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Heterosis for yield and yield contributing characters under terminal heat stress in wheat (*Triticum aestivum* L.)

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Abstract
To study the effect of terminal heat stress on yield and yield contributing characters, six females and eight males were crossed in a line x tester fashion to generate 48 crosses and were evaluated in a randomized block design (RBD) with three replications in the fields of Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola over two environments. Estimates of heterobeltiosis and standard heterosis were collected for various yield and yield contributing characters, including number of days to 50% flowering, number of days to maturity, grain yield, plant height, number of effective tillers/plant, number of grains/ear head, thousand grain weight, grain weight/plant, and harvest index.

Keywords: Wheat, heat stress, heterosis, late sown

Introduction
Elevated temperatures negatively affect wheat production, as each 1°C rise in ambient temperature can bring about a four percent reduction in grain weight (Acevedo *et al*., 1991) [1]. Heat stress has a detrimental impact on various growth and developmental phases of wheat, such as, heat stress during anthesis and grain-filling stages hastens maturity, resulting in a notable decrease in grain size and weight, leading to substantial yield losses. However, the degree of impact depends upon the duration of heat exposure and the growth stage at which high temperatures occur. Various yield-related traits could serve as effective indicators for assessing heat stress tolerance (Araus *et al*., 1998) [2].
Globally, approximately 7 Mha of cultivated wheat is under continual heat stress, whereas terminal heat stress adversely affects approximately 40 percent of irrigated wheat (Joshi *et al*., 2007) [3]. Rising temperatures can cause early flowering and shorter grain-filling periods, reducing crop duration, and ultimately lowering yields (Lamaoui *et al*., 2018) [4]. Moreover, the quality and productivity of wheat are also impaired to a considerable extent owing to abiotic stresses such as heat and drought (Liu *et al*., 2016) [5]. Grain production must be increased to feed the immensely growing world population, which could only be accomplished by developing high-yielding, climate-smart, abiotic stress-tolerant varieties. Therefore, there is a dire need to understand the mechanisms behind heat tolerance and develop genotypes that are either tolerant to terminal heat stress or mature early without yield losses and thus escape stress. The adverse impact of climate change on wheat production necessitates the urgent development of different adaptation strategies, and one promising option is to develop thermotolerant genotypes. Thus, it is crucial to focus on sustaining wheat yields by identifying tolerant genotypes and promoting breeding strategies and management practices that can enhance heat stress resilience and safeguard wheat production from the adverse effects of heat stress.
The magnitude of variability present in the germplasm as well as the extent of heritability of desired characters impacts the success of every crop improvement program (Kahrizi *et al*., 2010) [6]. Moreover, heterosis breeding provides a means to overcome yield barriers, and consequently, production can be enhanced through the development of new cultivars with wider genetic bases and better performance under various agroclimatic conditions. Exploitation of heterotic effects has been employed in self-pollinated crops, such as wheat, providing an option for commercial utilization of wheat (Singh *et al*., 2004) [7].

Materials and Methods

The experimental material consisted of 14 genotypes selected as parents based on the range of genetic diversity for different characters including yield and yield components. The parents, comprising of six females and eight males were crossed in a line × tester fashion to generate 48 crosses (F_1s). The 14 parents and 48 F_1s were evaluated in the field along with 2 checks, in a randomized block design (RBD) with three replications in the fields of Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth under late sown (LS) and timely sown (TS) conditions.

Crosses were carried out in line × tester fashion among the selected 6 females and 8 males. Hand emasculation followed by pollination was followed for crossing. Observations were taken for yield and yield contributing characters *viz*., number of days to 50% flowering, number of days to maturity, grain yield (kg/plot), plant height (cm), number of effective tillers/plant, number of grains/ear head, thousand grain weight (g), grain weight/plant (g), and harvest index (%).

Estimation of average heterosis (H_1), heterobeltiosis (H_2), and standard heterosis (H_3)

Heterobeltiosis and standard heterosis were calculated separately for individual environments using the following formulae.

A) Heterobeltiosis

It is estimated as percent increase or decrease over the superior or better parent (Fonseca and Patterson, 1968) [8] as follows.

Heterobeltiosis, (%)

$$H_2 = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{F_1}$ = Mean performance of F_1

$\overline{BP}$ = Mean performance of the better parent or superior parent of a cross

B) Standard heterosis

It is estimated as percent increase or decrease over standard commercial check (Meredith and Bridge, 1972) [9] as follows.

Standard heterosis, (%)

$$H_3 = \frac{\overline{F}_1 - \overline{CHECK}}{\overline{CHECK}} \times 100$$

where,

$\overline{F_1}$ = Mean performance of F_1

$\overline{CHECK}$ = Mean performance of the check variety

Results and Discussion

The estimates of average heterosis (H_1), heterobeltiosis (H_2), and standard heterosis (H_3) were computed for yield and yield contributing characters under each environment.

Estimation of heterobeltiosis

Heterobeltiosis serves as a valuable indicator for determining which combinations of parental lines have the greatest potential for generating transgressive segregants. The heterobeltiosis was studied under late sown (LS) and timely sown (TS) and is presented character-wise (Table 1).

1. Days to 50% flowering

In LS, for days to 50% flowering, 29 crosses exhibited significant heterobeltiosis in the desirable direction. The highest heterobeltiosis in the desirable direction was observed for the cross AKAW 5023 x DBW 31 (-17.32%) followed by AKAW-4210-6 x AKAW-2862-1 (-16.57%) and AKAW-4800 x AMBER (-14.44%). The range of heterobeltiosis for the character was from -17.32 percent to 10.00 percent. In TS, 7 crosses exhibited significant heterobeltiosis in the desirable direction. The highest heterobeltiosis in the desirable direction was observed for the cross AKW-770 x AKAW-3717 (-17.21%) followed by AKAW-5023 x AKAW-3717 (-10.23%) and HI-1418 x AKAW-3717 (-6.98%). The range of heterobeltiosis for the character was from -17.21 percent to 25.38 percent.

2. Days to maturity

In LS, AKAW 5023 x DBW 31 showed the maximum heterobeltiosis (-13.46%) in the desirable direction for days to maturity, with 35 of the 48 crosses showing significant and negative heterobeltiosis. The heterobeltiosis ranged between -13.46 percent and 5.50 percent. Other crosses with a higher magnitude of negative heterobeltiosis for the character were AKW-770 x DBW-31 (-11.07%) and AKAW-4800 x DBW-31 (-10.54%). AKW-770 x AKAW-3717 showed the maximum heterosis (-12.28%) in the desirable direction for days to maturity, in TS, with 22 of the 48 crosses showing significant and negative heterobeltiosis. The heterobeltiosis ranged between -12.28 percent and 16.54 percent. Other crosses with a higher magnitude of negative heterobeltiosis for the character were AKAW-5023 x AKAW-3717 (-9.56%) and HI-1418 x AKAW-3717 (-8.72%).

3. Grain yield/plot

In LS, Grain yield/plant displayed a range of -45.77 percent to 48.87 percent for heterobeltiosis. Positively significant heterobeltiosis was recorded for seven crosses and the cross HI 1418 x AKAW 4498 recorded the maximum magnitude of heterobeltiosis at 48.87 percent followed by AKAW-4800 x HI-1454 (37.46%) and HI-1418 x AKAW-3719 (11.60%). Grain yield/plant displayed a range of -37.44 percent to 35.33 percent for heterobeltiosis in TS. Positively significant heterobeltiosis was recorded for 15 crosses and the cross AKAW 4800 x AKAW 4498 recorded the maximum magnitude of heterobeltiosis at 35.33 percent followed by AKAW-1071 x DBW-31 (35.06%) and AKAW-4800 x HI-1454 (33.35%).

4. Plant height

Among the 48 crosses, in LS, 17 showed significant heterobeltiosis in the negative direction for plant height, and the maximum was observed for the cross AKAW 1071 x HI 1454 (-23.32%) followed by AKAW-5023 x AKAW-2862-1 (-19.84%) and AKAW-4800 x AKAW-3719 (-18.18%). Heterobeltiosis for the character ranged from -23.32 percent to 23.40 percent. Among the 48 crosses, in TS, 38 showed significant heterobeltiosis in the negative direction for plant height, and the maximum was observed for the cross

AKAW 4210-6 x AKAW 2862-1 (-20.62%) followed by HI-1418 x AKAW-2862-1 (-20.39%) and AKAW-1071 x AKAW-2862-1 (-20.08%). Heterobeltiosis for the character ranged from -20.62 percent to 4.23 percent.

5. Effective tillers/plant

Effective tillers/plant displayed significant and positive heterobeltiosis for 11 crosses in LS, of which AKW 770 x AKAW 3719 (31.01%) recorded the highest value. Other crosses with better heterobeltiosis for the character were AKAW-1071 x DL-788-2 (26.79%) and AKW-770 x AMBER (21.57%). The range of heterobeltiosis for effective tillers/plant was between -49.09 percent and 31.01 percent. Effective tillers/plant displayed significant and positive heterobeltiosis for 10 crosses, in TS, of which AKW 770 x AKAW 4498 (54.46%) recorded the highest. Other crosses with better heterobeltiosis for the character were AKW-770 x AMBER (49.76%) and AKAW-5023 x AKAW-4498 (40.85%). The range of heterobeltiosis for effective tillers/plant was between -43.18 percent and 54.46 percent.

6. Grains/ear head

In LS, out of 48 crosses, 27 recorded significant heterobeltiosis in the desirable direction for grains/ear head. The heterobeltiosis value varied between -20.12 percent and 31.26 percent. The cross AKAW 4210-6 x AKAW 3717 recorded the highest heterobeltiosis (31.26%) followed by AKAW-4800 x AKAW-4498 (30.86%) and AKAW-4800 x AMBER (21.02%). Out of 48 crosses, in TS, 27 recorded significant heterobeltiosis in the desirable direction for grains/ear head. The heterobeltiosis value varied between -37.09 percent and 50.55 percent. The cross AKAW 4800 x HI 1454 (50.55%) recorded the highest heterobeltiosis followed by AKAW-4800 x AKAW-3719 (48.03%) and AKAW-4800 x AMBER (47.67%).

7. Thousand grain weight

For thousand grain weight, in LS, the highest heterobeltiosis was observed in AKAW 4210-6 x AKAW 3717 (62.39%) followed by AKAW-4210-6 x AKAW-2862-1 (53.20%) and AKAW-1071 x AKAW-2862-1 (49.70%). The magnitude of heterobeltiosis displayed a range between -45.93 percent and 62.39 percent. For thousand grain weight, in TS, the highest heterobeltiosis was observed in HI 1418 x AKAW 2862-1 (15.57%) followed by AKAW-4210-6 x AKAW-3717 (12.80%) and AKAW-5023 x AKAW-4498 (8.18%). Seven crosses displayed positively significant heterobeltiosis. The magnitude of heterobeltiosis displayed a range between -24.50 percent and 15.57 percent.

8. Grain weight/plant

In LS, significant heterobeltiosis in the positive direction was displayed in 14 crosses for grain weight/plant. A range from -52.49 percent to 87.02 percent was observed for heterobeltiosis for the character. AKAW-5023 x DBW-31 exhibited the highest magnitude of heterobeltiosis (87.02%). Other better performing crosses with high heterobeltiosis in the positive direction were AKW-770 x AKAW-4498 (74.49%) and AKAW-4210-6 x AKAW-2862-1 (69.50%). Significant heterobeltiosis in the positive direction was displayed in eight crosses for grain weight/plant in TS. A range from -51.92 percent to 31.43 percent was observed for heterobeltiosis for the character. AKAW 1071 x AKAW 4498 (31.43%) exhibited the highest magnitude of heterobeltiosis. Other better performing crosses with high heterobeltiosis in the positive direction were AKAW-5023 x AKAW-4498 (25.73%) and AKAW-5023 x AKAW-3719 (25.71%).

9. Harvest index

In LS, among the crosses, 10 showed positive and significant heterobeltiosis for harvest index. The highest magnitude of heterobeltiosis was recorded in the cross AKAW 1071 x AKAW 3717 (35.65%) followed by AKAW-1071 x AMBER (29.13%) and HI-1418 x AKAW-3719 (28.83%). The heterobeltiosis values ranged between -40.52 percent and 35.65 percent. Among the crosses, in TS, 18 showed positive and significant heterobeltiosis for harvest index. The highest magnitude of heterobeltiosis was recorded in the cross AKAW 4800 x AKAW 3719 (63.89%) followed by AKAW-4210-6 x DL-788-2 (31.57%) and AKAW-4210-6 x HI-1454 (31.21%). The heterobeltiosis values ranged between -39.94 percent and 63.89 percent.

Estimation of standard heterosis

The standard heterosis for the characters was studied under late sown (LS) and timely sown (TS) and is presented character-wise (Table 2)

1. Days to 50% flowering

Of the 48 crosses studied, in LS, 21 exhibited significant standard heterosis in the desirable direction for days to 50% flowering. Standard heterosis over the best check (PDKV SARDAR) ranged between -12.94 percent and 10.59 percent and the highest standard heterosis over the best check in the desirable direction was observed for the cross AKAW 5023 x DBW 31 and AKAW-4210-6 x AKAW-4498 (-12.94%) followed by AKW-770 x DL-788-2 and AKW-770 x HI-1454 (-12.35%). Of the 48 crosses studied, in TS, 19 exhibited significant standard heterosis in the desirable direction for days to 50% flowering. Standard heterosis over the best check (PDKV SARDAR) ranged between -15.24 percent and 18.1 percent and the highest standard heterosis over the best check in the desirable direction was observed for the cross AKW 770 x AKAW 3717 (-15.24%) followed by AKW-770 x AKAW-4498 (-10.00%) and AKAW-5023 x DL-788-2 (-8.57%).

2. Days to maturity

For days to maturity, in LS,12 crosses showed significant and negative standard heterosis over the best check ((PDKV SARDAR), and the cross AKAW 4210-6 x AKAW 4498 displayed the maximum heterosis -4.4 percent in the desirable direction followed by AKAW-5023 x DBW-31 (-4.26%), and AKW-770 x HI-1454 (-4.04%). The range for standard heterosis over the best check varied from - 4.4 percent to 11.45 percent.For days to maturity, in TS, 19 crosses showed significant and negative standard heterosis over the best check (PDKV SARDAR), and the cross AKW 770 x AKAW 3717 displayed the maximum heterosis of -7.02 percent in the desirable direction followed by AKW-770 x AKAW-4498 (-6.90%), and AKAW-5023 x AKAW-4498 (-4.26%). The range for standard heterosis over the best check varied from -7.02 percent to 17.10 percent.

3. Grain yield/plot

Grain yield/plant displayed positively significant standard heterosis over the best check ((PDKV SARDAR) for 14 crosses in LS, and AKAW 4800 x HI 1454 recorded the maximum at 38.51 percent followed by AKAW-4210-6 x AMBER (31.97%), and HI-1418 x AKAW-4498 (29.69%). The value of standard heterosis over the best check for the character ranged from -32.05 percent to 38.51 percent.Grain yield/plant displayed positively significant standard heterosis over the best check (PDKV SARDAR) for 25 crosses in TS, and AKAW 1071 x DBW 31 recorded the maximum at 47.24 percent followed by AKAW-4210-6 x AKAW-3719 (47.04%), and AKAW-4800 x AKAW-4498 (46.69%). The value of standard heterosis over the best check for the character ranged from -34.58 percent to 47.24 percent.

4. Plant height

For plant height, in LS, among the 48 crosses, 22 showed standard heterosis over the best check (MACS 6478) in the negative direction, and the maximum was observed for the cross AKAW 1071 x HI 1454 (-24.6%) followed by AKAW 5023 x AKAW 3719 (-23.89%), and AKAW 5023 x AKAW 2862-1 (-19.35%). The standard heterosis range over the best character check was between -24.6 percent and 16.43 percent.For plant height, among the 48 crosses, in TS, two showed standard heterosis over the best check (PDKV SARDAR) in the negative direction, and the maximum was observed for the cross AKAW 4210-6 x DBW 31 (-1.05%). The range of standard heterosis over the best check for the character was between -1.05 percent and 16.49 percent.

5. Effective tillers/plant

The number of effective tillers/plant displayed significant and positive heterosis for three crosses in LS, and the value of standard heterosis over the best check (PDKV SARDAR) ranged between -49.33 percent and 30.4 percent. The cross AKW 770 x AKAW 3719 (30.40%) recorded the highest positive standard heterosis over the best check followed by AKAW-1071 x DL-788-2 (17.17%), and AKAW-1071 x HI-1454 (9.58%).Effective tillers/plant displayed significant and positive heterosis for four crosses in TS, and the value of standard heterosis over the best check (MACS 6478) ranged between -57.5 percent and 23.84 percent. The cross AKW 770 x AMBER (23.84%) recorded the highest positive standard heterosis over the best check followed by HI-1418 x AKAW-4498 (17.36%), and AKW-770 x AKAW-4498 (11.27%).

6. Grains/ear head

Standard heterosis over the best check (PDKV SARDAR) in LS for grains/ear head ranged from -24.17 percent to 13.83 percent. Among the crosses, 10 recorded significant standard heterosis over the best check in the desirable direction for grains/ear head, and the highest was observed in AKAW 4210-6 x AKAW 3717 (13.83%), followed by AKW-770 x AKAW-4498 (12.31%) and AKAW-4800 x AKAW-4498 (11.42%).Standard heterosis over the best check (MACS 6478) in TS for grains/ear head ranged from -41.99 percent and 22.88 percent. Among the crosses, 15 recorded significant standard heterosis over the best check in the desirable direction for grains/ear head, and the highest was observed in AKAW 4800 x HI 1454 (22.88%), followed by AKAW-1071 x AKAW-3717 (22.53%) and AKAW-4210-6 x AKAW-4498 (22.53%).

7. Thousand grain weight

Five of the 48 crosses in LS showed significant and positive standard heterosis over the best check (MACS 6478) for thousand grain weight, which ranged between -45.68 percent and 24.74 percent. The highest standard heterosis over the best check in the desired direction was recorded in the cross AKAW 4210-6 x AKAW 3717 (24.74%) followed by AKAW-4800 x AKAW-3719 (11.70%) and HI-1418 x AKAW-4498 (9.29%). Fourteen of the 48 crosses in TS showed significant and positive standard heterosis over the best check (PDKV SARDAR) for thousand grain weight, which ranged between -24.56 percent and 22.31 percent. The highest standard heterosis over the best check in the desired direction was recorded in the cross HI 1418 x AKAW 2862-1 (22.31%) followed by AKAW-4210-6 x AKAW-3717 (19.23%) and AKAW-5023 x AKAW-4498 (17.93%).

8. Grain weight/plant

For grain weight/plant, in LS, positively significant standard heterosis over the best check (PDKV SARDAR) was displayed in five crosses. The standard heterosis over the best check values for the character varied from -65.52 percent to 40.46 percent and the highest was recorded for AKW 770 x AKAW 4498 (40.46%), followed by AKAW-1071 x AKAW-3717 (37.20%) and AKAW-4800 x DBW-31 (31.64%). For grain weight/plant, in TS, positively significant standard heterosis over the best check (MACS 6478) was displayed in nine crosses. The standard heterosis over the best check values for the character varied from -35.54 percent to 52.99 percent and the highest was recorded for AKAW 1071 x AKAW 4498 (52.99%), followed by AKW-770 x AKAW-4498 (49.47%) and AKAW-4210-6 x AKAW-2862-1 (47.13%).

9. Harvest index

In LS, among the crosses, six showed positive and significant standard heterosis over the best check (PDKV SARDAR) for harvest index, and the highest was recorded in the cross AKAW 4210-6 x AKAW 4498 (15.56%) followed by AKAW-1071 x AKAW-3717 (15.41%) and AKAW-4210-6 x DBW-31 (14.31%). The range of standard heterosis over the best check for the character was -39.74 percent to 15.56 percent.Among the crosses, in TS, six showed positive and significant standard heterosis over the best check (MACS 6478) for harvest index, and the highest was recorded in the cross AKAW 4800 x AKAW 3719 (18.00%) followed by AKAW-4210-6 x DL-788-2 (15.71%) and AKAW-4210-6 x HI-1454 (15.40%). The range of standard heterosis over the best check for the character was -40.08 percent to 18.00 percent.

Similar results under terminal heat stress conditions regarding the estimates of heterosis for yield and yield contributing characters in wheat have been reported by Borghi and Perenzin (1994) [10], Saini *et al.*, (2006) [11], Ribadia *et al.*, (2007) [12], Ashutosh *et al.*, (2011) [13] and Beche *et al.*, (2013) [14]. For characters such as days to 50% flowering and days to maturity, negative estimates of heterosis are desirable. Similar negative values for the traits have been reported by Sadeque *et al*. (1991) [15] while Palve *et al*. (1987) [16] reported results in contradiction to the present study for both traits. Both positive and negative values of heterosis for days to maturity have been reported by Masood *et al*. (2005) [17]. Yadav and Narshinghani (2000)

[18] and Prakash and Joshi (2003) [19] also observed significant negative heterosis followed by negative inbreeding depression for days to heading and days to maturity in wheat. Similar results were also reported by Sharma and Tandon (1998) [20], Singh (2003) [21], and Jahanzeband Khaliq (2004) [22].

Significant positive heterosis is important in selecting crosses for yield and yield related characters in breeding programmes. In the case of grain yield per plant, Borghi *et al.* (1986) [23] found a six percent increase in average heterosis over the mid parent. However average heterosis of 41 percent and 72 percent was observed respectively by Zehr *et al.* (1997) [24] and Solomon *et al.* (2006) [25]. In agreement with the study, positive estimates of heterosis for grain yield were also reported by Singh *et al.* (2004) [26] and Gooding and Kindred (2005) [27]. However, negative heterosis for grain yield has been reported by Farooq and Khaliq (2004) [28]. These findings are in confirmation with Ijaz *et al.*, (2002) [29]; Hussain *et al.* (2004) [30]; Sharma *et al.* (2004) [31].

Table 1: Heterobeltiosis (%) for different characters under each environment

S.N.	Crosses	Days to 50% flowering		Days to maturity		Grain yield/plot	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	-6.08**	6.25**	-4.14**	3.86**	-18.04**	-15.29**
2	AKAW 4800 x AKAW 3717	-10.56**	7.14**	-7.57**	5.13**	-37.18**	-6.77**
3	AKAW 4800 x AKAW 4498	4.44**	8.04**	2.98**	5.4**	-22.53**	35.33**
4	AKAW 4800 x DL 788-2	-7.22**	10.71**	-5.22**	6.12**	-15.02**	-2.07
5	AKAW 4800 x HI 1454	-1.11	-2.23*	-1.63**	-0.17	37.46**	33.35**
6	AKAW 4800 x AKAW 3719	-2.22**	-2.68**	-1.76**	-1.71**	-28.13**	10.64**
7	AKAW 4800 x DBW 31	-12.22**	8.04**	-10.54**	4.91**	-32.13**	2.59*
8	AKAW 4800 x AMBER	-14.44**	2.23*	-9.69**	-1.82**	-13.97**	24.92**
9	AKAW 1071 x AKAW 2862-1	0.55	7.91**	-1.21**	4.95**	-37.57**	-31.39**
10	AKAW 1071 x AKAW 3717	0.56	-4.19**	-2.68**	-5.77**	-39.27**	3.03**
11	AKAW 1071 x AKAW 4498	-10.8**	10.05**	-9.72**	1.94**	-20.95**	17.06**
12	AKAW 1071 x DL 788-2	1.7*	6.22**	-1.94**	-1.25**	-2.47	18.4**
13	AKAW 1071 x HI 1454	-4.55**	3.83**	-6.17**	-2.22**	-4.41**	-15.69**
14	AKAW 1071 x AKAW 3719	-6.82**	7.18**	-7.44**	5.64**	-9.94**	5.57**
15	AKAW 1071 x DBW 31	2.23**	4.78**	-1.06**	-2.39**	-11.4**	35.06**
16	AKAW 1071 x AMBER	3.41**	3.83**	-1.41**	-2.22**	-11.07**	29.58**
17	AKAW 5023 x AKAW 2862-1	-3.31**	-6.05**	-2.31**	-8.5**	-43.37**	-6.32**
18	AKAW 5023 x AKAW 3717	2.26**	-10.23**	-0.14	-9.56**	-38.21**	-23.19**
19	AKAW 5023 x AKAW 4498	-9.04**	1.57	-5.1**	-4.03**	-18.6**	-16.06**
20	AKAW 5023 x DL 788-2	-8.43**	0.52	-4.39**	-3.25**	-15.02**	-37.44**
21	AKAW 5023 x HI 1454	-3.01**	6.81**	-1.08**	-0.96*	-14.32**	-21.16**
22	AKAW 5023 x AKAW 3719	-3.01**	0.99	-1.65**	-1.14**	-5.85**	-0.68
23	AKAW 5023 x DBW 31	-17.32**	3.14**	-13.46**	-3.49**	-28.46**	4.9**
24	AKAW 5023 x AMBER	-1.7*	-0.51	0	-4.24**	-41.27**	-10.82**
25	AKW 770 x AKAW 2862-1	-6.08**	-4.65**	-4.21**	-7.2**	-45.77**	-28.49**
26	AKW 770 x AKAW 3717	-9.04**	-17.21**	-7.7**	-12.28**	-7.32**	-23.83**
27	AKW 770 x AKAW 4498	9.15**	1.61	5.5**	2.44**	-16.86**	-31.05**
28	AKW 770 x DL 788-2	-9.15**	12.21**	-5.13**	6.27**	0.04	-28.32**
29	AKW 770 x HI 1454	-9.15**	16.86**	-5.42**	7.13**	-10.03**	-28.05**
30	AKW 770 x AKAW 3719	-1.22	0.49	-0.65**	0	-5.95**	-17.03**
31	AKW 770 x DBW 31	-12.85**	13.83**	-11.07**	2.93**	-3.74**	-11.81**
32	AKW 770 x AMBER	-2.27**	25.38**	2.17**	16.54**	-16.01**	2.86*
33	HI 1418 x AKAW 2862-1	-4.97**	0.47	-2.72**	-4.11**	-40.1**	-34.47**
34	HI 1418 x AKAW 3717	-7.34**	-6.98**	-6.22**	-8.72**	4.58**	-14.97**
35	HI 1418 x AKAW 4498	-6.98**	12.37**	-7.54**	7.85**	48.87**	-4.69**
36	HI 1418 x DL 788-2	5.23**	23.3**	0.07	11.16**	9.09**	-3.1**
37	HI 1418 x HI 1454	-9.88**	21.02**	-9.16**	10.51**	-6.42**	-25.11**
38	HI 1418 x AKAW 3719	5.81**	0	0.27	1.72**	11.6**	-5.9**
39	HI 1418 x DBW 31	0.56	7.45**	-2.45**	-0.91*	-26.34**	-22.99**
40	HI 1418 x AMBER	2.84**	5.58**	-0.54*	-1.19**	-41.69**	-10.21**
41	AKAW 4210-6 x AKAW 2862-1	-16.57**	-0.47	-10.54**	-5.06**	-39.7**	-5.04**
42	AKAW 4210-6 x AKAW 3717	6.21**	0	1.89**	-3.51**	10.39**	20.95**
43	AKAW 4210-6 x AKAW 4498	-12.94**	16.13**	-7.78**	2.46**	-23.16**	-4.35**
44	AKAW 4210-6 x DL 788-2	-5.29**	11.35**	-3.4**	1.6**	1.7	-4.38**
45	AKAW 4210-6 x HI 1454	10**	4.32**	3.82**	-1.78**	-19.05**	10.8**
46	AKAW 4210-6 x AKAW 3719	2.94**	0.49	1.77**	0.68	-30.3**	29.28**
47	AKAW 4210-6 x DBW 31	4.47**	10.11**	-0.4	0.43	-32.85**	1.5
48	AKAW 4210-6 x AMBER	-5.11**	6.6**	-2.24**	-0.66	8.48**	10.61**
	SE(m) ±	0.40	0.67	0.22	0.43	1.70	2.31
	CD (5%)	0.78	1.33	0.43	0.85	3.37	4.57
	CD (1%)	1.04	1.76	0.56	1.12	4.45	6.04

S.N.	CROSSES	Plant height		Effective tillers/plant		Grains/earhead	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	0.05**	-14.77**	-19.66**	-43.18**	13.74**	28.15**
2	AKAW 4800 x AKAW 3717	-5.38**	-7.09**	-5.49	-14.51**	9.88**	25.4**
3	AKAW 4800 x AKAW 4498	5.91**	-12.18**	-10.85**	4.55	30.86**	25.81**
4	AKAW 4800 x DL 788-2	6.6**	-4.8**	-9.46**	-20.28**	14.32**	43.01**
5	AKAW 4800 x HI 1454	-11.83**	-5.21**	-23.44**	-4.02	-9**	50.55**
6	AKAW 4800 x AKAW 3719	-18.18**	2.56**	-49.09**	-39.86**	2.51**	48.03**
7	AKAW 4800 x DBW 31	-3.23**	-3.73**	13.83**	-2.94	18.82**	35.11**
8	AKAW 4800 x AMBER	2.49**	-2.41**	18.44**	-6.82**	21.02**	47.67**
9	AKAW 1071 x AKAW 2862-1	-2.56**	-20.08**	-45.42**	-18.49**	-2.54**	10.35**
10	AKAW 1071 x AKAW 3717	23.4**	2.1**	11.69**	-8.39**	7.9**	21.61**
11	AKAW 1071 x AKAW 4498	-5.6**	-11.68**	15.44**	11.27**	-11.25**	10.35**
12	AKAW 1071 x DL 788-2	9.35**	-3.24**	26.79**	38.43**	7.16**	2.8*
13	AKAW 1071 x HI 1454	-23.32**	-0.98	11.91**	-29.82**	-18.71**	-9.86**
14	AKAW 1071 x AKAW 3719	6.57**	2.79**	-17.2**	-9.69**	0.4	-1.07
15	AKAW 1071 x DBW 31	5.77	-7.55**	-5.38	-42.21**	3.59**	19.51**
16	AKAW 1071 x AMBER	1.36**	-6**	-6.67*	20.31**	2.89**	0.46
17	AKAW 5023 x AKAW 2862-1	-19.84**	-15.88**	-28.91**	-25.79**	-13.48**	6.08**
18	AKAW 5023 x AKAW 3717	9.23**	-6.72**	-8.71**	-25.76**	1.89**	-23.02**
19	AKAW 5023 x AKAW 4498	2.25**	-12.29**	-0.51	40.85**	8.02**	6.07**
20	AKAW 5023 x DL 788-2	4.49**	-0.92	-10.17**	-5.62	-5.32**	9.36**
21	AKAW 5023 x HI 1454	-2.82**	-1.58**	-8.41**	-42.35**	-20.12**	41.27**
22	AKAW 5023 x AKAW 3719	-15.5**	-4.12**	4.18	-41.32**	-4.19**	35.95**
23	AKAW 5023 x DBW 31	21.54	4.23**	-1.49	-32.18**	12.48**	-20.08**
24	AKAW 5023 x AMBER	-1.15	-3.68**	14.26**	-42.06**	4.18**	26.98**
25	AKW 770 x AKAW 2862-1	1.35	-19.23**	-9.83**	-12.99**	-1.1**	-16.87**
26	AKW 770 x AKAW 3717	-1.53**	-2.46**	-19.26**	7.17**	0.8*	13.97**
27	AKW 770 x AKAW 4498	10.09**	-11.32**	-11.56**	54.46**	10.87**	6.07**
28	AKW 770 x DL 788-2	-7.34**	1.58**	-28.54**	-19.85**	-2.38**	37.56**
29	AKW 770 x HI 1454	-3.16	-3.31**	-18.86**	5.2	-0.15	5.29**
30	AKW 770 x AKAW 3719	1.22**	-2.97**	31.01**	-26.02**	4.58**	-15.16**
31	AKW 770 x DBW 31	-15.19**	-1.71**	16.24**	-39.45**	-1.9**	-2.99*
32	AKW 770 x AMBER	-6.01**	-7.57**	21.57**	49.76**	-7.97**	-1.09
33	HI 1418 x AKAW 2862-1	-11.17**	-20.39**	-24.15**	15.45**	7.11**	-30.83**
34	HI 1418 x AKAW 3717	-6.62**	-10.8**	-9.21**	-28.32**	-6.57**	-21.01**
35	HI 1418 x AKAW 4498	3.51**	-12.87**	-19.56**	23.27**	14.81**	-33.55**
36	HI 1418 x DL 788-2	-6.52	-3.14**	-17.38**	4.09	-18.98**	-0.56
37	HI 1418 x HI 1454	-0.5**	-1.87**	-2.03	-15.63**	-3.85**	-3.92**
38	HI 1418 x AKAW 3719	2.41	1.4**	-11.3**	-41.8**	10.46**	17.09**
39	HI 1418 x DBW 31	1.05**	-3.59**	8.89**	-7.44**	8.88**	-19.76**
40	HI 1418 x AMBER	3.61**	-6.27**	2.83	-26.29**	10.7**	-1.58
41	AKAW 4210-6 x AKAW 2862-1	2.51**	-20.62**	-32.65**	-16.28**	17.08**	-4.91**
42	AKAW 4210-6 x AKAW 3717	10.17**	-9.74**	-17.49**	-42.07**	31.26**	7.59**
43	AKAW 4210-6 x AKAW 4498	4.1**	-10.32**	5.5*	-13.38**	7.97**	32.87**
44	AKAW 4210-6 x DL 788-2	5.35**	-1.44**	1.45	-4.9	-3.93**	3.05*
45	AKAW 4210-6 x HI 1454	-7.64**	1.51**	-11.72**	-1.32	-15.47**	5.89**
46	AKAW 4210-6 x AKAW 3719	-6.28	-2.97**	-4.42	8.59**	-9.35**	-37.09**
47	AKAW 4210-6 x DBW 31	-1.45*	-6.3**	-12.37**	-32.12**	5.37**	-29.12**
48	AKAW 4210-6 x AMBER	1.82	-7.55**	-2.23	-21**	6.12**	-23.46**
	SE(m) ±	0.54	0.40	0.18	0.24	0.12	0.57
	CD (5%)	1.06	0.79	0.36	0.48	0.24	1.13
	CD (1%)	1.41	1.04	0.47	0.64	0.32	1.50

S.N.	CROSSES	Thousand grain weight		Grain weight/plant		Harvest index	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	-17.65**	-3.12	-5.94	-12.52**	-2.24	8.39**
2	AKAW 4800 x AKAW 3717	-2.5	-12.22**	-14.7**	-0.5	-0.89	-9.82**
3	AKAW 4800 x AKAW 4498	-13.68**	-24.5**	26.73**	4.98	-12.11**	28.96**
4	AKAW 4800 x DL 788-2	-16.88**	-22.75**	28.25**	-16.28**	-8.16	24.41**
5	AKAW 4800 x HI 1454	-34.11**	-18.02**	-52.49**	18.41**	-1.39	22.91**
6	AKAW 4800 x AKAW 3719	8.69**	2.38	-44.62**	3.85	-27.51**	63.89**
7	AKAW 4800 x DBW 31	-19.12**	-21.36**	12.55*	-18.6**	-11.66**	-6.62**
8	AKAW 4800 x AMBER	-12.9**	-9.81**	25.65**	4.02	-0.76	0.49
9	AKAW 1071 x AKAW 2862-1	49.7**	-9.63**	-9.04	-27.28**	-24.72**	-30.49**
10	AKAW 1071 x AKAW 3717	-16.86**	1.2	68.32**	16.98**	35.65**	-1.91
11	AKAW 1071 x AKAW 4498	-31.49**	-6.31**	-18.57*	31.43**	-23.72**	7.92**
12	AKAW 1071 x DL 788-2	-5.29	-11.7**	25.4**	15.21**	-27.37**	-17.67**
13	AKAW 1071 x HI 1454	-19.52**	4.48	-35.7**	-18.8**	-4.54	9.23**
14	AKAW 1071 x AKAW 3719	17.23**	-5.23*	44.2**	11.04*	17.02**	15.47**
15	AKAW 1071 x DBW 31	-1.85	-7.49**	28.16**	0.56	-7.51	9.03**
16	AKAW 1071 x AMBER	13.56**	-0.97	33.05**	-1.06	29.13**	15.7**
17	AKAW 5023 x AKAW 2862-1	-28.02**	0.67	-30.15**	-7.96	10**	-4.22
18	AKAW 5023 x AKAW 3717	-28.14**	-4.11	63.62**	-47.96**	4.12	-27.01**
19	AKAW 5023 x AKAW 4498	-11.78**	8.18**	0.68	25.73**	-29.37**	0.85
20	AKAW 5023 x DL 788-2	-14.07**	-16.4**	-12.22	-3.93	-21.05**	16.01**
21	AKAW 5023 x HI 1454	-33.38**	-3.74	-30.93**	11.38	-15.81**	-14.16**
22	AKAW 5023 x AKAW 3719	-5.92	-5.95*	-36.44**	25.71**	-40.52**	-3.04
23	AKAW 5023 x DBW 31	21.65**	-23.93**	87.02**	-40.15**	-18.37**	-21.62**
24	AKAW 5023 x AMBER	-14.6**	-16.74**	15.75	-4.79	4.88	-19.6**
25	AKW 770 x AKAW 2862-1	-23.24**	-13.35**	9.9	-51.92**	-0.3	-13.01**
26	AKW 770 x AKAW 3717	-1.45	-2.75	-6.77	-41.21**	-10.93**	9.12**
27	AKW 770 x AKAW 4498	2.23	-12.16**	74.49**	-17.34*	-4.41	4.76
28	AKW 770 x DL 788-2	-6.03*	-19.18**	-22.93**	-28.06**	6.86	-16.32**
29	AKW 770 x HI 1454	-1.45	-9.53**	-7.89	-29.2**	-3.54	-23.23**
30	AKW 770 x AKAW 3719	-42.66**	-2.78	29.8**	-29.93**	-24.01**	11.22**
31	AKW 770 x DBW 31	-45.93**	-12.16**	-37.02**	-33.34**	-0.83	-39.94**
32	AKW 770 x AMBER	-33.13**	-11.01**	-47.98**	-35.31**	-11.5**	-12.01**
33	HI 1418 x AKAW 2862-1	-22.94**	15.57**	-34.66**	-31.78**	6.11	-30.82**
34	HI 1418 x AKAW 3717	-17.13**	-2.94	-25.48**	-14.37**	-9.19*	-32.95**
35	HI 1418 x AKAW 4498	15.51**	-0.16	58.36**	-29.75**	9.79*	3.84
36	HI 1418 x DL 788-2	-35.74**	-10.42**	-26.62**	15.62**	13.22**	-30.29**
37	HI 1418 x HI 1454	-35.72**	-6.74**	-7.21	-28.06**	-5.67	1.07
38	HI 1418 x AKAW 3719	-6.95**	6.57*	15.66*	-4.16	28.83**	2.92
39	HI 1418 x DBW 31	-17.55**	-0.55	11.42	-8.4	19.52**	-0.53
40	HI 1418 x AMBER	-5.02*	-19.91**	41.55**	-8.75	-4.34	-11.71**
41	AKAW 4210-6 x AKAW 2862-1	53.2**	1.87	69.5**	-20.28**	-1.4	14.95**
42	AKAW 4210-6 x AKAW 3717	62.39**	12.8**	64.33**	6.56	-27.68**	17.58**
43	AKAW 4210-6 x AKAW 4498	-19.47**	-10.64**	-4.83	21.9**	11.6**	10.72**
44	AKAW 4210-6 x DL 788-2	3.31	7.35**	21.53**	11.7*	-10.91**	31.57**
45	AKAW 4210-6 x HI 1454	-33.31**	6*	-14.58*	-6.13	-19.82**	31.21**
46	AKAW 4210-6 x AKAW 3719	14.71**	-2.75	-48.99**	1.13	1.5	2.01
47	AKAW 4210-6 x DBW 31	14.03**	2.96	-18.58*	-26.5**	10.39**	-16.03**
48	AKAW 4210-6 x AMBER	49.2**	0.9	1.01	-42.64**	10.06**	-7.07**
	SE(m) ±	0.98	1.11	0.49	0.56	1.66	1.13
	CD (5%)	1.93	2.19	0.98	1.12	3.28	2.23
	CD (1%)	2.55	2.89	1.29	1.47	4.33	2.95

Table 2: Standard heterosis (%) for different characters under each environment

S.N.	Crosses	Days to 50% flowering		Days to maturity		Grain yield/plot	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	0	13.33**	3.74**	13.02**	3.59**	-6.76**
2	AKAW 4800 x AKAW 3717	-5.29**	14.29**	0.37	14.4**	-28.93**	8.84**
3	AKAW 4800 x AKAW 4498	10.59**	15.24**	11.45**	14.7**	-21.93**	46.69**
4	AKAW 4800 x DL 788-2	-1.76*	18.1**	2.57**	15.48**	-14.37**	6.15**
5	AKAW 4800 x HI 1454	4.71**	4.29**	6.46**	8.64**	38.51**	44.54**
6	AKAW 4800 x AKAW 3719	3.53**	3.81**	6.31**	6.96**	-23.64**	19.93**
7	AKAW 4800 x DBW 31	-7.06**	15.24**	-1.03**	14.16**	-31.6**	11.84**
8	AKAW 4800 x AMBER	-9.41**	9.05**	-2.27**	6.84**	4.66**	35.4**
9	AKAW 1071 x AKAW 2862-1	7.06**	10.48**	8.14**	11.88**	-21.1**	-24.49**
10	AKAW 1071 x AKAW 3717	4.71**	-1.9*	6.53**	-0.12	-31.31**	20.28**
11	AKAW 1071 x AKAW 4498	-7.65**	9.52**	-1.17**	7.26**	-31.13**	15.06**
12	AKAW 1071 x DL 788-2	5.29**	5.71**	7.34**	3.9**	-15.54**	25.65**
13	AKAW 1071 x HI 1454	-1.18	3.33**	2.71**	2.88**	-17.22**	-17.13**
14	AKAW 1071 x AKAW 3719	-3.53**	6.67**	1.32**	11.16**	-4.31**	3.77**
15	AKAW 1071 x DBW 31	7.65**	4.29**	9.46**	2.7**	-13.12**	47.24**
16	AKAW 1071 x AMBER	7.06**	3.33**	7.92**	2.88**	8.18**	30.22**
17	AKAW 5023 x AKAW 2862-1	2.94**	-3.81**	5.43**	-2.46**	-28.42**	3.11*
18	AKAW 5023 x AKAW 3717	6.47**	-8.1**	8.44**	-4.14**	-30.1**	-10.33**
19	AKAW 5023 x AKAW 4498	-11.18**	-7.62**	-3.15**	-4.26**	-29.08**	-19**
20	AKAW 5023 x DL 788-2	-10.59**	-8.57**	-2.42**	-3.48**	-32.05**	-33.61**
21	AKAW 5023 x HI 1454	-5.29**	-2.86**	0.95**	-1.2**	-31.55**	-34.58**
22	AKAW 5023 x AKAW 3719	-5.29**	-2.38*	0.37	-1.38**	6.21**	-5.13**
23	AKAW 5023 x DBW 31	-12.94**	-6.19**	-4.26**	-3.72**	-29.86**	14.37**
24	AKAW 5023 x AMBER	1.76*	-6.67**	4.92**	-3.78**	-28.55**	-10.38**
25	AKW 770 x AKAW 2862-1	0	-2.38*	3.37**	-1.08**	-31.45**	-21.29**
26	AKW 770 x AKAW 3717	-5.29**	-15.24**	0.22	-7.02**	4.84**	-11.08**
27	AKW 770 x AKAW 4498	5.29**	-10**	7.04**	-6.9**	-27.57**	-33.46**
28	AKW 770 x DL 788-2	-12.35**	-8.1**	-3.74**	-3.42**	-20.01**	-23.93**
29	AKW 770 x HI 1454	-12.35**	-4.29**	-4.04**	-2.64**	-28.12**	-32.75**
30	AKW 770 x AKAW 3719	-4.71**	-2.86**	0.81**	-2.58**	6.79**	-20.74**
31	AKW 770 x DBW 31	-8.24**	1.9*	-1.61**	1.32**	-5.62**	-3.86**
32	AKW 770 x AMBER	1.18	17.62**	7.19**	17.1**	6.29**	3.37**
33	HI 1418 x AKAW 2862-1	1.18	2.86**	5.14**	2.22**	-24.29**	-27.87**
34	HI 1418 x AKAW 3717	-3.53**	-4.76**	1.83**	-3.24**	18.29**	-0.73
35	HI 1418 x AKAW 4498	-5.88**	-0.48	-0.07	-0.3	29.69**	3.52**
36	HI 1418 x DL 788-2	6.47**	3.33**	8.14**	2.76**	-12.77**	5.24**
37	HI 1418 x HI 1454	-8.82**	1.43	-1.83**	2.16**	-25.24**	-18.66**
38	HI 1418 x AKAW 3719	7.06**	-3.33**	8.36**	-0.9*	18.58**	2.2
39	HI 1418 x DBW 31	5.88**	-3.81**	7.92**	-2.46**	-27.78**	-16.04**
40	HI 1418 x AMBER	6.47**	-0.95	7.48**	-0.72	-29.06**	-2.48*
41	AKAW 4210-6 x AKAW 2862-1	-11.18**	1.9*	-3.45**	1.2**	-23.78**	8.01**
42	AKAW 4210-6 x AKAW 3717	10.59**	2.38*	10.64**	2.28**	29.53**	41.21**
43	AKAW 4210-6 x AKAW 4498	-12.94**	2.86**	-4.4**	0.06	-9.84**	8.79**
44	AKAW 4210-6 x DL 788-2	-5.29**	-1.9*	0.15	-0.78*	19.33**	8.76**
45	AKAW 4210-6 x HI 1454	10**	-8.1**	7.63**	-4.08**	-5.01**	26.03**
46	AKAW 4210-6 x AKAW 3719	2.94**	-2.86**	5.5**	-1.68**	-18.22**	47.04**
47	AKAW 4210-6 x DBW 31	10**	-1.43	10.2**	-1.14**	-21.21**	15.45**
48	AKAW 4210-6 x AMBER	-1.76*	0	2.57**	-0.18	31.97**	25.81**
	SE(m) ±	0.40	0.67	0.22	0.43	1.70	2.31
	CD (5%)	0.78	1.33	0.43	0.85	3.37	4.57
	CD (1%)	1.04	1.76	0.56	1.12	4.45	6.04

S.N.	CROSSES	Plant height		Effective tillers/plant		Grains/earhead	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	3.18**	9.63**	-16.43**	-45.04**	4.91**	13.82**
2	AKAW 4800 x AKAW 3717	-2.42**	6**	-21.19**	-17.31**	-8.74**	8.65**
3	AKAW 4800 x AKAW 4498	9.22**	5.65**	-19.02**	1.13	11.42**	3.46**
4	AKAW 4800 x DL 788-2	9.93**	5.49**	-16.34**	-22.89**	7.04**	16.72**
5	AKAW 4800 x HI 1454	-9.07**	5.04**	-25.03**	-7.16**	-12.42**	22.88**
6	AKAW 4800 x AKAW 3719	-15.63**	13.64**	-49.33**	-41.83**	-13.96**	20.82**
7	AKAW 4800 x DBW 31	-0.2	6.68**	-6.29*	-5.13*	2.79**	14.31**
8	AKAW 4800 x AMBER	5.7**	8.14**	-2.5	-9.86**	5.74**	20.53**
9	AKAW 1071 x AKAW 2862-1	-1.97*	2.8**	-43.22**	-23.22**	-13.56**	11.18**
10	AKAW 1071 x AKAW 3717	16.43**	16.49**	-0.09	-11.39**	-4.3**	22.53**
11	AKAW 1071 x AKAW 4498	-9.07**	6.25**	4.86	-19.84**	-21.28**	11.18**
12	AKAW 1071 x DL 788-2	3.18**	4.21**	17.17**	4.17	2.95**	3.57**
13	AKAW 1071 x HI 1454	-24.6**	6.65**	9.58**	-48.25**	-21.76**	-9.18**
14	AKAW 1071 x AKAW 3719	0.55	10.71**	-17.58**	-16.46**	-10.95**	-0.32
15	AKAW 1071 x DBW 31	-0.2	-0.43	-15.36**	-43.52**	-8.12**	20.41**
16	AKAW 1071 x AMBER	-2.22**	1.75**	-16.52**	-0.51	-8.74**	1.22
17	AKAW 5023 x AKAW 2862-1	-19.35**	8.2**	-26.05**	-30.1**	-24.17**	-5.78**
18	AKAW 5023 x AKAW 3717	0.81	6.43**	-23.88**	-28.18**	-13.49**	-33.3**
19	AKAW 5023 x AKAW 4498	-1.51	5.51**	-9.63**	1.47	-8.02**	-12.78**
20	AKAW 5023 x DL 788-2	-2.57**	3.99**	-16.98**	-28.97**	-11.35**	-27.06**
21	AKAW 5023 x HI 1454	-4.44**	3.29**	-10.32**	-57.5**	-23.13**	-5.78**
22	AKAW 5023 x AKAW 3719	-23.89**	0.63	3.7	-45.72**	-18.65**	4.65**
23	AKAW 5023 x DBW 31	9.78**	9.39**	-20.55**	-33.71**	-4.49**	-32.38**
24	AKAW 5023 x AMBER	-4.64**	4.26**	-10.27**	-52.09**	-11.54**	-8.57**
25	AKW 770 x AKAW 2862-1	1.97*	3.9**	-6.2*	-18.04**	-9.13**	-26.16**
26	AKW 770 x AKAW 3717	-2.62**	11.28**	-32.67**	3.66	-7.38**	-1.25
27	AKW 770 x AKAW 4498	8.87**	6.68**	-19.67**	11.27**	12.31**	-12.78**
28	AKW 770 x DL 788-2	-8.37**	2.26**	-33.97**	-39.68**	-8.6**	-7.17**
29	AKW 770 x HI 1454	-4.23**	-0.67	-20.55**	-22.44**	-3.91**	-28.95**
30	AKW 770 x AKAW 3719	0.1	-0.82	30.4**	-31.57**	-3.91**	-34.7**
31	AKW 770 x DBW 31	-16.13**	0.25	-6.25*	-40.81**	-9.87**	-17.92**
32	AKW 770 x AMBER	-7.06**	0.04	-4.53	23.84**	-15.45**	-28.77**
33	HI 1418 x AKAW 2862-1	-10.64**	2.4**	-21.1**	9.92**	-6.13**	-38.56**
34	HI 1418 x AKAW 3717	-6.15**	1.77**	-24.29**	-30.67**	-19.51**	-30.34**
35	HI 1418 x AKAW 4498	4.03**	4.82**	-26.93**	17.36**	4.13**	-41.41**
36	HI 1418 x DL 788-2	-6.05**	0.99	-23.65**	-0.9	-24.14**	-12.31**
37	HI 1418 x HI 1454	0	2.31**	-4.07	-19.67**	-7.47**	-15.27**
38	HI 1418 x AKAW 3719	2.92**	5.71**	-11.71**	-44.59**	-4.83**	3.25*
39	HI 1418 x DBW 31	1.56	0.52	-12.17**	-9.53**	-6.2**	-29.24**
40	HI 1418 x AMBER	4.13**	1.46**	-19.25**	-29.82**	-4.62**	-13.21**
41	AKAW 4210-6 x AKAW 2862-1	3.12**	2.11**	-29.94**	-21.14**	10.44**	-12.31**
42	AKAW 4210-6 x AKAW 3717	7.01**	2.98**	-26.24**	-43.97**	13.83**	-0.78
43	AKAW 4210-6 x AKAW 4498	1.11	7.89**	-4.16	-33.2**	-6.37**	22.53**
44	AKAW 4210-6 x DL 788-2	2.32**	4.08**	-6.25*	-26.66**	-10.05**	-4.97**
45	AKAW 4210-6 x HI 1454	-9.17**	7.19**	-13.56**	-23.9**	-18.65**	-2.35
46	AKAW 4210-6 x AKAW 3719	-8.97**	2.46**	-4.86	0.45	-21.39**	-41.99**
47	AKAW 4210-6 x DBW 31	-4.28**	-1.05	-21.66**	-33.65**	-8.62**	-34.64**
48	AKAW 4210-6 x AMBER	-1.11	0.07	-12.59**	-34.67**	-7.97**	-29.41**
	SE(m) ±	0.54	0.40	0.18	0.24	0.12	0.57
	CD (5%)	1.06	0.79	0.36	0.48	0.24	1.13
	CD (1%)	1.41	1.04	0.47	0.64	0.32	1.50

S.N.	CROSSES	Thousand grain weight		Grain weight/plant		Harvest index	
		LS	TS	LS	TS	LS	TS
1	AKAW 4800 x AKAW 2862-1	-15.38**	7.82**	-15.17**	-16.02**	-15.31**	-4.44*
2	AKAW 4800 x AKAW 3717	0.2	-2.31	-23.07**	-5.64	-14.14**	-13.04**
3	AKAW 4800 x AKAW 4498	-11.29**	-15.97**	14.3**	-9.47*	-23.43**	-3.08
4	AKAW 4800 x DL 788-2	-14.58**	-14.02**	1.44**	2.36	-15.65**	-10.9**
5	AKAW 4800 x HI 1454	-32.29**	-8.75**	-57.15**	-21.1**	-14.57**	4.21
6	AKAW 4800 x AKAW 3719	11.7**	13.94**	-29.96**	-10.45*	-37.2**	18**
7	AKAW 4800 x DBW 31	-16.88**	-12.48**	31.64	53**	-23.47**	-6.12**
8	AKAW 4800 x AMBER	-10.5**	1.36	-16.81**	-10.3*	-14.03**	-4.82*
9	AKAW 1071 x AKAW 2862-1	-2.27	-4.36	-44.77**	-22.46**	-35.95**	-38.72**
10	AKAW 1071 x AKAW 3717	-36.14**	0.14	37.2**	34.16**	15.41**	-5.4*
11	AKAW 1071 x AKAW 4498	-40.55**	2.13	-51.69**	-18.44**	-33.54**	-6.79**
12	AKAW 1071 x DL 788-2	-38.17**	-4.01	-22**	-1.38	-33.29**	-28.89**
13	AKAW 1071 x HI 1454	-33.12**	8.51**	-56.62**	-15.02**	-18.79**	-5.66*
14	AKAW 1071 x AKAW 3719	-17.82**	-6.22*	-25.95**	10.52*	-0.44	-0.27
15	AKAW 1071 x DBW 31	-24.6**	-8.45**	-34.2**	15.48**	-21.31**	9.62**
16	AKAW 1071 x AMBER	-16.69**	11.31**	-31.68**	0.16	9.86*	9.59**
17	AKAW 5023 x AKAW 2862-1	-45.68**	6.55*	-57.58**	3.82	11.43**	-15.56**
18	AKAW 5023 x AKAW 3717	-44.8**	-4.9	-26.98**	-19.71**	5.48	-29.61**
19	AKAW 5023 x AKAW 4498	-23.43**	17.93**	-40.29**	-10.44*	-28.45**	-24.2**
20	AKAW 5023 x DL 788-2	-35.15**	-9.12**	-45.37**	-24.16**	-20.03**	-14.65**
21	AKAW 5023 x HI 1454	-44.64**	-0.03	-53.45**	-29.01**	-14.71**	-27.23**
22	AKAW 5023 x AKAW 3719	-29**	-6.73**	-49.09**	-11.68**	-39.74**	-28.67**
23	AKAW 5023 x DBW 31	-6.55**	-24.56**	-16.53**	-25.01**	-17.31**	-21.19**
24	AKAW 5023 x AMBER	-35.55**	-6.42*	-48.34**	-3.57	6.24	-23.85**
25	AKW 770 x AKAW 2862-1	-22.83**	-8.29**	-27.15**	-7.44	6.25	-23.3**
26	AKW 770 x AKAW 3717	-0.93	-3.11	-38.22**	2.16	-5.08	5.23*
27	AKW 770 x AKAW 4498	2.77	-4.25	40.46**	49.47**	1.87	-21.26**
28	AKW 770 x DL 788-2	-5.54*	-12.14**	-48.89**	-23.85**	13.88**	-40.08**
29	AKW 770 x HI 1454	-0.93	-6.05*	-37.92**	-29.03**	2.8	-34.91**
30	AKW 770 x AKAW 3719	-42.36**	-3.13	-13.96**	-28.45**	-19.02**	-19.92**
31	AKW 770 x DBW 31	-45.64**	-12.49**	-58.29**	-2.76	5.69	-39.62**
32	AKW 770 x AMBER	-32.78**	0.01	-65.52**	-14.06**	-5.69	-16.66**
33	HI 1418 x AKAW 2862-1	-27.09**	22.31**	-52.11**	-19.04**	-8.61*	-38.48**
34	HI 1418 x AKAW 3717	-21.6**	-5.53*	-45.36**	-3.31	-21.78**	-35.34**
35	HI 1418 x AKAW 4498	9.29**	8.83**	0.29**	36.68**	-4.35	-7.66**
36	HI 1418 x DL 788-2	-39.2**	-2.62	-46.22**	20.44**	3.99	-38.01**
37	HI 1418 x HI 1454	-39.18**	-3.15	-31.99**	-19.21**	-18.75**	-10.13**
38	HI 1418 x AKAW 3719	-11.96**	2.67	-15.18**	2.49	10.96**	-8.48**
39	HI 1418 x DBW 31	-21.99**	-2.59	-18.3**	6.57	2.94	0.01
40	HI 1418 x AMBER	-10.14**	-9.99**	3.78	-1.68	-17.6**	-16.38**
41	AKAW 4210-6 x AKAW 2862-1	6.45**	7.82**	22.53**	47.13**	2.1	1.35
42	AKAW 4210-6 x AKAW 3717	24.74**	19.23**	0.44**	46.86**	-25.12**	13.39**
43	AKAW 4210-6 x AKAW 4498	-30.11**	-2.59	-33.99**	19.58**	15.56**	-2.63
44	AKAW 4210-6 x DL 788-2	-28.21**	16.69**	-15.7**	10.87*	-7.75*	15.71**
45	AKAW 4210-6 x HI 1454	-44.58**	12.05**	-40.74**	-4.36	-16.97**	15.4**
46	AKAW 4210-6 x AKAW 3719	-19.59**	2.8	-64.64**	1.84	5.11	-10.29**
47	AKAW 4210-6 x DBW 31	-12.4**	8.84**	-43.52**	-11.44**	14.31**	-15.57**
48	AKAW 4210-6 x AMBER	9.46**	13.4**	-29.93**	-35.54**	13.97**	-11.98**
	SE(m) ±	0.98	1.11	0.49	0.56	1.66	1.13
	CD (5%)	1.93	2.19	0.98	1.12	3.28	2.23
	CD (1%)	2.55	2.89	1.29	1.47	4.33	2.95

Conclusion

By considering the standard heterosis values over the best check in the desirable direction for grain yield per plant and other yield contributing characters, crosses AKAW 4210-6 × AKAW 2862-1, AKAW 4210-6 × AKAW 3717, HI 1418 × AKAW 4498, AKW 770 × AKAW 4498, and AKAW 1071 × AKAW 3717 were identified as the best under late sown conditions and under timely sown conditions, the best crosses were AKAW 4800 × DBW 31, AKW 770 × AKAW 4498, AKAW 4210-6 × AKAW 2862-1, AKAW 4210-6 × AKAW 3717, and HI 1418 × AKAW 4498. Over the environments, for yield and yield contributing characters and quality parameters, the best crosses with highest standard heterosis values were AKAW 4210-6 × AKAW 2862-1, HI 1418 × AKAW 4498, AKAW 4800 × DBW 31, AKAW 1071 × AKAW 3717, AKW 770 × AKAW 4498, and AKAW 4210-6 × AKAW 3717. In conclusion, this study helps in understanding the genetic basis of yield and yield-contributing characters in wheat genotypes under terminal heat stress. The superior crosses identified from the study based on the heterotic estimates can be utilized for developing heat-tolerant wheat varieties with desirable yield performance, contributing to sustainable wheat production in challenging environments.

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