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RESEARCH ARTICLE

Inheritance and selection for earliness in bread wheat affected by water stress

Hassan, M. S., M. A. Ali and Fatma G. Abd-Elmalek

Department of Agronomy, Faculty of Agriculture, South Valley University, Qena, Egypt

Abstract

The current research for the study of gene action for days to heading was applied under water stress at South Valley Univ., Exp. Farm, Qena, Egypt in 2022/2023 and 2023/2024 seasons. The materials consisted of 28 F_2-generations and their 8 parents. Mean squares due to additive and non-additive genetic variances were highly significant under both environments in the two seasons. The additive component accounted for a greater proportion than the non-additive component in the F_2-generations under all conditions, this highlights that additive gene effects played the most significant role in the inheritance of earliness. High narrow sense heritability for heading date under both environments in both seasons was observed. The differences between environments, among genotypes and genotypes × environments interaction were significant ($p<0.01$) for all the studied traits. Comparing the correlated traits under water stress conditions with normal irrigation illustrated that these traits under first condition were lower than under second condition. The response to selection for earliness as percentage of deviation from the F_2-populations ranged from -15.58 ($P_3 \times P_4$) to 1.38 % ($P_3 \times P_8$) and from -15.49 ($P_3 \times P_4$) to 9.68% ($P_2 \times P_8$) under normal and water stress environments, respectively. The correlated response in grain weight/spike, 100-grain weight and grain yield was decreased under both conditions. Direct selection for early maturity under water stress conditions is anticipated to be more efficient compared to indirect selection.

Keywords: Wheat, water-stress, earliness, gene action, selection

1. Introductio

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Egypt and the world, which are used in human food and animal feed. It is extensively utilized for further one third of the globe population due to its high converting and numerous utilizations, high nutritive value, linked with high crop production (El-Said, 2018).

In Egypt, wheat holds significant importance as one of the primary nutritional cereal crops. It is widely used in rural areas, often blended with maize flour, to produce bread, macaroni, biscuits, and various sweets.
Additionally, wheat straw serves as a valuable source of fodder for livestock. The total area dedicated to wheat cultivation has reached approximately 1.35 million hectares, producing around 8.87 million metric tons, with an average yield of 6.57 metric tons per hectare, according to the Foreign Agricultural Service/USDA (2024). Wheat production in Egypt falls short of meeting local consumption needs, highlighting the importance of focused efforts to boost production. Increasing wheat output is crucial to addressing the growing demand and narrowing the disparity between production and consumption. Closing this gap has long been a national priority for Egypt. Earliness is a crucial trait in wheat (*Triticum aestivum* L.) genotypes, with early-maturing varieties being particularly valued for their capacity to escape challenges such as drought, heat stress, diseases, pests, and other stresses encountered toward the end of the growing season (Awan *et al.*, 2019). Drought remains

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***Corresponding author: Mohamed Ahmed Ali**
Email: mohamed_agr@yahoo.com
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one of the most significant challenges in plant production, presenting ongoing difficulties for agricultural scientists in the current scenario, which affects both area and yield of crop. It affects the crops yield especially of cereals and poses a serious threat to food security of entire continent. Water stress is generally accompanied by heat in dry season (Dash and Mohanty, 2001).

At times, the traits chosen for drought tolerance may not align well with the specific needs of a target region. For instance, if a trait that enables survival during the seedling stage does not similarly influence drought response in later stages, breeding efforts focused on seedling survival might be ineffective, particularly if drought predominantly impacts the flowering or grain-filling stages (Reynolds *et al.,* 2001). Hybridization methods, like diallel selective mating, can play a key role in improving such traits and aiding in the identification of drought-tolerant progenies (Kumar and Sharma, 2005).

Wheat maturity plays a vital role in determining its adaptability to diverse environments, making it a key focus in wheat breeding programs, especially in regions where water scarcity occurs during the middle to late stages of the growing season. In lower latitudes, temperature and radiation levels remain relatively stable during the heading and grain-filling phases. Under such conditions, early maturity is crucial as it enables timely harvesting and safeguards the crop against abiotic stresses like drought, as noted by Poehlman (1995). Breeders focus on identifying and utilizing desirable genes and gene complexes, with the selection of favorable individuals remaining a central element in all breeding programs. Gene action plays a crucial role in selecting the appropriate breeding methodology for developing cultivar types, such as hybrids, pure lines, or synthetics. Diallel cross mating designs are commonly employed to analyze genetic effects among parental variations and to estimate variance components and heritability within plant populations derived from randomly selected parental varieties, as highlighted by Sadeghi *et al.* (2013). Heritability estimates serve as variable breeding parameters that help determine the extent of genetic gain achievable through selection. They highlight the significant role genetic effects play in governing the inheritance of economically valuable traits. The genetic component of variation is regarded as a crucial factor that can be effectively utilized alongside heritability (Mesele *et al.,* 2016).

The objectives of this research were to:

1- Investigate the nature of gene action for earliness in wheat.

2- Select for early heading and to test the best selection condition.

3- Assess the correlated response in number of grains/spike, 100-grain weight and grain yield/plant, this could assist in shaping future breeding strategies aimed at developing suitable genotypes.

2. Materials and Methods

The current research was carried out at the Experimental Farm of South Valley Univ., Qena, Egypt during two growing seasons (2022/2023 and 2023/2024). 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).

The experimental materials comprised thirty six genotypes of wheat; 28 F$_2$-generations and their eight parents. These crosses resulted from a half diallel crossing among the eight parents. The parents were varied in its origin and widely different in their agronomic traits. The code, local names, pedigree and origin of these parents are illustrated in Table 1.

In 2022/2023 growing season, the thirty-six genotypes were sown in the experimental area on 26th of November under two levels of irrigation water quantities; normal = full irrigation and water stress = 50% of full irrigation.

The full irrigation treatments were irrigated every 7 days, while the treatments which exposed to water stress were irrigated every 15 days. Randomized Complete Block Design (RCBD) with three replications for each treatment was used. The experimental unit comprised a single row of 3.5 m length for each genotype in each replication. Row to row and plant to plant spacing were 30 and 10 cm, respectively. Seeds were grown in holes (Made with the help of a dibble) at the rate of two seeds per site which were later thinned to single healthy seedling/site after germination. All the other agricultural operations including weeding control, fertilizers, hoeing, etc. except irrigation were carried out uniformly to reduce experimental error in both experiments. Days to heading was rerecorded as the number of days from planting to the day when 50% of the heads were protruded from the flag leaf sheath. Under normal irrigation, the earliest head of each plot was labeled. At maturity, the earliest plant from each of the 28 F_2-generations was selected accordingly the intensity of selection was 1/105. In 2023/2024 growing seasons, the 64 genotypes (28 F_2-generations, the 28 earliest F_3-selected families and the eight parents) were studied under the two irrigation regimes as before. At maturity, number of grains/spike and grain yield/plant were measured for each individual plant on thirty random plants from the middle portion of each plot in the replicated experiment. 100-grain weight was recorded on plot mean basis.

Combined analysis of variance over the two irrigation regimes was performed for all the studied traits after test of the homogeneity (Steel *et al*., 1997).

The genetic analysis for earliness and narrow sense heritability were calculated using diallel analysis as described by Hayman (1954). Following the failure of the assumption of a unity slope for the Wr/Vr regression line, for epistasis proposed by Jinks *et al* (1969) was used and the parents involved in the non-allelic interaction were identified and removed from the diallel analysis was performed on the remaining interaction free tables.

Response to selection for earliness and correlated response in number of grains/spike, 100-grain weight and grain yield/plant were calculated as deviation of the selected families from both the F_2 mean and the better parent of each population. 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 environments divided by the same difference of the respective unselected F_2 population as described by Falconer (1990).

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

No.	Name	Pedigree	Origin
P_1	Line#158	ATTILA-3//LESNA*2/261-9/3/JOHARA-10	ICARDA
P_2	Shamiss-3	ICW97-0137-7AP-OAPS-21AP-OAPS-OAP	ICARDA
P_3	Gemmeiza-11	BOW"S"/KVZ"S"//7C/SER182/3/GIZA168/SAKHA61	Egypt
P_4	Sakha-93	SAKHA92/TR810328. S.8871-1S-2S-1S-0S	Egypt
P_5	Misr-2	SKAUZ/BAV92	Egypt
P_6	Shandaweel-1	SITE//MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC	Egypt
P_7	Sids-1	HD2172/PAVON"S"//1158.57/MAYA74"S"	Egypt
P_8	Giza-168	MRL/BUC/SERI. CM93046-8M-0Y-0M-ZY-0B-0GZ	Egypt

3. Results and Discussion

3.1.1. The genetic system controlling heading date

Mean squares due to environments, genotypes and genotypes × environments interaction were highly significant (Table 3). From through two scaling tests (t^2 test and regression analysis), the additive–dominance model was partially adequate for earliness in the F$_2$-generations. In several researches of genetic mechanisms in wheat, the additive–dominance model was also found to be partially adequate for earliness (Ahmad *et al.*, 2011; Jadoon *et al.*, 2013; Afridi *et al.*, 2017; El-Said, 2018 and Al-Timimi *et al.*, 2020). However, the additive–dominance model was found to be fully adequate for days to heading in wheat populations by Nazir *et al*. (2014).

Mean squares due to both additive "a" and non-additive "b" genetic variances were highly significant under normal and water stress conditions in the two seasons (Table 2). The additive component accounted for a greater proportion than the non-additive component in the F$_2$-generations under all tested conditions. This indicates that the additive gene effects were the most important in the inheritance of earliness. These results reveal that selection could be applied for early heading in the F$_2$ in these populations. Higher selection advance is expected to occur after the first cycle of selection than after the second one. El-Morshidy *et al.* (2010), Ali, (2011), Hassan (2014), Mahdy *et al.* (2014), Mahdy *et al.* (2015), Al-Ashkar (2020) and Nassar *et al.* (2020) who found that the genetic variation exhausted after two cycles of selection for early heading. Data in Table 2 presented that both additive "a" and non-additive "b" differed from treatment to another in the two seasons, showing that the interaction of the two components (Additive and dominance) with environments. Similar results were obtained by many investigators (Afridi *et al.,* 2017; Qabil, 2017; Abd El-Hady *et al.,* 2018, El-Said, 2018; Zaied *et al.,* 2018 and Khan and Hassan, 2018) who displayed higher additive genetic component in magnitude as compared to their corresponding dominance. While, Jadoon *et al.* (2013) and Ahmad *et al* (2019) mentioned that the two genetic components *i.e*., additive (a) and non-additive (b) were equally important in the inheritance of Heading date as both components differed significantly. On the other side, Al-Timimi *et al*. (2020) indicated that the dominant type of gene action was the most prevalent genetic component in the inheritance of days to heading. In the F$_2$-populations, the b$_1$ component was highly significant for days to heading at normal and water stress conditions in the two seasons, showing that dominance deviation in one direction.

Table 2. Estimation of genetic components of variation for days to heading under normal (N) and water stress (S) conditions.

Item	df		Mean squares			
			Days to heading in 2022/2023		Days to heading in 2023/2024	
			N	S	N@	S
a	7	5@	117.17**	134.59**	63.68**	115.42**
b	28	15	12.47**	15.02**	15.53**	10.34**
b$_1$	1	1	23.93**	33.02**	74.07**	21.92*
b$_2$	7	5	3.38**	4.20**	4.82**	9.03**
b$_3$	20	9	15.07**	17.91**	14.98**	10.21**
Block × a	14	10	0.72	0.60	1.03	0.54
Block × b	56	30	0.48	0.37	0.51	0.23
Block × b$_1$	2	2	0.04	0.10	0.37	1.08
Block × b$_2$	14	10	0.30	0.17	0.19	0.35
Block × b$_3$	40	18	0.56	0.46	0.70	0.58
Block interaction	126	70	0.29	0.23	0.28	0.27

*, **; Significant at 5 and 1% probability levels, respectively.

a = additive gene effect, b = dominance gene effect, b$_1$ = directional dominance deviation, b$_2$ = genes distribution among parents and b$_3$ = effect of specific gene.

Each item is tested against the block interaction. @ Two array omitted (6 parents).

However, the b_2 component had highly significant values under the two treatments of irrigation in the first and second seasons. It suggests that asymmetrical distribution of dominant and recessive alleles in the F_2-populations. Moreover, the component b_3 was highly significant at both irrigation levels in both seasons, indicating that the residual dominance effect produced from additive × additive, additive × dominance and dominance × dominance interactions (Table 2). 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).

3.1.2. Graphical (Wr/Vr) analysis

The Wr/Vr graphical analysis of days to heading in the F_2-generations under normal and water stress conditions in the two seasons are illustrated in Figures 1. It indicated that epistatic effects were absent under all tested environments, except under normal irrigation in the second season. So, the test of epitasis suggested by Jinks *et al.* (1969) was used to determine the interacting parents. The Wr/Vr graphs were significantly different from zero but not from unity after omitting arrays No. 1 and 3 from the diallel table. This indicates that the genetic system can be inferred as additive, without the complexity of non-allelic interactions. The distribution of array points along the regression line for this trait in the F_2 generations highlights the genetic diversity among the parents. Additionally, the relative placement of these parental points around the regression line varied between the two seasons across the two environments (Fig. 1). For instance, in the second season the point representing the latest parent P_3 occupied the position furthest of the origin point at normal conditions, exhibiting that it possessed the most recessive alleles.

However, it occupied a position near the point of origin under water stress conditions, revealing a high proportion of dominant alleles. Similar results were obtained by Kheiralla and Sherif (1992), Kheiralla *et al.* (2001) and Ali and Abo-El-Wafa (2006).

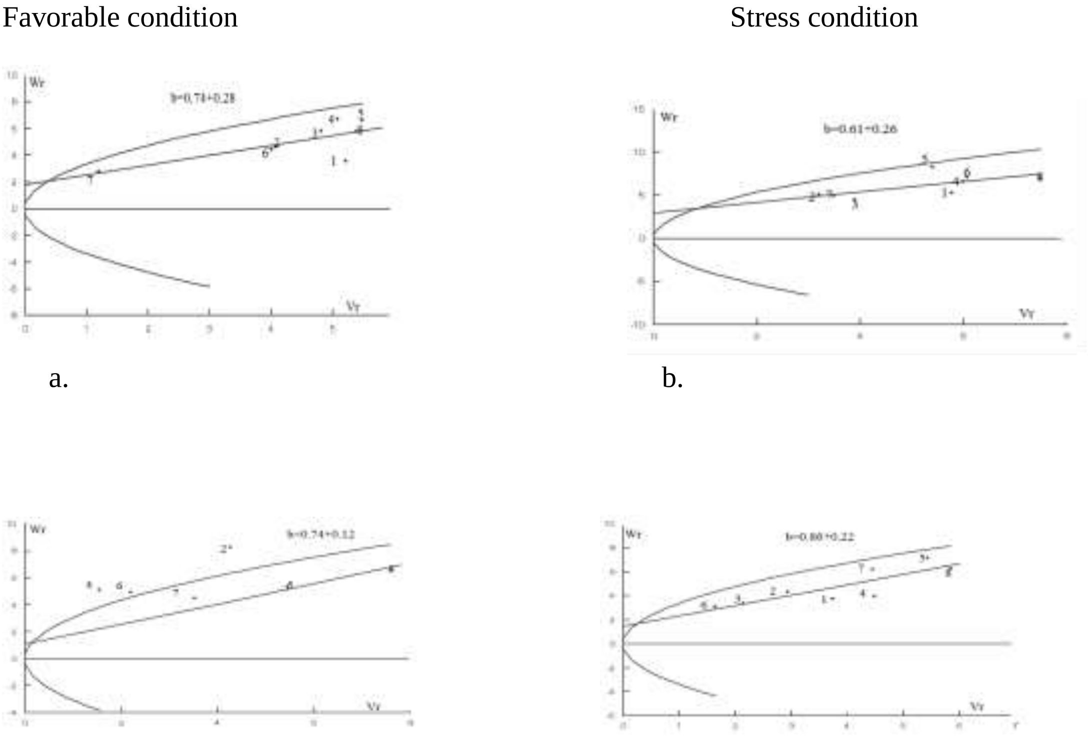
3.1.3. Genetic components of the F_2-generations.

The estimated values of all the genetic components of variation (D, H_1, H_2, F and E) along with standard errors and related parameters under normal and water stress conditions are presented in Table 3.

Genetic statistical parameters from the half diallel analysis according to Hayman fashion (Hayman 1954 a and b) were provided in Table 3.

These parameters provided further genetic information about days to heading. The additive component (D) reached the significant level of probability for this trait in the F_2-generations under normal and water stress environments in the first and second seasons. It noted that the first season compared to the second one and water stress conditions to the normal irrigation gave greater estimates of the additive effect for days to heading. These results illustrate that the additive gene effects were involved in the inheritance of this trait in the F_2-generations under all environments (Table 3). The analysis of genetic components showed that the dominance component H_1 was highly significant These results illustrate that the additive gene effects were different for days to heading under normal and water stress conditions in 2022/2024 and 2023/2024 seasons and much higher of estimate than "D" one under all environments, this suggests that dominance gene action was the primary genetic factor influencing the inheritance of this trait. Similar results were obtained by Afridi *et al.* (2017), Khan and Hassan (2018) and Al-Timimi *et al.* (2020).

However, the dominance component H_2 associated with gene distribution was highly significant value for days to heading under normal and water stress conditions in the first and second seasons. The H_2 values were smaller than the H_1 values for this trait under all environments (Table 3). This reveals that


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 normal and water stress conditions

Table 3. Estimates of the genetic parameters for days to heading of 8 parents and their derived F_2-populations sown under normal (N) and water stress (S) conditions.

Parameters	Days to heading in 2022/2023		Days to heading in 2023/2024	
	N	S	N@	S
D	11.23±0.77	14.27±0.86	9.39±0.65	11.32±0.65
H_1	33.21±7.10	40.52±7.92	24.28±6.62	29.16±5.94
H_2	30.59±6.18	36.97±6.89	20.73±5.91	22.20±5.17
F	4.57±3.64	8.16±4.06	6.69±3.17	7.28±3.05
E	0.10±4.12	0.08±4.60	0.10±3.94	0.09±3.45
$(H_1/4D)^{1/2}$	0.86	0.84	0.81	0.81
$H_2/4H_1$ (uv)	0.23	0.23	0.21	0.19
KD/KR	1.002	1.002	1.004	1.003
$h^2_{(ns)}$	0.64	0.69	0.75	0.77

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.

@ Two array omitted (6 parents).

unequal allele frequency in the parents. These results are in agreement with those reported by Kumar *et al.* (2015), Qabil (2017), Abd El-Hady *et al.* (2018), Zaied *et al.* (2018) and Al-Timimi *et al.* (2020).

Moreover, positive and significant F values were observed for days to heading in the F_2-

generations under both environments in the two seasons except under normal irrigation in the first season, demonstrating asymmetry of gene frequency among the parental populations. For other case, positive and insignificant F value under normal irrigation condition in the first season for the same trait, this highlights a higher prevalence of increasing dominant alleles compared to recessive ones within the parental populations, as shown in Table 3. Similar results were reported by Kumar *et al.* (2015) showed that positive and significant value of 'F' for days to heading in the F_1-crosses. Afridi *et al.* (2017) displayed that positive F value was non-significant for days to heading.

The environmental effect (E) was positive and insignificant for days to heading in the F_2-generations under normal and water stress conditions in both seasons, indicating that the relative frequencies of dominant and recessive alleles for this trait were equal among the parents (Table 3). Similar results were obtained by Afridi *et al.* (2017) and Al-Timimi *et al.* (2020).

In the F_2-generations for days to heading under both conditions in the two seasons, average degrees of dominance $(H_1/4D)^{1/2}$ indicated that earliness was influenced by both additive and non-additive gene actions. It was lower than one, which suggested a low level of dominance of the loci affecting this trait and showing the additive type of gene action with an increasing pattern of additive genes. This illustrates the presence of partial dominance and could be improved through individual phenotypic selection in the early generation for this character (Table 3). The last studies demonstrated additive and non-additive gene actions governed the days to heading in bread wheat (Ahmad *et al.*, 2013; Farshadfar *et al.*, 2013; Kumar *et al*, 2015; Qabil, 2017; Abd El-Hady *et al*, 2018 and Zaied *et al.*, 2018). However, Abd El-Rahman (2013), Kumar *et al.* (2015), Qabil (2017), Abd El-Hady *et al.* (2018), Zaied *et al.* (2018) and Ahmad *et al.* (2019) revealed that the average degree of dominance was below unity, indicating that the earliness trait in bread wheat is predominantly governed by additive gene effects. In contrast, Kumar *et al.* (2019), Al-Timimi *et al.* (2020) and Kamara *et al.* (2021) found that the average degree of dominance was higher than one in the heading date across all tested environments.

The proportion of genes with positive and negative effects in the parents as indicated by H2/4H1 was below than its maximum value (0.25) for days to heading under normal and stress irrigation conditions in the first and second seasons, suggesting asymmetrical distribution of positive and negative alleles among the parental population for this character (Table 3). These results are in agreement with Kumar *et al.* (2015) and Afridi *et al.* (2017) who demonstrated the asymmetrical distribution of positive and negative genes among the parental genotypes in relation to days to heading within the F_2 generations. The values of KD/KR were more than unity for days to heading under normal and stress irrigation conditions in the first and second seasons, illustrating the asymmetrical distribution of positive and negative alleles among the parents. The proportion of dominant and recessive genes showed that the dominant alleles govern this character in the F_2-generations under all tested environments (Table 3).

The results illustrated high values of heritability in narrow sense for this trait under both conditions in the two seasons, revealing that most phenotypic variability was due to genetic causes. Solomon and Abuschagne (2004) observed a high heritability for days to heading, potentially attributed to the influence of a few major genes in wheat. High heritability for days to heading in their genetic analysis of earliness in spring wheat, conducted under both normal and stress conditions was also reported by Farooq *et al.* (2011), Afridi *et al.* (2017) and El-Said (2018). On the other hand, low narrow sense heritability for days to heading was observed by Al-Timimi *et al.* (2020).

3.2. Selection criterion

3.2.1. Selection for early heading

Significant ($p<0.01$) differences between environments for earliness and all the studied correlated traits *viz.*, number of grain/spike, 100-grain weight and grain yield/plant (Table 4) as expected for normal and stress irrigation levels. Similar findings were also reported in wheat by many scientists (Eid, 2009; Awan *et al.*, 2011; El-Hosary and Nour Eldeen, 2015; Mwadzingeni *et al.*, 2017; Mwadzingeni *et al.*, 2018; Dhoot *et al.*, 2020; Kamara *et al.*, 2021 and Adnan *et al.*, 2022).

The differences among genotypes were found to be significant ($p<0.01$) for earliness and correlated traits, presenting thereby the presence of a wide range of variability. Mean squares due to the interaction of genotypes × environments were significant ($p<0.01$) for earliness and correlated traits, illustrating that it is essential to assess genotypes for such traits under different environments in order to identify the best genotypes for a particular environment (Table 4). Similar observations were made by Mwadzingeni *et al.* (2017) and Dhoot *et al.* (2020). In addition, it shows also that the parents, F_2-generatins and F_3-families groups were apparently quite different reflecting the significant responses to selection. Similar results were obtained by Kheiralla and El-Dafrawy (1994) and Ali and Abo-El-Wafa (2006).

Days to 50% heading are an important trait of wheat. Wheat cultivars genetically vary in number of days to 50% heading from early to late. Earlier genotypes provide enhanced reliability during the harvest, particularly in environments characterized by water scarcity during that period. So inbreeding programs of bread wheat heading should also be considered 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-families exhibited a wide variation for this trait under normal and water stress conditions.

The mean values and range of days to 50% heading of the 8 parents, their 28 F_2-populations and the earliest 28 F_3-selected families under normal and water stress conditions as well as the selection advance (Once measured as percentage of deviation from the F_2-populations and the other from the earlier parent) are displayed in Tables 5 and 6. With respect to F_2-generations, the cross $P_3 \times P_8$ when planted under normal irrigation conditions produced significantly earlier average days to heading (72.67 days) and the later days to heading (83.33 days) for the cross $P_1 \times P_8$. Whereas, earlier plants (62.00 days) was obtained from the cross $P_2 \times P_8$ and the later plants (74.00 days) for the cross $P_1 \times P_7$ was recorded from plots where crop was sown under water stress condition.

Mean values of genotypic performance for all F_2-generations under normal and water stress conditions for days to heading were 79.67 and 68.27 days, respectively. Thus, at water stress conditions the head in emergence 9 days were reduced as compared to the normal irrigation conditions. 12.6% day's loss was noticed during water stress condition.

For the F_3-selected families (Table 5), earlier plants (65.00 days) was obtained from the cross $P_3 \times P_4$ but the later plants (78.67 days) was recorded by the cross $P_2 \times P_3$ when it sown under normal irrigation followed by the same crosses when sown at water stress conditions (60.00 and 71.67 days, respectively). The average of days to heading for all the F_3-selected families were 72.19 and 65.26 days at normal and water stress conditions, respectively. Water stress conditions decreased days to heading overall crosses by 6.9%.

The significant genotype × environment interaction implies that the genotypes were observed to have different relative days to heading across water treatments. The pooled data of 2023/2024 season further indicated that interaction between irrigation levels and genotypes was highly significant. At normal

Table 4. The combined analysis of variance of eight traits of the 8 parents, their 28 F_2-populations and 28 earliest F_3-selected families sown under normal (N) and water stress (S) conditions in growing winter season (2023/2024).

S. O. V.	df	Mean squares			
		Selection criteria	Correlated traits		
		Heading date	Number of grains/plant	100-grain weight (g)	Grain yield/plant (g)
Environments (Env.)	1	5961.38^{**}	9943.01^{**}	101.90^{**}	2240.85^{**}
Rep/Env.	4	15.85	77.86	1.40	6.12
Genotypes (G)	63	77.97^{**}	383.41^{**}	1.60^{**}	151.46^{**}
Parents (P)	7	38.57^{**}	514.52^{**}	1.25^{**}	227.46^{**}
F_2	27	30.18^{**}	277.38^{**}	1.23^{**}	151.94^{**}
F_3	27	30.02^{**}	405.15^{**}	0.58^{**}	118.17^{**}
P vs. F_2 vs. F_3	2	1508.52^{**}	1062.44^{**}	21.70^{**}	328.28^{**}
G × Env.	63	16.32^{**}	66.30^{**}	0.78^{**}	6.48^{**}
Error	252	0.67	13.54	0.13	1.73

**; Significant at 1% probability levels

and water stress conditions, respectively, the earliest F_3-selected family was the cross $P_3 \times P_4$ which registered the mean of 65.00 and 60.00 days. This highlights the remarkable carry-over effect achieved by enhancing earliness potential through selective processes under normal conditions. However, under water stress conditions, the cross $P_3 \times P_6$ was significantly different from the previous cross but it was insignificantly different during normal irrigation conditions. This exhibits evidence of genotype × environment interactions. Contrariwise, the cross $P_2 \times P_4$ illustrated insignificant response to selection under stress conditions, while it exhibited significantly response to selection under normal conditions.

Generally, days to heading of the F_2-generations were affected greatly than the F_3-selected families by water stress. However, the F_3-selected families were earlier than the F_2-generations about 6 and 3 days at the normal and water stress conditions, respectively.

3.2.2. Response to selection for selection criterion (Days to heading)

The response to selection calculation for earliness as percentage deviation from the F_2-populations and the earlier parent and the sensitivity are presented in Table 6. The response to selection for earliness as percentage deviation from the F_2-populations ranged from -15.58 ($P_3 \times P_4$) to 1.38% ($P_3 \times P_8$) and from -12.09 ($P_2 \times P_7$) to 10.01% ($P_3 \times P_8$) during favorable and water stress conditions, respectively. It noted that the range of the selection advance estimated as deviation % from the F_2-populations was generally greater under water stress than that observed under normal irrigation. During favorable and water stress conditions, the response to selection as % deviation from the earlier parent ranged from -16.24 ($P_3 \times P_6$) to 1.77% ($P_4 \times P_8$) and from 15.79 ($P_5 \times P_8$ and $P_7 \times P_8$) to 2.39% ($P_2 \times P_3$), respectively. Most crosses had significantly desirable selection advances under both conditions as a percentage of deviation from the F_2-generations and the earlier parent. Most crosses depicted an indication of transgressive segregation for earliness in heading date, which increases the opportunity to accumulate different genes affecting this character. Transgressive segregation for earliness was observed by Kheiralla and El-Defrawy (1994), Ali and Abo-El-Wafa (2006), El-Morshidy *et al.*

Table 5. Average of days to heading for the 8 parents and their 28 F_2-populations of wheat sown under normal (N) and water stress (S) conditions in the 2022/2023 and 2023/2024 seasons.

Genotypes	Days to heading			
	2022/2023		2023/2024	
	N	S	N	S
P_1	82.00	78.00	77.00	75.00
P_2	84.00	79.00	80.00	74.00
P_3	85.67	75.00	83.67	70.00
P_4	77.00	71.00	75.00	69.00
P_5	87.33	83.00	82.00	79.67
P_6	79.00	75.00	78.00	75.00
P_7	83.00	80.00	81.00	76.00
P_8	81.67	79.00	79.67	77.00
Range	77.00-87.33	71.00-83.00	75.00-83.67	70.00-79.67
Average	82.46	77.50	79.54	74.46
$P_1 \times P_2$	83.00	79.00	79.67	65.67
$P_1 \times P_3$	82.00	78.33	75.33	66.67
$P_1 \times P_4$	80.00	74.00	79.67	71.00
$P_1 \times P_5$	81.00	78.33	76.67	68.00
$P_1 \times P_6$	76.67	72.67	79.00	67.33
$P_1 \times P_7$	83.00	78.00	78.67	74.00
$P_1 \times P_8$	83.33	75.00	83.33	71.33
$P_2 \times P_3$	81.67	74.67	77.67	66.67
$P_2 \times P_4$	79.00	75.00	76.67	68.00
$P_2 \times P_5$	84.00	79.00	81.00	67.33
$P_2 \times P_6$	80.00	77.67	75.67	71.67
$P_2 \times P_7$	82.67	77.33	79.00	69.67
$P_2 \times P_8$	84.67	78.67	80.67	62.00
$P_3 \times P_4$	82.00	74.00	77.00	71.00
$P_3 \times P_5$	86.33	77.33	82.00	65.67
$P_3 \times P_6$	79.67	75.00	77.33	68.00
$P_3 \times P_7$	82.67	76.00	77.67	63.33
$P_3 \times P_8$	82.00	79.67	72.67	70.00
$P_4 \times P_5$	82.00	76.00	78.00	67.00
$P_4 \times P_6$	76.00	70.00	75.00	65.33
P4 × P_7	80.00	77.00	75.33	67.00
$P_4 \times P_8$	77.33	72.00	78.33	69.67
$P_5 \times P_6$	81.00	77.00	76.67	71.00
$P_5 \times P_7$	82.67	80.67	78.00	69.67
$P_5 \times P_8$	83.33	79.33	81.67	67.00
$P_6 \times P_7$	81.67	75.33	79.00	68.67
$P_6 \times P_8$	80.33	76.00	76.00	68.33
$P_7 \times P_8$	81.00	76.67	77.67	68.27
Range	76.67-86.33	72.00-80.67	72.67 – 83.33	62.00 – 71.67
Average	81.39	76.42	78.05	68.19
L.S.D$_{0.05}$	0.88	0.80	0.86	1.65

Table 6. Mean of days to heading of the F_2-populations and the earliest F_3- selected families of the 28 crosses sown during normal and water stress (S) conditions and the response to selection, as well as the average performance of F_3-selected families and the sensitivity.

Populations	Normal irrigation				Water stress conditions				Sensitivity
	F_2	F_3	% Response to selection from		F_2	F_3	% Response to selection from		
			F_2	Bp			F_2	Bp	
$P_1 \times P_2$	79.67	73.67	-7.53**	-4.33**	65.67	64.00	-2.54**	-13.51**	0.69
$P_1 \times P_3$	75.33	69.33	-7.96**	-9.96**	66.67	66.00	-1.00	-5.71**	0.38
$P_1 \times P_4$	79.67	75.67	-5.02**	0.89^{ns}	71.00	63.00	-11.27**	-8.70**	1.46
$P_1 \times P_5$	76.67	73.67	-3.91**	-4.33**	68.00	66.00	-2.94**	-12.00**	0.88
$P_1 \times P_6$	79.00	71.00	-10.13**	-7.79**	67.33	65.00	-3.46**	-13.33**	0.51
$P_1 \times P_7$	78.67	70.67	-10.17**	-8.23**	74.00	64.33	-13.07**	-14.23**	1.36
$P_1 \times P_8$	83.33	77.33	-7.20**	0.43^{ns}	71.33	65.33	-8.41**	-12.89**	1.00
$P_2 \times P_3$	77.67	78.67	1.29*	-1.66**	66.67	71.67	7.50**	2.39*	0.64
$P_2 \times P_4$	76.67	69.67	-9.13**	-7.11**	68.00	61.33	-9.81**	-11.12**	0.96
$P_2 \times P_5$	81.00	71.00	-12.35**	-11.25**	67.33	69.00	2.48**	-6.76**	0.15
$P_2 \times P_6$	75.67	70.67	-6.61**	-9.40**	71.67	63.33	-11.64**	-14.41**	1.84
$P_2 \times P_7$	79.00	75.00	-5.06**	-6.25**	69.67	63.00	-9.57**	-14.86**	1.29
$P_2 \times P_8$	80.67	72.67	-9.92**	-8.79**	62.00	68.00	9.68**	-8.11**	0.25
$P_3 \times P_4$	77.00	65.00	-15.58**	-13.33**	71.00	60.00	-15.49**	-13.04**	0.83
$P_3 \times P_5$	82.00	74.00	-9.76**	-9.76**	65.67	66.00	0.50	-5.71**	0.49
$P_3 \times P_6$	77.33	65.33	-15.52**	-16.24**	68.00	62.00	-8.82**	-11.43**	0.36
$P_3 \times P_7$	77.67	70.67	-9.01**	-12.76**	63.33	66.00	4.22**	-5.71**	0.33
$P_3 \times P_8$	72.67	73.67	1.38*	-7.53**	70.00	69.67	-0.47	-0.47	1.50
$P_4 \times P_5$	78.00	76.00	-2.56**	1.33*	67.00	69.00	2.99**	0.00	0.64
$P_4 \times P_6$	75.00	70.00	-6.67**	-6.67**	65.33	65.00	-0.51	-5.80**	0.52
$P_4 \times P_7$	75.33	68.33	-9.29**	-8.89**	67.00	65.00	-2.99**	-5.80**	0.40
$P_4 \times P_8$	78.33	76.33	-2.56**	1.77**	69.67	68.00	-2.40**	-1.45	0.96
$P_5 \times P_6$	76.67	72.67	-5.22**	-6.84**	71.00	64.00	-9.86**	-14.67**	1.53
$P_5 \times P_7$	78.00	74.00	-5.13**	-8.64**	69.67	64.00	-8.14**	-15.79**	1.20
$P_5 \times P_8$	81.67	72.67	-11.02**	-8.79**	67.00	65.33	-2.49**	-15.15**	0.50
$P_6 \times P_7$	79.00	70.00	-11.39**	-10.26**	68.67	65.00	-5.34**	-13.33**	0.48
$P_6 \times P_8$	76.00	72.00	-5.26**	-7.69**	68.33	64.33	-5.85**	-14.23**	1.00
$P_7 \times P_8$	77.67	71.67	-7.72**	-10.04**	68.27	64.00	-6.25**	-15.79**	0.82
Average	78.05	72.19	-7.58	-7.22	68.19	65.26	-4.29	-9.70	

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

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

(2010), Hassan (2014), Aglan and Farhat (2014), Afridi *et al.* (2017), Qabil (2017), Awan *et al.* (2019), Kumar *et al.* (2019), Kamara *et al.* (2021) and Adnan *et al.* (2022).

3.4. Sensitivity to the environment

Antagonistic selection increased the sensitivity in nine F_3-selected families, led to a mean sensitivity in 14 F_3-selected families and decreased sensitivity in 5 F_3-selected families (Table 6).

3.5. Means and correlated response of other studied traits under both normal and water stress conditions.

Mean of the correlated traits (number of grains/spike, 100-grain weight and grain yield/plant) is demonstrated in Table 7. At normal and water stress conditions, the average of all F_2-generations for number of grains/spike was 48.50 and 36.79 grains, respectively. Among the F_2-generations, the cross $P_1 \times P_5$ produced highest grains; 60.94 and 50.89 grains, while lowest grains; 33.85 and 17.67 grains was produced by the cross $P_4 \times P_8$ at normal and water stress conditions, respectively. The average of number of grains/spike for the F_3-selected families under normal irrigation was 44.46 grains, which ranged from 24.17 ($P_4 \times P_8$) to 57.33 ($P_2 \times P_6$). Likewise, it ranged from 20.00 ($P_4 \times P_8$) to 45.42 ($P_1 \times P_4$) with an average of 32.86 grains under water stress conditions (Table 7). These results may be due to the fact that increasing irrigation levels caused an increase in number of spikelets/spike which accompanied by a higher number of grains/spike, also may be due to the increase information of more fertile spikelets.

As for 100-grain weight, the F_2-generation $P_6 \times P_7$ had the slightest value (3.73 g), whereas the heaviest value (6.70 g) was observed by the cross $P_2 \times P_8$ under normal irrigation. Likewise, at water stress the slightest and heaviest values (2.62 g) and (4.53 g) were recorded for the crosses $P_3 \times P_4$ and $P_2 \times P_3$, respectively. The average value computed for 28 F_2-populations was 4.85 and 3.51 g under normal and water stress conditions, respectively (Table 7). Under normal irrigation, the F_3-selected families $P_5 \times P_6$ had the slightest value (3.14 g), while the heaviest value (4.76 g) was recorded by the cross $P_2 \times P_6$. Likewise, the slightest and heaviest values 2.33 and 4.04 g observed for the crosses $P_3 \times P_5$ and $P_2 \times P_3$ under water stressed condition, respectively. The mean value calculated of 28 F_3-selected families were 3.85 and 3.18 g under normal and water stressed conditions, respectively. It is clear that water stress decreased 100-grain weight by 27.63 and 17.4% as compared to the normal irrigation for the F_2-generations and F_3-selected families, respectively (Table 7).

Concerning grain yield/plant, the F_2-generations $P_1 \times P_6$ gave the lowest mean value (14.56 g), while the highest value (33.60 g) was recorded by the cross $P_3 \times P_4$ under normal irrigation. Likewise, under water stress conditions, the minimum and maximum mean values (11.01 g) and (28.14 g) were obtained through the crosses $P_3 \times P_5$ and $P_3 \times P_4$, respectively. In addition, the average value overall 28 F_2-generations were 22.74 and 17.35 g at normal and water stress conditions, respectively. For the F_3-selected families, the mean value varied from 12.47 for the cross $P_2 \times P_5$ to 31.72 for the cross $P_3 \times P_4$ with a trail mean19.88 g under normal irrigation. Likewise, under water stress condition, it varied from 10.01 for the cross $P_3 \times P_8$ to 23.50 for the cross $P_3 \times P_4$ with a trail mean 15.25 g (Table 8). Thus the grain yield/plant of crosses (F_2 and F_3-generations) was decreased because of water stress and hence favorable environment was superior to other. The mean value of grain yield/plant of all F_2-generations and F_3-selected families were more by 5.39 and 4.63 g under normal irrigation than the crosses sown under water stressed condition. Thus it is clear that water stress caused reduction in grain yield reached to 24 and 23%, respectively. These findings were consistent with the results obtained by other investigators as Mwadzingeni *et al.* (2017),

Table 7. Average of number of grains/spike, 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 water stress (S) conditions.

Populations	number of grains/spike				100-grain weight (g)				Grain yield/plant (g)			
	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
$P_1 \times P_2$	38.30	31.47	31.47	24.17	5.55	3.50	3.47	3.28	26.59	24.36	21.00	16.61
$P_1 \times P_3$	36.39	34.44	34.17	33.97	5.37	3.61	3.94	3.47	19.93	19.19	18.11	17.12
$P_1 \times P_4$	59.17	55.83	48.75	45.42	5.25	4.35	3.37	2.92	28.10	25.12	22.61	18.62
$P_1 \times P_5$	60.94	54.75	50.89	37.22	4.51	4.73	3.98	3.07	25.31	20.44	18.44	15.74
$P_1 \times P_6$	43.50	40.33	40.33	22.17	5.67	3.35	3.82	2.34	14.56	12.69	11.38	11.36
$P_1 \times P_7$	57.11	55.83	42.00	43.97	4.82	3.37	3.93	3.32	25.57	21.55	19.90	15.71
$P_1 \times P_8$	44.09	39.53	37.50	32.05	4.75	3.53	3.25	2.60	25.42	20.89	18.63	14.91
$P_2 \times P_3$	58.75	52.33	36.95	28.55	4.62	4.32	4.53	4.04	15.83	14.93	11.93	11.75
$P_2 \times P_4$	53.70	37.58	37.58	25.25	4.99	4.06	3.93	3.67	19.72	15.30	13.30	12.09
$P_2 \times P_5$	46.75	40.03	37.50	30.83	4.52	3.99	3.35	3.84	14.93	12.47	12.69	10.96
$P_2 \times P_6$	57.25	57.33	24.17	27.08	5.06	4.76	4.06	3.26	23.45	22.76	21.69	16.62
$P_2 \times P_7$	49.35	49.33	36.47	26.14	4.71	3.77	3.25	3.21	24.12	18.47	17.46	13.55
$P_2 \times P_8$	50.70	51.00	39.22	36.14	6.70	3.89	3.88	3.44	17.49	16.27	15.25	12.68
$P_3 \times P_4$	45.25	45.33	40.39	33.33	4.29	3.74	2.62	3.56	33.60	31.72	28.14	23.50
$P_3 \times P_5$	38.86	32.80	32.80	31.67	4.01	4.22	3.52	2.33	15.17	13.07	11.01	10.58
$P_3 \times P_6$	55.75	53.72	43.72	40.31	5.49	3.85	3.35	2.90	29.10	26.54	21.61	19.29
$P_3 \times P_7$	42.30	42.30	35.25	36.67	4.29	3.73	3.63	3.30	25.26	22.50	17.73	19.04
$P_3 \times P_8$	41.25	37.92	31.12	28.00	4.96	3.37	3.33	3.31	16.95	13.64	13.64	10.01
$P_4 \times P_5$	56.17	48.61	40.00	38.33	4.10	4.14	3.36	3.14	18.82	14.81	12.22	10.25
$P_4 \times P_6$	45.83	45.83	30.75	34.22	4.94	4.74	2.70	3.10	25.91	22.85	17.78	19.54
$P_4 \times P_7$	56.47	56.47	42.25	40.00	4.90	3.65	3.40	3.13	32.33	29.66	25.44	22.04
$P_4 \times P_8$	33.85	24.17	17.67	20.00	4.77	4.13	3.82	3.25	19.37	16.07	12.82	11.73
$P_5 \times P_6$	45.83	46.42	28.25	36.67	4.56	3.14	3.26	2.99	24.93	21.79	19.42	17.18
$P_5 \times P_7$	58.05	56.39	41.25	42.42	5.29	3.38	3.20	2.86	21.57	18.04	14.72	17.47
$P_5 \times P_8$	51.14	47.14	44.25	44.58	4.95	3.65	3.59	3.42	29.58	26.42	22.87	19.31
$P_6 \times P_7$	41.58	26.05	26.05	21.58	3.73	3.42	3.20	3.31	19.18	17.90	14.56	13.03
$P_6 \times P_8$	46.35	42.56	42.56	32.58	4.97	4.03	3.46	2.90	29.29	22.81	20.41	16.03
$P_7 \times P_8$	43.25	39.50	36.89	33.21	4.13	3.85	3.18	3.17	14.79	14.36	11.05	11.28
Average	48.50	44.46	36.79	32.86	4.85	3.85	3.51	3.18	22.74	19.88	17.35	15.25
P_1	29.67		26.75		3.41		3.12		15.77		12.54	
P_2	44.89		43.33		5.61		3.90		20.35		18.61	
P_3	36.64		34.47		5.57		3.61		30.73		23.74	
P_4	59.17		55.14		4.90		3.80		35.65		29.13	
P_5	47.80		41.33		5.22		3.61		17.71		15.80	
P_6	46.42		42.39		4.46		3.74		18.78		17.26	
P_7	59.06		47.83		5.39		3.25		22.55		16.62	
P_8	53.25		43.39		4.72		3.16		17.72		14.97	
Average	47.11		41.83		4.91		3.52		22.41		18.58	
$L.S.D_{0.05}$	5.12		6.57		0.51		0.63		2.57		1.51	

Qabil (2017), Mwadzingeni *et al.* (2018), Kumar *et al.* (2019), Ahmad *et al.* (2020), Al-Timimi *et al.* (2020), Dhoot *et al.* (2020) and Kamara *et al.* (2021) exhibited that water stress at any stage reduced all these traits.

Correlated response of the correlated traits

The correlated response measured as percentage of deviation from the F_2-populations and the better parent for number of grains/spike, 100 grain weight and grain yield/plant under normal and water stress conditions are presented in Table 8. It noticed that direct selection for earliness accompanied with reduction% in number of grains/spike and 100-grain weight was, on average, higher than that in grain yield/plant at normal and water stress conditions. The effectiveness of selection was demonstrated through the diminished impact of stress reduction observed in the correlated response in number of grain/spike, 100-grain weight and grain yield/plant. The correlated response to early heading was more pronounced, than direct response. Most of selections were lower in number of grains/spike, 100 grain weight and grain yield/plant than the better parent under both environments except two crosses ($P_1 \times P_5$) and ($P_1 \times P_7$). In only one cross $P_2 \times P_6$ number of grains/spike, 100 grain weight and grain yield/plant did not differ from the F_2 mean under normal irrigation, whereas these traits were significantly reduced under water stress conditions. While the crosses $P_3 \times P_7$ and $P_5 \times P_7$ did not differ from the F_2 mean at water stress condition, whereas these traits were significantly decreased at normal irrigation. In four crosses ($P_2 \times P_4$, $P_3 \times P_{7,}$ $P_5 \times P_7$ and $P_7 \times P_8$), both 100-grain weight and grain yield/plant were significantly decreased under normal irrigation, but benefitted from early heading under water stress conditions in100-grain weight and grain yield/plant production. These selections were not to be selected if selection was conducted under normal irrigation conditions, as there is insufficient information about their performance under water stress. Two crosses ($P_4 \times P_6$ and $P_5 \times P_8$) benefitted from earliness in the form of more grain yield production under water stress conditions and both revealed a significant grain yield reduction under favorable conditions, but the only difference was that in the first cross the grains/spike and grain weight was not affected under normal irrigation (Table 8).

4. Conclusion

Mean squares due to additive and non-additive genetic variances were highly significant under both environments in the two seasons. The additive component accounted for a greater proportion than the non-additive component in the F_2-generations under all conditions. High narrow sense heritability for heading date under both environments in both seasons was observed. Highly significant differences between environments, among genotypes (parents, their F_2-populations and F_3-selected families) and the genotypes × environments interaction for all traits under study were observed. Selection for earliness in these populations was efficient to increase the selection criterion and could be accompanied by adverse effects on all correlated traits under study. However, one of these selections was good grain yield under stress condition. So, selection and testing based on this limited sample of populations and conditions at favorable or stress conditions alone may not be the most effective approach for increasing yield under water stress conditions.

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.

Table 8. The correlated response in number of grains/spike, 100-grain weight and grain yield/plant after selection for early heading in 21 F_2-populations of wheat plant sown under favorable and water stress conditions.

Pop.	Spike length				100-grain weight				Grain yield/plant			
	Favorable condition		Water stress condi.		Favorable condition		Water stress condition		Favorable condition.		Water stress condition	
	% 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
$P_1 \times P_2$	-17.82**	-29.89**	-23.22**	-44.23**	-36.94**	-37.65**	-5.48	-15.97	-8.40	19.68**	-20.90**	-10.76**
$P_1 \times P_3$	-5.35	-6.00	-0.58	-1.46	-32.77**	-35.15**	-11.93	-3.79	-3.71	-37.55**	-5.49	-27.92**
$P_1 \times P_4$	-5.63	-5.63	-6.83	-17.63**	-17.20**	-11.22	-13.25	-23.00**	-10.61*	-29.55**	-17.65**	-36.09**
$P_1 \times P_5$	-10.16*	14.53	-26.86**	-9.94	4.88	-9.33	-22.86**	-14.96	-19.23**	15.45*	-14.64**	-0.40
$P_1 \times P_6$	-7.28	-13.11*	-45.04**	-47.71**	-41.01**	-24.96**	-39.15**	-37.79**	-12.83	-32.42**	-0.18	-34.17**
$P_1 \times P_7$	-2.24	-5.46	4.70	-8.07	-30.06**	-37.41**	-15.52*	2.26	-15.72**	-4.43	-21.04**	-5.48
$P_1 \times P_8$	-10.34**	-25.77**	-14.52*	-26.13**	-25.68**	-25.21**	-20.00*	-17.81	-17.82**	17.89**	-19.97**	-0.42
$P_2 \times P_3$	-10.92*	16.58**	-22.72**	-34.11**	-6.49	-23.04**	-10.82	3.50	-5.69	-51.42**	-1.54	-50.53**
$P_2 \times P_4$	-30.01**	-36.48**	-32.82**	-54.21**	-18.65**	-27.73**	-6.45	-5.89	-22.41**	-57.08**	-9.10	-58.49**
$P_2 \times P_5$	-14.39**	-16.27**	-17.78**	-28.85**	-11.79*	-28.92**	14.63	-1.62	-16.50	-38.74**	-13.66*	-41.14**
$P_2 \times P_6$	0.15	23.52**	12.05	-37.50**	-5.86	-15.14**	-19.70*	-16.48*	-2.96	11.82	-23.37**	-10.71**
$P_2 \times P_7$	-0.03	-16.46**	-28.33**	-45.35**	-19.97**	-32.90**	-1.23	-17.76*	-23.42**	-18.09**	-22.41**	-27.22**
$P_2 \times P_8$	0.59	-4.23	-7.85	-16.71**	-41.91**	-30.70**	-11.43	-11.96	-6.98	-20.05**	-16.83**	-31.86**
$P_3 \times P_4$	0.18	-23.38**	-17.47**	-39.55**	-12.67*	-32.75**	35.71**	-6.23	-5.60	-11.02**	-16.49**	-23.96**
$P_3 \times P_5$	-15.59*	-31.38**	-3.47	-23.38**	5.15	-24.25**	-33.71**	-35.30**	-13.85	-57.48**	-3.86	-55.44**
$P_3 \times P_6$	-3.64	15.74**	-7.80	-4.91	-29.98**	-30.90**	-13.45	-22.55**	-8.80	-13.65**	-10.74**	-18.76**
$P_3 \times P_7$	0.00	-28.37**	4.02	-23.34**	-13.12*	-32.99**	-9.18	-8.60	-10.93*	-26.78**	7.39	-19.81**
$P_3 \times P_8$	-8.08	-28.79**	-10.02	-35.47**	-32.10**	-39.46**	-0.40	-8.13	-19.53*	-55.63**	-26.62**	-57.86**
$P_4 \times P_5$	-13.45*	-17.84**	-4.17	-30.48**	0.97	-20.58**	-6.74	-17.38*	-21.31**	-58.47**	-16.16**	-64.83**
$P_4 \times P_6$	0.00	-22.54**	11.28	-37.94**	-3.98	-3.27	14.69	-18.44*	-11.81*	-35.92**	9.93*	-32.91**
$P_4 \times P_7$	0.00	-4.56	-5.33	-27.46**	-25.44**	-32.22**	-7.84	-17.47*	-8.26*	-16.80**	-13.36**	-24.33**
$P_4 \times P_8$	-28.61**	-59.15**	13.19	-63.73**	-13.41*	-15.65**	-14.92	-14.40	-17.04*	-54.93**	-8.51	-59.73**
$P_5 \times P_6$	1.27	-2.90	29.81**	-13.49*	-31.14**	-39.81**	-8.18	-19.96*	-12.60*	16.00*	-11.55**	-0.46
$P_5 \times P_7$	-2.87	-4.52	2.84	-11.32	-36.11**	-37.29**	-10.63	-20.78**	-16.37**	-20.00**	11.89*	5.11
$P_5 \times P_8$	-7.82	-11.47*	0.75	2.75	-26.21**	-30.03**	-4.74	-5.26	-10.68*	49.14**	-15.55**	22.19**
$P_6 \times P_7$	-37.35**	-55.88**	-17.17	-54.89**	-8.32	-36.61**	3.33	-11.59	-6.69	-20.64**	-10.49*	-24.49**
$P_6 \times P_8$	-8.18	-20.08**	-23.44**	-24.91**	-18.79**	-14.55**	-16.27	-22.46**	-22.13**	21.43**	-21.45**	-7.11
$P_7 \times P_8$	-8.68	-33.12**	-27.71**	-44.25**	-20.65**	-39.15**	-0.21	-2.36	-2.96	-36.34**	2.04	-32.16**
Average	-8.79	-15.46	-9.97	-28.72	-19.62	-27.46	-8.42	-14.01	-12.67	-19.49	-11.08	-26.06

Competing interests

The authors declare that they have no conflicts f interest.

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Authors' contributions

All authors contributed equally to this study.

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