quantitative traits in Virginia bunch varieties of groundnut. *Indian J. Agric. Sci.* 56: 816-821.

El-Hendawy SE, Hassan WM, Al-Suhaibani NA, Schmidhalter U (2017). Spectral assessment of drought tolerance indices and grain yield in advanced spring wheat lines grown under full and limited water irrigation. *Agric. Water Manag.* 182: 1-12. doi:10.1016/j.agwat.2016.12.003.

Gazal A, Dar ZA, Wani SH, Lone AA, Shikari AB, Ali G, Abidi I (2016). Molecular breeding for enhancing resilience against biotic and abiotic stress in major cereals. *SABRAO J. Breed. Genet*. 48(1): 1-32.

IPCC (2013). Intergovernmental Panel on Climate Change. Summary for Policymakers. In Climate Change: The Physical Science Basis; Contribution of Working Group I to the Fifth Assessment Report of IPCC. Cambridge University Press: Cambridge, UK, pp. 203.

Jan S, Mohammad F, Khan F (2015). Genetic potential and heritability estimates of yield traits in F_3 segregating populations of bread wheat. *Int. J. Environ.*4: 107-115.

Johnson HW, Robinson HF, Comstock RE (1955). Estimates of genetic and environmental variability in soybean. *Agron. J.* 47: 314-318.

Kamruzzaman M, Hwang S, Choi SK, Cho J, Song I, Song J, Jeong H, Jang T, Yoo S (2020).

Evaluating the impact of climate change on paddy water balance using the apex-paddy model. *Water* 12. doi:10.3390/w12030852.

Kumar S, Kumari P, Kumar U, Grover M, Singh AK, Singh R, Sengar RS (2013). Molecular approaches for designing heat-tolerant wheat. *J. Plant Biochem. Biotechnol.* 22: 359-371. doi.org/10.1007/s13562-013-0229-3.

Li H, Rasheed A, Hickey LT, He Z (2018). Fast-forwarding genetic gain. *Trends Plant Sci.* 23: 184-186. doi:10.1016/j.tplants.2018.01.007.

Li P, Ma B, Palta JA, Ding T, Cheng Z, Lv G, Xiong Y (2021). Wheat breeding highlights drought tolerance while ignoring the advantages of drought avoidance: A meta-analysis. *Eur. J. Agron.* 122: 126196, https://doi.org/10.1016/j.eja.2020.126196.

Mahdy EE, El-Karamity AE, Mokadem SA, AbdElmawgood AL, Fouad HM (2015). Selection for grain yield in bread wheat under normal irrigation and drought stress conditions. *J. Plant Prod. Mansoura Univ.,* 6: 547-562.

Mansour E, Moustafa ESA, Desoky EM, Ali MMA, Yasin MAT, Attia A, Alsuhaibani N, Tahir MU, El-Hendawy S (2020). Multidimensional evaluation for detecting salt tolerance of bread wheat genotypes under actual saline field growing conditions. *Plants (Basel)* 9. doi.org/10.3390/plants9101324.

Merida-Garcia R, Liu G, He S, Gonzalez-Dugo V, Dorado G, Galvez S, Solis I, Zarco-Tejada PJ, Reif JC, Hernandez P (2019). Genetic dissection of agronomic and quality traits based on association mapping and genomic selection approaches in durum wheat grown in Southern Spain. *PLoS One* 14: e0211718. doi:10.1371/journal.pone.0211718.

Mickelbart MV, Hasegawa PM, Bailey-Serres J (2015). Genetic mechanisms of abiotic stress tolerance translate to crop yield stability. *Nature Rev. Genet.* 16: 237-251. doi.org/10.1038/nrg3901.

Mwadzingeni L, Shimelis H, Dube E, Laing MD, Tsilo TJ (2016). Breeding wheat for drought tolerance: Progress and technologies. *J. Integr. Agric.* 15: 935-943. doi:10.1016/s2095-3119(15)61102-9.

Putri NE, Sutjahjo SH, Trikoesoemaningtyas, Nur A, Suwarno WB, Wahyu Y (2020). Wheat transgressive segregants and their adaptation in the tropical region. *SABRAO J. Breed. Genet.* 52(4): 506–522.

Rauf S, Al-Khayri JM, Zaharieva M, Monneveux P, Khalil F (2016). Breeding strategies to enhance drought tolerance in crops. In: Al-Khayri JM, Jain SM, Johnson DV (eds.), Advances in plant breeding strategies: Agronomic, abiotic and biotic stress traits. Cham: Springer International Publishing, pp. 397-445.

Saleem B, Khan A, Shahzad M, Ijaz F (2016). Estimation of heritability and genetic advance for various metric traits in seven F_2 populations of bread wheat (*Triticum aestivum* L.). *J. Agric. Sci., Belgrade* 61: 1-9. doi:10.2298/jas1601001s.

Sallam A, Alqudah AM, Dawood MFA, Baenziger PS, Borner A (2019). Drought stress tolerance in wheat and barley: Advances in physiology, breeding and genetics research. *Int. J. Mol. Sci.* 20. doi:10.3390/ijms20133137.

Sardouei-Nasab S, Mohammadi-Nejad G, Nakhoda B (2019). Yield stability in bread wheat germplasm across drought stress and non-stress conditions. *Agron. J.* 111: 175-181. doi:10.2134/agronj2018.06.0381.

SAS 9.2 (2008). Statistical Analysis System, version 9.2. SAS Institute Inc. Cary, NC, USA.

Shauka S, Kousar I, Fatima S, Shukat R, Ali A, Ahmad J, Akhtar N, Nadeem M, Farooq J, Ramzan M (2021). Evaluation of spring wheat genotypes for terminal heat stress. *SABRAO J. Breed. Genet*. 53 (2): 239-247.

Singh B (2001). Plant Breeding: Principles and Methods, 6th ed/Ed. Kalyani Publishers, New Delhi, India.

Singh RK, Choudhary BD (1987). Biometrical Methods in Quantitative Genetics. Kalyani Publishers, New Delhi, India.

Snedecor GW, Cochran WG (1967). Statistical Methods 6th ed. Ames, Iowa, Iowa State University, USA.

Sohail A, Rahman H, Farhat Ullah, Shah SMA, Burni T, Ali S (2018). Valuation of F_4 bread wheat (*Triticum aestivum* L.) genotypes for genetic variability, heritability, genetic advance, and correlation studies. *J. Plant Breed. Genet.* 6: 1-7.

Swailam MA, Mowafy SAE, EL-Naggar NZA, Mansour E (2021). Agronomic responses of diverse bread wheat genotypes to phosphorus levels and nitrogen forms in a semiarid environment. *SABRAO J. Breed. Genet*. 53(4) 592-608; https://doi.org/10.54910/sabrao2021.53.4.4.

Swelam DA (2015). Yield stability of some wheat genotypes under normal and water stress conditions. Zagazig University, Egypt.

Tembo B (2021). Genotype by environment interaction analysis of wheat (*Triticum aestivum* L.) grain yield under rain-fed conditions in Zambia. *SABRAO J. Breed. Genet*. 53(4): 609-619; https://doi.org/10.54910/sabrao2021.53.4.5.

Wricke G, Weber WE (1986). Quantitative Genetics and Selection in Plant Breeding. De Gruyter, Berlin, Germany.