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## Research Article

# Genetic variability and heritability for yield and associated traits of synthetically derived wheat population under normal and late planting condition

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## ABSTRACT

A set of five synthetic wheat lines were crossed with four well-adapted cultivars using a 5 × 4 Line × Tester scheme, during the Rabi 2021-22, resulting in the development of 20 F<sub>1</sub> hybrids. These F<sub>1</sub> hybrids along with their parental genotypes were evaluated in the Rabi 2022-23 at the University of Agriculture, Peshawar, Pakistan, to examine genetic variability, heritability estimates (broad- and narrow-sense) and expected selection responses for yield-related traits under two sowing conditions: normal planting (mid-November) and late planting (mid-December). Experiments were carried out in randomized complete block design (RCBD) replicated three times. Broad-sense heritability values were generally higher under normal sowing compared to late planting. Narrow-sense heritability was notably greater for spike initiation and plant height under normal planting, whereas traits such as spikes per plant, spikelets per spike, 1000-grain weight, biological yield and grain yield exhibited moderate narrow-sense heritability under late sowing. In contrast, traits including spike initiation, plant height, spike length and grain yield adjudged low narrow-sense heritability in the late environment. The expected genetic gains were consistently higher in normal planting as compared to late sowing with values recorded for days to spike initiation (3.70 vs. 0.25), plant height (3.62 vs. 0.17), spikes plant-1 (1.09 vs. 0.88), grains spike-1 (1.94 vs. 1.89), 1000 grains weight (1.62 vs. 1.12), biological yield (4.67 vs. 2.82) and grain yield (1.88 vs. 0.27). The prime objective of this study was to select the best genotypes considering high broad sense heritability to proceed further for the varietal selection and use as a parent in local hybridization scheme.

**Keywords:** Synthetic wheat; genetic variability; heritability; yield associated traits, normal and late planting condition.

## INTRODUCTION

Wheat remains the major focus of crop research due to its significant role in ensuring global food security as well as the need to improve both grain yield and quality. Although wheat breeding has made considerable progress, there's still a pressing need to enhance its genetic potential to meet the needs of the growing population. To achieve this goal several strategies can be utilized including horizontal expansion of cultivated areas and vertical strategies by developing climate resilient varieties. A thorough understanding of genetic variability and inheritance patterns of key agronomic traits is therefore crucial for wheat breeding success (Sharma et al., 2025). Genetic exploitation, especially hybridization, has been shown to be an effective method of increasing productivity across diverse agro climatic conditions.



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The objective of modern breeding is to develop varieties with high yield potential, drought tolerance, and resistance to pests and diseases. The selection of desirable genotypes can occur at early filial generations, when traits are highly heritable, or at later generations, after homozygosity has become well established. Direct yield selection is however, frequently hampered by environmental variation and genetic segregation in the early generations. Therefore, breeders frequently target yield contributing traits that are easy to evaluate and have a positive correlation with final yield (Shrungarpawar et al., 2021). A quantitative trait can be improved by enhancing genetic variability in the germplasm and increasing the heritability of desirable characteristics. Selection becomes more efficient when yield-related traits are highly heritable, such as spikes per unit area, grains per spike and grain weight (Patil et al., 2024). As a key genetic parameter, heritability aids in predicting selection response and future performance. A recent study indicates that high heritability coupled with strong genetic advance are indicative of additive genetic variances which make selection more effective (Singh et al., 2024; Chachar et al., 2024). The effective identification of superior genotypes needs the thorough understanding of genetic parameters such as variability, heritability and genetic advancement. While heritability indicates the proportion of trait transmission from parent to offspring, genetic advance provides additional information about the expected progress under selection. Recent research emphasizes that heritability estimates based solely on phenotypic expression have limited practical utility unless interpreted in conjunction with genetic advancement. In light of this, the current study evaluated wheat genotypes with the objectives to estimate variability, heritability and genetic advance for yield and yield-associated traits.

## MATERIALS AND METHODS

The research work was carried out at Research Farm of the University of Agriculture, Peshawar. Five synthetic lines (lines) and four adaptable wheat cultivars (tester) were crossed in Line  $\times$  tester fashion to develop F<sub>1</sub> hybrid population during 2021-22 cropping season. The selected synthetic wheat lines performed best under abiotic stress condition were received from the Wide Wheat Program, National Agricultural Research Centre (NARC), Islamabad, Pakistan (Table 1). Among the testers, Fakhr-e-Sarhad and Atta Habib are full season cultivars while Khyber-87 and Saleem-2000 are short season cultivars in Khyber Pakhtunkhwa Province of Pakistan. The experiment was laid out in triplicate RCB design with plot size of 2 m<sup>2</sup> (Row length: 2m, No. of Rows: 4, Row to row distance: 25 cm).

Data were recorded on days to heading, days to maturity, leaf area, spikes plant<sup>-1</sup>, spikelets spike<sup>-1</sup>, grains spike<sup>-1</sup>, 1000-kernel weight, biological yield, grains yield plant<sup>-1</sup> and harvest index. Data were analyzed using mixed effect model proposed by Annicchiarico (2002). Traits showed significant differences were further analyzed using line  $\times$  tester procedure of Kempthorne (1957). The data was analyzed by using SAS (Version 8.1) statistical software and MS Excell.

Table 1. List of five synthetic lines, four testers and 20 F<sub>1</sub>s obtained from line  $\times$  tester mating.

Genotypes	Pedigree
<b>Synthetic Lines</b>	
Syn L1	SNIPE/YAV79//DACK/TEAL/3/Ae.tauschii
Syn L2	ALTAR84/ Ae. Tauchii
Syn L3	ROK/KML// Ae. Tauchii
Syn L4	ACO89/ Ae. Tauchii
Syn L5	DOY1/ Ae. Tauchii
<b>Testers</b>	
Fakhr-e-Sarhad	PFAU"S"/SERI/BIW"S"
Khyber-87	KVZ/TRM//PTM/ANA(LIRA "S")
Saleem-2000	CHAM-6//KITE/PGO
Atta Habib	Inqalab91*2/Tukuru
<b>F<sub>1</sub> Hybrids</b>	
Syn L1 $\times$ Fakhre Sarhad	Syn L1 $\times$ Saleem 2000
Syn L2 $\times$ Fakhre Sarhad	Syn L2 $\times$ Saleem 2000
Syn L3 $\times$ Fakhre Sarhad	Syn L3 $\times$ Saleem 2000
Syn L4 $\times$ Fakhre Sarhad	Syn L4 $\times$ Saleem 2000
Syn L5 $\times$ Fakhre Sarhad	Syn L5 $\times$ Saleem 2000
Syn L1 $\times$ Khyber 87	Syn L1 $\times$ Atta Habib
Syn L2 $\times$ Khyber 87	Syn L2 $\times$ Atta Habib
Syn L3 $\times$ Khyber 87	Syn L3 $\times$ Atta Habib

Syn L4xKhyber 87	Syn L4xAtta Habib
Syn. L5xKhyber 87	Syn L5x Atta Habib

### Estimation of variance component

Additive ( $\sigma^2_a$ ) and dominance ( $\sigma^2_d$ ) components of genetic variance for each trait both under normal and late test environment were computed as;

$$\sigma^2_a = 2\text{Cov. HS or } 2 \sigma^2_{gca}$$

$$\sigma^2_d = \text{Cov. FS} - 2\text{Cov. HS or } \sigma^2_{sca}$$

$\sigma^2_a$  = Additive genetic variance and  $\sigma^2_d$  = Dominance genetic variance of a trait.

### Estimation of heritability and selection response

Broad and narrow-sense heritability were estimated for each trait under both test environments independently as follows,

$$\text{Broad-sense heritability } (h^2_{bs}) = \frac{V_g}{V_p}$$

$$\text{Narrow-sense heritability } (h^2_{ns}) = \frac{V_A}{V_p}$$

Expected selection response (Re) using 20% selection intensity as per procedure of Falconer and Mackay (1996) under each test condition  $Re = i \times \sigma_p \times h^2_{ns}$

Where,  $i = 1.40$  at 20% selection intensity

$\sigma_p$  = square root of phenotypic variance of a trait under a specific environment

## RESULTS AND DISCUSSION

### Genotype × environment interaction

The analysis of variance (ANOVA) across two planting conditions (normal and late) showed highly significant differences ( $P \leq 0.01$ ) for all recorded traits including days to heading and maturity, flag leaf area, plant height, spikes plant-1, spike length, spikelets per spike, grains per spike, 1000-grain weight, biological yield, grain yield and harvest index (table 2, 3 & 4). It is evident from these results that both phenological and yield contributing traits in wheat are strongly influenced by planting environments. Similarly, among the wheat genotype (09 parental lines and 20 F<sub>1</sub> hybrids) highly significant differences were recorded for the studied traits across environments, demonstrating sufficient genetic diversity for these traits. Partitioning of genetic variation further highlighted significant differences among parental lines (five lines and four testers) and their hybrids, underscoring the distinct genetic contributions of each group. In addition, highly significant response was observed for the genotype × environment interaction and its sub components (parent × environment and F<sub>1s</sub> × environment), indicating that genotypes, parents, and hybrids responded differently to change in planting conditions. Because G × E interactions were significant for all studied traits. So, Independent ANOVA was performed under each environment to capture trait specific responses. These findings are in line with Khare et al. (2024) and Bhandari and Poudel (2024) who reported highly significant response of environment, genotype, and their interactions in wheat.

### Days to spike initiation

The ANOVA results showed highly significant differences ( $P \leq 0.01$ ) for days to spike initiation among all genotypes (table 2). Estimates of variance components for days to spike initiation revealed that additive, dominance, and environmental variances were 8.51, 1.46, and 0.38 under normal planting, and 0.35, 2.87, and 0.63 under late planting (Table 5). In both sowing conditions, genetic variance (sum of additive and dominance effects) exceeded environmental variance indicating that genetic factors were the primary contributors to variation in heading time.

Broad-sense heritability was high under both conditions (0.96 in normal and 0.84 in late planting) suggesting strong genetic control and good prospects for selection. However, narrow-sense heritability was markedly higher under normal planting (0.82) compared to late planting (0.09) reflecting the diminished role of additive genetic variance in stressed environments. For spike initiation the expected genetic gain was higher for normal sowing (3.70) as compared to late sowing (0.25) suggesting the stronger selection efficiency under optimal planting conditions. The Qiao et al. (2023) highlighted the importance of additive effects across multiple environments which further, identified novel genomic regions influencing flowering and heading dates in bread wheat. Similarly, Prasad et al. (2021) reported a high heritability of heading traits and extensive genetic advancement among diverse wheat genotypes. The Kim et al. (2025)

observed that variation in heading dates is controlled by major genes such as VRN-1 and PPD-1 while also uncovering new loci that contribute to adaptation under autumn-sowing conditions. Hence it is concluded that days to spike initiation is generally strong genetically controlled trait and the relative contribution of additive variance declines under stress reduce selection efficiency under late sowing conditions.

Table 2. Mean squares from ANOVA across two environments (normal and late planting) for days to heading, maturity, leaf area, plant height and spikes plant<sup>-1</sup> of wheat parents and F<sub>1</sub> hybrids.

SOV	DF	Days to spike initiation	Days to maturity	Leaf area	Plant height	Spikes plant <sup>-1</sup>
Environment	1	19584.57**	32993.19**	1815.78**	18931.91**	4907.92 **
Reps w/n environment	4	0.35	1.42	2.77	3.03	0.37
Genotypes	28	35.38**	38.19 **	69.61**	74.38**	30.33**
Parents	8	79.64**	43.25 **	105.29**	75.65 **	22.03**
F <sub>1s</sub>	19	15.53*	8.35 **	18.99 **	21.03**	14.40 **
Parents vs F <sub>1s</sub>	1	58.36**	564.83**	745.92**	1077.87**	399.29**
Genotypes × Environment	28	27.22**	23.54**	6.66**	75.12**	38.53**
Parents × Environment	8	20.98**	16.41**	4.06*	176.21**	19.09**
F <sub>1s</sub> × Environment	19	16.25 **	12.37**	7.00 **	35.55**	16.92 **
Error	112	0.50	0.51	1.79	1.68	0.51

\*, \*\* = Significant at 5 and 1% probability level, respectively, DF: Degrees of freedom.

Table 3. Combined mean squares result for two environmental conditions (N & L) for spike. Length (SL), spikelets. spike<sup>-1</sup>(SPS) and grains spike<sup>-1</sup>(GPS) of wheat parents and F<sub>1</sub> hybrids.

Source	D.F	SL	SPS	GPS
Environment	1	380.03**	361.21**	14902.68**
Reps w/n environment	4	0.13	0.61	0.67
Genotypes	28	2.87**	10.94**	89.38**
Parents	8	2.84 **	3.65 *	47.57 **
F <sub>1s</sub>	19	2.72**	10.60**	74.02**
Parents vs F <sub>1s</sub>	1	6.15 <sup>NS</sup>	75.67**	715.72**
Genotypes × Environment	28	2.36**	9.75**	55.03**
Parents × Environment	8	4.23**	3.27**	17.43**
F <sub>1s</sub> × Environment	19	1.21**	8.01**	47.61**
Error	112	0.09	0.24	1.14

\*, \*\* = Significant at 5 and 1% probability level, respectively, NS: Non-Significant, DF: Degrees of freedom.

### Days to maturity

Highly significant variations ( $P \leq 0.01$ ) were recorded for days to maturity among genotypes (table 2). Analysis of genetic variance for days to maturity revealed contrasting patterns under different planting regimes. The dominance variance (3.85) was significantly greater than additive variance (0.63) under normal planting, whereas additive variance (2.45) dominated dominance variance (1.04) under late planting (table 5). This shift suggested that environmental conditions strongly influence the relative contribution of genetic components to maturity expression.

Heritability estimates showed that broad-sense heritability was very high under normal planting (0.95) but slightly reduced under late planting (0.83). In contrast, narrow-sense heritability was low under normal conditions (0.13) but increased considerably under late sowing (0.58), indicated that additive effects became more prominent when plants face stress from delayed planting. Similar patterns of high broad-sense heritability for maturity traits in wheat have been reported in recent studies, confirmed the strong genetic control of this trait across environments. These findings are in similarity with the results of Patil et al. (2024). The expected genetic gain (selection response) for days to maturity was modest under normal planting (0.41) but more pronounced under late planting (1.67). This showed that in stress prone environments the selection for earliness is more effective. Recent investigations on wheat germplasm also

highlight moderate to high genetic advance for maturity traits, supporting the potential for improvement through targeted selection. Sharma et al. (2025) and Kumar et al. (2024) conducted trials and got uniform results.

Table 4. Combined Mean square results across environments (N & L sowing conditions) for 1000-grain weight (TGW), biological yield (BY), grain yield (GY) and harvest index (HI) of wheat parents and F<sub>1</sub> hybrids at Peshawar.

SOV	DF	TGW	BY plant <sup>-1</sup>	GY plant <sup>-1</sup>	HI
Environment	1	2284.65**	65812.96**	11184.05**	0.002**
Reps w/n environment	4	1.82	3.55	2.09	0.0008
Genotypes	28	87.49**	318.50**	79.82**	0.008**
Parents	8	105.37*	299.97**	9.33*	0.012**
F <sub>1</sub> s	19	42.09**	160.00**	30.30**	0.005**
Parents vs F <sub>1</sub> s	1	807.35**	3478.21**	1584.40**	0.045**
Genotypes × Environment	28	10.29**	43.05**	7.80**	0.005**
Parents × Environment	8	17.66**	28.77**	3.16**	0.007**
F <sub>1</sub> s × Environment	19	2.77**	48.69**	7.06**	0.004**
Error	112	0.46	2.34	0.88	0.0003

\*, \*\* = Significant at 5 and 1% probability level, respectively, DF: Degrees of freedom.

### Leaf area

The ANOVA results showed highly significant differences ( $P \leq 0.01$ ) among the genotypes for leaf area (table 2). Genetic variance components for flag leaf area showed contrasting behavior across planting environments. Under normal sowing, dominance variance was markedly higher than additive variance, indicating a stronger role of non-additive gene action. In contrast, under late planting, additive variance (1.52) surpassed dominance variance (0.93) indicating strong influence of additive effects under stress conditions (Table 5).

Heritability estimates also showed that in normal planting broad-sense heritability was high (0.81) and then drop to moderate level under late planting (0.52). However, the narrow-sense heritability remained relatively low in both environments (0.13 under normal and 0.32 under late planting) indicating ineffective efficiency of selection based solely on additive variance. The predicted genetic gain (selection response) for flag leaf area was modest under normal planting (0.48) but nearly doubled under late planting (0.98). It is evident from this result that under stress prone environment the selection becomes more effective due to the high contribution of additive variance for flag area trait. Gorinoiu et al. (2024) studied diverse wheat genotypes and observed similar results for flag area trait. Similarly, Lohani et al. (2025) observed novel QTLs influencing leaf morphology under diverse environmental conditions in Sichuan wheat germplasm, indicating the role of additive genetic factors. Moreover, natural allelic variation in flag leaf dimensions has been associated with improved grain yield potential, emphasizing the value of this trait in breeding programs (Schierenbeck et al. 2024).

### Plant height

All genotypes are highly significantly different ( $P \leq 0.01$ ) for plant height (table 2). Genetic variance analysis for plant height revealed clear differences between planting environments. Under normal sowing both additive (11.1) and dominance (5.83) variances were substantially greater than the environmental variance, highlighting strong genetic control of this trait. In contrast, under late planting, additive variance (0.30) was lower than both dominance (3.83) and environmental variance (1.89), highlighting that under stress conditions the non-additive effect and environmental factors play a more prominent role (Table 5). Heritability estimates portrayed that broad-sense heritability was very high under normal planting (0.92) but declined to a moderate level under late planting (0.69). Meanwhile, narrow-sense heritability was moderate under normal conditions (0.60) but dropped sharply under late planting (0.05), indicating limited efficiency of selection for plant height in stress environments. In normal planting, genetic gain (selection response) was greater (3.62) than in late planting (0.17) indicating that selection for plant height works better under favorable condition. It is reported by Sharma et al. (2025) that plant height was highly heritable among diverse wheat panels in the north-western Himalayas, while Patil et al. (2024) observed significant genetic variability and heritability

estimates for plant height traits among Indian wheat germplasm. Similarly, Kumar et al. (2024) noted a moderate to high heritability for the plant height trait, indicating the possibility of genetic improvement through targeted selection.

Table 5. Additive, dominance and environmental variances, broad-sense heritability (BS) narrow-sense heritability and selection response for various attributes of wheat under two (N & L) environmental conditions.

Traits	Environment	Additive ( $\sigma^2_a$ )	dominance ( $\sigma^2_d$ )	environmental variances ( $\sigma^2_e$ )	heritability ( $h^2_{bs}$ )	heritability ( $h^2_{ns}$ )	selection response ( $R_e$ )
Spike initiation	Normal	8.51	1.46	0.38	0.96	0.82	3.70
	Late	0.35	2.87	0.63	0.84	0.09	0.25
Days to maturity	Normal	0.63	3.85	0.24	0.95	0.13	0.41
	Late	2.45	1.04	0.73	0.83	0.58	1.67
Leaf area (cm <sup>2</sup> )	Normal	0.89	4.65	1.29	0.81	0.13	0.48
	Late	1.52	0.93	2.3	0.52	0.32	0.98
Plant height (cm)	Normal	11.1	5.83	1.48	0.92	0.60	3.62
	Late	0.30	3.83	1.89	0.69	0.05	0.17
No. of Spikes plant <sup>-1</sup>	Normal	2.50	7.02	0.83	0.92	0.24	1.09
	Late	0.71	0.38	0.19	0.85	0.55	0.88
Spike length (cm)	Normal	0.09	0.88	0.05	0.95	0.09	0.12
	Late	0.09	0.50	0.12	0.83	0.13	0.15
No. of Spikelets spike <sup>-1</sup>	Normal	0.29	0.34	0.15	0.81	0.37	0.46
	Late	6.37	1.00	0.34	0.96	0.83	3.21
No. of Grains spike <sup>-1</sup>	Normal	10.21	42.77	1.31	0.98	0.19	1.94
	Late	3.87	3.33	0.98	0.88	0.47	1.89
1000- grain wt. (g)	Normal	3.87	6.98	0.40	0.96	0.34	1.62
	Late	1.94	3.42	0.52	0.91	0.33	1.12
Biological yield (g plant <sup>-1</sup> )	Normal	24.26	25.94	2.72	0.95	0.46	4.67
	Late	11.18	17.67	1.97	0.94	0.36	2.82
Grain yield (g plant <sup>-1</sup> )	Normal	4.68	6.39	1.07	0.91	0.39	1.88
	Late	0.34	2.09	0.68	0.78	0.11	0.27
Harvest index (%)	Normal	0.00004	0.0002	0.00013	0.65	0.11	0.001
	Late	0.0027	0.00046	0.00042	0.88	0.75	0.06

### Number of spikes plant<sup>-1</sup>

Genetic variance analysis for spikes per plant revealed contrasting patterns across environments. Under normal planting, dominance variance (7.02) was considerably higher than additive variance (2.50), suggesting a stronger role of non-additive gene action. In contrast, under late planting, additive variance surpassed dominance variance, highlighting the increased importance of additive effects under stress conditions.

Heritability estimates revealed that broad-sense heritability was very high under normal planting (0.92) but slightly reduced under late planting (0.85). Meanwhile, narrow-sense heritability was low under normal conditions (0.24) but increased under late planting (0.55), indicating that additive variance contributes more substantially when plants face delayed sowing stress (Table 5).

Under the normal planting (1.09) the predicted genetic gain (selection response) was higher as compared to late planting (0.88), reflecting greater efficiency of selection in favorable environments. These results are supported by Patil et al. (2024) who noted moderate to high heritability for spike associated traits in Indian wheat germplasm, whereas Sharma et al. (2025) reported significant variability and heritability for spikes per plant among diverse Himalayan wheat germplasm. Kumar et al. (2024) emphasized the role of additive variance in spike number under stress conditions, supporting the potential for improvement through targeted selection.

### **Spike length**

Analysis of variance for spike length revealed highly significant difference ( $P \leq 0.01$ ) (table 3). Results showed that spike length revealed consistently greater dominance variance than additive variance under both normal and late planting environments, highlighting predominance of non-additive genetic effects in the expression of this trait. Accordingly, a sharp contrast was observed between broad and narrow sense heritability estimates. Under normal planting, broad-sense heritability was very high (0.95) while narrow-sense heritability remained low (0.09). Similarly, under late planting broad-sense heritability was moderate to high (0.83), but narrow-sense heritability was again low (0.13) (table 5). Based on these results, it was found that the spike length trait is governed by dominance and epistatic interactions rather than additive gene action in the studied germplasm.

The expected genetic gain (selection response) was modest, with values of 0.12 under normal planting and 0.15 under late planting, suggesting limited scope for improvement by direct selection. These results confirm the variability of heritability estimates for spike length across environment and different genetic backgrounds. According to Patil et al. (2024) spike length was moderately heritable in Indian wheat germplasm while Sharma et al. (2025) observed significant variability and moderate heritability for Himalayan wheat. Similarly, Kumar et al. (2024) reported the influence of non-additive variance on spike-related traits reinforcing the limited efficiency of selection based solely on additive effects.

### **Number of spikelets spike<sup>-1</sup>**

Analysis of variance showed highly significant differences ( $P \leq 0.01$ ) (table 3). Results showed that spikelets per spike revealed contrasting effects of both additive and dominance across planting conditions. Additive (0.29) and dominance (0.34) variances were almost same with slightly higher values for dominance under normal planting. Conversely, the additive variance (6.37) was approximately six times higher than dominance variance (1.00) under late planting, indicating the stronger role of additive gene action under stress conditions (table 5).

Heritability estimates further explained that broad-sense heritability was high under both environments (0.81 under normal and 0.96 under late planting) while narrow-sense heritability was moderate under normal planting (0.37) but very high under late planting (0.83). The higher proportion of dominance variance under normal planting reduced narrow sense heritability, whereas the predominance of additive variance under late planting enhanced the efficiency of selection. The relatively greater dominance variance under normal planting contributed to reduced narrow-sense heritability, whereas the predominance of additive variance under late planting enhanced the efficiency of selection.

Under normal planting the expected genetic gain (selection response) was modest (0.46) and relatively higher (3.21) under late planting condition. This indicates that the most effective approach for spikelet number is selection under stress conditions. Similar findings were reported by Patil et al. (2024) for spike-related traits in Indian wheat germplasm. Sharma et al. (2025) studied diverse Himalayan wheat germplasm and observed significant variability and high heritability for spikelets per spike. Moreover, Kumar et al. (2024) highlighted the potential for improvement in spikelet spike<sup>-1</sup> under stress environments through targeted selection due to the predominance of additive variance for this trait.

### **Grains spike<sup>-1</sup>**

Analysis of variance for grains per spike showed significant differences ( $P \leq 0.01$ ) across planting conditions (table 3). The dominance variance (42.77) was higher under normal planting condition, indicating the effect of non-additive gene action. However, the effect of both additive (3.87) and dominance (3.33) variances were nearly equal under late planting, indicating the balanced contribution of both the genetic components (table 5).

The results were further clarified by the differences of heritability estimates which portrayed that broad-sense heritability was very high under both environments (0.98 under normal and 0.88 under late planting), whereas narrow-sense

heritability was low under normal conditions (0.19) but moderate under late planting (0.47). The major reason for this disparity is that dominance variance dominates when condition is favorable whereas additive variance dominates under stressful condition.

The expected genetic gains (selection response) were almost identical across environments (1.94 grains under normal and 1.89 under late planting), suggesting that selection efficiency for grains spike-1 remains relatively stable despite environmental variations. Under both the environments the Broad-sense heritability was very high (0.98 under normal and 0.88 under late planting). In contrast, the narrow sense heritability remained low under normal conditions (0.19) but moderate under late planting (0.47). This variation is due to dominance variance that dominates under favorable condition while additive variance becomes effective when the environmental condition is stressful. The findings are similar with Patil et al. (2024) who noted moderate to high heritability in Indian wheat germplasm for grains spike-1 trait. Across diverse Himalayan wheat germplasm Sharma et al. (2025) observed significant variability and moderate narrow-sense heritability for grains per spike trait, while Kumar et al. (2024) highlighted the limited genetic advance for this trait due to the predominance of non-additive variance. Overall, these results suggest that grains spike<sup>-1</sup> trait is not responsive strongly to early generation selection and the improvement may require the recurrent selection or advance breeding strategies.

### **1000 grain weight**

Analysis of variance revealed highly significant difference ( $P \leq 0.01$ ) among the genotypes (table 4). Dominance variance surpassed the additive genetic variance for 1000 grains weight in both normal and late planting conditions, highlighting the significance of non-additive gene action for this trait. As a result, in both the environments the broad-sense heritability ( $h^2_{bs}$ ) was significantly higher than narrow-sense heritability ( $h^2_{ns}$ ). Under normal planting,  $h^2_{bs}$  was 0.96 compared to  $h^2_{ns}$  of 0.34 while under late planting,  $h^2_{bs}$  was 0.91 and  $h^2_{ns}$  0.33 (table 5).

The predicted genetic gain (selection response) was 1.62 under normal planting and 1.12 under late planting, indicating moderate potential for improvement. As per these findings the predominance of non-additive variance limits the efficiency of direct selection in early generations due to strong heritability of this trait. Similar results were reported by Patil et al. (2024) who studied Indian wheat germplasm and observed moderate to high heritability estimates for grain weight, highlighting the influence of environmental effects on trait expression. Sharma et al. (2025) observed significant variability and moderate narrow-sense heritability for 1000 grains weight across diverse Himalayan wheat genotypes, highlighting the role of additive variance plays under stress condition and is dominated by dominance effects under favorable condition. Similarly, Kumar et al. (2024) observed limited genetic advancement for grain weight, supporting the need for advance breeding strategies or recurrent selection to achieve meaningful advancement.

### **Biological yield plant<sup>-1</sup>**

Highly significant variations ( $P \leq 0.01$ ) were observed for biological yield per plant among all genotypes (table 4). The genetic variance analysis of biological yield per plant revealed significant contributions from additive as well as dominance components across environments. During normal planting, additive variance (25.94) was slightly higher than dominance variance (24.26), whereas during late planting, additive variance (17.67) clearly exceeded dominance variance (11.18) (table 5). It is evident that both types of genetic variance are important but additive effects are more pronounced under stress. Heritability estimates confirmed strong genetic control of biological yield. Broad-sense heritability was consistently high under both environments (0.95 under normal and 0.94 under late planting). In contrast, narrow-sense heritability was moderate under normal planting (0.46) and slightly lower under late planting (0.36), reflecting the influence of dominance variance.

A greater selection response was observed under normal planting conditions (4.67) compared with late planting (2.82). This indicates that selection for biological yield is more effective when growing conditions are favorable. These findings showed that biological yield is governed by both additive variance and dominance variance, however clearly greater genetic advancement occurs under normal sowing conditions. According to Patil et al. (2024), biological yield in Indian wheat shows high broad-sense heritability, while narrow-sense heritability remains moderate due to the influence of dominance effects. Sharma et al. (2025) also observed considerable variation and moderate narrow-sense heritability in wheat panels from the Himalayan region. In contrast, Kumar et al. (2024) highlighted the prominent effects of additive variance under stress conditions suggesting the use of targeted selection.

### **Grain yield plant<sup>-1</sup>**

Analysis of variance for grain yield plant<sup>-1</sup> showed highly significant differences ( $P \leq 0.01$ ) (table 4) among all the genotypes. Dominance variance was consistently greater than additive variance under both planting regimes. Under normal sowing, additive, dominance and environmental variances were estimated as 4.68, 6.39, and 1.07, respectively.

In contrast, under late planting, the values declined to 0.34, 2.09, and 0.68. Based on this consistent pattern, it could be concluded that grain yield is primarily determined by non-additive genetic effects irrespective of environmental factors. Heritability estimates reinforced this conclusion. Higher Broad-sense heritability was recorded under both conditions (0.91 in normal planting and 0.78 in late planting) whereas  $h^2_{ns}$  was moderate under normal planting (0.39) and decline under late planting (0.11). The expected genetic gain was also greater under normal conditions (1.88) as compared to late sowing (0.27) recommending that for higher grain yield the direct selection is more effective under normal planting.

These results are consistent with Khan et al. (2025) who observed high  $h^2_{bs}$  but limited  $h^2_{ns}$  for yield traits in durum wheat due to the effects of dominance variance. Sharma et al. (2025) observed significant for grain yield among diverse Himalayan wheat genotypes. Similarly, studies in Indian wheat germplasm have demonstrated that non-additive effects restrict genetic advance, necessitating advanced breeding techniques such as recurrent selection or hybridization. It is concluded that grain yield is highly heritable and simple selection methods are ineffective due to the predominance of additive variance. Therefore, breeding strategies that exploit dominance and epistatic interactions are essential to achieve better genetic improvement in wheat yield.

### Harvest index

Analysis of variance revealed highly significant variance pattern ( $P \leq 0.01$ ) for harvest index across planting environments (table 4). The dominance variance dominated additive variance under normal planting condition indicating the predominance of non-additive gene action. On the other hand, in late planting the additive variance surpassed dominance variance showing the pronounced additive effect under stressful environment (Table 5). Under normal planting, broad-sense heritability was moderate (0.65) but increased under late planting (0.88). In contrast, under normal planting conditions the narrow-sense heritability was very low (0.11) but rose considerably under late planting (0.75). It is clear from these results that during stress condition the selection efficiency enhances for harvest index trait due to significant role plays by additive variance. Normal planting resulted in little genetic gain (0.003) while late planting resulted in more (0.06). It showed the potential of high genetic improvement under stress prone environment. Similarly, Patil et al. (2024) reported moderate heritability and genetic advance among diverse wheat germplasm for harvest index trait. Across diverse environments Praveenkumar et al. (2025) reported significant variation and heritability across multiple wheat genotypes. Similarly, Gaur et al. (2025) emphasized the role of additive variance in shaping harvest index particularly under challenging environments. These findings suggest that stress environments not only expose genetic variability more clearly but also enhance the prospects for targeted selection strategies in wheat breeding.

### CONCLUSION

Heritability (both broad and narrow-sense) and selection response for variable parameters over two planting environments were comparatively greater in magnitude for normal than late. conditions. Estimates of  $h^2_{bs}$  was high (ranging from 65% to 98%) for all attributes across two environmental conditions whereas narrow-sense heritability showed moderate to low values. The Expected genetic gains were consistently higher in normal planting as compared to late sowing. Synthetic-L1, Synthetic-L3, and Synthetic-L4 among lines and Fakhre-Sarhad and Khyber-87 among testers performed outstanding for attributes e.g., spikes plant<sup>-1</sup>, spikelets spike<sup>-1</sup>, grains spike<sup>-1</sup>, 1000-grain weight, and grain yield under one or both environments. Similarly, F<sub>1</sub> hybrid Synthetic-L<sub>1</sub> × Saleem-2000, Synthetic-L<sub>2</sub> × Atta Habib, Synthetic-L<sub>3</sub> × Atta Habib and Synthetic-L<sub>5</sub> × Atta Habib were best for most of the yield traits under normal test environment.

### AUTHOR'S CONTRIBUTION

Durr-e-Nayab designed, supervised and conducted this piece of research work. Muhammad Khalid, Lubna Naz, Sumayya, Sadia Mukhtiar, Shah Fahad, Murad Ali, Farmanullah Khan, Monsif Ur Rehman and Aamir Iqbal compiled and analyzed the data. Durr-e-Nayab and Muhammad Khalid wrote the research Paper. Lubna Naz, Sumayya Inayat, Sadia Mukhtiar, Shah Fahad, Murad Ali, Farman ullah Khan, Monsif Ur Rehman and Aamir Iqbal reviewed the research paper. All authors read and approved to submit the research paper to the journal.

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## AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed in this study are presented within this article in the form of tables.

## ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

## CONSENT FOR PUBLICATION

All authors have reviewed the manuscript and approved it for publication.

## CONFLICT OF INTERESTS

The authors and co-authors of this manuscript declare that there is no any conflict of interest in connection with this research study.

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