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Posted Date: 10 January 2025

doi: 10.20944/preprints202501.0839.v1

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Article

Studies on Component of Genetic Variance, Combining Ability and Heterotic Response for Yield and Yield Components in Wheat (*Triticum aestivum* L.)

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Abstract: Research was conducted at three locations during the *Rabi* seasons of 2022–2023 and 2023–2024 with objective to find out the effects of General Combining Ability (GCA), Specific Combining Ability (SCA), and heterotic response on various yield and yield component traits in wheat. In Phase I, forty-five (45) hybrids were generated by the cross of fifteen lines with three testers. Phase II, Randomized Complete Block Design was used with three replications, data were analyzed. Best lines for GCA were DH-3086, PBW-757 and tester PBW ZN1. Thus, GCA results can be used to improve yield; parent selection, and broad adaptability. High estimates of SCA found in genotypes PBW-677 X PBW-343, PBW-822 X PBW ZN1 and DH-3086 X PBW-343. This indicates SCA results can be used for **identification of best crosses**. **Heterosis over** better parent and standard varieties were identified (best genotypes were PBW-822 X PBW ZN1 and DH-3086 X PBW ZN1) can be used exploitation of heterosis for wheat improvement. Thus, research provide valuable insights into inheritance patterns for yield-related traits that underpin the development of advanced breeding techniques, including hybrid breeding and selection of superior parent that aimed at improvement of wheat production to ensure resilience against environmental stresses.

Keywords: Combining ability; Heterotic response; wheat; yield and yield component

1.0. Introduction

Wheat (*Triticum aestivum* L.), a member of the Poaceae family, is an allohexaploid species with 21 chromosome pairs arranged into three sub-genomes; A, B, and D. It has a BBAAADD genome composition and a chromosome number of $2n = 6x = 42$ [1]. It was developed through natural hybridization between Emmer wheat (AABB) (*Triticum dicoccon*), also known as "farro," and Goat grass (DD) (*Aegilops tauschii*), and commonly referred to as hard grass [2]. Wheat is a self-pollinating plant with spike type of inflorescences that contains three anthers connected to the base by slender filaments, enclosed within bract-like structures called the lemma and palea that enclosed its fruit called caryopsis [3].

Productivity of Wheat in India and Nigeria

The data (2021-22) from the Farmers Welfare unit, Ministry of Agriculture and, of Indian Government and Federal Ministry of Agriculture and Rural Development (FMARD) of Nigeria, reveals a significant difference in wheat productivity per hectare between India's and Nigeria's top wheat-producing states. In India, states like Punjab and Haryana achieve much higher productivity, with yields ranging from 4.8–5.2 tons/ha and 4.5–4.9 tons/ha, respectively. Other Indian states, like

Western Uttar Pradesh and Gujarat, also produce more than 3 tons/ha. In contrast, Nigeria's leading wheat-producing states, such as Borno and Kano, have considerably lower productivity, with yields ranging from 1.5–2.0 tons/ha. The lowest yields in India, like in Jharkhand (1.5–1.8 tons/ha), are comparable to some of the highest yields in Nigeria [4]. Thus, India's wheat productivity per hectare is significantly higher than Nigeria's across most states, indicating more advanced agricultural practices for wheat cultivation in India (Table 1).

1.2. Concept of Genetic Variance

The line in to tester is a powerful mating design to find the best combiner to be used for further crop improvement. Thus, study of gene action that controls the expression of different characters could aid selection of good parents. When a genotype exhibits high mean yield and little variability over a range of environmental conditions, it is said to be stable genotype [5]. Choice of consistent genotypes that are suited for wider environmental conditions required sufficient knowledge of component of genetic variance [6, 9 and 7], reported that, knowledge on correlation between yields and yield influencers aids the selection of desirable/superior parents and best cross combinations for the commercial exploitation of high yielding parent in conventional breeding programme. Therefore, understanding that relationship between the two is essential for yield improvement in wheat. According to [8] stated that "degree of genetic determination (DGD) which considered as ratio of genetic variance over phenotypic variance, this can be used to estimate potentially high yielding population in relation with yield influencing traits is useful for any successful breeding programme. Thus, breeder must understand some behavior on how gene expressed in the inheritance of all traits under studies. Thus, crop yield is the sum of all individual yield components operating together with small and cumulative effects to the final yield. Yield is polygenically controlled and breeding for high yielding genotypes required knowledge of mode of gene expression [9]. The study of heterosis has become essential, not optional, due to the challenges involved in developing commercial hybrid seeds in wheat. Exploiting heterosis economically effective in wheat breeding programme [10, 9].

Sprague and Tatum [11] this concept described general and specific combining abilities. GCA reflects mean yield/performance of a line across different cross combinations, while SCA represents the deviation from GCA, showing whether the performance exceeds or falls short of expectations. It was noted that genes with additive effects play more significant role in GCA, whereas SCA is influenced by dominance genes and epistatic effects (inter-allelic interactions). Combining ability serves as effective tool for selecting desirable parents capable of producing crosses with high genetic value. The level of hybrid vigor depends on combining ability of the genotypes used in the hybridization. Genotype capable of transmitting favorable traits or hybrid vigor to their offspring are considered to have high combining ability (good combiners). Combining ability helps in identifying parental lines that contribute favorable traits to their offspring. This allow researcher to choose the best parental genotype of wheat, leading to development of high-yielding and stress-tolerant varieties. For developing countries, where resources for extensive breeding programs may be limited, this approach can be used to maximize the chances of success with fewer inputs [12].

1.3. Constraint and Study's Outcome

Despite the fast and steady increase in population of India and Nigeria (being ranked as 55th among wheat producing countries), wheat production currently encounters many constraints that affect its yield and quality like salinity, heat stress and insufficient breeding information such as genetic variances, GCA, SCA, adaptability, and exploitation of heterosis. Previous studies used very limited number of genotypes for their experiments that can lead to inconsistency of research findings due experimental errors. The present studies used 67 wheat genotypes that are enough to increase precision and reduces experimental errors. Most of existing studies were conducted either on India or Nigeria but not both, leaving a serious gap between these two diverse agro ecological zones. Thus by including Nigerian locations, the present study adds valuable data on how wheat genotypes perform in African climates, contributing to relatively under-researched region with sufficient

breeding information such as genetic variances, GCA, SCA, adaptability, and exploitation of heterosis that will be used for yield optimization and provides breeders greater opportunity for further wheat improvement. The present investigation also provides valuable insights into inheritance patterns of yield-related traits that underpin the development of advanced breeding techniques, including hybrid breeding and selection of superior parent that aimed at improvement of wheat production to ensure resilience against different environmental stresses that ultimately contributes to sustainable agricultural practices that aimed at wheat improvement to mitigate food insecurity for the growing population.

To boost wheat yield, plant breeders have explored commercial hybrid seed production through genetic/cytoplasmic male sterility, and the use of some chemicals that induce sterility in wheat. However, due to the polyploidy of wheat and the technical difficulties involved in producing hybrid seeds on a commercial scale, these efforts have little to no practical significance. Therefore, an amicable remedies to this scenarios is the exploitation of heterosis and identification of superior parent, high yield potential crosses and effective selection is quite necessary for wheat improvement [13]. Heterosis breeding is one of key option for wheat improvement due to challenges associated with the introduction of large scale hybrid seeds in Wheat production, hybrid breeding is rewarded. [9]. Reif *et al.* [14], reported that, heterosis breeding is an eco-friendly and non-transgenic method of breeding programme.

1.4. Some Limitations of the Study

The limitations of the current study are as follows; it did not incorporate molecular markers or genomic tools to explore the genetic basis of the observed traits. To address this challenge, future research could integrate marker-assisted/accelerated selection (MAS) or genome/genomic selection (GS) to identify or track beneficial alleles associated with high yield and stress tolerance. This strategy would streamline the breeding process and increase the precision in selecting desirable traits.

2.0. Material and Methods

2.1 Material and Experimental Site

Experimental materials consisted of 67 wheat genotypes, including fifteen lines, three testers, four checks, and forty-five (45) F₁s crosses/hybrids were generated through the hybridization of fifteen female lines with three male testers to conduct stability analyses for yield and yield components. The planting material comprised fifteen lines. BHU 25, WB-02, BHU 31, HD 3721, PBW 725, CRD GEHNU1, PBW 550, PBW 677, PBW 822, HD 3117, DBW 173, HD 3086, DBW 222, CSW 18, and PBW 757. The three testers were PBW ZN1, PBW 343, and HD 3326, with four checks HD 2967, DBW 187, Norman, and Borlaug-100. Other materials included Breeder's kit. SPAD (Soil Plant Analysis Development) handheld meter, meter rule, electric balance (Compax-Cx-600), seed counting machine, digestion apparatus, sodium hydroxide, hydrochloric acid, and more.

Table 1. List of parents and four checks (Sources and Status (released var/advanced line etc.).

Sr.		Status (released variety/advanced line etc.)	
No.	Genotype	Source of genotypes	etc.)
1	BHU 25	Banaras Hindu University (BHU)	Released Variety
2	WB-02	Private Sector (West Bengal)	Released Variety
3	BHU 31	Banaras Hindu University (BHU)	Released Variety
4	HD 3721	ICAR-IIWBR	Released Variety
		Punjab Agricultural University	
5	PBW 725	(PAU)	Released Variety

ICAR-IIWBR/Collaborator		
6	CRD GEHNU1	Institute Released Variety
Punjab Agricultural University		
7	PBW 550	(PAU) Released Variety
Punjab Agricultural University		
8	PBW 677	(PAU) Released Variety
Punjab Agricultural University		
9	PBW 822	(PAU) Released Variety
10	HD 3117	ICAR-IIWBR Released Variety
11	DBW 173	ICAR-IIWBR Released Variety
12	HD 3086	ICAR-IIWBR Released Variety
13	DBW 222	ICAR-IIWBR Released Variety
14	CSW 18	ICAR-IIWBR Released Variety
Punjab Agricultural University		
15	PBW 757	(PAU) Released Variety
Punjab Agricultural University		
16	PBW ZN1 (tester1)	(PAU) Released Variety
Punjab Agricultural University		
17	PBW 343 (tester2)	(PAU) Released Variety
18	HD 3326(tester3)	ICAR-IIWBR Released Variety
19	HD 2967 (check1)	ICAR-IIWBR Released Variety
20	DBW 187 (check2)	ICAR-IIWBR Released Variety
21	Norman (check3)	CIMMYT/ICAR Collaborations Released Variety
Borlaug-		
22	100(check4)	CIMMYT/ICAR Collaborations Released Variety

Table 2. Pedigree of parents and four checks.

S		
N	Genotype	Pedigree of genotypes
1	BHU 25	-
T.DICOCCONC19309/AE.SQUARROSA(409)/3/MILAN/S87230// BAV92/4/2*		
2	WB-02	MILAN/S8732/ 0//BAV92
3	BHU 31	-
4	HD 3721	ND/VG 9144//KALYANSONA/BLUEBIRD/3/YACO/4/VEE#5
5	PBW 725	PBW621//GLUPR 0/3* PBW 568/3/ PBW 621
CRD		
6	GEHNU1	-
7	PBW 550	WH 594/RAJ 3856//W 485
8	PBW 677	PFAU/MILAN/5/CHEN/Ae, squarrosa// BCN/32/VEE#7 /BOW/4/PASTOR
9	PBW 822	-
10	HD 3117	HD 2733/ HD 2824 // DW 1278
11	DBW 173	KAUZ//AA//KAUZ/P BW602

12	HD 3086	DBW14/HD2733//HUW468 KACHU/SAUAL/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA/5/BOW/C	ROW//
13	DBW 222	BUC/PVN/3/YR/4/TRAP#1/7/ATTILA/2*PASTOR	
14	CSW 18	-	
15	PBW 757	PBW550/YR15/6* AVOCET/3/2*PBW550/4/PBW568+YR36/3* PBW550 T. dicoccon C19309/Ae. sauarrosa (409)/3/	
16	PBW ZN1	MILAN/S87230//BAV92/4/2*MILAN/S87230/BAV92	
17	PBW 343	ND/VG 144//KAL/BB/3/YACO'S'/4/VEE#5'S	
18	HD 3326	-	
19	HD 2967	ALONDRA/CUCKOO//URES81/HD-2160-M/ HD-2278	
20	DBW 187	NAC/THAC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/ KACHU	
21	Norman Borlaug-	-	
22	100	BABAX/Lr//BABAX	

Table 3. Salient feature of Selected Parents (parents and four checks).

S Genotyp N e	Source	Duration (Days)	Eco-system	Salient Features
1 BHU 25	Banaras Hindu University (BHU)	~140-150	Irrigated	High yield, resistance to lodging.
2 WB-02	Private Breeder (West Bengal)	~130-140	Irrigated	Early maturity, disease resistance.
3 BHU 31	Banaras Hindu University (BHU)	~140-150	Irrigated	Adaptable variety with moderate rust resistance.
4 HD 3721	ICAR-IIWBR	~145	Irrigated	High grain quality, rust resistance.
5 PBW 725	Punjab Agricultural University (PAU)	~140-145	Irrigated	Rust resistance, higher protein content.
6 CRDGE HNU1	ICAR-IIWBR	~140-150	Conservation Agriculture	Suitable for zero tillage, high yield.
7 PBW 550	Punjab Agricultural University (PAU)	~140-145	Irrigated	Suitable for chapati, rust resistant.
8 PBW 677	Punjab Agricultural University (PAU)	~140	Irrigated	Early sowing, rust resistance.
9 PBW 822	Punjab Agricultural University (PAU)	~140	Irrigated	High yielding, suitable for timely sowing.
10 HD 3117	ICAR-IIWBR	~135-145	Irrigated	High tillering ability, rust resistant.
1 DBW 1 173	ICAR-IIWBR	~140	Irrigated	High yield potential, suitable for timely sowing.
1 HD 3086	ICAR-IIWBR	~135-140	Irrigated	High yielding, rust and Karnal bunt resistance.
1 DBW 3 222	ICAR-IIWBR	~140-145	Irrigated	Excellent chapati quality, rust resistant.
1 CSW 18	ICAR-IIWBR	~140	Conservation Agriculture	Early sowing, suitable for zero tillage, rust resistant.
1 PBW 757	Punjab Agricultural University (PAU)	~135-140	Advanced Line	Testing phase for high yield and adaptability.
1 PBW 6 ZN1	Punjab Agricultural University (PAU)	~140-145	Advanced Line	Testing phase with improved disease resistance.

1 7	PBW 343	Punjab Agricultural University (PAU)	~135-140	Irrigated	High yield, widely adopted.
1 8	HD 3326	ICAR-IIWBR	~140-145	Irrigated	Resistant to rust and foot rot, suitable for bread and chapati.
1 9	HD 2967	ICAR-IIWBR	~140	Irrigated	High yield, resistant to stripe and leaf rust.
2 0	DBW 187	ICAR-IIWBR	~140-145	Irrigated	High protein content, rust resistant.
2 1	Norman	CIMMYT/ICAR Collaborations	~135-140	Irrigated	High yield, rust resistant, good for bread quality.
2 2	Borlaug-100	CIMMYT/ICAR Collaborations	~140-145	Irrigated	Rust resistant to improve centenary of Norman Borlaug's birth.

2.2. Methods

In Phase I (2022-23 *Rabi* season), an Augmented Design was employed to generate forty-five F₁ hybrids through the hybridization of fifteen lines/females with three testers/males, through line X tester mating design as described by [15]. In Phase II, during the *Rabi* season of 2023-24, Randomized Complete Block Design (RCBD) with three replications was used. Standard agronomic practices were followed as recommended. The research took place at three locations; Lovely Professional University, India; Kebbi State University of Science and Technology, Aliero, Nigeria; and the Lake Chad Wheat Research Institute, Nigeria. Emasculation and pollination procedures were performed, and quantitative data were collected based on guidelines from the International Board for Plant Genetic Resources (IBPGR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) [16] for wheat descriptors. Qualitative data, such as chlorophyll/green pigment content, were measured using a SPAD (Soil Plant Analysis Development) meter, and protein/crude content was assessed using the micro Kjeldahl method. Data were analyzed using ANOVA [17], line x tester analysis, combining ability [15], and heterosis estimation [18].

2.2.1. Experimental Sites

The environmental conditions at the three experimental sites were as follows; location one was the Teaching and Research Farm, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India, located at a latitude of 31.2245° N and longitude of 75.7711° E, at an altitude of approximately 243 m above sea level, with an annual rainfall of 527.1 mm. Location two was the Teaching and Research Farm of Kebbi State University of Science and Technology Aliero, Kebbi State (KSUSTA), Nigeria, situated in the Sudan Savanna agro-ecological zone at latitude 13°08' N and longitude 50°15' E, with an altitude of around 250 m above sea level and annual rainfall ranging from 1500 to 1700 mm. The third location was the Lake Chad Wheat Research Institute in Borno State, Nigeria, located at latitude 11.8467° N and longitude 13.1571° E, at an altitude of approximately 325 m above sea level, with annual rainfall between 900 and 1500 mm. In Punjab, India, temperatures ranged from 19°C (January) to 36°C (April), with lows between 8°C (January) and 21°C (April). In Kebbi State, Nigeria, temperatures varied from 17.1°C (January) to 27°C (April), and in Borno State, Nigeria, temperatures ranged from 14°C (January) to 24°C (April). Regarding soil types, Location I (India) has fertile, alluvial soils with low organic matter content. Location II (Kebbi State) features generally sandy or loamy soils with lower organic matter content, while Location III (Borno State) has sandy or loamy soils (entisols or aridisols) that are nutrient-depleted. Punjab experiences cooler winters during the two *Rabi* seasons, while Kebbi and Borno States have drier climates, with Borno being the driest site out of the three locations. Weather report 2023-2024 *Rabi* seasons across three locations on climate variability during evaluation period as per below:

Table 4. Weather report 2023-2024 seasons across three locations.

Borno state Nigeria 2023	Kebbi state Nigeria 2023	Phagwara Punjab state India
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Month	High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)	High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)	High Temp (°C)	Low Temp (°C)	R. H. (%)	Rainfall (mm)
October	36	23	15	45	37.4	25.5	36.3	58	32	20	54	14
November	34	18	0	25	37.1	22.4	0	29	27	15	52	30
December	31	15	0	20	34.4	18.1	0	20	21	10	58	25
Rabi season 2024												
January	31	14	0	15	34.7	17.1	0	20	19	8	60	75
February	34	17	0.2	14	37.8	19.8	0.53	18	23	10	57	61
March	38	20	1	17	40.8	23.3	4.9	24	29	15	52	51
April	41	24	3	21	42.3	27	24.2	36	36	21	45	39
May	40	27	13.5	35	41.3	29.8	75.5	49	40	26	38	27
June	37	26	63	50	38.8	28.8	94.9	58	41	29	50	50
July	33	24	115	65	35.4	26.3	170.2	70	36	28	73	211
August	31	23	198	75	32.8	24.4	179.1	79	34	26	67	150
September	33	24	80	68	34.7	24.9	151.1	76	34	24	60	101

Source: Nigerian Meteorological Agency (Nimet) report for the two State **Source:** Punjab Agricultural University of Agric.

2.2.2. Statistical Analysis

Analysis of Variance was one of the statistical methods employed to analyze the data [17], line × tester analysis [15], and Analysis of Variance for Combining Ability [15], and heterosis estimation [18].

2.2.2.1. Estimation of GCA and SCA variances and their effects

The estimate of GCA and SCA variances and their effects were carried out by line × tester method using data sourced from F₁ generation and its parents.

The method for analysis were described below:

X_{ijk} = is the submission of $\mu + g_i + g_j + s_{ij} + e_{ijk}$

Where:

μ = Mean

g_i = for estimation of GCA effects on i^{th} T, $i = 1, 2, \dots, T$.

g_j = GCA effect estimation, $j^{th} = T$, $j = 1, 2, \dots, L$.

s_{ij} = submission the effect of SCA with $i^{th} = T$ and $j^{th} = L$ crosses

e_{ijk} = total error in relation with ijk^{th} data, where $k =$ stand for $1, 2, \dots$ replications

Individual estimated effects as follows:

$$\mu = \frac{X_{...}}{mfr}$$

(i) For individual estimation:

Where:

$X_{...}$ = stand as submission of cross combinations

(ii) g_i = Also stand as $\frac{X_{i..}}{fr} - \frac{X_{...}}{mfr}$

Where:

X_i = submission of i^{th} T across all L with their replicates.

(iii) g_j = stand as submission of $\frac{X_{.j}}{mr} - \frac{X_{...}}{mfr}$

Where:

$X_{.j}$ = submission of j^{th} L divided by T and their replicates.

(iv) s_{ij} = submission of $\frac{X_{ij}}{r} - \frac{X_{i.}}{fr} - \frac{X_{.j}}{mr} + \frac{X_{...}}{mfr}$

Where:

X_{ij} = Submission of ij^{th} in all crosses like (L and T) divided by replicates.

Standard of error on GCA was found through:

Standard error for GCA of F = $\sqrt{(Me \div rm)}$

Standard error GCA in T = $\sqrt{(Me \div rf)}$

Standard error for SCA = $\sqrt{(Me \div rf)}$

Standard Error ($g_m - g_f$) line = $\sqrt{(2Me \div rm)}$

Standard Error ($g_m - g_f$) tester = $\sqrt{(2Me \div rf)}$

Standard Error ($S_{ij} - S_{kl}$) = $\sqrt{(2Me \div r)}$

Where:

Me = Error MS

g_m = genotype of male

g_f = genotype of male

Critical Differences Calculation:

Critical Differences (C.D) = t at 5% $\times$ SED; 1% probability levels at error d.f.

Table 5. ANOVA for estimation of SCA and GCA variances and their effects is given below.

SV	df	SS	MS
Rep.	(r-1)	$\Sigma \frac{x^2..K}{mt} - \dots \frac{x^2}{mtr}$	
Trt (Hybrids)	(lt-1)	$\Sigma \frac{X^2ij}{r} - \frac{x^2...}{mfr}$	
T	(t-1)	$\Sigma \frac{X^2i...}{fr} - \frac{x^2...}{mfr}$	Mm
L	(l-1)	$\Sigma \frac{X^2j}{mr} - \frac{x^2...}{mfr}$	Mf
L x T	(t-1) (l-1)	$\Sigma \frac{X^2ij}{r} - \Sigma \frac{x^2i..}{fr} - \Sigma \frac{x^2j..}{mr} + \frac{x^2..}{Mfr}$	
E. var.	(lt-1) (r-1)	By d.	
Total	(mfr-1)	$\Sigma \frac{X^2}{ijk} - \frac{x^2...}{mfr}$	

Where, L=female (f), T=male (m), r=replication, SV=source of variation and E=error

$x_{..k}$ = total of LXT in k^{th} rep.

X_{ij} = total of ij^{th} combination of crosses for all replicates,

x_i = submission of j^{th} T across lines with replicates,

$x^2.j.$ = lines submission divided by L and replicates,

$x_{ij} \dots$ = total number of all LXT crosses over replicates,
 σ^2_e = sum of error variation,
 R = sum replicates,
 M = tester,
 F = lines,
 M_m = Mean square as a result of tester .S. due to males,
 M_f = Mean square as a result of lines,
 M_{mf} = Mean square as a result of LXT,
 M_e = Mean square as a result of error' submission

2.2.2.2. Genetic Components

$$\text{Covariance of half - sib (F)} = \frac{M_f - M_{fm}}{r \times m}$$

$$\text{Covariance of half - sib (T)} = \frac{M_m - M_{fm}}{r \times f}$$

$$\text{Covariance of half - sib (mean)} = \frac{1}{r[2(f \times m) - f - m]} \left[\frac{(m-1)M_m + (f-1)M_f}{m+f-2} - M_{f \times m} \right]$$

$$\text{Covariance of full - sib (mean)} = \frac{(M_m - M_e) + (M_{fm} - M_e) + (M_f - M_e)}{r \times 3} +$$

$$\frac{6 \times r \text{ Covariance of half - sib (mean)} - (r \times f) + (r \times m) \text{ Covariance half - sib (mean)}}{r \times 3}$$

Where:

M_f = Females mean squares

M_m = Males mean squares

M_{fm} = Females x Males mean squares

M_e = Mean squares error

r = Replications number

f = Females number

m = Males number

$$\sigma^2_{gca} = \text{Covariance of half-sib (mean)} = \left[\frac{1+F}{4} \right] \sigma^2 A$$

Therefore:

$\sigma^2 A = 2 \text{ Covariance of half-sib (mean)}$; if $F = 1$ and

$\sigma^2 A = 4 \text{ Covariance of half-sib (mean)}$; If $F = 0$

$$\sigma^2_{sca} = \frac{(M_{fm} - M_e)}{r}$$

$$\sigma^2_{sca} = \left[\frac{1+F}{2} \right]^2 \sigma^2 D$$

Therefore:

$\sigma^2 D (sca) = \sigma^2$; if $F = 1$, and

$\sigma^2 D (sca) = 4 \times \sigma^2$; if $F = 0$

Where:

F = Inbreeding coefficient

Mean degree of dominance

Calculated using formula given by Kempthorne and Curnow (1961).

$$\text{Average degree of dominance} = \sqrt{(\sigma^2_{\text{sca}})/(2\sigma^2_{\text{gca}})} \text{ or } \sqrt{(\sigma^2_{\text{D}})/(\sigma^2_{\text{A}})}$$

Where, σ^2_{sca} = Estimation of variance due to sca.

σ^2_{gca} = Estimation of variance due to gca

2.2.2.3. Heterosis over Better Parent and Standard Variety

Heterosis was calculated based on an increase or decrease in mean values of the crosses (F₁'s) compared to better parent (Heterobeltiosis) and standard variety (Standard Heterosis) (%).

$$1. \quad \text{The heterosis over better parent (Heterobeltiosis)} = \frac{\bar{F}_1 - \bar{BP}}{\bar{BP}} \times 100$$

$$2. \quad \text{The heterosis over standard variety (Standard heterosis)} = \frac{\bar{F}_1 - \bar{SV}}{\bar{SV}} \times 100$$

Where:

$\bar{F}_1$ = Mean of F₁

$\bar{BP}$ = Better - parent mean

$\bar{SV}$ = Standard variety mean

The test of significance was determined by using the following formulae:

$$'t'(\text{The heterobeltiosis}) = \frac{\bar{F}_1 - \bar{BP}}{S.E.}$$

$$'t'(\text{Standard heterosis}) = \frac{\bar{F}_1 - \bar{SV}}{S.E.}$$

Standard error of the hybrid vigor over better - parent and the standard variety = $\sqrt{2Me/r}$

Where:

Me = Variance of mean error

r = Replications numbers

Critical Differences (C.D) = $t \times SE$; 5 or 1% p-value at error d.f.

3.0. Results and Discussion

3.1. Analysis of variance for combining ability and estimates of components of genetic variance

Analysis of variance (ANOVA) recorded significant different ($p < 0.001$) among female, male and female x male reported that, no single genotype was significant for all traits across three locations, however, some genotypes that consistently exhibit high GCA values across different environments were PBW-757 and DBW-222. Some crosses that consistently exhibit high SCA like PBW-677XPBW-343, PBW-757X PBW ZN1, CRDGEHNU1XPBW ZN1 and HD-3721XHD-3326 (Table 6). Since no single genotype was significant for all traits, selection of individual traits might overlook the importance of combined traits. Thus, breeder can develop selection indices that combine multiple prioritized traits, adjusting their weights based on the breeding objective(s) and environmental conditions. This method enables the simultaneous improvement of multiple traits and genotypes by focusing on critical traits that directly affect yield. The result was commemorated research conducted by Barot *et al.* [19] and Gami *et al.* [13], who noted that none of the genotypes showed significant differences across all traits studied. Estimates of genetic variance components revealed that certain

characters, such as "GYP" (374.5) and "BY" (219.8) (Table 6), had high genotypic variance, suggesting strong gene action over these traits. As mentioned by Barot *et al.* [19] and Kumar *et al.* [21], genetic variance was highly related to additive gene effect. The relative contributions of additive and non-additive gene effects for yield and its components showed that the additivity of gene for most of yield related traits accounted for relatively low proportions of the total genetic variance. In contrast, non-additive gene action made the largest contribution to the overall genetic variation. As a result, heterosis breeding is highly effective for improving yield. For instance, the additive contribution to protein content was 0.0%, while non-additive 8.8% in spikelets number per main spike, additive contribution was 0.74%, and the non-additive contribution was 1.78%; while for productive tillers number additive contribution recorded 1.78%, while non-additive was 2.17%. The additive contribution for biological yield was 1.76%, while non-additive was 1.34%; for harvest index, the additive contribution was 2.83%, and non-additive was 1.34%; and the relative contributions of grain yield per plant were 1.43% for additive and 5.51% for non-additive (Table). Certain traits, such as "CLC" and "GYP," exhibited moderate additive variance (10.57 and 5.35, respectively), indicating that these traits can be selected for breeding programs since they are influenced by additive genetic effects (Table 7). These findings were in conformity with results of Hajer *et al.* [5] and Fellahi *et al.* [12], reported additivity gene effects can be leveraged for genotype improvement in wheat.

Table 6. Analysis of variance for combining ability for 16 characters in L x T mating design in wheat.

Characters d.f.	Source of variation			
	LINE	TESTER	LINE X TESTER	Error
	14	2	28	218
Number of productive tiller (NPT)	3.83*	1.76	1.54	1.61
Biomass yield (BY)	2.31*	1.08	0.94	32.39
Harvest index (%)	6.22**	0.75	1.43	15.23
Grain yield/plant (GY/P)	11.53**	4.31*	5.43**	10.47
Grain weight/spike (GW/S)	1.16	1.21	0.93	0.17
1000-grain weight (g) (1000-GW)	1.25	5.33*	1.31	3.52
Spike length (cm) (SL),	2.41*	5.64*	2.89**	0.63
Number of grains/spike (NG/S)	4.03**	0.52	1.59	14.55
Flag leaf area (FLA)	180.45**	210.07**	79.13**	3.82
Plant height (cm) (PH)	2.85**	1.38	3.66**	63.97
Days to 50% heading (DH)	5.87**	0.58	5.92**	61.82
Days to maturity (DM)	7.85**	32.03**	7.95**	42.52
Chlorophyll content	4.04**	1.18	0.81	37.32
Protein content	1.46*	0.978*	3.94	0.37
Grain-filling period (GFP)	4.01	8.23**	1.67**	51.8
Number of spikelets/spike (NS/S)	3.55**	1.16	2.23*	0.84

“*” and “**” for 5% and 1% Level of Significance.

Table 7. Estimates of components of genetic variance for various yield contributing traits in wheat.

Variance components	Traits									
	CLC	PC	NSS	NPT	NGS	GWS	TGW	BY	HI	GYP

Female Variance (σ^2_{fm})	4.45	0.0	0.04	0.13	1.31	0.00	0.0	1.63	2.70	2.35
Male Variance (σ^2_m)	0.10	0.0	0.0	0.00	0.0	0.00	0.1	0.03	0.0	0.0
Female x male Variance (σ^2_{fmxm})	0.0	0.12	0.11	0.09	0.95	0.0	0.12	0.0	0.73	5.15
Genotype Variance (σ^2_g)	339.4	5.57	10.82	17.96	165.1	0.89	25.42	219.8	218.04	374.5
Additive Variance (σ^2_A)	10.57	0.0	0.08	0.32	2.88	0.00	0.15	3.87	6.18	5.35
Dominance Variance (σ^2_D)	0.0	0.49	0.46	0.39	3.82	0.0	0.49	0.0	2.93	20.63
Degree of dominance (σ^2_D/σ^2_A)	0.0	0.0	5.48	1.22	1.32	0.0	3.2	0.0	0.47	3.85
Narrow Heritability (h^2)	0.45	0.0	0.10	0.25	0.24	0.06	0.08	0.26	0.43	0.18

Chlorophyll content (CLC), Protein content (PC), Number of spikelet/spike (NS/S), Number of productive tiller (NPT), Number of grain per spike (NGS), Grain weight/spike (GW/S), 1000-grain weight (g) (TGW), Biomass yield (BY), Harvest index (HI %) and Grain yield/plant (GY/P).3.2. *Estimates of general and specific combining ability (GCA and SCA) effects.*

For general combining ability (GCA), WB-02 was identified as the best line for grain filling period (GFP 2.33, Rank 1). Gami et al. [13] also noted that some male parents showed significant differences in their GCA values for traits such as days to 50% heading and grain filling period. PBW ZN1 was the top tester for nearly all yield-related traits, including the number of productive tillers (0.02, Rank 1), grain yield per plant (0.53, Rank 1), and the number of spikelets per spike (0.06, Rank 1) (Table 8).

Four parents were identified as promising combiners for GCA in relation with yield related characters in wheat, suggesting the parent could serve as potential promising candidates for further breeding programs, such as the development of synthetic varieties or for enhancing grain yield. These parents are listed hierarchically as follows: PBW ZN1, PBW-757, PBW-822, and DBW-173.

The best identified parents with high-GCA (like DH-3086 and PBW-757) could be cross with other genotypes with high-GCA to combine favorable traits using pedigree breeding (to develop synthetic variety) and pure line selection. Can also can be used for recurrent parent selection using backcross breeding programs to improve the performance (consistent performance) of other lines. High GCA parents can serve as ideal foundation parents for large-scale breeding programs (table 8). It is suggested that additive gene actions predominated in the observed traits, implying that the environment had little to no impact on these characters. Gupta *et al.* [20], Kumar *et al.* [21], and Kumar *et al.* [9], also reported that environmental factors have minimal or no effect on additive gene action. No single genotype recorded high GCA and SCA values across different environments. However, some genotypes that consistently exhibit high GCA values across different environments were PBW-757 and DBW-222. Some crosses that consistently exhibit high SCA like PBW-677XPBW-343, PBW-757X PBW ZN1, CRDGEHNU1XPBW ZN1 and HD-3721XHD-3326. Due some mechanisms naturally possessed by wheat, some genotypes like BHU-25, PBW-550, BHU-31, HD-3721 and PWB-725 recorded high tolerance for multiple environmental stresses as evidenced showed by their relatively higher GCA estimates across the most of their traits and environments.

For specific combining ability (SCA), the positive values indicates better than expected, while negative values indicates lower than expected [11]. Highest SCA value (ranked 1st) recorded in DBW-222 X PBW ZN1 (0.49) for NPT (number of productive tiller); PBW-822 X PBW ZN1 for GYP (Grain Yield per Plant) (3.79); DH-3086 X PBW-343 for HI (Harvest Index) (0.67). However, poor SCA recorded in CRD GEHNU 1 X HD-3326 (ranked 45th for spike length) (Table 7). According to Askander *et al.* [22] and Fellahi *et al.* [12] stated that, high SCA is used for hybrid vigor and superior

performance in specific crosses while low-SCA crosses can be stably inherited and improved over time. Six crosses revealed significant positive SCA effects for yield and yield related characters, listed hierarchically as follows: DBW-222 × PBWZN1, DH-3086 × PBWZN1, PBW-677 × PBW-343, HD-3721 × HD-3326, and CRD GEHNU1 × PBWZN1.

Conclusively for GCA and SCA, the information on GCA effect could be used in selection of superior parents; estimation of half-sib families; and for pure line selection method. While information for SCA could be used useful in selection of superior cross combinations for heterosis breeding; an estimation of full sib families and the information on both GCA and SCA can be applied for reciprocal recurrent selection.

The magnitude of GCA varies across different traits due to additively effects while SCA also varies due to non-additive effects. Thus, GCA is typically more stable across environments because the additive genetic effects are less influenced by environmental variability. However, SCA being non-additive, is more susceptible to environmental changes, making it more variable across the traits that are sensitive to environmental conditions [8].

Table 8. Estimates of general combining ability (GCA) effects of 15 lines of different characters for combined locations.

GENOTYPES	NPT	RA	FLA	RA	GFP	RA	GYP	RA	HI	RA	NSS	RA	SL	RA
		NK		NK		NK		NK		NK		NK		NK
BHU-25 (LINE1)	-0.71	15	-0.02	8	2.27	2	-2.15	15	-3.02	15	-0.07	10	-0.19	12
WB-02 (LINE2)	-0.42	14	-0.91	13	2.33	1	-1.09	14	-1.30	13	-0.07	11	-0.30	14
BHU-31 (LINE4)	-0.10	12	-7.26	15	0.97	5	-1.06	13	-0.50	10	-0.14	14	0.08	7
HD-3721 (LINE5)	-0.10	11	-0.35	10	2.12	4	-0.59	11	-1.69	14	-0.06	9	-0.27	13
PWB-725 (LINE1)	-0.00	10	0.88	5	2.25	3	-0.59	10	-0.56	11	-0.18	15	-0.17	11
CRD GEHNU1 (LINE6)	0.18	4	-3.15	14	-0.85	11	-0.44	8	-0.19	8	-0.10	13	0.13	5
PBW-550 (LINE7)	0.12	7	0.14	7	-0.85	10	0.44	6	-0.18	7	-0.02	8	0.10	6
PBW-677 (LINE8)	0.16	5	1.03	4	-1.84	14	-0.65	12	0.57	5	0.08	4	-0.01	8
PBW-822 (LINE9)	0.32	1	0.30	6	-0.40	8	1.14	3	1.16	4	0.10	3	-0.03	9
HD-3117 (LINE10)	0.15	6	1.66	3	-1.60	13	-0.51	9	-0.58	12	-0.09	12	0.14	4
DBW-173 (LINE11)	0.27	2	-0.48	12	0.31	6	0.60	5	2.32	1	-0.01	7	-0.36	15
DH-3086 (LINE12)	-0.24	13	-0.22	9	-0.27	7	1.96	1	-0.38	9	0.08	5	0.45	1
DBW-222 (LINE13)	0.26	3	-0.41	11	-2.23	15	1.09	4	0.49	6	0.19	2	0.27	2
CSW-18 (LINE14)	0.07	8	5.98	1	-0.81	9	0.39	7	2.05	2	0.06	6	-0.06	10
PBW-757 (LINE15)	0.01	9	2.83	2	-1.39	12	1.47	2	1.81	3	0.27	1	0.22	3
SE(gca for line)	0.25		0.31		0.35		0.56		1.02		0.25		0.21	
SE(gi-gj) for line	0.35		0.43		0.50		0.80		1.45		0.36		0.29	
Estimates of general combining ability (GCA) effects of 3 testers of different characters for combined locations														
PBW ZN1 (TESTER 1)	0.02	1	-0.10	2	0.27	2	0.53	1	0.00	2	0.06	1	-0.11	3
PBW-343 (TESTER 2)	-0.00	2	1.56	1	-1.53	3	0.08	2	0.28	1	0.03	2	0.18	1
HD-3326 (TESTER 3)	-0.01	3	-1.46	3	1.25	1	-0.61	3	-0.29	3	-0.09	3	-0.06	2
SE(gca for tester)	0.11		0.13		0.15		0.25		0.45		0.11		0.09	
SE(gi-gj) for tester	0.15		0.19		0.22		0.35		0.64		0.16		0.13	
SE(sij-skl) for tester	0.61		0.76		0.86		1.39		2.51		0.62		0.51	
Estimates of specific combining ability (SCA) effects of 45 crosses of different characters for combined locations														
BHU-25XPBW ZN1	-0.08	34	-5.45	38	1.60	3	-0.75	27	-1.04	45	-0.01	22	0.19	12
BHU-25XPBW-343	-0.26	42	1.90	17	-0.48	32	-2.50	42	0.21	12	-0.00	19	0.14	15

BHU-25XHD-3326	-0.16	39	3.49	11	0.85	14	-1.31	33	0.09	21	-0.17	35	-0.33	38
WB-02XPBW ZN1	-0.04	27	-5.60	40	-0.12	24	0.55	18	0.16	19	-0.01	21	-0.23	35
WB-02XPBW-343	-0.09	36	3.48	12	1.01	12	-1.06	30	0.03	24	0.06	17	-0.14	29
WB-02XHD-3326	-0.16	40	-0.00	24	1.14	7	-1.81	36	-0.51	40	-0.24	39	0.37	7
BHU-31XPBW ZN1	-0.1	37	-5.36	37	1.27	5	-1.26	32	-0.00	28	0.22	8	0.09	17
BHU-31XPBW-343	-0.02	24	-1.55	28	1.11	10	-2.54	43	-0.18	33	-0.21	37	-0.70	44
BHU-31XHD-3326	0.05	15	-9.88	45	-1.53	40	1.53	11	0.06	23	-0.37	45	0.61	2
HD-3721XPBW ZN1	0.08	12	4.22	8	1.71	1	-0.05	23	0.01	25	0.18	12	-0.38	41
HD-3721XPBW-343	-0.32	44	-5.19	36	0.06	21	-2.35	41	0.14	20	-0.28	41	0.07	18
HD-3721XHD-3326	0.17	5	0.14	23	0.06	22	1.133	12	-0.56	41	-0.07	26	0.30	10
PWB-725X PBW ZN1	-0.08	32	2.91	15	0.18	19	0.00	22	0.06	22	-0.33	44	-0.47	43
PWB-725X PBW-343	-0.01	23	1.92	16	1.09	11	-2.10	40	-0.66	43	0.18	11	0.15	14
PWB-725X HD-3326	0.09	11	-2.80	32	0.68	17	0.82	13	0.46	3	-0.32	43	0.32	9
CRDGEHNU1XPBW ZN1	0.26	3	9.31	3	-0.22	25	0.68	16	-0.02	30	-0.04	23	0.77	1
CRDGEHNU1XPBW 343	0.05	18	-8.39	44	-0.65	33	0.34	19	0.28	10	-0.15	32	0.18	13
CRDGEHNU1XHD-3326	-0.19	41	-8.22	43	0.14	20	-1.97	39	-0.30	37	-0.08	28	-0.95	45
PBW-550X PBW ZN1	-0.08	33	-4.24	33	0.76	15	0.73	14	0.33	9	0.07	16	-0.12	28
PBW-550X PBW-343	0.14	9	3.40	13	-1.46	39	-0.37	25	-0.31	38	-0.13	30	-0.21	34
PBW-550X HD-3326	0.03	20	1.16	21	-0.03	23	0.58	17	-0.05	31	-0.00	20	0.34	8
PBW-677XPBW ZN1	-0.06	30	-5.12	35	-0.40	30	-2.87	45	0.00	27	-0.28	42	-0.38	42
PBW-677XPBW-343	0.11	10	3.33	14	-2.32	45	2.81	5	0.43	5	0.58	1	0.39	6
PBW-677XPBW-343	0.07	13	4.19	9	1.12	9	-1.33	34	-0.29	35	-0.07	27	-0.00	25
PBW-822X PBW ZN1	0.16	6	-1.20	27	1.70	2	3.79	1	0.47	2	0.01	18	-0.15	31
PBW-822X PBW-343	0.06	14	7.39	4	-1.64	42	-1.05	29	-0.40	39	-0.06	25	0.50	5
PBW-822X HD-3326	0.00	22	-5.49	39	-0.39	29	-0.30	24	0.21	13	0.30	5	-0.35	39
HD-3117X PBW ZN1	0.15	7	10.74	1	-2.25	44	-0.75	28	-0.59	42	0.24	7	-0.07	26
HD-3117X PBW-343	0.00	21	0.15	22	-0.31	28	0.17	21	-0.00	29	-0.23	38	0.00	24
HD-3117X HD-3326	-0.04	28	-7.05	42	1.16	6	-0.50	26	0.46	4	-0.25	40	0.07	19
DBW-173X PBW ZN1	-0.07	31	-4.85	34	-0.87	36	-2.82	44	0.18	17	0.21	10	-0.33	37
DBW-173X PBW-343	0.31	2	-0.02	25	-0.45	31	1.68	10	0.19	14	-0.09	29	0.27	11
DBW-173X HD-3326	-0.03	26	3.75	10	1.60	4	2.42	8	0.17	18	-0.16	34	0.05	20
DH-3086X PBW ZN1	-0.03	25	-6.43	41	-0.28	27	3.15	3	0.01	26	-0.15	33	0.11	16
DH-3086X PBW-343	-0.29	43	1.45	20	0.94	13	2.95	4	0.67	1	0.11	15	-0.14	30
DH-3086X HD-3326	0.14	8	4.45	7	-0.89	37	-1.93	38	-0.77	44	0.25	6	0.02	23
DBW-222X PBW ZN1	0.49	1	-1.72	30	-0.83	35	3.40	2	0.18	16	0.21	9	0.53	4
DBW-222X PBW-343	0.05	17	1.74	18	0.704	16	0.69	15	0.23	11	0.40	2	-0.20	33
DBW-222X HD-3326	-0.36	45	-0.96	26	-1.81	43	-1.77	35	-0.30	36	-0.13	31	-0.32	36
CSW-18XPBW ZN1	-0.04	29	1.61	19	-0.24	26	0.24	20	0.39	6	-0.19	36	-0.09	27
CSW-18XPBW-343	0.05	16	6.07	6	-1.08	38	1.75	9	0.37	8	-0.05	24	0.05	21
CSW-18XHD-3326	0.05	19	6.15	5	0.61	18	-1.16	31	-0.27	34	0.40	4	0.03	22
PBW-757X PBW ZN1	0.23	4	10.25	2	-1.57	41	2.43	7	-0.14	32	0.40	3	0.54	3
PBW-757X PBW-343	-0.13	38	-1.67	29	1.12	8	2.58	6	0.19	15	0.13	14	-0.36	40
PBW-757X HD-3326	-0.09	35	-2.02	31	-0.76	34	-1.88	37	0.39	7	0.16	13	-0.17	32
SE (sca effect)	0.43		0.53		0.61		0.98		1.77		0.44		0.36	

Note: Ranking is in ascending order (i.e. 1 is the best followed by 2 on and on). Number of productive tiller (NPT), Flag leaf area (FLA), Grain-filling period (GFP), Grain yield/plant (GY/P), Harvest index (HI %), Number of spikelet/spike (NS/S) and Spike length (cm) (SL).

Table 9. Estimates of general combining ability effects of 15 lines of different characters for combined locations.

GENOTYPES	1000GW	RANK	DM	RANK	GWS	RANK	PH	RANK	PC	RANK	CLC	RANK	BY	RANK
BHU-25 (LINE1)	0.12	6	7.07	1	8.07	10	-2.23	14	-	12	-4.46	15	-	13
WB-02 (LINE2)	0.38	7	2.66	5	-0.13	14	3.49	3	0.16	6	0.68	6	2.06	8
BHU-31 (LINE4)	0.04	9	-1.77	9	-0.07	13	3.82	2	0.13	8	-2.34	14	0.06	2
HD-3721 (LINE5)	-0.64	15	-4.37	15	0.08	2	4.60	1	0.10	7	0.48	7	2.77	4
PWB-725 (LINE1)	0.26	11	-2.03	11	0.18	1	-0.35	7	-	1	2.06	4	1.97	1
CRD GEHNU1 (LINE6)	0.26	2	-2.70	12	0.02	6	1.75	4	0.14	9	2.60	2	3.77	7
PBW-550 (LINE7)	0.58	12	-1.25	8	0.02	5	1.70	5	-	13	-0.78	9	-	10
PBW-677 (LINE8)	0.08	10	-0.40	7	0.02	7	0.02	6	0.24	10	-1.61	12	0.41	12
PBW-822 (LINE9)	-0.00	14	4.40	2	0.05	4	-1.48	11	0.07	4	-2.22	13	-	15
HD-3117 (LINE10)	-0.68	3	4.29	3	0.02	9	-0.58	8	0.05	2	-1.05	10	4.40	5
DBW-173 (LINE11)	-0.12	8	3.37	4	-0.05	11	-1.35	10	0.07	5	-0.77	8	1.43	11
DH-3086 (LINE12)	0.54	13	-0.03	6	-0.06	12	-1.08	9	0.22	3	4.76	1	-	9
DBW-222 (LINE13)	-0.14	5	-1.81	10	0.02	8	-4.89	15	0.22	11	1.51	5	0.22	6
CSW-18 (LINE14)	-0.06	4	-3.22	13	-0.14	15	-1.73	13	0.16	15	-1.08	11	-	14
PBW-757 (LINE15)	-0.64	1	-4.18	14	0.07	3	-1.69	12	0.02	14	2.23	3	3.95	3
SE(gca for line)	0.33		0.20		0.09		0.88		0.10		0.57		2.38	
SE(gi-gj)for line)	0.46		0.28		0.13		1.24		0.17		0.81		1.23	
Estimates of general combining ability effects of 3 testers of different characters for combined locations														
PBW ZN1 (TESTER 1)	-0.21	3	-0.03	2	0.04	1	0.55	1	-4.62	3	-0.58	3	0.40	1
PBW-343 (TESTER 2)	0.32	1	-3.15	3	-0.00	2	-0.92	3	4.13	1	0.55	1	-	3
HD-3326 (TESTER 3)	-0.10	2	3.19	1	-0.03	3	0.37	2	4.89	2	0.02	2	0.33	2
SE(gca for tester)	0.14		0.09		0.04		0.39		0.07		0.25		0.06	
SE(gi-gj)tester	0.20		0.12		0.06		0.55		0.11		0.36		0.55	
SE(sij-skl)tester	0.80		0.49		0.23		2.16		0.43		1.41		0.77	
Estimates of general combining ability effects of 45 crosses of different characters for combined locations														
BHU-25XPBW ZN1	0.00	25	2.51	16	-0.16	43	1.06	19	0.04	14	1.30	7	-	32
BHU-25XPBW-343	0.02	23	0.85	24	0.09	11	-0.92	29	10.22	33	-1.03	33	1.07	39
BHU-25XHD-3326	0.05	16	-3.37	33	0.07	13	-0.13	23	-0.17	36	-0.26	26	-	3
WB-02XPBW ZN1	-0.02	30	-3.66	34	-0.07	34	1.22	18	-0.21	22	0.52	14	2.60	2
WB-02XPBW-343	0.02	21	3.11	13	-0.08	35	-5.03	42	-0.03	3	1.08	10	3.67	42
WB-02XHD-3326	0.05	15	0.54	26	0.16	4	3.81	6	0.40	38	-1.61	40	3.00	31
BHU-31XPBW ZN1	0.07	12	1.62	21	0.00	25	6.65	3	-0.21	41	-1.69	41	-0.98	6
BHU-31XPBW-343	-0.00	27	3.63	10	0.13	6	3.56	7	-0.24	4	-1.45	35	2.42	29
BHU-31XHD-3326	-0.06	33	-5.26	39	-0.13	39	-	45	0.39	23	3.14	3	-0.70	35
HD-3721XPBW ZN1	-0.16	41	-5.03	36	0.14	5	-2.26	33	-0.05	7	0.31	19	-1.71	26
HD-3721XPBW-343	-0.16	42	3.52	11	-0.01	27	2.34	14	0.30	12	-0.13	24	-0.28	27
HD-3721XHD-3326	-0.13	39	1.51	22	-0.13	38	-0.07	22	0.07	39	-0.17	25	-0.31	19
PWB-725X PBW ZN1	0.03	19	-9.88	43	0.16	3	2.95	11	-0.22	24	-0.98	32	0.59	20
PWB-725X PBW-343	-0.10	37	8.00	2	-0.22	45	-6.13	44	-0.06	1	0.22	21	-0.47	28
PWB-725X HD-3326	-0.01	28	1.88	20	0.05	15	3.17	10	0.74	40	0.76	12	-0.11	25
CRDGEHNU1XPBWZN1	0.33	2	8.51	1	-0.06	32	0.70	20	-0.24	32	1.12	9	1.02	15
CRDGEHNU1XPBW343	0.13	7	-	44	0.04	16	-0.33	24	-0.15	18	0.45	18	1.96	7

CRDGEHNU1XHD-3326	-0.08	36	2.17	19	0.02	21	-0.36	25	0.19	10	-1.57	38	-2.98	41
PBW-550X PBW ZN1	-0.16	40	6.96	4	-0.07	33	1.66	15	-0.11	28	-1.75	42	-3.18	43
PBW-550X PBW-343	0.08	11	-	45	0.03	17	-1.15	31	-0.02	20	-1.51	36	2.65	5
PBW-550X HD-3326	-0.01	29	3.84	9	0.03	18	-0.51	27	-0.19	35	3.26	1	0.52	21
PBW-677XPBW ZN1	0.02	22	-2.85	32	-0.04	31	1.52	16	-0.18	34	-1.97	44	-2.22	37
PBW-677XPBW-343	0.05	17	0.15	27	0.07	12	3.22	9	-0.24	42	1.14	8	-2.48	38
PBW-677XPBW-343	-0.11	38	2.69	15	-0.03	29	-4.75	39	0.47	2	0.83	11	4.71	1
PBW-822X PBW ZN1	-0.63	45	-1.44	30	0.00	23	-4.72	38	0.05	13	-0.50	28	1.49	9
PBW-822X PBW-343	0.04	18	-5.54	40	0.12	8	1.47	17	0.02	17	2.04	5	-1.94	36
PBW-822X HD-3326	0.14	5	6.99	3	-0.13	36	3.25	8	0.12	11	-1.53	37	0.45	22
HD-3117X PBW ZN1	0.33	1	-5.07	37.5	0.05	14	-0.46	26	0.21	9	-1.59	39	0.72	18
HD-3117X PBW-343	-0.02	31	5.48	5	-0.16	42	-4.62	37	-0.21	37	1.45	6	0.81	16
HD-3117X HD-3326	-0.04	32	-0.41	29	0.10	10	5.08	5	0.26	8	0.13	22	-1.53	34
DBW-173X PBW ZN1	0.10	8	-5.07	37.5	0.18	1	-5.00	41	-0.14	31	-0.83	30	-2.77	40
DBW-173X PBW-343	-0.00	26	2.82	14	-0.00	26	8.42	2	-0.01	19	0.57	13	1.43	11
DBW-173X HD-3326	-0.07	34	2.25	18	-0.17	44	-3.41	35	0.36	6	0.26	20	1.34	12
DH-3086X PBW ZN1	-0.30	44	0.74	25	-0.13	40	-4.03	36	0.36	5	0.50	16	0.28	23
DH-3086X PBW-343	0.06	13	-2.02	31	-0.02	28	-5.62	43	-0.12	29	0.45	17	1.15	14
DH-3086X HD-3326	-0.20	43	1.28	23	0.16	2	9.66	1	-0.02	21	-0.95	31	-1.43	33
DBW-222X PBW ZN1	-0.08	35	4.40	6	0.03	19	2.89	12	-0.24	43	3.19	2	-0.77	30
DBW-222X PBW-343	0.03	20	-4.36	35	0.11	9	-3.28	34	0.03	15	-2.70	45	0.73	17
DBW-222X HD-3326	0.22	3	-0.04	28	-0.15	41	0.39	21	-0.08	26	-0.48	27	0.03	24
CSW-18XPBW ZN1	0.06	14	3.96	8	0.00	24	-0.74	28	-0.26	44	-0.55	29	-3.21	44
CSW-18XPBW-343	0.09	10	3.52	12	-0.13	37	5.62	4	-0.07	25	0.51	15	1.48	10
CSW-18XHD-3326	0.02	24	-7.48	42	0.12	7	-4.87	40	-0.14	30	0.04	23	1.72	8
PBW-757X PBW ZN1	0.15	4	4.29	7	-0.03	30	-1.45	32	-0.08	27	2.93	4	2.99	4
PBW-757X PBW-343	0.10	9	2.30	17	0.02	20	2.46	13	-0.32	45	-1.09	34	1.29	13
PBW-757X HD-3326	0.14	6	-6.6	41	0.00	22	-1.01	30	0.03	16	-1.83	43	-4.29	45
SE (sca effect)	0.57		0.35	0.16		1.53	0.30		1.00		2.13			

Note: Ranking is in ascending order (i.e. 1 is the best followed by 2 on and on). 1000-grain weight (g) (1000-GW), Days to maturity (DM), Grain weight/spike (GW/S), Plant height (cm) (PH), Protein content (PC), chlorophyll content (CLC) and Biomass yield (BY).

3.3. Estimation of heterosis over better parent and four standard varieties in wheat across three locations

Heterosis is highly preponderance in cross-pollinated crops whereas, very limited in self-pollinated species like wheat Thus, progeny showing additive effects indicated that, the plants cannot take advantage of heterosis, however, dominance and over dominance gene action is essential for heterosis [22]. Therefore, standard heterosis (SV1-SV4) (standard variety) for grain yield per plant recorded across four varieties and three locations revealed the highest and positive BP (better parent) heterosis in PBW-822X PBW ZN1 with 51.51 while lowest and negative BP heterosis WB-02XHD-3326 with -8.09. Highest standard heterosis recorded in DH-3086X PBW ZN1 with 62.86 in SV2 while the lowest standard heterosis recorded in BHU-25XPBW-343 with -7.65 in SV3 (Table 8) this indicate the present of both additive and dominance genetic variances. Askander's *et al.* [22] study showed that, the tested attributes had both positive and negative heterosis for all the traits, therefore, dominant genetic variance is more preponderance than additive genetic variance. PBW-677XPBW-343 shows the highest BP heterosis (26.12%) indicating that this cross exceeds its better parent in terms of harvest index. While PBW-822X PBW ZN1 Shows very high values across standard heterosis (61.99%) in SV1 and (30.56%) in SV3. This cross is likely very adaptable across multiple environments or standards (Table 10). Summarily, the results can be used to improve yield; parent selection, broad adaptability and identification of best crosses. Heterosis for inferior and superior better parent and standard varieties were identified. For number of productive tillers PBW-822 X PBW ZN1 and PBW-757 X PBW ZN1 outweighed the performers of SV1 (118.53), SV2 (78.08), SV3 (57.75), and SV4 (73.58) while WB-02 X HD-3326 and BHU-25 X HD-3326 show the least heterosis for both in better parent and standard heterosis (SV2 -8.34, SV3 -18.8) (Table 10). It is therefore proved that, heterosis in cross-pollinated crops is highly preponderance, whereas, very limited in self-pollinated species like wheat [18]. Days to 50% Heading for various wheat crosses across three locations (Table 12). "Days to 50% heading" measures the time from the emergence of heads to 50% of the plants produces heads, it is also an

indicator of length of days to reach maturity level. Different wheat crosses, represented by combinations of plant varieties, were tested under various environments in three distinct locations. The dataset includes different types of crosses (BHU-25XPBW ZN1, PBW-757X PBW ZN1) tested against standard checks, labeled BP, SV1, SV2, SV3, and SV4, with maturity times varied significantly across locations. For example, the cross PBW-757X PBW ZN1 took an additional 35.85 to 52.38 days to reach 50% heading at location 2 compared to other crosses. At location 1, very few crosses showed delayed heading than in location 3, suggesting that location 3 may have had conditions that either delayed or varied maturation times more than the other locations, as reported by Gami *et al.* [13] that maturity period had been influenced by environmental factors. While some crosses showed large variation for grain number per spike across location (Table 14). For example, the cross "BHU-25XPBW ZN1" shows a relatively low grains' number per spike in location 1 (ranging from 9.4 to 27.05 across the lines) compared to location 2, where the number of grains per spike ranges much higher (from 31.78 to 68.96). This suggests that certain crosses may be better adapted to specific locations like SV4 in cross "BHU-31XPBW ZN1" at location 1 has a high grain count per spike of 38.05, indicating that SV4 contributes positively to grain number in this cross. This is also seen across other crosses where SV4 consistently produces higher counts compared to BP and other lines. The results was supported by Askander *et al.* [22] reported that some wheat genotypes reproduced their yield faithfully across different environmental conditions. The hybrids that recorded significant positive hybrid vigor yield components recorded the top six (6) hybrids namely; PBW-822X PBW ZN1, DH-3086X PBW-343, PBW-757X PBW ZN1, DBW-173X PBW-343, WB-02XPBW ZN1 and DH-3086X HD-3326.

The observed level of heterosis in certain crosses served as potential parents to generate high-yielding/performance and resilient wheat couple with incorporating complementary traits, such as stress tolerance, into these high-yielding crosses through methods like heterosis breeding, backcross breeding, or marker-assisted selection. Followed by conducting multi-location trials to assess the stability of heterosis across environments and can be used as genome editing tools to identify and select favorable alleles for hybrid development [6].

Some physiological and biochemical mechanisms underlying heterosis in wheat includes; physiological factors like photosynthetic efficiency, resource use efficiency (efficiency in nutrient and water utilization), resistance to environmental stresses (high resistant increase high heterosis), and rate of growth and biomass accumulation rate (high rate increase high heterosis). While biochemical mechanisms of heterosis involves enzymes activities like nitrogen assimilation, carbohydrate metabolism, and antioxidant defense (often more active in hybrids compared to the parents). Also heterosis expressed in genes of hybrids compared to the parents [5].

The magnitude of heterosis varies across different traits and environments due to several factors. According to Shull [23] there are several factors that affect the variation in heterosis such as presence of additive effect (low heterosis) and non-additive effect (high heterosis), mode of pollination of parents (wheat is self-pollinated, thus, heterosis will be low).

The potential advantages of hybrid breeding in wheat offers several advantages over traditional breeding methods, in that, hybrid breeding allowed systematic improvement of population by application of pure line selection and exploitation of heterosis simultaneously. Hybrid breeding can lead to faster genetic improvements by effectively utilization of mode of gene action with greater precision and efficiency. Additionally, it allows for the simultaneous combination of complementary traits from various parental lines.

The genetic diversity of the parental lines can be maintained through the prevention of inbreeding depression (breeding within closely related parental line), secondly to perform wide crosses and the use of backcrossing judiciously, and creation of populations with broad genetic variability. Other methods are polyploid or double haploid breeding and asexual or apomictic seed production [5].

Some natural mechanisms in wheat includes; Wheat naturally genetic, biochemical and physiological mechanisms that makes it thrive and produce reasonable yield under different

environmental stresses such mechanisms includes; heat shock proteins, superoxide dismutase and homeostasis for example, osmotic adjustment [2].

Table 10. Estimation of heterosis over better parent and four standard varieties in wheat across three locations.

		Grain yield per plant														
		Location 1					Location 2					Location 3				
SN	Cross	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	VS3	SV4	BP	SV1	SV2	SV3	SV4
1	BHU-25XPBW ZN1	10.19 *	14.88 **	13.41 **	-2.55	7.91	40.78 **	-6.72**	45.30 **	42.94 **	37.60 **	10.94 **	13.58 **	14.35 **	-17.58 **	8.53 **
2	BHU-25XPBW-343	8.36	8.86	7.47	-7.65 *	2.26	30.64 **	16.15 **	38.79 **	36.53 **	31.43 **	1.77	7.13 **	7.86 **	-22.26 **	2.37
3	BHU-25XHD-3326	3.57	17.83 **	16.33 **	-0.04	10.68 *	11.78 **	8.39 **	26.89 **	24.83 **	20.16 **	8.75 **	22.02 **	22.85 **	-11.45 **	16.59 **
4	WB-02XPBW ZN1	25.33 **	30.67 **	29.00 **	10.85 **	22.74 **	31.66 **	11.88 **	35.89 **	33.68 **	28.69 **	26.61 **	29.62 **	30.51 **	-5.93 **	23.86 **
5	WB-02XPBW-343	11.64 *	12.16 **	10.73 *	-4.86	5.35	34.96 **	11.47 **	43.38 **	41.05 **	35.78 **	17.92 **	24.12 **	24.97 **	-9.92 **	18.61 **
6	WB-02XHD-3326	-8.09 *	4.57	3.23	-11.29 **	-1.78	18.75 **	24.17 **	34.80 **	32.61 **	27.66 **	17.78 **	32.15 **	33.05 **	-4.10 *	26.27 **
7	BHU-31XPBW ZN1	20.48 **	25.61 **	24.01 **	6.56	17.99 **	22.41 **	15.78 **	26.34 **	24.29 **	19.64 **	21.73 **	24.63 **	25.48 **	-9.56 **	19.09 **
8	BHU-31XPBW-343	13.02 **	16.84 **	15.36 **	-0.88	9.76 *	19.58 **	7.37 **	27.04 **	24.98 **	20.31 **	13.29 **	19.25 **	20.06 **	-13.46 **	13.95 **
9	BHU-31XHD-3326	3	17.19 **	15.70 **	-0.58	10.08 *	30.21 **	28.56 **	47.81 **	45.41 **	39.98 **	27.38 **	42.92 **	43.89 **	3.71 *	36.56 **
10	HD-3721XPBW ZN1	21.30 **	26.46 **	24.85 **	7.28	18.78 **	23.30 **	5.26 **	27.26 **	25.19 **	20.51 **	36.75 **	40.00 **	40.96 **	1.6	33.78 **
11	HD-3721XPBW-343	19.21 **	19.76 **	18.24 **	1.6	12.50 **	21.60 **	26.65 **	29.18 **	27.08 **	22.33 **	14.30 **	20.32 **	21.14 **	-12.69 **	14.97 **
12	HD-3721XHD-3326	18.94 **	35.33 **	33.60 **	14.80 **	27.12 **	20.56 **	13.28 **	36.86 **	34.64 **	29.61 **	19.81 **	34.43 **	35.35 **	-2.45	28.45 **
13	PWB-725X PBW ZN1	8.3	12.91 **	11.47 *	-4.22	6.06	37.73 **	24.27 **	42.15 **	39.84 **	34.62 **	37.18 **	40.44 **	41.40 **	1.92	34.20 **
14	PWB-725X PBW-343	16.96 **	17.50 **	16.01 **	-0.32	10.37 *	30.81 **	17.84 **	38.97 **	36.71 **	31.60 **	10.24 **	16.04 **	16.84 **	-15.79 **	10.89 **
15	PWB-725X HD-3326	15.52 **	31.43 **	29.75 **	11.49 **	23.45 **	24.93 **	20.86 **	41.82 **	39.51 **	34.30 **	16.23 **	30.41 **	31.30 **	-5.36 **	24.61 **
16	CRDGEHNU1XPBWZN1	6.1	25.07 **	23.48 **	6.1	17.48 **	50.49 **	20.53 **	55.33 **	52.80 **	47.09 **	-10.12 **	23.85 **	24.70 **	-10.12 **	18.35 **
17	CRDGEHNU1XPBW343	7.16	26.32 **	24.71 **	7.16	18.65 **	35.95 **	21.81 **	44.44 **	42.09 **	36.78 **	-6.14 **	29.34 **	30.22 **	-6.14 **	23.59 **
18	CRDGEHNU1XHD-3326	-2	15.53 **	14.05 **	-2	8.52 *	28.62 **	14.64 **	46.01 **	43.64 **	38.27 **	-17.27 **	14.00 **	14.78 **	-17.27 **	8.94 **
19	PBW-550X PBW ZN1	19.74 **	27.47 **	25.85 **	8.14 *	19.74 **	21.55 **	20.26 **	28.36 **	26.27 **	21.55 **	48.55 **	55.46 **	56.53 **	12.82 **	48.55 **
20	PBW-550X PBW-343	24.97 **	33.04 **	31.34 **	12.86 **	24.97 **	26.49 **	20.46 **	34.38 **	32.20 **	27.26 **	25.46 **	32.07 **	32.97 **	-4.16 *	26.20 **
21	PBW-550X HD-3326	19.84 **	36.34 **	34.61 **	15.66 **	28.07 **	21.53 **	21.52 **	37.96 **	35.72 **	30.65 **	20.82 **	35.55 **	36.48 **	-1.63	29.53 **
22	PBW-677XPBW ZN1	6.37	10.89 *	9.48 *	-5.93	4.17	36.60 **	23.24 **	40.99 **	38.70 **	33.52 **	9.53 **	12.14 **	12.91 **	-18.62 **	7.15 **
23	PBW-677XPBW-343	33.49 **	35.21 **	33.49 **	14.70 **	27.01 **	31.90 **	21.17 **	40.13 **	37.86 **	32.71 **	41.50 **	48.95 **	49.97 **	8.09 **	42.33 **
24	PBW-677XPBW-343	6.01	20.61 **	19.07 **	2.32	13.29 **	23.59 **	18.86 **	40.30 **	38.02 **	32.86 **	6.28 **	19.25 **	20.06 **	-13.46 **	13.95 **

25	PBW-822X PBW ZN1	51.51 **	57.96 **	55.95 **	34.00 **	48.38 **	13.28 **	25.93 **	32.82 **	30.67 **	25.78 **	37.14 **	58.75 **	59.83 **	15.20 **	51.69 **
26	PBW-822X PBW-343	24.53 **	25.10 **	23.51 **	6.13	17.51 **	23.80 **	32.76 **	45.16 **	42.80 **	37.47 **	11.22 **	28.74 **	29.62 **	-6.58 **	23.01 **
27	PBW-822X HD-3326	18.87 **	35.24 **	33.52 **	14.73 **	27.04 **	16.64 **	35.93 **	36.77 **	34.55 **	29.52 **	16.06 **	34.34 **	35.26 **	-2.51	28.37 **
28	HD-3117X PBW ZN1	14.71 **	19.59 **	18.07 **	1.45	12.34 **	28.35 **	26.14 **	48.37 **	45.96 **	40.51 **	5.22 *	20.14 **	20.96 **	-12.81 **	14.80 **
29	HD-3117X PBW-343	22.28 **	22.84 **	21.28 **	4.21	15.39 **	33.16 **	33.28 **	53.93 **	51.43 **	45.77 **	6.46 **	21.55 **	22.38 **	-11.79 **	16.15 **
30	HD-3117X HD-3326	5.93	20.53 **	18.99 **	2.24	13.21 **	30.99 **	24.22 **	51.42 **	48.96 **	43.40 **	4.15	18.92 **	19.73 **	-13.70 **	13.63 **
31	DBW-173X PBW ZN1	18.97 **	24.03 **	22.45 **	5.22	16.50 **	23.71 **	35.62 **	27.68 **	25.61 **	20.92 **	19.92 **	22.77 **	23.61 **	-10.90 **	17.32 **
32	DBW-173X PBW-343	43.13 **	43.79 **	41.96 **	21.98 **	35.07 **	18.26 **	31.99 **	25.63 **	23.59 **	18.97 **	45.23 **	52.87 **	53.92 **	10.94 **	46.07 **
33	DBW-173X HD-3326	20.64 **	37.26 **	35.51 **	16.44 **	28.93 **	18.81 **	32.89 **	34.87 **	32.68 **	27.72 **	41.50 **	58.75 **	59.84 **	15.21 **	51.70 **
34	DH-3086X PBW ZN1	25.74 **	31.09 **	29.42 **	11.21 **	23.14 **	57.79 **	11.32 **	62.86 **	60.22 **	54.23 **	29.52 **	58.22 **	59.30 **	14.82 **	51.19 **
35	DH-3086X PBW-343	47.24 **	47.92 **	46.04 **	25.49 **	38.95 **	41.72 **	22.08 **	50.57 **	48.12 **	42.58 **	23.09 **	50.36 **	51.39 **	9.12 **	43.68 **
36	DH-3086X HD-3326	8.52 *	23.46 **	21.89 **	4.74	15.97 **	33.50 **	14.21 **	51.54 **	49.08 **	43.51 **	0.02	22.19 **	23.03 **	-11.33 **	16.76 **
37	DBW-222X PBW ZN1	17.21 **	44.68 **	42.83 **	22.73 **	35.90 **	50.47 **	33.65 **	55.31 **	52.78 **	47.07 **	11.52 **	46.33 **	47.34 **	6.19 **	39.83 **
38	DBW-222X PBW-343	12.27 **	38.57 **	36.81 **	17.56 **	30.17 **	32.13 **	24.51 **	40.38 **	38.10 **	32.94 **	5.00 *	37.78 **	38.72 **	-0.01	31.65 **
39	DBW-222X HD-3326	-0.72	22.55 **	20.99 **	3.96	15.11 **	31.73 **	31.68 **	49.54 **	47.11 **	41.61 **	-9.31 **	19.01 **	19.82 **	-13.64 **	13.72 **
40	CSW-18XPBW ZN1	29.53 **	35.04 **	33.32 **	14.56 **	26.85 **	32.31 **	31.34 **	36.56 **	34.34 **	29.32 **	7.87 **	34.14 **	35.05 **	-2.66	28.17 **
41	CSW-18XPBW-343	37.75 **	38.39 **	36.62 **	17.40 **	29.99 **	21.38 **	33.69 **	28.96 **	26.86 **	22.12 **	23.92 **	54.09 **	55.15 **	11.83 **	47.24 **
42	CSW-18XHD-3326	10.53 **	25.76 **	24.16 **	6.69	18.13 **	26.70 **	25.57 **	43.84 **	41.50 **	36.21 **	-2.17	21.65 **	22.48 **	-11.72 **	16.24 **
43	PBW-757X PBW ZN1	38.73 **	46.00 **	44.14 **	23.86 **	37.15 **	39.40 **	22.21 **	45.37 **	43.00 **	37.66 **	42.54 **	47.38 **	48.39 **	6.96 **	40.83 **
44	PBW-757X PBW-343	27.01 **	33.67 **	31.97 **	13.39 **	25.56 **	46.33 **	29.90 **	55.46 **	52.93 **	47.22 **	44.53 **	52.14 **	53.18 **	10.41 **	45.38 **
45	PBW-757X HD-3326	15.69 **	31.63 **	29.95 **	11.66 **	23.64 **	16.13 **	31.47 **	31.83 **	29.69 **	24.85 **	14.68 **	28.67 **	29.55 **	-6.62 **	22.95 **

“*” and “**” for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= ORMAN and SV4= BORLAUG 100

Table 11. Estimation of heterosis over better parent and four standard varieties in wheat across three locations.

	Harvest index		
	Location 1	Location 2	Location 3

SN	Crosses	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4
												11.70		10.37		
1	BHU-25XPBW ZN1	10.70 *	8.75	12.75 *	5.17	1.1	-3.34	34.70 **	-3.29	-2.25	-7.37**	**	8.78 **	**	21.65 **	5.70 **
							17.38		20.43			16.14		20.27		
2	BHU-25XPBW-343	8.47	6.57	10.49 *	3.06	-0.93	**	38.36 **	**	21.72 **	15.35 **	**	18.54 **	**	32.56 **	15.19 **
							11.65		12.39			23.83		27.37		
3	BHU-25XHD-3326	-1.72	3.91	7.73	0.49	-3.41	**	34.84 **	**	13.59 **	7.64 **	**	25.54 **	**	40.40 **	21.99 **
				16.53			14.57		16.00			39.58		27.64		
4	WB-02XPBW ZN1	9.99 *	12.41 *	**	8.7	4.49	**	33.36 **	**	17.24 **	11.10 **	**	25.80 **	**	40.69 **	22.25 **
				13.99			12.65		15.58			23.41		27.79		
5	WB-02XPBW-343	7.59	9.95 *	**	6.33	2.21	**	34.84 **	**	16.81 **	10.70 **	**	25.96 **	**	40.86 **	22.40 **
							27.15		28.74					12.89		
6	WB-02XHD-3326	-4.39	1.09	4.81	-2.24	-6.03	**	47.95 **	**	30.12 **	23.31 **	9.76 **	11.27 **	**	24.44 **	8.12 **
				15.14			15.21		20.04			27.78		26.80		
7	BHU-31XPBW ZN1	6.77	11.06 *	**	7.4	3.24	**	53.31 **	**	21.32 **	14.97 **	**	24.97 **	**	39.76 **	21.44 **
				18.38					11.32			22.68		27.04		
8	BHU-31XPBW-343	9.78 *	14.19 **	**	10.42 *	6.15	6.84 **	64.46 **	**	12.51 **	6.62 **	**	25.21 **	**	40.03 **	21.67 **
				17.99			27.93		33.29			10.53		13.69		
9	BHU-31XHD-3326	7.63	13.81 **	**	10.05 *	5.79	**	55.08 **	**	34.72 **	27.67 **	**	12.06 **	**	25.32 **	8.89 **
				17.22			13.08					32.04		27.20		
10	HD-3721XPBW ZN1	9.94 *	13.06 **	**	9.33	5.1	**	50.35 **	9.13 **	10.30 **	4.53 *	**	25.37 **	**	40.20 **	21.83 **
							27.98		31.31			12.61		16.62		
11	HD-3721XPBW-343	4.24	7.2	11.14 *	3.67	-0.35	**	35.47 **	**	32.72 **	25.77 **	**	14.94 **	**	28.54 **	11.69 **
				23.19			16.68		17.45							
12	HD-3721XHD-3326	12.39 **	18.83 **	**	14.91 **	10.46 *	**	44.57 **	**	18.71 **	12.50 **	-2.19	-0.84	0.6	10.89 **	-3.23
							24.27		28.85			27.01		28.87		
13	PWB-725X PBW ZN1	2.76	2.76	6.53	-0.63	-4.48	**	55.99 **	**	30.22 **	23.41 **	**	27.01 **	**	42.05 **	23.43 **
				15.10			17.84		22.18							
14	PWB-725X PBW-343	11.02 *	11.02 *	**	7.36	3.2	**	65.02 **	**	23.49 **	17.02 **	5.84 **	8.02 **	9.60 **	20.81 **	4.97 *

				23.90			20.86		25.31		20.02		23.45			
15	PWB-725X HD-3326	13.03 **	19.51 **	**	15.57 **	11.09 *	**	60.23 **	**	26.65 **	20.02 **	**	21.67 **	**	36.07 **	18.23 **
				16.03			26.31		24.97		34.47		22.97			
16	CRDGEHNU1XPBWZN1	8.23	11.92 *	**	8.23	4.03	**	92.60 **	**	26.31 **	19.70 **	**	21.20 **	**	35.54 **	17.78 **
				16.98			23.10		26.30		23.48		27.87			
17	CRDGEHNU1XPBW343	9.11	12.83 *	**	9.11	4.89	**	70.10 **	**	27.65 **	20.97 **	**	26.03 **	**	40.95 **	22.47 **
							18.08		18.86		23.32		26.84			
18	CRDGEHNU1XHD-3326	1.54	7.36	11.31 *	3.82	-0.2	**	70.17 **	**	20.13 **	13.84 **	**	25.01 **	**	39.81 **	21.48 **
				20.63			19.43		24.69		21.41		26.76			
19	PBW-550X PBW ZN1	8.16	16.35 **	**	12.51 **	8.16	**	79.13 **	**	26.03 **	19.43 **	**	24.94 **	**	39.72 **	21.41 **
				19.61			19.62		24.89				12.89			
20	PBW-550X PBW-343	7.25	15.37 **	**	11.57 *	7.25	**	57.97 **	**	26.23 **	19.62 **	8.12 **	11.26 **	**	24.43 **	8.12 **
				21.28			20.68		26.00		11.19		16.10			
21	PBW-550X HD-3326	8.75	16.99 **	**	13.13 **	8.75	**	48.31 **	**	27.35 **	20.68 **	**	14.42 **	**	27.97 **	11.19 **
				14.90			27.78		27.78		27.18		27.18			
22	PBW-677XPBW ZN1	13.14 **	10.83 *	**	7.18	3.03	**	63.47 **	**	29.15 **	22.39 **	**	25.35 **	**	40.18 **	21.81 **
				26.12			22.45		25.63		23.05		27.42			
23	PBW-677XPBW-343	26.12 **	21.65 **	**	17.64 **	13.08 **	**	70.80 **	**	26.98 **	20.33 **	**	25.59 **	**	40.45 **	22.04 **
							22.43		23.24		23.57		27.11			
24	PBW-677XPBW-343	2.33	8.2	12.17 *	4.63	0.58	**	69.96 **	**	24.56 **	18.04 **	**	25.28 **	**	40.10 **	21.74 **
				26.20			30.27		30.56		36.57		27.63			
25	PBW-822X PBW ZN1	24.27 **	21.73 **	**	17.72 **	13.16 **	**	61.99 **	**	31.96 **	25.05 **	**	25.80 **	**	40.68 **	22.24 **
				16.31			34.16		37.65				11.42			
26	PBW-822X PBW-343	21.39 **	12.19 *	**	8.49	4.29	**	82.09 **	**	39.13 **	31.84 **	7.60 **	9.81 **	**	22.81 **	6.71 **
				21.99			40.01		40.94		13.59		16.83			
27	PBW-822X HD-3326	11.29 *	17.67 **	**	13.79 **	9.38 *	**	60.37 **	**	42.45 **	34.99 **	**	15.15 **	**	28.78 **	11.90 **
							34.65		30.79		24.67		14.36			
28	HD-3117X PBW ZN1	2.71	0.61	4.31	-2.71	-6.48	**	89.63 **	**	32.19 **	25.27 **	**	12.71 **	**	26.05 **	9.53 **

				14.90			34.68		38.19					10.39		
29	HD-3117X PBW-343	13.25 **	10.82 *	**	7.17	3.02	**	65.80 **	**	39.66 **	32.35 **	6.61 **	8.80 **	**	21.68 **	5.73 **
				16.79			27.95		28.79			23.85		27.39		
30	HD-3117X HD-3326	6.54	12.65 *	**	8.94	4.72	**	77.86 **	**	30.17 **	23.35 **	**	25.55 **	**	40.41 **	22.01 **
				18.63			40.94		40.61			33.02		27.23		
31	DBW-173X PBW ZN1	13.89 **	14.43 **	**	10.66 *	6.37	**	60.93 **	**	42.12 **	34.68 **	**	25.39 **	**	40.24 **	21.85 **
				22.01			33.38		36.85			23.01		27.38		
32	DBW-173X PBW-343	17.13 **	17.68 **	**	13.80 **	9.40 *	**	71.51 **	**	38.31 **	31.07 **	**	25.55 **	**	40.41 **	22.00 **
				21.28			36.88		37.79			23.36		26.89		
33	DBW-173X HD-3326	10.64 *	16.98 **	**	13.12 **	8.74	**	58.53 **	**	39.26 **	31.97 **	**	25.06 **	**	39.86 **	21.53 **
				19.57			15.71		15.42			35.58		27.47		
34	DH-3086X PBW ZN1	14.14 **	15.33 **	**	11.53 *	7.21	**	60.08 **	**	16.65 **	10.55 **	**	25.64 **	**	40.51 **	22.09 **
				24.81			23.37		26.58			22.83		27.20		
35	DH-3086X PBW-343	19.14 **	20.38 **	**	16.41 **	11.91 *	**	-2.89	**	27.93 **	21.24 **	**	25.37 **	**	40.20 **	21.83 **
							17.64		18.42			10.16		13.31		
36	DH-3086X HD-3326	3.39	9.32	13.33 *	5.71	1.62	**	76.94 **	**	19.68 **	13.42 **	**	11.68 **	**	24.89 **	8.52 **
				22.49			38.08		38.57			14.64		13.64		
37	DBW-222X PBW ZN1	11.71 *	18.15 **	**	14.26 **	9.83 *	**	98.31 **	**	40.05 **	32.72 **	**	12.01 **	**	25.27 **	8.84 **
				22.44			25.82		29.09			18.89		23.12		
38	DBW-222X PBW-343	11.67 *	18.11 **	**	14.21 **	9.79 *	**	51.06 **	**	30.47 **	23.64 **	**	21.35 **	**	35.71 **	17.92 **
							35.64		36.53			15.34		18.64		
39	DBW-222X HD-3326	-1.23	4.46	8.3	1.02	-2.9	**	41.04 **	**	37.99 **	30.77 **	**	16.93 **	**	30.77 **	13.63 **
				25.78			43.41		36.17			37.24		26.99		
40	CSW-18XPBW ZN1	23.86 **	21.33 **	**	17.33 **	12.78 **	**	46.05 **	**	37.63 **	30.43 **	**	25.17 **	**	39.98 **	21.63 **
				22.38			35.10		38.62			23.42		27.81		
41	CSW-18XPBW-343	26.90 **	18.05 **	**	14.15 **	9.73 *	**	64.53 **	**	40.10 **	32.76 **	**	25.97 **	**	40.88 **	22.41 **
				15.51			29.34		30.19			23.82		27.36		
42	CSW-18XHD-3326	5.37	11.41 *	**	7.74	3.57	**	60.65 **	**	31.58 **	24.70 **	**	25.53 **	**	40.38 **	21.98 **

43	PBW-757X PBW ZN1	11.00 *	15.32 **	19.56			26.35			26.71			24.70			27.84	
				**	11.52 *	7.2	**	68.19 **	**	28.07 **	21.37 **	**	26.00 **	**	40.92 **	22.44 **	
44	PBW-757X PBW-343	11.62 *	15.96 **	20.22			31.27			34.69			23.39			27.77	
				**	12.14 *	7.8	**	71.79 **	**	36.13 **	29.00 **	**	25.93 **	**	40.84 **	22.38 **	
45	PBW-757X HD-3326	12.47 **	18.92 **	23.28			35.42			36.32			24.17			27.72	
				**	15.00 **	10.54 *	**	57.19 **	**	37.77 **	30.56 **	**	25.88 **	**	40.78 **	22.32 **	

*** and ** for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= NORMAN and SV4= BORLAUG 100

Table 12. Estimation of heterosis over better parent and four standard varieties in wheat across three locations .

		Number of spikelet per spike															
		Location 1					Location 2					Location 3					
SN	Cross	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	VS3	SV4	BP	SV1	SV2	SV3	SV4	
1	BHU-25XPBW ZN1	6.18 *	5.31 *	4.95 *	5.99 *	3.73	12.00 *	13.76 *	7.02	15.44 *	21.47 **	11.23 **	12.98 **	1.78	-12.91 **	20.63 **	
2	BHU-25XPBW-343	4.88	5.62 *	5.25 *	6.30 *	4.03	-17.04 **	3.13	-2.99	4.65	10.12	-4.68 *	26.64 **	14.08 **	-2.38	35.22 **	
3	BHU-25XHD-3326	-0.13	2.79	2.43	3.45	1.24	11.31	0.61	-5.35	2.1	7.43	33.53 **	24.12 **	11.82 **	-4.32 *	32.53 **	
4	WB-02XPBW ZN1	3.01	2.16	1.81	2.82	0.63	5.44	7.1	0.75	8.68	14.36 *	30.06 **	32.11 **	19.01 **	1.84	41.06 **	
5	WB-02XPBW-343	2.89	3.62	3.26	4.29	2.06	-9.88 *	12.03	5.39	13.69 *	19.62 **	0.84	33.97 **	20.69 **	3.27	43.05 **	
6	WB-02XHD-3326	-2.35	0.51	0.17	1.16	-1	16.55 *	12.93 *	6.24	14.60 *	20.58 **	29.58 **	28.60 **	15.86 **	-0.86	37.32 **	
7	BHU-31XPBW ZN1	3.99	3.14	2.78	3.8	1.59	-14.72 *	-9.18	-14.57 *	-7.84	-3.03	19.44 **	30.00 **	17.11 **	0.21	38.81 **	
8	BHU-31XPBW-343	0.25	0.96	0.61	1.61	-0.56	-23.97 **	-5.49	-11.09	-4.1	0.91	0.63	33.69 **	20.44 **	3.06	42.75 **	
9	BHU-31XHD-3326	-4	-1.19	-1.53	-0.56	-2.68	8.16	15.18 *	8.35	16.88 **	22.99 **	25.98 **	37.12 **	23.53 **	5.70 **	46.41 **	
10	HD-3721XPBW ZN1	7.66 **	7.85 **	7.48 **	8.55 **	6.23 *	-0.9	0.66	-5.31	2.15	7.48	45.39 **	47.68 **	33.04 **	13.84 **	57.69 **	
11	HD-3721XPBW-343	-1.86	-1.17	-1.51	-0.53	-2.65	-10.63 *	11.1	4.51	12.74 *	18.63 **	1.32	34.61 **	21.26 **	3.76	43.73 **	
12	HD-3721XHD-3326	0.77	3.72	3.36	4.38	2.16	19.00 *	0.85	-5.13	2.34	7.68	59.07 **	47.86 **	33.21 **	13.98 **	57.89 **	
13	PWB-725X PBW ZN1	-1.73	-1.73	-2.07	-1.1	-3.21	0.19	1.77	-4.26	3.28	8.67	41.08 **	43.30 **	29.10 **	10.47 **	53.02 **	
14	PWB-725X PBW-343	4.93 *	5.67 *	5.31 *	6.35 *	4.09	2.51	27.43 **	19.87 **	29.31 **	36.06 **	-3.49	28.21 **	15.50 **	-1.17	36.90 **	
15	PWB-725X HD-3326	-1.85	1.03	0.68	1.68	-0.49	3.9	3.9	-2.26	5.44	10.94	50.92 **	50.92 **	35.96 **	16.34 **	61.15 **	
16	CRDGEHNU1XPBWZN1	2.15	1.5	1.15	2.15	-0.03	43.05 **	45.30 **	36.69 **	47.45 **	55.15 **	12.01 **	45.30 **	30.90 **	12.01 **	55.15 **	
17	CRDGEHNU1XPBW343	2.42	3.15	2.79	3.81	1.6	13.24 **	40.77 **	32.43 **	42.85 **	50.31 **	17.17 **	55.66 **	40.23 **	20.00 **	66.21 **	

18	CRDGEHNU1XHD-3326	-2.02	0.85	0.5	1.49	-0.67	33.21 **	31.27**	23.49 **	33.21 **	40.16 **	12.67 **	46.16 **	31.67 **	12.67 **	56.06 **
19	PBW-550X PBW ZN1	2.08	3.63	3.28	4.3	2.08	1.45	3.05	-3.06	4.57	10.03	32.31 **	34.39**	21.07 **	3.6	43.50 **
20	PBW-550X PBW-343	0.05	1.58	1.23	2.23	0.05	0.61	25.06**	17.65 **	26.91 **	33.54 **	-5.86 **	25.06 **	12.67 **	-3.59	33.54 **
21	PBW-550X HD-3326	2.61	5.62 *	5.25 *	6.30 *	4.03	48.62 **	39.19**	30.94 **	41.25 **	48.62 **	48.62 **	39.19**	25.39 **	7.30 **	48.62 **
22	PBW-677XPBW ZN1	-1.33	-0.99	-1.33	-0.35	-2.47	-19.85 **	-14.80 *	-19.85 **	-13.54 *	-9.03	33.23 **	47.89**	33.23 **	14.00 **	57.91 **
23	PBW-677XPBW-343	8.82 **	9.59**	9.21 **	10.29 **	7.94 **	1.87	26.64**	19.13 **	28.51 **	35.22 **	-4.68 *	26.64**	14.08 **	-2.38	35.22 **
24	PBW-677XPBW-343	-1.99	0.87	0.53	1.52	-0.64	-1.61	4.58	-1.61	6.13	11.67	36.58 **	51.60 **	36.58 **	16.87 **	61.88 **
25	PBW-822X PBW ZN1	6.73 **	5.85 *	5.49 *	6.53 *	4.26	6.97	8.65	2.21	10.26	16.02 *	30.11 **	32.16 **	19.06 **	1.88	41.12 **
26	PBW-822X PBW-343	3.28	4.01	3.65	4.68	2.45	7.55	33.70**	25.77 **	35.67**	42.76 **	13.61 **	50.94**	35.98 **	16.35 **	61.17 **
27	PBW-822X HD-3326	6.01 *	9.11 **	8.74 **	9.82 **	7.47**	29.47 **	23.63**	16.30 **	25.46**	32.01 **	29.47 **	23.63**	11.37 **	-4.70 *	32.01 **
28	HD-3117X PBW ZN1	7.94 **	7.34 **	6.97 **	8.03 **	5.73 *	23.12 **	25.06**	17.65 **	26.91 **	33.54 **	23.12 **	25.06**	12.67 **	-3.59	33.54 **
29	HD-3117X PBW-343	0.94	1.65	1.3	2.3	0.12	7.58	33.74**	25.81 **	35.71 **	42.80**	4.80 *	39.22 **	25.42 **	7.32 **	48.66 **
30	HD-3117X HD-3326	-2.64	0.21	-0.14	0.85	-1.3	12.41	8.15	1.74	9.75	15.48 *	62.71 **	51.25**	36.26 **	16.59**	61.50 **
31	DBW-173X PBW ZN1	2.46	5.84 *	5.47 *	6.52 *	4.25	-9.98	-8.56	-13.98 *	-7.2	-2.36	36.31 **	38.46**	24.74 **	6.74 **	47.85**
32	DBW-173X PBW-343	-4.89 *	-1.75	-2.09	-1.12	-3.22	-24.55 **	-6.21	-11.77 *	-4.82	0.15	6.58 **	41.60**	27.56 **	9.15**	51.19**
33	DBW-173X HD-3326	0.27	3.58	3.22	4.24	2.02	14.63 *	0.78	-5.2	2.27	7.61	44.66 **	34.47**	21.14 **	3.66	43.59**
34	DH-3086X PBW ZN1	-3.61	-0.29	-0.64	0.35	-1.79	9.68	11.41	4.81	13.06 *	18.96 **	45.94 **	48.24 **	33.55 **	14.27 **	58.29 **
35	DH-3086X PBW-343	0.43	3.88	3.53	4.55	2.32	-6.37	16.39**	9.49	18.11 **	24.27**	1.76	35.19**	21.79 **	4.22 *	44.36 **
36	DH-3086X HD-3326	2.41	5.94 *	5.57 *	6.62 **	4.35	36.69 **	9.92	3.41	11.55	17.37 **	51.87 **	42.83**	28.68 **	10.11 **	52.51 **
37	DBW-222X PBW ZN1	7.33 **	7.84 **	7.47 **	8.53 **	6.22 *	21.64 **	37.68**	29.52 **	39.71 **	47.01 **	5.53 **	38.46**	24.74 **	6.74**	47.85**
38	DBW-222X PBW-343	8.11 **	8.88 **	8.50 **	9.58 **	7.24 **	3.03	28.07**	20.48 **	29.96 **	36.75 **	-3.6	28.07**	15.38 **	-1.27	36.75 **
39	DBW-222X HD-3326	-0.26	2.66	2.31	3.32	1.12	18.26 **	33.85**	25.92 **	35.83 **	42.93 **	2.02	33.85**	20.59 **	3.18	42.93 **
40	CSW-18XPBW ZN1	-0.19	-0.5	-0.84	0.14	-2	12.64 *	18.57**	11.54 *	20.33**	26.61 **	29.92 **	42.86**	28.70 **	10.13 **	52.55**
41	CSW-18XPBW-343	3.03	3.76	3.4	4.43	2.2	6.54	32.44**	24.59 **	34.40 **	41.42 **	-0.31	32.44**	19.32 **	2.1	41.42**
42	CSW-18XHD-3326	5.42 *	8.50**	8.13 **	9.20**	6.87**	24.43 **	30.99**	23.22 **	32.92 **	39.86 **	19.11 **	30.99**	18.00 **	0.97	39.86 **
43	PBW-757X PBW ZN1	11.68 **	10.77 **	10.38 **	11.48 **	9.10 **	10.92 *	24.33**	16.96 **	26.17 **	32.76 **	7.17 **	24.33**	12.01 **	-4.16 *	32.76**
44	PBW-757X PBW-343	5.39 *	6.13 *	5.77 *	6.81 **	4.54	-18.66 **	1.11	-4.88	2.61	7.97	5.60 **	40.29**	26.39 **	8.15 **	49.80 **
45	PBW-757X HD-3326	4.15	7.20 **	6.83 **	7.89**	5.59 *	-7.6	3.57	-2.57	5.11	10.59	16.30 **	34.92**	21.55 **	4.01	44.06 **

“*” and “**” for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= NORMAN and SV4= BORLAUG 100

Table 12. Estimation of heterosis over better parent and four standard varieties in wheat across three locations

S/N	Crosses	Days to 50% heading														
		Location 1					Location 2					Location 3				
		BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4
1	BHU-25XPBW ZN1	-7.8	-1.14	-9.41 *	5.26	10.64 *	14.35 **	4.37	17.94 **	-8.68 **	39.15 **	6.12 **	12.55 **	21.50 **	-8.45 **	9.70 **
2	BHU-25XPBW-343	-17.38 **	-11.41 *	-18.82 **	-5.67	-0.85	-5.65 *	-13.89 **	-2.69	-24.65 **	14.81 **	-2.71 **	-6.93 **	0.47	-24.30 **	-9.28 **
3	BHU-25XHD-3326	-8.16	-1.52	-9.76 *	4.86	10.21	6.96 **	-2.38	10.31 **	-14.58 **	30.16 **	12.27 **	6.93 **	15.42 **	-13.03 **	4.22 **
4	WB-02XPBW ZN1	-10.83 *	-6.08	-13.94 **	0.00	5.11	-15.81 **	-15.48 **	-4.48	-26.04 **	12.70 **	-9.39 **	-3.90 **	3.74 **	-21.83 **	-6.33 **
5	WB-02XPBW-343	-23.83 **	-19.77 **	-26.48 **	-14.57 **	-10.21	-20.95 **	-20.63 **	-10.31 **	-30.56 **	5.82	-8.30 **	-4.33 **	3.27 **	-22.18 **	-6.75 **
6	WB-02XHD-3326	-3.61	1.52	-6.97	8.1	13.62 *	4.74	5.16 *	18.83 **	-7.99 **	40.21 **	5.81 **	10.39 **	19.16 **	-10.21 **	7.59 **
7	BHU-31XPBW ZN1	3.19	10.65 *	1.39	17.81 **	23.83 **	18.05 **	-3.97	8.52 **	-15.97 **	28.04 **	-5.71 **	0.00	7.94 **	-18.66 **	-2.53 **
8	BHU-31XPBW-343	-3.9	3.04	-5.57	9.72	15.32 **	-12.61 **	-20.24 **	-9.87 **	-30.21 **	6.35	-4.93 **	-8.23 **	-0.93	-25.35 **	-10.55 **
9	BHU-31XHD-3326	-13.83 **	-7.6	-15.33 **	-1.62	3.4	4.27	-12.70 **	-1.35	-23.61 **	16.40 **	-4.93 **	-8.23 **	-0.93	-25.35 **	-10.55 **
10	HD-3721XPBW ZN1	-9.41 *	-1.14	-9.41 *	5.26	10.64 *	17.07 **	-4.76	7.62 **	-16.67 **	26.98 **	0.82	6.93 **	15.42 **	-13.03 **	4.22 **
11	HD-3721XPBW-343	-11.15 *	-3.04	-11.15 *	3.24	8.51	11.30 **	1.59	14.80 **	-11.11 **	35.45 **	10.76 **	6.93 **	15.42 **	-13.03 **	4.22 **
12	HD-3721XHD-3326	-35.19 **	-29.28 **	-35.19 **	-24.70 **	-20.85 **	31.75 **	10.32 **	24.66 **	-3.47	47.09 **	20.63 **	16.45 **	25.70 **	-5.28 **	13.50 **
13	PWB-725X PBW ZN1	-1.14	-1.14	-9.41 *	5.26	10.64 *	-9.13 **	-9.13 **	2.69	-20.49 **	21.16 **	-10.20 **	-4.76 **	2.80 **	-22.54 **	-7.17 **
14	PWB-725X PBW-343	-3.04	-3.04	-11.15 *	3.24	8.51	12.70 **	12.70 **	27.35 **	-1.39	50.26 **	23.81 **	23.81 **	33.64 **	0.7	20.68 **
15	PWB-725X HD-3326	-4.56	-4.56	-12.54 **	1.62	6.81	3.17	3.17	16.59 **	-9.72 **	37.57 **	12.55 **	12.55 **	21.50 **	-8.45 **	9.70 **
16	CRDGEHNU1XPBWZN1	1.21	-4.94	-12.89 **	1.21	6.38	-5.90 **	7.54 **	21.52 **	-5.90 **	43.39 **	2.46 **	25.97 **	35.98 **	2.46 **	22.78 **
17	CRDGEHNU1XPBW343	7.03	4.18	-4.53	10.93 *	16.60 **	-28.82 **	-18.65 **	-8.07 **	-28.82 **	8.47 **	-19.72 **	-1.3	6.54 **	-19.72 **	-3.80 **
18	CRDGEHNU1XHD-3326	14.57 **	7.6	-1.39	14.57 **	20.43 **	-36.11 **	-26.98 **	-17.49 **	-36.11 **	-2.65	-17.61 **	1.3	9.35 **	-17.61 **	-1.27
19	PBW-550X PBW ZN1	16.73 **	8.75	-0.35	15.79 **	21.70 **	-5.85	-23.41 **	-13.45 **	-32.99 **	2.12	-6.12 **	-0.43	7.48 **	-19.01 **	-2.95 **
20	PBW-550X PBW-343	-8.98	-11.41 *	-18.82 **	-5.67	-0.85	-14.78 **	-22.22 **	-12.11 **	-31.94 **	3.7	-10.55 **	-8.23 **	-0.93	-25.35 **	-10.55 **
21	PBW-550X HD-3326	18.30 **	5.7	-3.14	12.55 *	18.30 **	29.86 **	8.73 **	22.87 **	-4.86 *	44.97 **	11.39 **	14.29 **	23.36 **	-7.04 **	11.39 **
22	PBW-677XPBW ZN1	-4.53	4.18	-4.53	10.93 *	16.60 **	4.48	-7.54 **	4.48	-19.10 **	23.28 **	-11.84 **	-6.49 **	0.93	-23.94 **	-8.86 **
23	PBW-677XPBW-343	-0.7	8.37	-0.7	15.38 **	21.28 **	10.87 **	1.19	14.35 **	-11.46 **	34.92 **	11.76 **	6.93 **	15.42 **	-13.03 **	4.22 **
24	PBW-677XPBW-343	-0.35	8.75	-0.35	15.79 **	21.70 **	-17.49 **	-26.98 **	-17.49 **	-36.11 **	-2.65	3.74 **	-3.90 **	3.74 **	-21.83 **	-6.33 **

25	PBW-822X PBW ZN1	-4.56	3.42	-5.23	10.12 *	15.74 **	-4.39	-22.22 **	-12.11 **	-31.94 **	3.7	-3.27 **	2.60 **	10.75 **	-16.55 **	0.00
26	PBW-822X PBW-343	-8.77 *	-1.14	-9.41 *	5.26	10.64 *	23.04 **	12.30 **	26.91 **	-1.74	49.74 **	23.53 **	18.18 **	27.57 **	-3.87 **	15.19 **
27	PBW-822X HD-3326	-1.75	6.46	-2.44	13.36 *	19.15 **	29.86 **	8.73 **	22.87 **	-4.86 *	44.97 **	22.90 **	13.85 **	22.90 **	-7.39 **	10.97 **
28	HD-3117X PBW ZN1	-0.36	4.18	-4.53	10.93 *	16.60 **	5.62 *	11.90 **	26.46 **	-2.08	49.21 **	12.65 **	19.48 **	28.97 **	-2.82 **	16.46 **
29	HD-3117X PBW-343	-2.91	1.52	-6.97	8.1	13.62 *	6.37 **	12.70 **	27.35 **	-1.39	50.26 **	26.43 **	24.24 **	34.11 **	1.06	21.10 **
30	HD-3117X HD-3326	-1.45	3.04	-5.57	9.72	15.32 **	-19.85 **	-15.08 **	-4.04	-25.69 **	13.23 **	3.08 **	1.3	9.35 **	-17.61 **	-1.27
31	DBW-173X PBW ZN1	-8.3	0.76	-7.67	7.29	12.77 *	-15.29 **	-18.65 **	-8.07 **	-28.82 **	8.47 **	-7.14 **	1.3	9.35 **	-17.61 **	-1.27
32	DBW-173X PBW-343	-4.84	4.56	-4.18	11.34 *	17.02 **	-2.48	-6.35 **	5.83 *	-18.06 **	24.87 **	-10.71 **	-2.60 **	5.14 **	-20.77 **	-5.06 **
33	DBW-173X HD-3326	2.08	12.17 *	2.79	19.43 **	25.53 **	-11.16 **	-14.68 **	-3.59	-25.35 **	13.76 **	-9.52 **	-1.3	6.54 **	-19.72 **	-3.80 **
34	DH-3086X PBW ZN1	13.06 *	5.32	-3.48	12.15 *	17.87 **	3.11	-7.94 **	4.04	-19.44 **	22.75 **	-9.39 **	-3.90 **	3.74 **	-21.83 **	-6.33 **
35	DH-3086X PBW-343	2.34	-0.38	-8.71 *	6.07	11.49 *	-13.91 **	-21.43 **	-11.21 **	-31.25 **	4.76	5.33 **	2.60 **	10.75 **	-16.55 **	0.04
36	DH-3086X HD-3326	21.24 **	4.18	-4.53	10.93 *	16.60 **	11.56 **	-0.4	12.56 **	-12.85 **	32.80 **	5.78 **	3.03 **	11.21 **	-16.20 **	0.42
37	DBW-222X PBW ZN1	6.53	-0.76	-9.06 *	5.67	11.06 *	35.12 **	9.92 **	24.22 **	-3.82	46.56 **	7.76 **	14.29 **	23.36 **	-7.04 **	11.39**
38	DBW-222X PBW-343	7.42	4.56	-4.18	11.34 *	17.02 **	10.87 **	1.19	14.35 **	-11.46 **	34.92 **	5.26 **	3.90 **	12.15 **	-15.49 **	1.27
39	DBW-222X HD-3326	28.44 **	3.04	-5.57	9.72	15.32 **	32.70 **	11.11 **	25.56 **	-2.78	48.15 **	22.37 **	20.78 **	30.37 **	-1.76 **	17.72**
40	CSW-18XPBW ZN1	-7.93	1.52	-6.97	8.1	13.62 *	12.24 **	5.56 *	19.28 **	-7.64 **	40.74 **	2.45 **	8.66 **	17.29 **	-11.62 **	5.91**
41	CSW-18XPBW-343	-3.45	6.46	-2.44	13.36 *	19.15 **	15.19 **	8.33 **	22.42 **	-5.21 *	44.44 **	25.43 **	25.97 **	35.98 **	2.46 **	22.78**
42	CSW-18XHD-3326	-1.03	9.13	0.09	16.19 **	22.13 **	-7.17 **	-12.70 **	-1.35	-23.61 **	16.40 **	-9.48 **	-9.09 **	-1.87 *	-26.06 **	-11.39
43	PBW-757X PBW ZN1	5.31	-1.9	-10.10 *	4.45	9.79	35.85 **	14.29 **	29.15 **	0.00	52.38 **	16.73 **	23.81 **	33.64 **	0.7	20.68**
44	PBW-757X PBW-343	9.77 *	6.84	-2.09	13.77 **	19.57 **	11.74 **	1.98	15.25 **	-10.76 **	35.98 **	5.65 **	5.19 **	13.55 **	-14.44 **	2.53**
45	PBW-757X HD-3326	11.89 *	-3.42	-11.50 *	2.83	8.09	23.11 **	3.57	17.04 **	-9.38 **	38.10 **	6.52 **	6.06 **	14.49 **	-13.73 **	3.38**

“*” and “**” for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= NORMAN and SV4= BORLAUG 100

Table 13. Estimation of heterosis over better parent and four standard varieties in wheat across three locations.

		Chlorophyll content														
		Location 1					Location 2					Location 3				
SN	Crosses	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4
			10.64	12.10			15.52				11.27					
1	BHU-25XPBW ZN1	5.53	**	**	5.05	9.15 **	**	12.10 **	6.32 **	6.57 **	**	4.65 **	-0.74 **	-0.74 **	-0.74 **	-0.98 **
							10.43									
2	BHU-25XPBW-343	-0.47	0.61	1.94	-4.47	-0.74	**	7.16 **	1.64	1.88	6.37 **	4.39 **	-0.98 **	-0.98 **	-0.98 **	-1.22 **
3	BHU-25XHD-3326	-0.64	6.48 *	7.88 *	1.1	5.05	2.8	8.64 **	3.04 *	3.29 *	7.84 **	3.10 **	-2.21 **	-2.21 **	-2.21 **	-2.44 **
			12.49	13.96												
4	WB-02XPBW ZN1	7.29 *	**	**	6.80 *	10.97 **	2.9	5.19 **	-0.23	0.0	4.41 **	-0.25	-1.72 **	-1.72 **	-1.72 **	-1.96 **
		15.79	17.06	18.60	11.14											
5	WB-02XPBW-343	**	**	**	**	15.48 **	-1.93	0.25	-4.92 **	-4.69 **	-0.49	-1.24 **	-2.70 **	-2.70 **	-2.70 **	-2.93 **
											10.29					
6	WB-02XHD-3326	-5.67	1.09	2.42	-4.02	-0.27	5.14 **	11.11 **	5.39 **	5.63 **	**	-4.48 **	-5.88 **	-5.88 **	-5.88 **	-6.11 **
			11.19	12.65												
7	BHU-31XPBW ZN1	6.05 *	**	**	5.57	9.69 **	8.21 **	7.41 **	1.87	2.11	6.62 **	0.25	0.00	-5.04 **	0.00	-0.24
		10.30	13.24	14.72												
8	BHU-31XPBW-343	**	**	**	7.51 *	11.71 **	1.74	0.99	-4.22 **	-3.99 **	0.25	-0.25	-0.49	-0.49	-0.49	-0.73 **
			17.26	18.80	11.34											
9	BHU-31XHD-3326	9.42 **	**	**	**	15.68 **	3.04 *	8.89 **	3.28 *	3.52 *	8.09 **	-1.97 **	-2.21 **	-2.21 **	-2.21 **	-2.44 **
10	HD-3721XPBW ZN1	1.76	6.69 *	8.09 *	1.3	5.25	3.95 **	10.37 **	4.68 **	4.93 **	9.56 **	1.49 **	0.0	0.0	0.0	-0.24
		12.01	13.24	14.72												
11	HD-3721XPBW-343	**	**	**	7.51 *	11.71 **	3.95 **	10.37 **	4.68 **	4.93 **	9.56 **	-2.99 **	-4.41 **	-4.41 **	-4.41 **	-4.65 **
											10.05					
12	HD-3721XHD-3326	-0.06	7.10 *	8.50 **	1.68	5.65	4.42 **	10.86 **	5.15 **	5.40 **	**	0.0	-1.47 **	-1.47 **	-1.47 **	-1.71 **
13	PWB-725X PBW ZN1	-1.5	3.28	4.63	-1.94	1.88	-2.96	-2.96	-7.96 **	-7.75 **	-3.68 *	-7.11 **	-7.11 **	-7.11 **	-7.11 **	-7.33 **

							11.11				10.29					
14	PWB-725X PBW-343	7.36 *	8.53 **	9.95 **	3.04	7.07 *	**	11.11 **	5.39 **	5.63 **	**	-2.21 **	-2.21 **	-2.21 **	-2.21 **	-2.44 **
				10.71									-		-	
15	PWB-725X HD-3326	1.97	9.28 **	**	3.76	7.81 *	2.57	8.40 **	2.81	3.05 *	7.60 **	0.00	1.12**	0.37	2.04**	-0.24
			10.58	12.03												
16	CRDGEHNU1XPBWZN1	4.99	**	**	4.99	9.09 **	5.16 **	10.62 **	4.92 **	5.16 **	9.80 **	-1.47 **	-1.47 **	-1.47 **	-1.47 **	-1.71 **
							-11.03		-11.24			-12.50	-12.50	-12.50	-12.50	
17	CRDGEHNU1XPBW343	2.92	8.39 **	9.82 **	2.92	6.93 *	**	-6.42 **	**	-11.03 **	-7.11 **	**	**	**	**	-12.71 **
				10.71												
18	CRDGEHNU1XHD-3326	1.97	9.28 **	**	3.76	7.81 *	-3.04 *	2.47	-2.81	-2.58	1.72	0.01	0.00	0.07	0.02	-0.24
		13.73	19.24	20.81	13.22											
19	PBW-550X PBW ZN1	**	**	**	**	17.64 **	0.0	0.74	-4.45 **	-4.23 **	0.02	0.00	0.25	0.25	0.25	0.00
		15.15	16.72	18.25	10.82				-12.88			-14.18	-13.97	-13.97	-13.97	
20	PBW-550X PBW-343	**	**	**	**	15.15 **	-8.82 **	-8.15 **	**	-12.68 **	-8.82 **	**	**	**	**	-14.18 **
		10.31	18.22	19.77	12.24											
21	PBW-550X HD-3326	**	**	**	**	16.63 **	1.64	7.41 **	1.87	2.11	6.62 **	-0.49	0.25	-0.25	-0.25	-0.49
22	PBW-677XPBW ZN1	0.85	5.73	7.12 *	0.39	4.31	-6.79 **	-1.73	-6.79 **	-6.57 **	-2.45	-6.86 **	-6.86 **	-6.86 **	-6.86 **	-7.09 **
		13.09	14.33	15.83												
23	PBW-677XPBW-343	**	**	**	8.55 **	12.79 **	-6.56 **	-1.48	-6.56 **	-6.34 **	-2.21	-7.84 **	-7.84 **	-7.84 **	-7.84 **	-8.07 **
24	PBW-677XPBW-343	-0.45	6.69 *	8.09 *	1.3	5.25	0.93	6.67 **	1.17	1.41	5.88 **	-4.41 **	-4.41 **	-4.41 **	-4.41 **	-4.65 **
		22.52	28.45	30.14	21.96											
25	PBW-822X PBW ZN1	**	**	**	**	26.72 **	-8.02 **	-3.70 *	-8.67 **	-8.45 **	-4.41 **	-2.24 **	-3.68 **	-3.68 **	-3.68 **	-3.91 **
		11.74	12.96	14.45			-11.32		-11.94			-11.94	-13.24	-13.24	-13.24	
26	PBW-822X PBW-343	**	**	**	7.26 *	11.44 **	**	-7.16 **	**	-11.74 **	-7.84 **	**	**	**	**	-13.45 **
		12.22	20.26	21.84	14.19											
27	PBW-822X HD-3326	**	**	**	**	18.65 **	1.64	7.41 **	1.87	2.11	6.62 **	1.49 **	1.23**	0.00	0.00	-0.24
28	HD-3117X PBW ZN1	-0.65	4.16	5.53	-1.1	2.76	-5.11 **	-3.70 *	-8.67 **	-8.45 **	-4.41 **	6.25 **	2.03**	3.54**	6.06**	-0.24

			10.03	11.48												
29	HD-3117X PBW-343	8.84 **	**	**	4.47	8.55 **	5.11 **	6.67 **	1.17	1.41	5.88 **	6.25 **	1.34	0.09	2.50**	-0.24
			10.44	11.89												
30	HD-3117X HD-3326	3.06	**	**	4.86	8.95 **	1.64	7.41 **	1.87	2.11	6.62 **	5.70 **	0.86	0.76	0.90**	-0.24
												11.48				
31	DBW-173X PBW ZN1	2.8	7.78 *	9.19 **	2.33	6.33 *	1.58	-4.94 **	-9.84 **	-9.62 **	-5.64 **	**	0.02	0.21	1.56**	-0.24
		17.41	18.70	20.25	12.70							10.00				
32	DBW-173X PBW-343	**	**	**	**	17.10 **	6.91 **	-0.74	-5.85 **	-5.63 **	-1.47	**	-0.25	-0.25	-0.25	-0.49
			13.65	15.14									-11.03	-11.03	-11.03	
33	DBW-173X HD-3326	6.05 *	**	**	7.90 **	12.12 **	3.74 *	9.63 **	3.98 **	4.23 **	8.82 **	-5.96 **	**	**	**	-11.25 **
34	DH-3086X PBW ZN1	2.54	7.51 *	8.92 **	2.07	6.06 *	-7.04 **	-2.22	-7.26 **	-7.04 **	-2.94	3.91 **	-2.21 **	-2.21 **	-2.21 **	-2.44 **
		19.91	21.22	22.81	15.09											
35	DH-3086X PBW-343	**	**	**	**	19.59 **	-9.62 **	-4.94 **	-9.84 **	-9.62 **	-5.64 **	-1.56 **	-7.35 **	-7.35 **	-7.35 **	-7.58 **
36	DH-3086X HD-3326	1.08	8.32 **	9.75 **	2.85	6.87 *	-4.67 **	0.74	-4.45 **	-4.23 **	0.00	5.96 **	0.25	0.25	0.25	0.00
		13.80	19.31	20.88	13.28											
37	DBW-222X PBW ZN1	**	**	**	**	17.70 **	1.67	5.19 **	-0.23	0.0	4.41 **	-2.92 **	-2.21 **	-2.21 **	-2.21 **	-2.44**
38	DBW-222X PBW-343	4.03	7.51 *	8.92 **	2.07	6.06 *	-8.11 **	-4.94 **	-9.84 **	-9.62 **	-5.64 **	-8.03 **	-7.35 **	-7.35 **	-7.35 **	-7.58**
39	DBW-222X HD-3326	0.64	7.85 *	9.26 **	2.4	6.39 *	-1.87	3.70 *	-1.64	-1.41	2.94	-4.14 **	-3.43 **	-3.43 **	-3.43 **	-3.67**
			12.42	13.89												
40	CSW-18XPBW ZN1	7.22 *	**	**	6.74 *	10.90 **	0.24	4.44 **	-0.94	-0.7	3.68 *	-2.71 **	-3.19 **	-3.19 **	-3.19 **	-3.42**
		21.67	22.99	24.61	16.78							-10.59	-11.03	-11.03	-11.03	-
41	CSW-18XPBW-343	**	**	**	**	21.34 **	-0.47	3.70 *	-1.64	-1.41	2.94	**	**	**	**	11.25**
		11.40	19.38	20.95	13.35											
42	CSW-18XHD-3326	**	**	**	**	17.77 **	-7.48 **	-2.22	-7.26 **	-7.04 **	-2.94	-1.72 **	-2.21 **	-2.21 **	-2.21 **	-2.44**
		18.42	24.15	25.78	17.88		10.65									
43	PBW-757X PBW ZN1	**	**	**	**	22.48 **	**	5.19 **	-0.23	0.00	4.41 **	-2.21 **	-2.21 **	-2.21 **	-2.21 **	-2.44**
		11.54	12.76	14.24								-10.54	-10.54	-10.54	-10.54	-
44	PBW-757X PBW-343	**	**	**	7.06 *	11.24 **	9.87 **	4.44 **	-0.94	-0.7	3.68 *	**	**	**	**	10.76**

45	PBW-757X HD-3326	0.32	7.51 *	8.92 **	2.07	6.06 *	-5.37 **	0.00	-5.15 **	-4.93 **	-0.74	0.00	1.07**	0.00	2.05**	-0.24
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“*” and “**” for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= NORMAN and SV4= BORLAUG 100

Table 14. Estimation of heterosis over better parent and four standard varieties in wheat across three locations.

		Number of grain per spike														
		Location 1					Location 2					Location 3				
SN	Crosses	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4	BP	SV1	SV2	SV3	SV4
1	BHU-25XPBW ZN1	9.40		27.05			43.47		68.96					33.29		42.96
			18.74 **	**	22.16 **	26.02 **	**	36.55 **	**	68.96 **	31.78 **	16.32	31.20 **	**	12.17	**
2	BHU-25XPBW-343	10.35 *		25.65			56.53		84.33							35.28
			17.43 **	**	20.82 **	24.63 **	**	48.97 **	**	84.33 **	43.77 **	17.12	24.15 *	26.13 *	6.14	**
3	BHU-25XHD-3326	14.62 **		30.52			38.02		62.54					56.10		67.43
			21.98 **	**	25.50 **	29.46 **	**	31.36 **	**	62.54 **	26.78 *	**	53.66 **	**	31.36 **	**
4	WB-02XPBW ZN1	14.28 **		32.71			43.79		77.91							38.55
			24.03 **	**	27.60 **	31.63 **	**	43.79 **	**	77.91 **	38.77 **	12.73	27.15 *	29.18 *	8.71	**
5	WB-02XPBW-343	15.96 **		30.07			37.39		70.00					32.10		41.68
			21.57 **	**	25.07 **	29.02 **	**	37.39 **	**	70.00 **	32.60 **	22.66 *	30.03 *	**	11.16	**
6	WB-02XHD-3326	15.64 **		31.37			44.27		78.51					56.10		67.43
			22.78 **	**	26.32 **	30.31 **	**	44.27 **	**	78.51 **	39.23 **	**	53.66 **	**	31.36 **	**
7	BHU-31XPBW ZN1	19.85 **		39.17			41.71		78.51					48.81		59.60
			30.07 **	**	33.82 **	38.05 **	**	44.27 **	**	78.51 **	39.23 **	**	46.48 **	**	25.22 *	**
8	BHU-31XPBW-343	24.04 **		38.30			40.88		77.46					61.54		73.26
			29.26 **	**	32.98 **	37.18 **	**	43.43 **	**	77.46 **	38.42 **	**	59.01 **	**	35.94 **	**
9	BHU-31XHD-3326	13.76 **		29.24			46.33		84.33							35.28
			20.79 **	**	24.27 **	28.19 **	**	48.97 **	**	84.33 **	43.77 **	10.07	24.15 *	26.13 *	6.14	**
10	HD-3721XPBW ZN1	7.10		24.37			71.34		71.34					61.94		73.68
			16.24 **	**	19.59 **	23.37 **	**	38.48 **	**	71.34 **	33.64 **	**	59.40 **	**	36.27 **	**

		24.84 **		39.19		78.96		78.96					37.27		47.23
11	HD-3721XPBW-343		30.09 **	**	33.84 **	38.07 **	**	44.63 **	**	78.96 **	39.58 **	27.46 *	35.12 **	**	15.51 **
		17.16 **		33.09		60.27		74.63							35.70
12	HD-3721XHD-3326		24.39 **	**	27.97 **	32.01 **	**	41.13 **	**	74.63 **	36.20 **	16.06	24.54 *	26.53 *	6.47 **
		13.14 *		31.39		41.86		75.52				35.07		54.77	66.00
13	PWB-725X PBW ZN1		22.80 **	**	26.34 **	30.33 **	**	41.86 **	**	75.52 **	36.90 **	**	52.35 **	**	30.25 **
		1.01				31.85		63.13							35.70
14	PWB-725X PBW-343		5.26	12.63 *	8.3	11.72 *	**	31.85 **	**	63.13 **	27.24 *	17.49	24.54 *	26.53 *	6.47 **
		19.53 **		35.79		48.97		84.33						31.70	41.25
15	PWB-725X HD-3326		26.91 **	**	30.57 **	34.69 **	**	48.97 **	**	84.33 **	43.77 **	20.8	29.63 *	**	10.83 **
	CRDGEHNU1XPBWZN	10.48 *		28.29		74.03		74.03						37.67	47.65
16	1		19.90 **	**	23.36 **	27.26 **	**	40.65 **	**	74.03 **	35.74 **	15.85	35.51 **	**	15.85 **
		22.04 **		36.08		62.39		62.39						47.75	58.46
17	CRDGEHNU1XPBW343		27.18 **	**	30.84 **	34.98 **	**	31.24 **	**	62.39 **	26.66 *	24.33 *	45.43 **	**	24.33 *
	CRDGEHNU1XHD-	14.10 **		29.62		55.48		69.40						44.69	55.19
18	3326		21.14 **	**	24.64 **	28.57 **	**	36.91 **	**	69.40 **	32.13 **	21.76 *	42.43 **	**	21.76 *
		11.09 *		29.00		32.48		69.85				32.18		51.46	62.45
19	PBW-550X PBW ZN1		20.57 **	**	24.04 **	27.96 **	**	37.27 **	**	69.85 **	32.48 **	**	49.09 **	**	27.46 **
		13.62 *		26.68		32.13		69.40				44.33		55.44	66.71
20	PBW-550X PBW-343		18.40 **	**	21.81 **	25.66 **	**	36.91 **	**	69.40 **	32.13 **	**	53.00 **	**	30.80 **
		11.67 *		26.86		27.94		64.03				45.26		58.36	69.84
21	PBW-550X HD-3326		18.56 **	**	21.98 **	25.83 **	**	32.57 **	**	64.03 **	27.94 **	**	55.87 **	**	33.26 **
		17.70 **		36.69		74.48		74.48						37.27	47.23
22	PBW-677XPBW ZN1		27.75 **	**	31.43 **	35.58 **	**	41.01 **	**	74.48 **	36.09 **	19.79	35.12 **	**	15.51 **
		17.06 **		30.53		73.13		73.13						37.27	47.23
23	PBW-677XPBW-343		21.99 **	**	25.51 **	29.47 **	**	39.93 **	**	73.13 **	35.04 **	27.46 *	35.12 **	**	15.51 **
		12.95 *		28.31		46.30		59.40						32.49	42.11
24	PBW-677XPBW-343		19.92 **	**	23.38 **	27.28 **	**	28.83 *	**	59.40 **	24.33 *	21.53 *	30.42 **	**	11.5 **

		8.84		26.39		49.19		78.36				37.67		47.65
25	PBW-822X PBW ZN1	18.12 **	**	21.53 **	25.37 **	**	44.15 **	**	78.36 **	39.12 **	20.14	35.51 **	**	15.85 **
		8.16		21.67		59.18		90.30			34.11		44.43	54.91
26	PBW-822X PBW-343	13.71 *	**	16.99 **	20.69 **	**	53.80 **	**	90.30 **	48.43 **	**	42.17 **	**	21.54 *
		16.47 **		32.31				38.96			43.80		56.76	68.14
27	PBW-822X HD-3326	23.66 **	**	27.23 **	31.24 **	16.23	12.3	**	38.96 **	8.38	**	54.31 **	**	31.92 **
		14.09 **		32.49		59.05		88.96					33.82	43.53
28	HD-3117X PBW ZN1	23.83 **	**	27.40 **	31.42 **	**	52.71 **	**	88.96 **	47.38 **	14.27	31.72 **	**	12.61 **
		10.34 *		25.37				45.37					35.81	45.66
29	HD-3117X PBW-343	17.17 **	**	20.54 **	24.35 **	22.36	17.49	**	45.37 **	13.39	15.97	33.68 **	**	14.29 **
		16.74 **		32.64		37.31		63.13			31.82		54.38	65.58
30	HD-3117X HD-3326	23.96 **	**	27.54 **	31.57 **	**	31.85 **	**	63.13 **	27.24 *	**	51.96 **	**	29.91 **
		4.96		22.34		61.56		91.94					44.69	55.19
31	DBW-173X PBW ZN1	14.34 **	**	17.63 **	21.35 **	**	55.13 **	**	91.94 **	49.71 **	26.27 *	42.43 **	**	21.76 *
		13.38 **		32.16				52.09					33.82	43.53
32	DBW-173X PBW-343	23.51 **	**	27.07 **	31.09 **	28.02 *	22.92 *	**	52.09 **	18.63	24.26 *	31.72 **	**	12.61 **
		13.34 **		32.11		37.69		63.58						
33	DBW-173X HD-3326	23.47 **	**	27.03 **	31.04 **	**	32.21 **	**	63.58 **	27.59 *	12.04	20.23	22.15	2.79
		9.37		27.01		26.56		78.51			29.40		48.28	59.03
34	DH-3086X PBW ZN1	18.70 **	**	22.12 **	25.98 **	**	44.27 **	**	78.51 **	39.23 **	**	45.95 **	**	24.78 *
		23.25 **		38.69		26.46		78.36			34.24		44.56	55.05
35	DH-3086X PBW-343	29.62 **	**	33.36 **	37.57 **	**	44.15 **	**	78.36 **	39.12 **	**	42.30 **	**	21.65 *
		19.55 **		35.81		33.97		88.96			41.61		54.38	65.58
36	DH-3086X HD-3326	26.93 **	**	30.59 **	34.71 **	**	52.71 **	**	88.96 **	47.38 **	**	51.96 **	**	29.91 **
		14.49 **		32.95		61.41		63.58			49.77		71.62	84.07
37	DBW-222X PBW ZN1	24.26 **	**	27.84 **	31.88 **	**	32.21 **	**	63.58 **	27.59 *	**	68.93 **	**	44.42 **
		16.21 **		31.85		86.16		88.66			37.29		54.77	66.00
38	DBW-222X PBW-343	23.23 **	**	26.78 **	30.79 **	**	52.47 **	**	88.66 **	47.15 **	**	52.35 **	**	30.25 **

		10.27 *		25.27		63.42		78.06		30.47		47.08		57.75		
39	DBW-222X HD-3326		17.08 **	**	20.45 **	24.25 **	**	43.91 **	**	78.06 **	38.88 **	**	44.78 **	**	23.77 *	**
		10.49 *		28.31		58.17		57.46		32.29		51.59		62.59		
40	CSW-18XPBW ZN1		19.92 **	**	23.38 **	27.28 **	**	27.26 *	**	57.46 **	22.82 *	**	49.22 **	**	27.57 **	**
		24.79 **		39.14		73.55		69.40				32.10		41.68		
41	CSW-18XPBW-343		30.04 **	**	33.78 **	38.01 **	**	36.91 **	**	69.40 **	32.13 **	22.66 *	30.03 *	**	11.16	**
		18.11 **		34.17		68.36		83.43				43.19		56.10		67.43
42	CSW-18XHD-3326		25.40 **	**	29.01 **	33.09 **	**	48.25 **	**	83.43 **	43.07 **	**	53.66 **	**	31.36 **	**
		16.02 **		34.73		64.32		63.58				34.72		54.38		65.58
43	PBW-757X PBW ZN1		25.92 **	**	29.55 **	33.64 **	**	32.21 **	**	63.58 **	27.59 *	**	51.96 **	**	29.91 **	**
		19.79 **		33.56		69.42		65.37				44.46		55.57		66.86
44	PBW-757X PBW-343		24.83 **	**	28.43 **	32.48 **	**	33.66 **	**	65.37 **	28.99 **	**	53.13 **	**	30.92 **	**
		9.85		24.80		46.44		59.55				32.48		44.43		54.91
45	PBW-757X HD-3326		16.63 **	**	20.00 **	23.79 **	**	28.95 **	**	59.55 **	24.45 *	**	42.17 **	**	21.54 *	**

*** and ** for 5% and 1% Level of Significance, BP stand for better parent and SV stand for standard variety, SV1=HD 2967, SV2= DBW 187, SV3= NORMAN and SV4= BORLAUG 100

4. Conclusion

Analysis of variance (ANOVA) recorded significant differences ($p < 0.001$), for the best lines and testers with high general combining ability (GCA) were DH-3086, PBW-757, and PBW ZN1. The top line $\times$ tester crosses with high SCA for yield components characters like total grain yield per plant, harvest index, and spike length were PBW-677 $\times$ PBW-343, PBW-822 $\times$ PBW ZN1, and DH-3086 $\times$ PBW-343. These lines and testers show potential for improving traits controlled by additive genes and can be used for selecting superior parents, developing inbred lines, and ensuring broad adaptability in wheat for GCA. For SCA, the findings can help for identify superior crosses and leverage the mode of gene actions for wheat improvement. With regards to the total grain yield per plant across the genotypes and locations, the highest positive better parent heterosis recorded in PBW-822 $\times$ PBW ZN1, while the lowest and negative better parent heterosis was observed in WB-02 $\times$ HD-3326, with a value of -8.09. The highest standard heterosis was recorded in DH-3086 $\times$ PBW ZN1, while the lowest standard heterosis was seen in BHU-25 $\times$ PBW-343.

Authors' Contributions:

The authors contributed to the conception and design of the experiment. T. S. B. was responsible for the methodology and writing the original draft of the manuscript. S. P. S., R. M. K., and K. S., provided formal analysis, supervision, critical review, and approval of final version of the manuscript.

Funding:

The research was funded by the Deanship of Graduate Studies and Scientific Research at Qassim University, Buraidah, Saudi Arabia (QU-APC-9/1), the Tertiary Education Trust Fund (TETFUND), Nigeria, and ICAR-Indian Institute of Vegetable Research, varanasi India, for financial support.

Conflict of Interest:

The authors declare that there is no conflict of interest regarding this manuscript.

Authors' Declaration:

All authors affirm that this article is original and has not been submitted or published elsewhere.

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