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RESEARCH ARTICLE

Effect of heat stress on the inheritance and selection for earliness in bread wheat

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Abstract

This investigation was carried out at South Valley Univ., Exp. Farm, Qena, Egypt for estimating the nature of the genetic system governing days to heading by involving parents in a 7 × 7 diallel cross and their F_2-generations, which were planted under two different sowing dates in 2022/2023 and 2023/2024. The mean squares for environments, genotypes, and genotypes × environments interaction were highly significant for all studied traits. Late planting date decreased all studied traits as compared with normal planting date. At normal and late planting dates, the response to selection for earliness as percentage of deviation from the F_2-populations varied from -17.30 ($P_4 \times P_6$) to -3.81% ($P_4 \times P_5$) and from -12.12 ($P_5 \times P_7$) to -1.52% ($P_4 \times P_5$), respectively. Additionally, at normal and late date, the correlated response in spike length, 100-grain weight and grain yield was reduced; the first and second traits were more affected than third. As expected, both additive and dominance types of gene actions control the inheritance of this trait; however, the additive type of gene action was most important in the inheritance of earliness. Both additive and non-additive genetic variances were highly significant in the F_2-generations under both conditions in both seasons. Furthermore, days to heading had high narrow sense heritability under heat stress conditions in both seasons, but a low one under favorable conditions. Consequently, direct selection for earliness at heat stress is expected to be more effective than indirect selection.

Keywords: inheritance, selection, bread wheat and heat stress

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important crops and the primary source of food; it is grown extensively in Egypt and globally. In the diets of people and animals across the world, it provides a significant source of both protein and carbohydrate. Wheat may be grown in a variety of climates, although it is most often produced in regions with moderate winters and somewhat hot summers. According to Foreign Agricultural Service/USDA, 2024, it is cultivated on about 222.70 million hectares around the world. The production and productivity of wheat is 790.38 million metric tons and 3.55 metric tons ha^{-1} in the world, 328 million tons. In Egypt, wheat is one of the most significant and nutrient-dense cereal crops. In rural regions, it is frequently used with maize flour to produce bread, macaroni, biscuits, and other treats. Furthermore, the straw serves as an animal feed source. The total cultivated area of wheat reached about 1.411 million hectares and the total production reached about 1.35 million hectares and the total production reached about 8.87 million metric tons with an average of 6.57 metric tons ha^{-1} (Foreign Agricultural Service/USDA, 2024). However, Egypt does not produce enough wheat for domestic use. In order to fulfill the ongoing demand and close the gap between production and consumption, this necessitates that everyone involved pay more attention to increasing output. Reducing the

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disparity between wheat output and consumption is one of Egypt's national goals.

Periodic drought and heat stressors linked to climate change provide a challenge to wheat productivity and output (Alexandratos and Bruinsma, 2012 and Daryanto *et al.*, 2016). It is a C_3 crop that is sensitive to drought stress and high temperature conditions, especially during the post-anthesis growth stages. High temperature affects crops in different ways including poor germination and plant establishment, reduced photosynthesis, leaf senescence, decreased pollen viability and consequently production of less grain with smaller grain size (Ugarte *et al*., 2007; Asseng *et al*., 2011).

One of the main goals of wheat breeding projects is early maturity. While choosing acceptable people has always been the main goal of all breeding efforts, breeders are also interested in desirable genes and gene combinations. When choosing a breeding technique to create a cultivar type (hybrid, pure line, synthetic, etc.), gene activity has a significant role (Afridi *et al.,* 2017).

In order to improve the efficiency of wheat breeding programs, the diallel analysis approach has been widely employed for parent selection as a suitable scheme to quickly gather genetic information on yield attributes (Kohan and Heidari, 2014). Variance components and heritability estimates are two examples of the genetic factors for which it has been frequently employed (Xiang and Li, 2001).

The present study was conducted to:

a. Draw information about genetic mechanism- controlling days to heading in wheat.
b. Select the best condition for earliness.
c. Evaluate the associated response for certain variables, such as spike length, 100-grain weight, and grain yield/plant, which may be useful in formulating future breeding plans to create appropriate genotypes.

2. Materials and Methods

This investigation was conducted at Qena (Agric. Exper. Farm of South Valley Univ., Egypt) in 2022/2023 and 2023/2024 seasons. The soil type is sandy loam (CaCO3 sand was 66.70%, silt was 21.30%, clay was 12%, PH was 7.93, organic matter was 0.30, EC was 9.95 dSm^{-1}, calcium carbonate was 5.8%, SO--4 was, 52.3, K^+ was 0.80, Ca^{++} was 11.5, Mg^{++} was 11.3, H CO-3 was 20.00 and Cl- was 27.50).

Seven wheat cultivars with widely different in agronomic traits and varying origins were used as experimental materials. They were crossed in a 7 × 7 using a one-way diallel mating design. Table 1 shows the code, local names, pedigree and place of origin for the seven cultivars.

On November 26^{th}, 2022/2023, a favorable sowing date, twenty-eight genotypes (21 F_2-progenies and their seven parents) were planted in the experimental area. The randomized complete block design (RCBD) was used to set up the experiment. For each genotype in each replication, each experimental unit was a single row that was 3.5 meters long. The intervals between plants and rows were 10 cm and 30 cm, respectively. With the use of a dibble, two to three seeds were cultivated in each hole. Following germination, the seeds were thinned to produce a single, healthy seedling or hill. Similar practice was followed for the conduct of late sown experiment on 26^{th} of December 2022/2023.

For both planting dates, the same agricultural practices such as fertilizer, irrigation, hoeing, etc. were used. The number of days from planting until 50% of the heads emerged from the flag leaf sheath was known as the "days to heading." Each plot's earliest head was identified on the typical sowing date. At maturity, the earliest plant from each of the 21 F_2-generations was chosen; as a result, the selection intensity

Table 1. The local names, pedigree and origin of the seven genotypes used in this study

No.	Name	Pedigree	Origin
P_1	Sakha-94	Opta/Rayon//KAVZ	Egypt
P_2	Misr-2	SKAUZ/BAV92	Egypt
P_3	Sids-1	HD2172/PAVON"S"//1158.57/MAYA74"S"	Egypt
P_4	Gimmaza-9	SKAUZ/BAV92.CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S	Egypt
P_5	Giza-168	MRL/BUC/SERI. CM93046-8M-0Y-0M-ZY-0B-0GZ	Egypt
P_6	Shandaweel-1	SITE//MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC	Egypt
P_7	Sids-12	BUC//7C/ALD/5/MAYA74/ON//1160,1473//BB/GII14/CHAT"s"/6/ MAYA/VUL//CMH74A.630/4/*SX	Egypt

was 1/105. The 49 genotypes (21 F_2-generations, the earliest 21 F_3 families, and their seven parents) were assessed throughout the two planting dates in the 2023/2024 growing seasons. The average minimum and maximum temperature in 2022/2023 and 2023/2024 seasons are shown in Table 2. At maturity, thirty randomly selected plants from the central section of each plot were measured for spike length (cm) and grain yield/plant (g) at maturity. Plot mean was used to register the 100-grain weight (g). The analysis of variance technique applied to determine the significance of mean differences (Steel *et al.,* 1997). Diallel analysis, which applies to Hayman (1954), was used to estimate the genetic analysis for earliness and heredity in a restricted sense. After the assumption of a unity slope for the Wr/Vr regression line failed, Jinks *et al.,* (1969) proposed epistasis, which was used to identify and eliminate the parents involved in the non-allelic interaction from the diallel analysis of the remaining interaction free tables. The divergence of the chosen families from the F_2 mean and the superior parent of each population were used to compute the response to selection for earliness and corresponding response in spike length, 100-grain weight, and grain yield/plant. According to Falconer (1990) such selection can be considered as antagonistic selection since the favorable sowing date (High) caused late flowering date estimates, while selection was in the opposite direction (Towards earliness). The sensitivity was calculated as the difference between the F_3 performances in high and low yield environments divided by the same difference of the respective unselected F_2 population as described by Falconer (1990).

3- Results and Discussion

3.1. Selection for early heading

The effects of environments were significant ($p<0.1$) on earliness and the correlated traits *viz.*, spike length, 100-grain weight, and grain yield/plant, demonstrating that the large differences in climatic changes prevailing in the two sowing dates. Mean squares due to genotypes were significant ($p<0.1$) for earliness and the correlated traits over environments. There was a large range of variations among the genotypes for all traits under investigation. A considerable variation among genotypes of wheat was reported by Mwadzingeni *et al.,* (2017), Mwadzingeni *et al.,* (2018), Ahmad *et al* (2019), Adnan *et al.,* (2022) and Bhandari and Poudel (2024). A highly significant genotypes × environments interaction was also observed for these traits (Table 3).

These data reflected that wheat entries responded differently to the heat stress, emphasizing the essential is assessment these genotypes under different environments in order to identify the best genotype for a particular

Table 2. Average minimum and maximum monthly temperature (°C) in 2022/2023 and 2023/2024 seasons

Season		2022/2023			2023/2024		
Month	Day	Max.	Min.	Average	Max.	Min.	Average
Nov.	22 – 30	27.02	12.04	19.53	28.10	12.92	20.51
	Average	27.02	12.04	19.53	28.10	12.92	20.51
	1 – 10	26.26	11.36	18.81	27.57	13.02	20.30
Dec.	11 – 20	27.82	12.04	10.03	27.15	13.82	20.49
	21 – 31	21.70	9.38	19.93	24.22	11.73	17.98
	Average	25.26	10.93	18.09	26.31	12.86	19.59
	1 – 10	21.66	7.66	14.66	25.20	10.63	17.92
Jan.	11 – 20	22.91	8.06	15.49	23.80	7.55	15.68
	21 – 31	25.59	10.18	17.89	20.90	8.56	14.73
	Average	23.39	8.63	16.01	23.30	8.91	16.11
	1 – 10	20.99	7.94	14.47	23.44	7.40	15.42
Feb.	11 – 20	23.42	8.40	15.91	24.54	10.05	17.30
	21 – 28	27.13	10.02	18.58	27.27	13.20	20.24
	Average	23.85	8.79	16.32	25.08	10.22	17.65
	1 – 10	33.39	14.92	24.16	38.02	13.82	25.92
March	11 – 20	25.21	13.07	19.14	31.29	15.73	23.51
	21 – 31	29.97	14.44	22.21	30.91	13.91	22.41
	Average	29.52	14.14	21.83	33.41	14.49	23.95
	1 – 10	35.07	16.19	25.63	34.31	20.48	27.40
April	11 – 20	34.02	18.26	26.14	35.11	19.45	27.28
	21 – 30	34.84	20.00	27.42	38.86	22.83	30.85
	Average	34.64	18.15	26.40	36.09	20.92	28.51
May	1 – 15	36.37	20.69	28.53	36.72	21.95	29.34
	Average	36.37	20.69	28.53	36.72	21.95	29.34

+ Source of Meteorological Authority, South Valley University, Qena of east.

environment. Similar observations were made by Mwadzingeni *et al.,* (2017), Mwadzingeni *et al.,* (2018), Dhoot *et al.,* (2020), Adnan *et al.,* (2022) and Bhandari and Poudel (2024). Nonetheless, it appears that the groups of parents, F_2-generatins, and F_3-selected families differed significantly, demonstrating the important responses to selection. Ali and Abo-El-Wafa (2006) found similar results in wheat, stating that a large selection progress is expected to occur after the first cycle of selection than after second one. The genetic variety was exhausted by two cycles of selection for early heading (Ali, 2011; Mwadzingeni *et al.*, 2017 and Dhoot *et al.*, 2020). Thus, we limited our analysis to the data from the initial selection cycle. The attenuation of stress reduction in the correlated response in the correlated traits demonstrated the efficacy of selection.Heading date is an important trait of wheat. Wheat genotypes genetically differ in days to heading from early to late. Earlier genotypes offer greater security during the harvest, the environment at that time being marked by a late sowing date. So in breeding programs, wheat heading should also consider as an important trait. Phenotypic expression of any trait is the outcome of the genotype × environment interaction. The evaluated parental genotypes, their F_2-populations and F_3-selected families exhibited a wide variation for this trait under all tested environments. Tables 4 and 5 show the selection advance (once expressed as a percentage of deviation from the F_2-populations and the other from the earlier parent) as well as the average performance and range of days to 50% heading of the 7 parents, 21 F_2-populations, and the earliest 21 F_3-selected families under

Tabe 3. The combined analysis of variance of seven traits of the 7 parents, their 21 F_2-populations and the earliest 21 F_3-families sown under the two sowing dates

S. O. V.	df	Mean squares			
		Selection criteria	Correlated traits		
		Heading date	Spike length (cm)	100-grain weight (g)	Grain yield/plant (g)
Environments (Env.)	1	2220.63**	183.75**	13.507**	995.613**
Rep/Env.	4	1.41	0.09	0.003	10.460
Genotypes (G)	48	112.88**	3.96**	0.490**	19.388**
Parents (P)	6	52.61**	1.05*	0.107**	6.073**
F_2	20	38.92**	1.98**	0.325**	5.157**
F_3	20	51.89**	2.20**	0.439**	3.117**
P vs. F_2 vs. F_3	2	1643.06**	49.99**	3.798**	364.357**
G × Env.	48	9.36**	1.38**	0.122**	2.81**
Error	192	2.40	0.49	0.029	1.07

**; Significant at 1% probability levels.

favorable and heat-stressed conditions.

Days to heading was considerably altered by wheat genotypes under favorable and late sowing dates. In 2023/2024 growing season, the data on days to heading registered the earliest (69.33 days) cross ($P_3 \times P_7$) but it was the latest (80.00 days) cross ($P_1 \times P_2$) with an average of 74.29 days in the F_2-populations under favorable sowing date. Whereas, the cross $P_5 \times P_6$ resulted in the earliest cross (62.00 days) while the two crosses ($P_2 \times P_6$ and $P_3 \times P_6$) gave the latest (71.33 days) with an average of 67.95 days late sowing date in the F_2- populations (Table 5). Regarding the earliest F_3-selected families; $P_5 \times P_7$ recorded the earliest cross (61.00 days) while $P_3 \times P_6$ gave the latest cross (75.00 days) with the trail mean 67.21 days under favorable sowing date. Whereas, at late sowing date, $P_5 \times P_7$ resulted in the earliest (58.00 days) family, while the family $P_3 \times P_6$ was the latest (67.00 days) with the trail mean 62.78 days. The significant genotypes × environments interaction can be confirmed from the mean values for days to heading as the genotype showing early in favorable sowing date did not show early heading date in the late sowing date which meant that the ranking of genotypes changed on the basis for their performance for days to heading under favorable and late sowing dates (Table 4). Generally, earlier plants were observed in both F_2-populations and the earliest F_3-selected families in the late sowing date as compared to the favorable ones by 5 and 7 days, respectively. Nonetheless, the F_3-selected families were around 7 and 5 days earlier than the F_2-populations at advantageous and late sowing times, respectively (Table 4). The cross $P_5 \times P_7$ was the first F_3-selected family to record the earliest means of 61.00 and 58.00 days at favorable and late sowing dates, respectively. This illustrates the exceptional carry-over effect obtained after increasing earliness potential through selecting under favorable sowing date. Moreover, at late sowing date, the cross $P_1 \times P_6$ had significantly later different from the previous cross but it was insignificantly different during favorable sowing date. This exhibits the evidence of genotype × environment interactions. On the other side, only one cross ($P_5 \times P_6$) displayed insignificant response to selection under stress environments, while it demonstrated significantly response to selection under favorable conditions.

Table 4. Average of days to heading of the 7 parents and their 21 F_2-populations of wheat sown under favorable (F) and late (S) sowing dates in the 2022/2023 and 2023/2024 seasons

Genotypes	Days to heading			
	2022/2023		2023/2024	
	F	S	F	S
P_1	83.33	75.67	78.00	71.33
P_2	83.00	74.00	76.00	72.67
P_3	84.00	76.00	81.00	74.67
P_4	81.67	78.00	80.00	70.00
P_5	74.67	69.00	72.00	66.67
P_6	79.00	70.67	74.00	69.33
P_7	75.33	68.00	71.00	63.33
Range	74.67-84.00	68.00-78.00	71.00-81.00	63.33-74.67
Average of parents	80.14	73.05	76.00	69.71
$P_1 \times P_2$	80.00	74.00	80.00	69.67
$P_1 \times P_3$	79.33	73.67	75.00	69.67
$P_1 \times P_4$	78.67	74.00	75.00	71.00
$P_1 \times P_5$	72.67	71.00	73.00	67.67
$P_1 \times P_6$	76.00	71.00	72.00	66.00
$P_1 \times P_7$	73.67	68.00	73.00	65.00
$P_2 \times P_3$	80.33	71.00	74.00	68.33
$P_2 \times P_4$	85.67	73.33	75.00	70.33
$P_2 \times P_5$	79.67	75.00	78.00	64.67
$P_2 \times P_6$	77.00	72.00	75.00	71.33
$P_2 \times P_7$	77.67	72.00	75.00	67.00
$P_3 \times P_4$	79.67	72.00	74.00	70.33
$P_3 \times P_5$	73.67	70.00	71.00	64.67
$P_3 \times P_6$	82.00	69.50	79.00	71.33
$P_3 \times P_7$	79.00	64.00	69.33	65.67
$P_4 \times P_5$	72.00	71.00	70.00	66.00
$P_4 \times P_6$	82.67	71.00	79.00	70.00
P4 × P_7	77.00	73.00	76.67	69.00
$P_5 \times P_6$	76.00	67.00	71.00	62.00
$P_5 \times P_7$	75.33	68.00	72.00	66.00
$P_6 \times P_7$	74.33	69.00	73.00	65.33
Range	72.00-85.67	64.00-75.00	69.33-80.00	62.00-71.33
Average of F_2	77.73	70.93	74.29	67.95
$L.S.D_{0.05}$	2.34	2.72	2.72	1.94

Table 5. Average of days to heading of the 21 F_2-populations and the earliest 21 F_3-selected families sown under favourable (F) and late (S) sowing dates and the response to selection and the sensitivity

Populations	Favorable sowing date				Late sowing date				Sensitivity
	F_2	F_3	% Response to selection from		F_2	F_3	% Response to selection from		
			F_2	Bp			F_2	Bp	
$P_1 \times P_2$	80.00	71.33	-10.84**	-6.14**	69.67	65.00	-6.70**	-8.87**	0.61
$P_1 \times P_3$	75.00	67.00	-10.67**	-14.10**	69.67	63.33	-9.10**	-11.22**	0.69
$P_1 \times P_4$	75.00	70.00	-6.67**	-10.26**	71.00	65.67	-7.51**	-6.19**	1.08
$P_1 \times P_5$	73.00	65.33	-10.51**	-9.26**	67.67	61.00	-9.86**	-8.50**	0.81
$P_1 \times P_6$	72.00	62.00	-13.89**	-16.22**	66.00	60.00	-9.09**	-13.46**	0.33
$P_1 \times P_7$	73.00	65.33	-10.51**	-7.99**	65.00	61.33	-5.65**	-3.16*	0.50
$P_2 \times P_3$	74.00	67.33	-9.01**	-11.41**	68.33	64.33	-5.85**	-11.48**	0.53
$P_2 \times P_4$	75.00	71.00	-5.33**	-6.58**	70.33	63.33	-9.95**	-9.53**	1.64
$P_2 \times P_5$	78.00	70.33	-9.83**	-2.32 ns	64.67	63.33	-2.07	-5.01**	0.53
$P_2 \times P_6$	75.00	65.00	-13.33**	-12.16**	71.33	63.33	-1.22**	-8.65**	0.45
$P_2 \times P_7$	75.00	71.00	-5.33**	0.00 ns	67.00	65.33	-2.49*	3.16*	0.71
$P_3 \times P_4$	74.00	65.00	-12.16**	-18.75**	70.33	62.00	-1.84**	-11.43**	0.82
$P_3 \times P_5$	71.00	67.33	-5.17**	-6.49**	64.67	60.33	-6.71**	-9.51**	1.11
$P_3 \times P_6$	79.00	75.00	-5.06**	1.35ns	71.33	67.00	-6.07**	-3.36**	1.04
$P_3 \times P_7$	69.33	64.00	-7.69**	-9.86**	65.67	60.33	-8.13**	-4.74**	1.00
$P_4 \times P_5$	70.00	67.33	-3.81**	-6.49**	66.00	65.00	-1.52	-2.50*	0.58
$P_4 \times P_6$	79.00	65.33	-17.30**	-11.72**	70.00	62.00	-1.43**	-10.57**	0.37
$P_4 \times P_7$	76.67	72.33	-5.66**	0.87 ns	69.00	66.33	-3.87**	4.74**	0.78
$P_5 \times P_6$	71.00	63.33	-10.80**	-12.04**	62.00	61.00	-1.61	-8.50**	0.26
$P_5 \times P_7$	72.00	61.00	-15.28**	-14.08	66.00	58.00	-12.12**	-8.42**	0.50
$P_6 \times P_7$	73.00	65.00	-10.96**	-8.45**	65.33	60.33	-7.65**	-4.74**	0.61
Average of F_2	74.29	67.21	-	-	67.95	62.78	-	-	-

-, + Sings refers to F_3 segregates earlier or later than the F_2 or the better parent (Bp), respectively.

*, ** Significant at 0.05 and 0.01% probability levels, respectively.

3.2. Response to selection for selection criteria (Days to heading)

Estimation of the response to selection for earliness as percentage of deviation from the F_2-populations and the earlier parent as well as the sensitivity is presented in Table 6.

The response to selection for earliness as percentage of deviation from the F_2-populations varied from -17.30** ($P_4 \times P_6$) to -3.81**% ($P_4 \times P_5$) and from -12.12** ($P_5 \times P_7$) to -1.52% ($P_4 \times P_5$) at favorable and heat stress conditions, respectively. Moreover, all crosses had a negatively significant (p<0.01) response to selection under both environments except three crosses *viz.*, $P_2 \times P_5$, $P_4 \times P_5$ and $P_5 \times P_6$ were insignificantly under late sowing date. During favorable sowing date, seventeen crosses illustrated negative and significant (p<0.01) response to selection as percentage of deviation from the earlier parent varied from -18.75** ($P_3 \times P_4$) to 1.87^{ns}% ($P_4 \times P_7$), but at late sowing date, all crosses gave negative and significant (p<0.01) earlier than the earlier parent except two crosses *i.e.*, $P_2 \times P_7$ and $P_4 \times P_7$ were significantly positive. It varied from -13.46** ($P_1 \times P_6$) to 4.74**% ($P_4 \times P_7$). Ahmad *et al.* (2019), Dhoot *et al.* (2020), Nassar *et al.* (2020), Kamara *et al.* (2021) and Adnan *et al.* (2022) observed transgressive segregation for earliness.

3.3. Sensitivity to the environment

The sensitivity of the F_3-selected families under favorable and heat stressed environments is observed in Table 6. Antagonistic selection increased the sensitivity in five F_3-selected families, led to a mean sensitivity in 12 F_3-selected families and decreased sensitivity in 4 F_3-selected families.

3.4. Average performance and correlated response of the correlated traits

3.4.1. Average performance

The average performance of the correlated traits (Spike length, 100 grain weight and grain yield/plant) is exhibited in Table 6. The average of all F_2-generations for spike length was 10.18 and 8.75 cm under favorable and heat stress environments, respectively. Among the F_2-generations, the cross $P_2 \times P_4$ were produced the longest spikes; 11.30 and 10.60 cm, shortest spikes;

8.43 and 7.50 cm was produced by the cross $P_5 \times P_7$ at normal and late sowing dates, respectively. The average spike length for the F_3-selected families under normal sowing date was 9.14 cm, which ranged from 7.63 ($P_5 \times P_7$) to 10.80 cm ($P_2 \times P_4$). Likewise, it varied from 6.00 ($P_2 \times P_7$) to 9.20 cm ($P_3 \times P_5$) with an average of 7.52 cm under late sowing date (Table 6). The mean values of 100-grain weight for the F_2-populations exhibited slighter (3.55 g) for the cross $P_1 \times P_5$, whereas, the cross $P_3 \times P_4$ registered the heaviest 100-grain weight (4.76 g) at favorable environment while under heat stress environment (3.32 g) and (4.23 g) for the crosses $P_4 \times P_5$ and $P_5 \times P_6$, respectively (Table 6). The mean values for 100-grain weight of all 21 F_2-generations were 4.08 and 3.68 g at favorable and heat stress conditions, respectively (Table 6). The average for 100-grain weight of all 21 F_3-selected families was 3.79 and 3.30 g at favorable and late sowing dates, respectively. Among the F_3-selected

families, $P_5 \times P_6$ were produced the heaviest grains; 4.29 and 4.19 g, the slightest grains; 3.53 and 2.45 g was obtained by the cross $P_4 \times P_5$ at favorable and heat stress environments, respectively (Table 6). The average of 100-grain weight of F_2-generations and F_3-selected families at favorable sowing date was 0.40 and 0.49 g more than the crosses sown at late sowing date. The average performance estimated for grain yield/plant of all 21 F_2-populations were 20.32 and 16.30 g at favorable and heat stress environments, respectively (Table 6). Among the F_2-generations, the greatest mean values was observed in the cross $P_3 \times P_5$ (22.98 and 18.97

Table 6. Average of spike length, 100-grain weight and grain yield/plant of 21-F_2-populations, earliest 21-F_3-selected families and their seven parents at normal (F) and late sowing dates (S)

Populations	Spike length				100-grain weight				Grain yield/plant			
	F		S		F		S		F		S	
	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
$P_1 \times P_2$	10.07	8.73	8.77	8.53	3.80	3.61	3.53	3.52	19.30	16.18	15.62	13.62
$P_1 \times P_3$	10.07	9.43	9.40	6.60	4.51	3.83	3.72	3.27	20.75	17.36	17.40	12.85
$P_1 \times P_4$	10.77	10.07	9.20	8.10	3.97	3.7	3.71	3.44	21.70	17.76	16.67	14.91
$P_1 \times P_5$	10.33	9.07	8.83	7.63	3.55	3.74	3.37	2.81	20.22	16.68	17.68	12.13
$P_1 \times P_6$	10.25	8.90	8.40	8.30	3.78	3.76	3.74	3.72	18.95	16.63	14.85	13.54
$P_1 \times P_7$	10.43	8.93	9.30	8.50	4.38	3.83	3.80	3.22	19.83	15.67	14.20	12.99
$P_2 \times P_3$	9.70	7.77	8.23	7.50	4.19	3.81	3.54	2.61	20.77	16.61	15.69	13.38
$P_2 \times P_4$	11.30	10.80	10.60	6.20	4.15	3.74	3.53	2.68	19.46	16.28	15.72	13.67
$P_2 \times P_5$	10.73	9.47	8.73	6.97	4.02	3.76	3.68	3.27	17.86	15.30	13.69	12.10
$P_2 \times P_6$	9.30	8.80	8.20	7.60	3.65	3.63	3.59	3.49	20.03	15.75	14.79	12.42
$P_2 \times P_7$	9.85	9.30	8.20	6.00	3.96	3.61	3.52	3.36	20.81	16.62	15.84	13.22
$P_3 \times P_4$	10.70	10.30	8.90	8.30	4.76	4.20	4.14	3.81	21.54	17.63	16.97	14.37
$P_3 \times P_5$	11.15	10.30	9.30	9.20	4.01	3.75	3.64	3.61	22.98	17.27	18.97	15.14
$P_3 \times P_6$	9.50	8.50	8.60	7.80	3.86	3.84	3.69	3.38	20.41	16.60	15.97	13.41
$P_3 \times P_7$	10.47	9.50	8.67	7.80	4.21	3.72	3.66	3.06	20.84	16.89	15.11	14.73
$P_4 \times P_5$	10.09	8.97	8.60	7.20	3.97	3.53	3.32	2.45	20.32	16.94	17.49	13.01
$P_4 \times P_6$	11.23	8.67	7.90	6.20	4.08	3.89	3.89	3.71	19.76	16.30	16.08	13.06
$P_4 \times P_7$	9.40	8.80	8.70	8.60	3.86	3.82	3.62	3.19	20.31	16.71	16.23	13.60
$P_5 \times P_6$	9.97	8.53	9.10	6.80	4.45	4.29	4.23	4.19	21.49	17.50	18.48	12.03
$P_5 \times P_7$	8.43	7.63	7.50	7.23	4.41	3.79	3.56	3.39	20.52	18.01	18.66	14.85
$P_6 \times P_7$	10.00	9.50	8.70	6.90	4.18	3.76	3.70	3.17	18.90	15.91	16.15	13.72
Average	10.18	9.14	8.75	7.52	4.08	3.79	3.68	3.30	20.32	16.70	16.30	13.46
P_1	10.10		8.50		4.14		3.78		20.48		16.22	
P_2	10.43		9.70		3.85		3.59		21.49		16.46	
P_3	11.70		8.20		4.08		3.96		21.50		16.88	
P_4	11.00		9.00		3.88		3.68		20.83		16.87	
P_5	9.70		8.50		3.89		3.58		19.62		15.62	
P_6	10.47		9.08		4.13		3.83		18.14		14.58	
P_7	10.75		7.60		4.04		3.44		18.62		16.07	
Average	10.59		8.65		4.00		3.69		20.10		16.10	
$L.S.D_{0.05}$	1.08		1.18		0.27		0.27		1.78		1.53	

g), the lowest mean values was registered by the cross $P_2 \times P_5$ (17.86 and 13.69 g) during favorable and heat stress environments, respectively (Table 6). The average performance of grain yield/plant for the F_3-selected families ranged from 15.30 ($P_2 \times P_5$) to 18.01 ($P_5 \times P_7$)with an average of 16.70 g at favorable environment. Likewise, it ranged from 12.03 ($P_5 \times P_7$) to 15.14 ($P_3 \times P_5$) with an average of 13.46 g at heat stress environments (Table 6). The average of grain yield/plant of F_2-generations and F_3-selected families at favorable environment was 4 and 3 g more than the crosses sown at heat stress environment. Thus, the grain weight and grain yield/plant of F_2-generations and F_3-selected families were decreased grain yield because of heat stress environment and hence favorable environment was superior to late sowing date. From the above data, it is demonstrated that the sowing at 26th of December (Late sowing date) decreased spike length, 100-grain weight and grain yield/plant by 13.79, 9.80 and 19.78% in the F_2-populations and by 20.84, 12.93 and 19.40% in the F_3 early selected families, respectively. Given that the highest temperature at this time was 33.41ºC under normal conditions and 36.09ºC under stress conditions, the decrease in both 100-grain weight and grain yield/plant may have resulted from rising temperatures during the grain filling phase under heat stress conditions (late planting date). Similar results were observed by Abd El-Hady *et al* (2018), Kumar *et al* (2019), Awan *et al* (2019), Ahmad *et al* (2019), Kamara *et al* (2021) and Adnan *et al* (2022) who found that spike length, 100-grain weight and grain yield were decrease under heat stress conditions (Late sowing date). Fischer and Maurer (1978) reported that if the temperature increased by 1ºC over the optimum range between the end of the tillering and the grain filling stage, grain production decreased by 4%.

3.4.2. Correlated response of the correlated traits

The correlated response of spike length, 100 grain weight and grain yield/plant is illustrated in Table 7. Direct selection for earliness was accompanied with an average undesirable decrease of the correlated response of the studied traits from the F_2-populations and the better parent under both conditions. Almost all selections produced less spike length, 100 grain weight and grain yield/plant than the better parent under both environments except the cross $P_5 \times P_7$ cross did not differ from the better parent under both conditions. Also, the cross $P_1 \times P_6$ did not differ from the F_2 mean under heat stress condition, whereas these traits were significantly decreased under favorable condition (Table 7). Similar results were obtained by Ali and Abo-El-Wafa (2006) for grain weight and grain yield/plant. Under favorable conditions, spike length and grain yield/plant in only one cross ($P_6 \times P_7$) did not deviate from the F_2 mean; under heat stress, however, these traits were markedly reduced. The cross $P_1 \times P_7$ was significantly reduced in spike length, 100-grain weight and grain yield/plant under favorable conditions, but benefitted from early heading under heat stress conditions in these traits. In three crosses were significantly decreased at heat stress conditions *viz*., $P_1 \times P_6$, $P_1 \times P_7$ and $P_3 \times P_7$, but it benefited from earliness under heat stress conditions (Table 7). If selection was carried out under a normal sowing date and there was no information available on their performance at a late sowing date, these selections were not to be selected. These results agree with reported by Ali and Abo-El-Wafa (2006), El-Morshidy *et al.* (2010), Singh *et al.* (2014), Mahdy *et al.* (2015), Kumar *et al.* (2019), Awan *et al.* (2019), Ahmad *et al.* (2019), Kamara *et al.* (2021) and Adnan *et al.* (2022). .3.1 .3The genetic system controlling heading date.

Table 8 shows the results of the diallel analysis of variance for heading traits in favorable and heat-stressed circumstances. The results demonstrated that both additive "a" and non-additive "b" genetic variances were significant (p<0.01) in the F2-generations under favorable and heat stress environments in the two seasons. In the genetic control of days to heading in the F2-populations in the two habitats over both seasons, the additive component accounted for a significantly larger proportion than the non-additive component, indicating that selection in the F2 in these materials is feasible. In the genetic control of days to heading in the F_2-populations in the two environments over both seasons, the additive component accounted for a much larger proportion than the non-additive component, indicating that selection in the F_2 in these materials is feasible. El-Morshidy *et al.* (2010), Ali (2011), Hassan (2014), Mahdy *et al.* (2015), Al-Ashkar (2020) and Nassar *et al.* (2020) demonstrated that two cycles of selection for early heading exhausted the genetic variation, and that greater selection advance is expected to

Table 7. The correlated response in spike length, 100-grain weight and grain yield/plant after selection for early heading in 21 F_2-populations of wheat plant sown under favorable and heat stress conditions

Populations	Spike length				100-grain weight				Grain yield/plant			
	Favorable envi.		Heat stress envi.		Favorable envi.		Heat stress envi.		Favorable envi.		Heat stress envi.	
	% Correlated response as a deviation from the		% Correlated response as a deviation from the		% Correlated response as a deviation from the		% Correlated response as a deviation from the		% Correlated response as a deviation from the		% Correlated response as a deviation from the	
	F_2	BP	F_2	BP	F_2	BP	F_2	BP	F_2	BP	F_2	BP
$P_1 \times P_2$	-13.31*	-16.30**	-2.74	-12.06	-5.00	-12.80**	-0.28	-6.88	-16.17**	-24.71**	-12.80**	-17.25**
$P_1 \times P_3$	-6.36	-19.40**	-29.79**	-22.35**	-15.08**	-7.49*	-12.10**	-17.42**	-16.34**	-19.26**	-26.15**	-23.87**
$P_1 \times P_4$	-6.50	-8.45	-11.96	-10.00	-6.80*	-10.63**	-7.28*	-8.99**	-18.16**	-14.74**	-10.56*	-11.62*
$P_1 \times P_5$	-12.20*	-10.20*	-13.59*	-10.24	5.35	-9.66**	-16.62**	-25.66**	-17.51**	-18.55**	-31.39**	-25.22**
$P_1 \times P_6$	-13.17*	-15.00**	-1.19	-8.59	-0.53	-9.18**	-0.53	-2.87	-12.24*	-18.80**	-8.82	-16.52**
$P_1 \times P_7$	-14.38**	-16.93**	-8.60	0.00	-12.56**	-7.49*	-15.26**	-14.81**	-20.98**	-23.49**	-8.52	-19.91**
$P_2 \times P_3$	-19.90**	-33.59**	-8.87	-22.68**	-9.07**	-6.62*	-26.27**	-34.09**	-20.03**	-22.74**	-14.72**	-20.73**
$P_2 \times P_4$	-4.42	-1.82	-41.51**	-36.08**	-9.88**	-3.61	-24.08**	-27.17**	-16.34**	-24.24**	-13.04**	-18.97**
$P_2 \times P_5$	-11.74*	-9.20	-20.16**	-28.14**	-6.47	-3.34	-11.14**	-8.91*	-19.05**	-28.80**	-11.61*	-26.49**
$P_2 \times P_6$	-5.38	-15.95**	-7.32	-21.65**	-0.55	-12.11**	-2.79	-8.88*	-21.37**	-26.71**	-16.02**	-24.54**
$P_2 \times P_7$	-5.58	-13.49**	-26.83**	-38.14**	-8.84*	-10.64**	-4.55	-6.41	-20.13**	-22.66**	-16.54**	-19.68**
$P_3 \times P_4$	-3.74	-11.97*	-6.74	-7.78	-11.76**	2.94	-7.97*	-3.79	-18.15**	-18.00**	-15.32**	-14.87**
$P_3 \times P_5$	-7.62	-11.97*	-1.08	8.24	-6.48	-8.09*	-0.82	-8.84*	-24.85**	-19.67**	-20.19**	-10.31*
$P_3 \times P_6$	-10.53	-27.35**	-9.30	-14.10*	-0.52	-7.02*	-8.40*	-14.65**	-18.67**	-22.79**	-16.03**	-20.56**
$P_3 \times P_7$	-9.26	-18.80**	-10.03	-4.88	-11.64**	-8.82**	-16.39**	-22.73**	-18.95**	-21.44**	-2.51	-12.74**
$P_4 \times P_5$	-11.10*	-18.45**	-16.28**	-20.00**	-11.08**	-9.25**	-26.20**	-33.42**	-16.63**	-18.67**	-25.61**	-22.88**
$P_4 \times P_6$	-22.80**	-21.18**	-21.52**	-31.72**	-4.66	-5.81	-4.63	-3.13	-17.51**	-21.75**	-18.78**	-22.58**
$P_4 \times P_7$	-6.38	-20.00**	-1.15	-4.44	-1.04	-5.45	-11.88**	-13.32**	-17.73**	-19.78**	-16.20**	-19.38**
$P_5 \times P_6$	-14.44**	-18.53**	-25.27**	-25.11**	-3.60	3.87	-0.95	9.40**	-18.57**	-10.81*	-34.90**	-25.14**
$P_5 \times P_7$	-9.49	-29.02**	-3.60	-14.94 ns	-14.06**	-6.19	-4.78	-5.31 ns	-12.23*	-8.21	-20.42**	-4.93 ns
$P_6 \times P_7$	-5.00	-11.63*	-20.69**	-24.01**	-10.05**	-8.96**	-14.32**	-17.23**	-10.92	-14.55**	-15.05**	-14.62**
Average	-10.16	-16.63	-13.72	-16.60	-6.87	-6.97	-10.34	-13.10	-17.74	-20.02	-16.91	-18.71

occur after the first cycle of selection than following the second. In addition, mean squares due to the two items "a" and "b" differed from environment to another. This reveals that the interaction of both components (Additive and dominance) with environments. Similar resultswere found by several workers (Afridi *et al.*; 2017, Abd El-Hady *et al.*; 2018, Khan and Hassan; 2018 and El-Said; 2018). However, Jadoon *et al*. (2013) found that because the two genetic components differed significantly, the additive (a) and non-additive (b) components were equally relevant in the inheritance of heading date. In contrast, Al-Timimi *et al.* (2020) observed that the dominance type of gene action was the most prevalent genetic component in inheritance of days to heading trait. Mean squares due to the item b_1 were significant ($p<0.01$) for days to heading in the F_2-generations under favorable and heat stress conditions in the two seasons, showing that the dominance deviation in one direction. However, in the F_2-populations at normal and late sowing dates in the first and second seasons, the mean square due to b2 component was significant ($p<0.01$) for this trait, indicating an imbalance in the distribution of dominant and recessive alleles. For days to heading, it is evident from this unequal genes distribution that some parents have far more dominant alleles than others. Additionally, specific genes/combination complexes for this trait in the F_2-populations and the parents at both sowing dates in the first and second seasons were responsible for the mean squares resulting from item b_3 values being significant ($p<0.01$), confirming residual dominance (Table 8). These results are in accordance with Ali and Abo-El-Wafa (2006), Afridi *et al.* (2017), Abd El-Hady *et al.* (2018), Khan and Hassan (2018) and El-Said (2018).

3.6. Graphical (Wr/Vr) analysis

The Wr/Vr graphical analysis (Figure 1) demonstrated that the additive-dominance model fitted the data under both conditions in the two seasons. Regression line does not deviate from unity, so epistasis is absent for this trait for the F_2-generations. This shows that the non-allelic interaction was absent for this trait.

The Wr/Vr graph indicated that the regression line crossed the Wr-axis at the positive part for the number of days to heading under heat stress conditions in the two seasons. This suggests that the gene action is incomplete or partial dominance, and early generation selection may be beneficial for this trait. The dominance rati $(H1/D)^{0.5}$, which was less than one, supported this conclusion. Genetic variability among the parents is reflected by the array points dispersed over the regression line for this trait in the F_2-generations. Parents would prefer delayed selection for this trait since, even under favorable conditions in the two seasons, negative intercepts of the Wr/Vr regression line suggested over-dominance gene activity may cause problem for selection in early generations. In the first season, for example, the point that represented the latest parent P_2 had the most recessive alleles because it was located farthest from the genesis point under normal irrigation. However, in the second season, it occupied a position near the point of origin under conditions of water stress, indicating a large fraction of dominant alleles. Similar results were obtained by Kheiralla and Sherif (1992), Kheiralla *et al*., (2001) and Ali and Abo-El-Wafa (2006).

3.7. Genetic components

Table 9 shows the estimates of the genetic parameters for days to heading of 7 parents and their 21 F_2-populations in the 2022/2023 and 2023/2024 seasons under favorable and heat-stressed conditions. In the first and second seasons, the F_2-generations under favorable and heat-stressed conditions had a significant ($P \leq 0.01$) additive effect "D" for days to heading, according to the genetic component of variance analysis. However, significant ($P \leq 0.01$) values

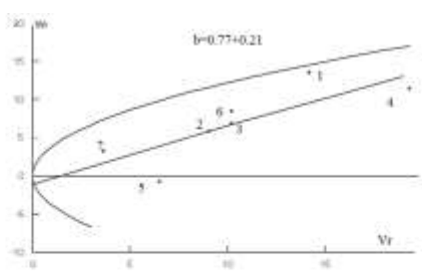
Table 8. Daillel analysis of variance for days to heading of the 7 parents and their 21 F_2-populations sown under favorable (F) and heat stress (S) conditions.

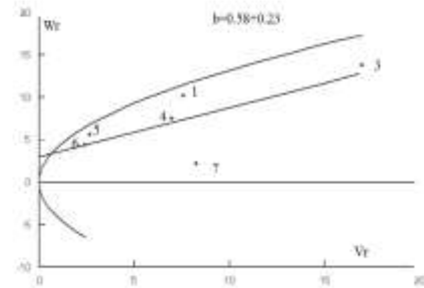
Item	df		Mean squares			
			Days to heading in 2022/2023		Days to heading in 2023/2024	
			F	S@	F	S@
a	6	5	179.29**	363.20**	112.57**	55.05**
b	21	15	38.11**	74.07**	72.95**	27.20**
b_1	1	1	104.93**	336.20**	69.52	118.41*
b_2	6	5	18.27**	23.80**	46.93**	30.09**
b_3	14	9	41.85**	72.87**	87.79**	15.47**
Block × a	12	10	0.49	5.86	7.69	2.28
Block × b	42	30	0.48	5.40	6.08	1.88
Block × b_1	2	2	0.08	0.07	8.31	5.87
Block × b_2	12	10	0.12	2.21	5.42	3.89
Block × b_3	28	18	0.66	7.77	6.19	0.33
Block interaction	96	70	0.27	3.15	3.70	1.13

*, **; Significant at 5 and 1% probability levels, respectively.
Each item is tested against the block interaction.
@ One array omitted (6 parents)

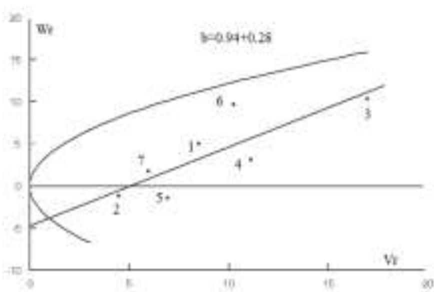
of dominance H_1 and H_2 illustrated for the same character in the F_2-generations under all tested conditions except at heat stress condition in the first season. This demonstrates how both additive and non-additive gene action play an important role in controlling this trait. For days to heading in the F_2-generations under both conditions in the two seasons, the asymmetrical distribution of positive and negative genes among the parental genotypes was demonstrated by the greater value of H_1 than H_2 and the ratio of $H_2/4H_1$ (Table 9). Similar results were obtained by Kumar *et al* (2015), Afridi *et al* (2017), Khan and Hassan (2018), Ahmad *et al*. (2019) and Al-Timimi *et al*. (2020) Kamara *et al.* (2021) found that H_1 values were greater than the H_2 values for days to heading. . Meanwhile, the results in Table 9 showed positive value of F in the F_2-generations under both conditions in 2022/2023 and 2023/2024 seasons, suggesting that the dominant alleles were more frequent than recessive ones for days to heading. Furthermore, the environmental variance "E" was non-significant and positive, suggesting that the absence of environmental factors on the trait's phenotypic expression. With the exception of the first season's favorable sowing date, the weighted measure of average degree of dominance $(H_1/4D)^{1/2}$ for days to heading under both conditions test was less than one, indicating the presence of partial dominance that could be enhanced by individual phenotypic selection in the early generation for this character under these conditions. However, in the first season, it was more than unity for days to heading in the F_2-generations under avorable conditions, suggesting that the presence of over dominance for this trait. Consequently, selection for this trait in the early segregating generations will be of little use under this condition. The asymmetrical distribution of positive and negative alleles among the parents was shown by the F_2-generations' $H_2/4H_1$ values, which were lower than their maximum value (0.25) for days to heading under favorable and

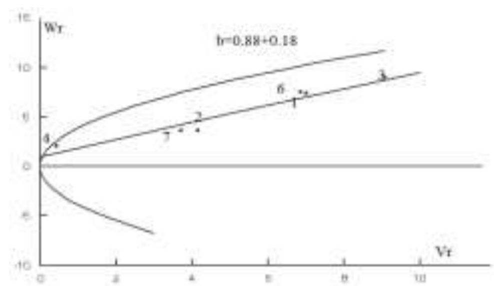
Favorable condition   Stress condition





a.   b.





c.   d.

Fig. 1.Wr/Vr graph for days to heading during the 2022/2023 season (a&b) and 2023/2024 season (c&d) under favorable and heat stress conditions.

heat stress conditions in the 2022/2023 and 2023/2024 seasons. The ratio of dominant to recessive genes suggested that the parents of these materials carried dominant alleles. For days to heading under favorable and late sowing dates in the first and second seasons, the ratio of dominant to recessive genes in the parents' KD/KR was greater than unity, indicating that the dominant alleles control this trait in the F_2-generations under all environments. Heritability estimates in narrow sense for days to heading (Table 9) were low at favourable conditions in the two seasons, indicating that most genetic variances were due to non-additive genetic effects for days to heading. These findings support the aforementioned results on genetic components in which H_1 estimates played a greater role in the inheritance of this character; therefore, selection would be effective in later generations. The narrow sense heritability was low for days to heading in the F_2-generation, according to similar findings by Jadoon *et al.*

Table 9. Estimates of the genetic parameters for days to heading of 7 parents and their derived 21 F_2-populations sown under favorable (F) and heat stressed (S) conditions

Parameters	Days to heading in 2022/2023		Days to heading in 2023/2024	
	F	S@	F	S@
D	14.90±2.28	16.57±2.79	14.08±2.09	14.59±0.57
H_1	93.75±22.00	26.99±28.35	128.20±20.11	46.82±5.51
H_2	76.96±19.39	23.64±25.33	103.24±17.72	36.27±4.85
F	4.36±10.93	9.76±13.57	26.60±9.98	14.73±2.74
E	0.92±12.93	0.92±16.88	0.92±11.81	0.48±3.24
$(H_1/4D)^{1/2}$	1.25	0.64	0.22	0.89
$H_2/4H_1$ (uv)	0.21	0.22	0.20	0.19
KD/KR	1.014	1.003	1.002	1.003
Narrow sense heritability	0.37	0.75	0.39	0.70

@ Six parents.

Where:
D = additive effect variance, H_1 = dominance effects, H_2 = non-additive effects, F= relative frequencies of dominant vs. recessive genes in the parents, E = expected environmental variation, $(H_1/4D)^{0.5}$ = mean degree of dominance at each locus, $H_2/4H_1$ = average frequency of + versus - alleles at loci exhibiting dominance, KD/KR =total number of dominant/recessive alleles in the parents and h^2(ns) = narrow sense heritability.

(2013), Afridi *et al.* (2017), Abd El-Hady *et al.* (2018), Zaied *et al.* (2018), Khan and Hassan (2018) and Kamara *et al*. (2021). Selection strategies for the best combiners that improve the trait of interest would be effective because the narrow-sense heritability of days to heading was rather high during heat stress conditions in both seasons. Zare-Kohan and Herdari (2014), Qabil (2017) and El-Said (2018) showed that the narrow sense heritability was high for days to heading.

4. Conclusion

The present study exhibited that mean squares due to environments, genotypes (parents, their F_2-populations and F_3-selected families) as well as the genotypes × environments interaction were significant (p<0.01) for selection criterion (Days to heading) and correlated traits under study. Selection for earliness in these populations was efficient to increase the selection criterion and could be accompanied with adverse effects on all studied correlated traits. The correlated response that the reduction% in spike length and 100-grain weight were, on average, more than that in grain yield under both environments. From results, it displayed that the lower spike length, 100-grain weight and grain yield/plant under both conditions when selection for earliness. However, one of these selections was good grain yield under stress condition. In order to increase yield under heat stress, selection and testing based solely on this small sample of populations and settings under favorable or stressful conditions might not be the most effective. The F_2-generations under both conditions and seasons showed significant (p<0.01) additive "a" and non-additive "b" genetic variations. In the genetic control of days to heading in the F_2-populations at the two environments during both seasons, the additive component accounted for a much larger percentage than the non-additive component.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

All authors of the manuscript have read and agreed to the publication

that all authors have agreed to the submission to the journal

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request

Competing interests

The authors declare that they have no conflicts of interest.

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Authors' contributions

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5. References

Abd El-Hady, A. and Ramadan, R. (2018). ‘Genetic analysis for yield and its components in bread wheat.’ Journal of Agricultural Chemistry and Biotechnology, 9(4), pp. 111-121.

Abd El-Hady, A. and Ramadan, R. (2018). ‘Genetical studies on yield and its components of four bread wheat cultivars.’ Journal of Agricultural Chemistry and Biotechnology, 9(4), pp. 123-135.

Adnan, M., Khan, A., Mohammad, F., Ali, F., and Hussain, Q. (2022). ‘Impact of late sowing on morphological and yield traits in 40s bread wheat.’ Journal of Soil, Plant and Environment, 1(1), pp. 1-18.

Afridi, K., Khan, N. U., Mohammad, F., Shah, S. J. A., Gu, S., Khalil, I. A., and Khan, S. M. (2017). ‘Inheritance pattern of earliness and yield traits in half-diallel crosses of spring wheat.’ Canadian Journal of Plant Science, 97(5), pp. 865-880.

Ahmad, F., Khan, S., Ahmad, S. Q., Khan, H., Khan, A., and Muhammad, F. (2011). ‘Genetic analysis of some quantitative traits in bread wheat across environments.’ African Journal of Agricultural Research, 6(3), pp. 686-692.

Ahmed, N., Chowdhry, M. A., Khaliq, I., and Maekawa, M. (2013). ‘The inheritance of yield and yield components of five wheat hybrid populations under drought conditions.’ Indonesian Journal of Agricultural Science, 8(2), pp. 53-59.

Ahmed, F., Khan, S., Ahmad, S. Q., Khan, H., Khan, A., and Muhammad, F. (2019). ‘Genetic analysis of some quantitative traits in bread wheat across environments.’ African Journal of Agriculture, 6(12), pp. 1-7.

Al-Ashkar, I., Alotaibi, M., Refay, Y., Ghazy, A., Zakri, A., and Al-Doss, A. (2020). ‘Selection criteria for high-yielding and early-flowering bread wheat hybrids under heat stress.’ PloS One, 15(8), e0236351. DOI: 10.1371/journal.pone.0236351.

Alexandratos, N. and Bruinsma, J. (2012). ‘World agriculture towards 2030/2050: No. 12-03.’ Rome, FAO.

Ali, M. A. (2011). ‘Response to pedigree selection for earliness and grain yield in spring wheat under heat stress.’ Asian Journal of Crop Science, 3(3), pp. 118-129.

Ali, M. A. and Abo-El-Wafa, A. M. (2006). ‘Inheritance and selection for earliness in spring wheat under heat stress.’ Assiut Journal of Agricultural Sciences, 37(4), pp. 77-94.

Al-Timimi, O. A. A., Al-Jubori, J. M. A., and El-Hosary, A. A. A. (2020). ‘Genetic analysis of F1 diallel cross in wheat (Triticum aestivum L.).’ Plant Archives, 20(2), pp. 4131-4137.

Asseng, S., Oster, I. F., and Turner, N. C. (2011). 'The impact of temperature variability on wheat yields.' pp. 997-1012.

Awan, S. I., Ahmed, M. S., Farooq, J., Ahmad, S. D., Ilyas, M., Shah, A. H., and Hasan, L. (2011). 'Genetic model analysis on seedling and maturity traits in wheat under rainfed conditions.' Frontiers of Agriculture in China, 5, pp. 486-496.

Awan, U., Sial, M. A., Mari, S. N., and Memon, M. H. (2019). 'Earliness and yielding ability of selected wheat (Triticum aestivum L.) lines based on field performance.' International Journal of Biosciences, 15(5), pp. 296-307.

Bhandari, R. and Poudel, M. R. (2024). 'Genotype × environment interaction and selection parameters for high yielding wheat genotypes under irrigated and heat stress environment.' Journal of Sustainable Agriculture and Environment, pp. 1-13.

Daryanto, S., Wang, L., and Jacinthe, P.-A. (2016). 'Global synthesis of drought effects on maize and wheat production.' PLoS One, 11, e0156362.

Dhoot, M., Sharma, H., Badaya, V. K., and Dhoot, R. (2020). 'Heterosis for earliness and heat tolerant trait in bread wheat (Triticum aestivum L.) over the environments.' International Journal of Current Microbiology and Applied Science, 9(3), pp. 624-630.

El-Morshidy, M. A., Kheiralla, K. A., Ali, M. A., and Ahmed, A. A. S. (2010). 'Efficiency of pedigree selection for earliness and grain yield in two wheat populations under water stress conditions.' Assiut Journal of Agricultural Sciences, 37, pp. 77-94.

El-Morshidy, M., Khairallah, K. A., Ali, M. A., and Said, A. A. (2010). 'Response to selection for earliness and grain yield in wheat (Triticum aestivum L.) under normal and water stress conditions.' Assiut Journal of Agricultural Sciences, 41(2), pp. 1-23.

El-Said, R. (2018). 'Assessment of genetical parameters of yield and its attributes in bread wheat (Triticum aestivum L.).' Journal of Agricultural Chemistry and Biotechnology, 9(10), pp. 243-251.

Falconer, D. S. (1990). 'Selection in different environments: effects on environmental sensitivity (reaction norm) and on mean performance.' Genetic Research, 50, pp. 57-70.

Foreign Agricultural Service/USDA (2024).

Hassan, M. S. (2014). 'Selection for earliness in bread wheat (Triticum aestivum L.) under infertile soil conditions.' Egyptian Journal of Agronomy, 36(2), pp. 77-187.

Hayman, B. I. (1954). 'The theory and analysis of diallel crosses II.' Genetics, 43, pp. 63-85.

Jadoon, S. A., Mohammad, F., Ullah, H., and Khalil, I. H. (2013). 'Gene action for pre and post-harvest traits in F2 wheat populations.' QScience Connect, 2012(1), pp. 11.

Jinks, J. L., Perkins, J. M., and Breese, E. L. (1969). 'A general method of detecting additive, dominance and epistatic variation for metrical traits. Application to inbred lines.' Heredity, 24, pp. 45-57.

Kamara, M. M., Ibrahim, K. M., Mansour, E., Kheir, A. M., Germoush, M. O., Abd El-Moneim, D., and Rehan, M. (2021). 'Combining ability and gene action controlling grain yield and its related traits in bread wheat under heat stress and normal conditions.' Agronomy, 11(8), pp. 1450.

Khan, S. N., and Hassan, G. (2018). 'Inheritance studies of yield and yield related traits in bread wheat genotypes.' Sarhad Journal of Agriculture, 34(4), pp. 948-954.

Kheiralla, K. A., and Sherif, T. H. I. (1992). 'Inheritance of earliness and yield in wheat under heat stress.' Assiut Journal of Agricultural Sciences, 23, pp. 105-126.

Kheiralla, K. A., El-Morshidy, M. A., and Zakaria, M. M. (2001). 'Inheritance of earliness and yield in bread wheat under favorable and late sowing dates.' The Second P1. Breed. Conf., October 2nd, Assiut University, pp. 219-239.

Kohan, M. Z., and Heidari, B. (2014). 'Diallel cross study for estimating genetic components underlying wheat grain yield.' Journal of Biological and Environmental Sciences, 8(22), pp. 37-51.

Kumar, D., Kerkhi, S. A., Singh, G., and Singh, J. B. (2015). 'Estimates of genetic parameters for grain yield, agro-morphological traits and quality attributes in bread wheat (Triticum aestivum L.).' Indian Journal of Agricultural Sciences, 85(5), pp. 622-627.

Kumar, J., Kumar, A., Kumar, M., Singh, S. K., and Singh, L. (2019). 'Inheritance pattern of genes for morpho-physiological and yield traits in wheat (Triticum aestivum L.).' Cereal Research Communications, 47(2), pp. 191-204.

Mahdy, E. E., El-Karamity, A. E., Mokadem, S. A., Abd-Elmawgood, A. L., and Fouad, H. M. (2015). 'Selection for earliness in bread wheat under normal irrigation and drought stress conditions.' Journal of Plant Production, 6(4), pp. 529-545.

Mwadzingeni, L., Shimelis, H., and Tsilo, T. J. (2017). 'Variance components and heritability of yield and yield components of wheat under drought-stressed and non-stressed conditions.' Australian Journal of Crop Science, 11(11), pp. 1425-1430.

Mwadzingeni, L., Shimelis, H., and Tsilo, T. J. (2018). 'Combining ability and gene action controlling yield and yield components in bread wheat (Triticum aestivum L.) under drought-stressed and non-stressed conditions.' Plant Breeding, 137(4), pp. 502-513.

Nassar, S. M. A., Moustafa, E. S. A., and Farag, H. I. A. (2020). 'Selection for earliness, yield and its components in bread wheat.' Egypt Journal of Plant Breeding, 24(1), pp. 81-97.

Ugarte, C., Calderini, D. F., and Slafer, G. A. (2007). 'Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale.' Field Crops Research, 100(2–3), pp. 240-248.

Qabil, N. (2017). 'Genetic analysis of yield and its attributes in wheat (Triticum aestivum L.) under normal irrigation and drought stress conditions.' Egyptian Journal of Agronomy, 39(3), pp. 337-356.

Singh, M., Sharma, P., Tyagi, B., and Singh, G. (2014). 'Heterosis for yield component traits and protein content in bread wheat under normal and heat-stress environment.' Cereal Research Communications, 42, pp. 151–162.

Steel, R. G. D., Torrie, J. H., and Dickey, D. A. (1997). 'Principles and procedures of statistics: A Biometrical Approach.' 3rd edition. McGraw Hill Book Co., Inc., New York, NY.

Xiang, B., and Li, B. (2001). 'A new mixed analytical method for genetic analysis of diallel data.' Canadian Journal of Forest Research, 31, pp. 2252 – 2257.

Zaied, K. A., Abd El-Hady, A. H., Ramadan, R. A., and Lasheen, A. S. M. (2018). 'Genetical studies on yield and its components of four bread wheat cultivars.' Journal of Agricultural Chemistry and Biotechnology, Mansoura University, 9(4), pp. 123-135.

Zare-Kohan, M., and Heidari, B. (2014). 'Diallel cross study for estimating genetic components underlying wheat grain yield.' Journal of Biological and Environmental Sciences, 8(22), pp. 37-51.