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Study of heterosis for grain yield and its components in wheat (*Triticum aestivum*) over normal and heat stress condition

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Abstract

Present investigations were carried out to exploit further breeding heat tolerant cultivars. Heterosis for yield and its component traits were studied in 10 parents and their 45 $F_{1's}$ in wheat (*Triticum aestivum* L.) under normal and heat stress condition. Cross combination HD-2733 x HUW-468 (50.24 %) depicted highest positive significant relative heterosis for grain yield followed by AAI-11 x HUW-468 (47.08%) and K-911 x HUW-468 (43.19%). Similarly AAI-11 x HUW-468 (36.17%) exhibited highest positive significant heterobeltiosis for grain yield followed by hybrids HD-2733 x HUW-468 (35.76%) and HD-2733 x AAI-16 (35.04%) in normal condition. In stressed condition, cross NW-1014 x NW-4035 (30.63 %) followed by K-9162 x NW-4035 (24.12 %) and K-911 x AAI-11 (22.93%) exhibited highest positive significant relative heterosis. Whereas cross combination NW-1014 x NW-4035 (27.76 %) depicted highest positive significant heterobeltiosis followed by hybrids K-9162 x NW-4035 (19.43%) and NW-4081 x K-9162 (15.99%) which may be exploited for developing hybrids with better yield and yield related traits in wheat. These crosses could be extensively used in breeding programme to develop superior segregants or better pure lines could be derived in further breeding programmes.

Keywords: wheat, heterosis, heat stress and grain yield

1. Introduction

Wheat (*Tritium aestivum* L.) is the second most important crop that contributes significantly to the global food and food security (Kumar *et al*., 2013) [19]. At global level, wheat occupies an area of 221.68 mha, with a production and productivity of 728.28 mt and 32.9 q/ha respectively. In India wheat occupies an area of about 30.23 mha with a production of 93.50 mt. and average productivity of 30.93 q/ha (Indian Institute of Wheat and Barley Research Annual Report, 2014). Best vegetative and reproduction growth of wheat plant is obtained at temperature 18-22 ºC (Gaffen and Ross, 1998; Alexander *et al*., 2006; Hennessy *et al*., 2008 and Reynolds *et al*., 2010) [9, 2, 14, 25].

Recently, climate change has increased the risks of exposure to higher temperature by manifold even for timely sown wheat. Heat stress due to rising ambient temperatures during grain growth is one of the major constraints in enhancing wheat productivity particularly when the crop sowing is delayed due to late harvesting of previous crops. Each degree rise in temperature causes 3-4% reduction in grain weight as revealed by studies under controlled and natural environments. The total wheat production in the country may get reduced by at least 4 million tons in any given year for each degree rise in ambient temperatures effecting the canopy temperature depression significantly, whereas other parameters such as anthesis, maturity, spike length, and grain-filling period were reduced as sowing was delayed which results in reduced grain yield (Tripathi *et al.,* 2005) [32]. Heterosis breeding provides the way to overcome the yield barriers. Wheat production can be enhanced through the development of new cultivars having wider genetic base and better performance under various agro-climatic conditions. Exploitation of heterotic effects is mainly accredited to cross pollinated crops but now-a-days the incidence is common in self-pollinated crops such as wheat, providing an option for commercially utilizing wheat (Singh *et al*., 2004; Kumar *et al*., 2011) [30, 18]. According to Rauf *et al. (*2012) [24] manipulation of heterosis is an important strategy for increasing the yield potential of wheat. However, wheat hybrids yielded 13.5% more than their parents due to hybrid stability, responsiveness to farm input) and better tolerance to abiotic stress (Farooq *et al*., 2014) [8]. The study of heterosis helps the breeders in eliminating less productive crosses in F_1 generation itself. The rejection of crosses, which shows no heterosis, would enable the breeder to concentrate the attention to few, but possibly more productive crosses.

The studies of heterosis in wheat in relation to terminal heat tolerance have also been reported by Borghi and Perenzin (1994) [5], Saini *et al.*, (2006) [27], Ribadia *et al.*, (2007) [26], Ashutosh *et al.*, (2011) [3] and Beche *et al.*, (2013) [14]. Keeping in view the general rule of breeding and the necessity of finding out superior heterotic crosses for grain yield we, therefore conducted this study with the objective of estimating the extent of heterosis in various wheat crosses obtained through half diallel mating scheme for normal and heat stress condition.

Material and Methods

In order to formulate valuable information regarding heterotic aspects of wheat hybrids this investigation was undertaken during *Rabi* 2013-2014 and 2014-2015 at Field Experimentation Center of Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture Technology & Sciences, Allahabad. The experimental materials consisted ten parents NW-4081(P1), HD-2733(P2), NW-1014(P3), K-911(P4), AAI-11(P5), K-307(P6), K-9162(P7), HUW-468(P8), AAI-16(P9) and NW-4035(P10) (mating design as per half diallel method of Griffing, 1956) [11] total of 57 entries (10 parents + 45 crosses) planted in a Randomized Block Design (RBD) comprising of three replications, with a double row plot of 2 meters length, maintaining a crop geometry of 22.5 x 5 cm. Observations were recorded for plant height (cm), days to maturity (days), spike length (cm), spike weight (g), grain filling period (days), grain yield (g/plant), thousand grain weight (g) and membrane stability (%).

The data were recorded on ten randomly selected competitive plants from each genotype in each replication except for grain filling period and days to maturity where the observations were recorded on plot basis. Data from ten plants were averaged replication wise and the mean value was subjected for statistical analysis for all characters studied. Membrane thermo stability test was done to screen for high temperature tolerant genotypes of wheat based on the percentage electrolyte leakage in flag leaves during anthesis stage.

For the estimates of heterosis the test of significance was carried out with't' test as given here under:

1. Estimation of heterosis (Turner, 1953)

Heterosis is expressed as percent (%) deviation from the mid parent. In the present experiment heterosis was estimated for 45 hybrids for the ten characters studied.

ha (%) $= \dfrac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$

Testing the significance, critical difference

C. D. (heterosis) = $(\overline{F_1} - \overline{MP}) \times t_{0.05}$

Where,

$\overline{F_1}$ = mean of F_1

$\overline{MP}$ = mean of parents of respective F_1

$(\overline{F_1} - \overline{MP}) = \sqrt{(2MS_e / r)}$

Where

MSe = mean sum of square due to error

r = number of replications

2. Estimation of heterobeltiosis

Heterobeltiosis is expressed as percent deviation towards desirable side *i.e*. maybe increase or decrease in performance over better parents.

hb (%) $= \dfrac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$

Its significance was tested using critical difference *i.e.* C. D.

CD (BP) = SE $(\overline{F_1} - \overline{BP}) \times t_{0.05}$

Where,

$\overline{BP}$ = mean of the desirable better parent

SE $(\overline{F_1} - \overline{BP}) = \sqrt{(2MS_e / r)}$

Where

MSe = mean sum of square due to error

r = number of replications

Result and Discussion

The mean values for all the fourteen characters of F_1 hybrids were compared with the values of mid parent (relative heterosis) and heterosis over better parent (heterobeltosis) expressed as percentage increase or decrease, are presented in Table 1 and Table 2 for different characters.

Plant Height

Dwarfness is desirable trait for wheat crop hence negative heterosis is favourable to avoid lodging thus producing stable yield. The cross K-307 x NW-4035 (-16.65%) showed highest relative heterosis in normal condition, crosses AAI-11 x K-307 and NW-1014 x K-911 (-17.32%) in stressed condition for the indicated trait. Among 45 hybrids 29 and 27 hybrids showed negative significant heterobeltosis for this trait in normal and stressed condition respectively. Highest heterobeltosis is shown by K-307 x NW-4035 (-17.25%) in normal condition and AAI-16 x NW-4035 (-20.70%) in late sown condition.

Present results showed many desirable negative estimates which are in accordance with the results of Abdullah *et al*. (2002) [1] and Rasul *et al*. (2002) [23].

Days to maturity

Genotypes with early maturing habits are generally desirable and negative heterosis for days to maturity is therefore a useful parameter. Highest relative heterosis for days to maturity was seen by HUW-468 x AAI-16 (-5.29%) in normal and HD-2733 x HUW-468 (-4.01%) in stressed condition depicted highest negative significant relative heterosis for days to maturity. Highest better parent heterosis is shown by HUW-468 x AAI-16 (-5.29%) in normal sowing condition and cross AAI-11 x NW-4035 (-4.35%) depicted highest negative significant heterobeltiosis in stressed condition for days to maturity. Percent heterosis over two check range from -3.27 (NW-4081 x K-911) to -3.87% (HD-2733 x HUW-468) in late sown condition.

Spike length

Spike length is a major yield component and is directly proportional to grains/spike. The longer the spike length, higher will be the grain yield. The cross combination AAI-11 x K-307 (12.99%) exhibited highest relative heterosis for normal sown condition, AAI-11 x K-307 and AAI-11 x NW-4035 (15.66 %) for late sown condition. Hybrid AAI-11 x NW-4035 (10.11%) depicted highest positive significant heterobeltiosis for spike length (cm) followed by hybrids AAI-11 x NW-4035 (10.11%) and NW-1014 x HUW-468 (9.13%) in normal condition. Similarly in stressed condition, hybrid

NW-4081 x NW-4035 (14.54%) exhibited highest positive significant heterobeltiosis followed by hybrids AAI-11 x NW-4035 (13.86%), AAI-11 x K-307 (13.25%) and NW-4081 x AAI-16 (13.85%).

Spike weight

Shows the weight of biological as well as economic yield of a spike which was highest positive significant for cross K-911 x NW-4035 (33.40%) normal condition, NW-1014 x K-307 (34.20%) in stressed condition as a relative heterosis. For heterobeltosis cross combination K-911 x NW-4035 (28.91%) in normal condition, K-911 x NW-4035 (30.25%) in stressed condition depicted highest positive significant heterosis.

Grain filling period

Grain filling is the duration between anthesis and physiological maturity and it is positively correlated with grain yield in wheat. Data for this trait revealed that hybrid NW-4081 x AAI-11 (16.36%) depicted highest positive significant relative heterosis for grain filling period followed by hybrids NW-1014 x K-307 (13.91%), NW-4081 x K-9162 (13.68%), NW-1014 x K-911 (13.42%) and NW-1014 x AAI-11 (13.12%). In late sown NW-1014 x K-307 (8.77%). Similarly in stressed condition, no hybrid depicted positive significant relative heterosis for grain filling period. Out of 45 hybrids 3 hybrids showed significant positive heterobeltiosis in normal condition and no hybrids showed significant positive heterobeltiosis in stressed condition. Hybrid NW-4081 x AAI-11 (13.27%) exhibited highest positive significant heterobeltiosis for grain filling period followed by hybrids NW-1014 x K-307 (12.93%) and NW-1014 x K-911 (11.97%) in normal condition.

Grain yield

Hybrid HD-2733xHUW-468 (50.24 %) depicted highest positive significant relative heterosis for grain yield followed by hybrids AAI-11xHUW-468 (47.08%), K-911xHUW-468 (43.19%), NW-1014xHUW-468 (38.63%) and HD-2733xK-9162 (37.89%) in normal condition. In stressed condition, cross NW-1014xNW-4035 (30.63 %) exhibited highest positive significant relative heterosis followed by hybrids K-9162xNW-4035(24.12 %), K-911xAAI-11(22.93%), NW-4081xHUW-468 (18.47%) and NW-4081xK-9162 (16.11%). Positive significant heterobeltiosis was shown by 14, 5 hybrids out of 45 hybrids in normal and stressed condition respectively. Hybrid AAI-11xHUW-468 (36.17%) exhibited highest positive significant heterobeltiosis for grain yield followed by hybrids HD-2733xHUW-468(35.76%), HD-2733xAAI-16 (35.04%), HD-2733xK-9162 (31.60%) and AAI-11xK-9162 (29.30%) in normal condition. Similarly in stressed condition, hybrid (NW-1014xNW-4035 (27.76 %) depicted highest positive significant heterobeltiosis followed by hybrids K-9162xNW-4035 (19.43%), NW-4081xK-9162 (15.99%) and NW-4081xHUW-468 (14.37%). Singh *et al.* (2013) [31] and Garg *et al*. (2015) [10] also showed similar positive and significant heterosis.

Thousand grain weight

It is an important selection criteria in breeding programs as it has a positive correlation with grain yield in wheat. Hybrid NW-1014 x HUW-468 (16.14%) depicted highest positive significant relative heterosis for thousand grain weight followed by hybrids K-307 x HUW-468 (14.93%), NW-1014 x AAI-11 (13.53%), NW-4081 x HUW-468 (13.02%), NW-4081 x AAI-16 (10.51%) and HD-2733 x HUW-468 (9.86%) in normal condition. Similarly in stressed condition, hybrid K-307 x HUW-468 (17.65%) exhibited highest positive significant relative heterosis followed by hybrids K-911 x HUW-468 (9.47%). Out of 45 hybrids 4, 1 hybrids showed significant positive heterobeltiosis in normal and stressed condition respectively. Hybrid NW-1014 x HUW-468 (15.91%) exhibited highest positive significant heterobeltiosis for normal condition followed by hybrids NW-1014 x AAI-11 (12.67%) and K-307 x HUW-468 (14.72%). Similarly in stressed condition, hybrid K-307 x HUW-468 (12.96%) exhibited positive significant heterobeltiosis. In the current studies many cross combinations suggest to increase thousand grain weight which is an important yield component. By exploiting heterosis for this attribute, many researchers found that this trait has direct contribution for increased grain yield in wheat (Dagustu, 2008) [6].

Membrane stability

Hybrid HD-2733 x K-307 (70.78%) depicted highest positive significant relative heterosis followed by hybrids NW-1014 x K-307(66.50%), NW-4081x AAI-16 (46.77) and NW-4081 x K-911(42.42%) in normal condition. Similarly in stressed condition, hybrid HD-2733x K-307 (68.08%) exhibited highest positive significant relative heterosis followed by hybrids, HD-2733 x K-911 (25.29%) and NW-1014 x K-307(42.78%). Estimates of heterobeltiosis for this trait revealed that out of 45 hybrids 5, 2 hybrids showed significant positive heterobeltiosis in normal and stressed condition respectively. Hybrid NW-4081x AAI-16 (43.67%) depicted highest positive significant heterobeltiosis followed by hybrids HD-2733 x K-307 (43.06%) in normal condition. Similarly in stressed condition, hybrid NW-1014 x K-307 (41.12%) depicted highest positive significant heterobeltiosis followed by hybrids HD-2733 x K-307 (64.79%).

Heat stress is an alarming threat that significantly reduces yield. Degree of heterosis is, however, important as it may be of value in deciding the directions of future breeding programme. The high values for heterotic effects indicated that the parent used for the study were widely diverse. Considerable high heterosis in certain hybrids and low in other revealed that nature of gene action varied with the genetic architecture of the plants. The present study helps to identify the cross combination, which are promising in breeding programme with highest positive significant and to study the performance and relationship of F_1 hybrids and parents and to select suitable parents and population. Such nature as well as magnitude of heterosis helps in identifying superior cross combination in normal and heat stress condition. The superiority of F_1 hybrids particularly over better parent is more useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants.

In the present study for normal condition cross combinations with highest positive significant relative heterosis were shown by HD-2733 x K-307 (membrane stability), AAI-11 x K-307 (spike length), K-911 x NW-4035 (spike weight), NW-4081 x AAI-11 (grain filling period), HD-2733xHUW-468 (grain yield) and NW-1014 x HUW-468 (thousand grain weight) whereas highest negative significant relative heterosis was shown by cross combination K-307 x NW-4035 (plant height) and HUW-468 x AAI-16 (days to maturity). Highest positive significant heterobeltiosis in normal condition shown by NW-4081x AAI-16 (membrane stability), AAI-11 x NW-4035 (spike length), K-911 x NW-4035 (spike weight), NW-4081 x

AAI-11 (grain filling period), AAI-11xHUW-468 (grain yield), NW-1014 x HUW-468 (thousand grain weight). Highest negative significant heterobeltiosis in normal condition shown by K-307 x NW-4035 (plant height) and HUW-468 x AAI-16 (days to maturity). Similarly highest positive significant relative heterosis in heat stressed condition shown HD-2733x K-307 (membrane stability), AAI-11 x K-307 and AAI-11 x NW-4035 (spike length), NW-1014 x K-307 (spike weight), NW-1014 x K-307 (grain filling period), NW-1014xNW-4035 (grain yield) K-307 x HUW-468 (thousand grain weight)) whereas highest negative significant relative heterosis was shown by cross combination AAI-11 x K-307 and NW-1014 x K-911 (plant height), HD-2733 x HUW-468 (days to maturity). Highest positive significant heterobeltiosis in heat stressed condition shown NW-1014 x K-307 (membrane stability), NW-4081 x NW-4035 (spike length), K-911 x NW-4035 (spike weight), NW-1014xNW-4035 (grain yield), K-307 x HUW-468 (thousand grain weight). Highest negative significant heterobeltiosis in heat stressed condition were AAI-16 x NW-4035 (plant height) and AAI-11 x NW-4035 (days to maturity).

The cross combinations like HD-2733xHUW-468, AAI-11xHUW-468, NW-1014xHUW-468, HD-2733xHUW-468 and NW-1014xNW-4035 maybe further exploited as their have high grain yield with its related traits. Similar finding were also carried out by Shah *et al.* (2004) [29], Punia *et al.* (2005) [22], Kumar (2008) [20], Jaiswal *et al.* (2010) [16], Khatun *et al.* (2010) [17], Devi *et al.* (2013) [7], and Gul *et al.* (2015) [12].

Table 1: Extent of relative heterosis% (Ha) and Heterobeltosis% (Hb) for plant height, spike length, spike weight and days to maturity in 45 cross combination of wheat.

Hybrids	Env.	Plant height		Spike length		Spike weight		Days to maturity	
		Ha	Hb	Ha	Hb	Ha	Hb	Ha	Hb
P1 x P2	Normal	4.14 **	-6.29 **	6.35	1.31	12.61	6.39	-3.71 **	-5.41 **
	Stress	-5.93 **	-13.02 **	4.24	3.35	10.21	-1.67	-1.65	-2.67
P1 x P3	Normal	-2.93 *	-4.65 **	-6.15	-10.13 *	-23.73 *	-32.09 **	-0.95	-1.89
	stress	-13.23 **	-14.02 **	-1.84	-2.56	-30.22 **	-37.15 **	1.82	1.52
P1 x P4	normal	-1.13	-5.21 **	-2.11	-2.14	11.39	6.53	-2.05	-2.97
	stress	2.25	0.99	4.06	-1.02	4.89	-0.42	-2.4	-3.27 *
P1 x P5	normal	-4.46 **	-7.46 **	-10.83 **	-12.25 **	-24.65 **	-26.85 **	-1.36	-1.89
	stress	-2.22	-3.44 *	-6.38	-8.56	-39.55 **	-39.97 **	0.44	-1.74
P1 x P6	normal	-4.65 **	-6.19 **	-12.89 **	-13.59 **	-23.91 **	-25.56 **	0	-1.08
	stress	3.40 *	1.43	-8.32 *	-12.28 **	-30.56 **	-33.73 **	0.46	0.3
P1 x P7	normal	2.65	-6.55 **	2.22	1.01	0.24	-1.64	1.8	-0.54
	stress	7.09 **	0.6	10.78 *	9.22	-3.07	-5.15	1.05	0.3
P1 x P8	normal	-0.7	-2.95	7.99 *	5.96	7.19	5.73	-1.89	-1.89
	stress	3.94 **	3.56 *	13.72 **	11.97 *	-9.63	-17.77 *	-0.6	-1.49
P1 x P9	normal	0.72	-4.91 **	4.49	1.28	5.39	0.94	-0.14	-0.54
	stress	2.79 *	-0.64	13.99 **	13.85 **	-2.18	-8.55	1.81	1.51
P1 x P10	normal	-1.99	-2.87	8.19 *	7.03	2.67	1.57	-4.75 **	-5.14 **
	stress	1.09	0.28	15.45 **	14.54 **	-1.13	-5.57	-1.05	-1.79
P2 x P3	normal	11.02 **	1.54	7.91	7.33	10.01	3.28	1.39	0.55
	stress	5.33 **	-3.42 *	6.98	5.3	12.88	11.69	0.75	-0.59
P2 x P4	normal	1.42	-5.08 **	-4	-8.58 *	7.43	6.07	-0.83	-1.65
	stress	-5.40 **	-11.51 **	-2.47	-6.47	8.27	1.39	-2.23	-2.37
P2 x P5	normal	-1.17	-8.41 **	7.78	4.28	7.17	-1.53	0.97	-0.27
	stress	0.11	-6.35 **	10.54 *	8.88	12.76	0	-2.64 *	-3.77 **
P2 x P6	normal	7.03 **	-2.26	8.96 *	4.6	-0.7	-4.18	0.42	-0.28
	stress	-2.58	-8.28 **	9.73 *	5.86	8.11	0.72	1.2	0
P2 x P7	normal	7.66 **	6.27 **	-0.33	-3.97	-0.16	-7.34	1.13	0.56
	stress	0.48	-1.2	0.07	-0.5	-0.91	-9.85	-1.49	-1.78
P2 x P8	normal	-2.72	-10.61 **	8.90 *	5.67	6.69	2.12	-4.26 **	-5.95 **
	stress	-8.47 **	-15.07 **	9.62 *	8.86	20.37 **	17.78 *	-4.01 **	-4.15 **
P2 x P9	normal	14.52 **	8.82 **	1.75	-0.06	6.68	5.18	-0.28	-1.63
	stress	9.51 **	4.59 **	2.64	1.88	14.95	9.3	-0.45	-1.19
P2 x P10	normal	5.42 **	-4.36 **	4.71	0.79	7.83	2.93	-0.55	-1.91
	stress	5.00 **	-3.62 *	9.53 *	9.46 *	6.88	-0.5	-0.3	-0.59
P3 x P4	normal	0.12	-2.32	2.6	-1.79	32.16 **	22.61 *	0.55	0.55
	stress	-4.14 **	-6.17 **	5.12	-0.71	28.96 **	21.98 **	0.6	-0.6
P3 x P5	normal	-8.76 **	-10.05 **	11.11 **	8.06	28.66 **	11.62	-1.23	-1.64
	stress	-7.18 **	-9.16 **	1.91	-1.17	27.92 **	14.51 *	-0.15	-2.61
P3 x P6	normal	-4.28 **	-4.44 **	6.51	2.79	28.92 **	17.08	0.97	0.83
	stress	-2.26	-4.97 **	8.17 *	2.77	34.20 **	26.28 **	3.50 **	3.34 *
P3 x P7	normal	-0.71	-8.10 **	8.22 *	4.82	21.59 *	6.47	1.68	0.28
	stress	0.76	-6.15 **	14.53 **	12.10 *	-6.98	-14.55	0.75	-0.3
P3 x P8	normal	-2.65	-3.15	11.89 **	9.13 *	9.66	-1.16	-0.68	-1.62
	stress	-2.15	-3.40 *	11.94 **	9.42 *	13.25	11.98	3.01 *	1.79
P3 x P9	normal	-3.88 **	-7.67 **	-1.3	-2.54	23.08 *	14.02	-1.64	-2.18
	stress	-2.73	-6.80 **	2.16	1.29	14.26	9.76	0.61	0
P3 x P10	normal	-11.19 **	-11.99 **	1.59	-1.71	14.47	2.9	-2.74 *	-3.27 *
	stress	-8.98 **	-9.07 **	3.24	1.68	18.06 *	11.01	0.45	-0.6

P4 x P5	normal	0.16	-0.9	0.47	-1.16	-10.63	-16.91	1.23	0.82
	stress	1.42	1.41	1.52	-1.2	-11.11	-16.16 *	0.73	-0.58
P4 x P6	normal	-3.43 *	-5.94 **	-2.85	-3.66	-0.75	-3.02	0.69	0.55
	stress	-0.9	-1.58	-1.43	-2.03	0.7	0.16	1.35	0.3
P4 x P7	normal	7.59 **	1.93	4.96	3.69	-3.03	-8.93	1.96	0.55
	stress	6.40 **	1.14	5.27	1.51	-2.38	-5.35	-0.45	-0.6
P4 x P8	normal	0.18	-1.77	6.83	4.79	6.46	3.17	-0.14	-1.08
	stress	-6.88 **	-7.69 **	6.09	2.43	19.28 **	14.04	-0.3	-0.3
P4 x P9	normal	4.40 **	2.75	8.97 *	5.6	15.43	15.26	-0.82	-1.36
	stress	5.05 **	2.79	10.93 **	5.63	12.54	10.74	-2.99 *	-3.57 *
P4 x P10	normal	-5.98 **	-9.07 **	-10.81 **	-11.79 **	33.40 **	28.91 **	-1.92	-2.45
	stress	-4.48 **	-6.41 **	-8.96 *	-12.75 **	31.07 **	30.25 **	-2.24	-2.38
P5 x P6	normal	-7.71 **	-9.16 **	12.99 **	12.08 **	-22.45 **	-26.30 **	0.55	0
	stress	-4.14 **	-4.79 **	15.66 **	13.25 **	-32.65 **	-36.14 **	-1.78	-4.06 **
P5 x P7	normal	0.82	-5.44 **	5.61	5.16	6.02	4.88	1.53	-0.27
	stress	0.26	-4.69 **	8.80 *	7.77	5.87	2.9	-1.18	-2.61
P5 x P8	normal	-8.28 **	-9.11 **	3.81	3.51	8.67	4.1	0.54	0
	stress	-4.57 **	-5.40 **	7.54	6.67	13.27	2.43	-2.2	-3.48 *
P5 x P9	normal	0.66	-1.97	7.24	5.6	8.67	1.17	-0.68	-0.82
	stress	2.57	0.37	11.54 **	9.08	16.21 *	7.95	-2.22	-4.06 **
P5 x P10	normal	-8.38 **	-10.47 **	10.70 **	10.11 *	0.12	-3.81	0.95	0.82
	stress	-4.84 **	-6.77 **	15.66 **	13.86 **	-5.31	-10.16	-2.94 *	-4.35 **
P6 x P7	normal	1.15	-6.52 **	-4.88	-5.24	5.36	1.17	0.42	-0.83
	stress	5.40 **	0.84	-2.67	-5.58	6.63	3.93	-1.2	-2.09
P6 x P8	normal	-12.84 **	-13.44 **	1.71	0.61	9.52	8.61	-2.73 *	-3.78 *
	stress	-10.34 **	-11.73 **	2.41	-0.53	16.83 *	11.12	0.15	-0.89
P6 x P9	normal	6.68 **	2.3	5.02	2.6	22.00 *	19.38	-1.78	-2.45
	stress	11.14 **	9.48 **	6.83	2.34	8.96	6.63	-0.15	-0.6
P6 x P10	normal	-16.65 **	-17.25 **	-2.46	-2.73	-6.04	-7.09	-1.23	-1.91
	stress	-11.10 **	-13.48 **	-2.04	-5.55	-17.13 *	-17.20 *	-0.6	-1.49
P7 x P8	normal	0.07	-6.93 **	5.7	4.94	7.76	4.32	2.63	0.27
	stress	1.22	-4.59 **	9.70 *	9.56 *	7.02	-0.65	-0.45	-0.6
P7 x P9	normal	16.47 **	12.05 **	9.16 *	7.05	15.86	8.96	1.11	-0.82
	stress	16.41 **	13.02 **	14.07 **	12.60 **	9.88	4.88	-0.45	-0.9
P7 x P10	normal	6.94 **	-1.84	-2.09	-2.19	6.64	3.53	1.67	-0.27
	stress	8.42 **	1.08	4.3	3.65	13.25	10.47	0.3	0.3
P8 x P9	normal	-4.12 **	-7.45 **	6.55	5.23	-4.03	-6.85	-5.29 **	-5.68 **
	stress	-1.01	-3.97 *	6.61	5.09	3.47	0.49	-1.5	-2.08
P8 x P10	normal	-3.19 *	-4.55 **	5.07	4.2	2.36	2.06	-1.49	-1.89
	stress	-1.26	-2.42	8.43 *	7.61	4.56	-0.62	-1.04	-1.19
P9 x P10	normal	-3.96 **	-8.54 **	-5.97	-7.89	-16.97	-19.65 *	-2.72 *	-2.72
	stress	-17.32 **	-20.70 **	-1.62	-2.28	-14.94 *	-16.82 *	-0.15	-0.6

Table 2: Extent of relative heterosis % (Ha) and heterobeltosis % (Hb) for grain filling period grain yield, test weight and membrane stability in 45 cross combination of wheat.

Hybrids	Env.	Grain filling Period		Grain yield		Test weight		Membrane stability	
		Ha	Hb	Ha	Hb	Ha	Hb	Ha	Hb
P1 x P2	normal	-3.8	-8.06	-10.68	-31.85	-8.86 *	-13.46 **	-14.3	-16.17
	stressed	-8.09	-11.48 *	-5.47	-9.07	-3.32	-5.47	-10.99	-11.7
P1 x P3	normal	-5.73	-6.14	-6.58	-11.19	-5.99	-6	23.11	23.01
	stressed	-7.08	-7.08	-2.68	-8.23	-14.31 **	-16.60 **	24.3	24.28
P1 x P4	normal	10.43 *	8.55	10.35	-0.46	-4.37	-9.19	42.42 **	40.62 *
	stressed	-12.17 *	-13.68 *	3.87	-0.84	-9.33 *	-13.10 *	20.33	6.75
P1 x P5	normal	16.36 **	13.27 *	-6.92	-19.8	-3.27	-4.01	-5.91	-15.77
	stressed	-4.1	-10.69 *	-20.23	-22.86	-9.12	-11.06 *	-8.38	-20.29
P1 x P6	normal	5.68	4.31	-14.09	-17.22	-2.73	-3.1	5.09	-10.35
	stressed	-7.02	-7.83	-16.62	-19.48	-13.61 **	-16.04 **	-11.89	-12.92
P1 x P7	normal	13.68 **	9.92	15.06	-2.58	1.05	-4.05	5.44	-7.78
	stressed	-2.59	-5.04	16.11	15.99	1.7	-1.92	-10.91	-11.74
P1 x P8	normal	-9.70 *	-13.71 *	35.98	9.87	13.02 **	12.80 *	15.06	-0.33
	stressed	-12.82 **	-15.70 **	18.47	14.37	-7.02	-8.18	11.69	-4.6
P1 x P9	normal	11.02 *	6.5	18.66	5.3	10.51 *	4.94	46.77 **	43.67 **
	stressed	-2.15	-5	-15.34	-24.14	-3.87	-7.14	8.75	-2.3
P1 x P10	normal	-6.44	-9.17	12.36	-0.99	-2.9	-7.64	11.1	-3.04
	stressed	-11.30 *	-12.82 *	-11.08	-14.35	-11.85 *	-15.24 **	3.09	-14.69
P2 x P3	normal	5.88	1.61	15.16	6.32	-4.86	-9.65 *	12.43	10.06
	stressed	-1.28	-4.92	-2.69	-11.52	-9.02	-9.45	9.76	8.87
P2 x P4	normal	-9.54 *	-12.10 *	30.6	27.27	-1.26	-1.28	42.24 **	37.42 *
	stressed	-13.81 **	-15.57 **	-16.63	-17.29	-3.31	-5.27	25.29 *	11.93

P2 x P5	normal	11.69 *	4.03	27.81	24.48	4.48	-0.07	7.64	-1.69
	stressed	-11.46 *	-14.50 **	6.59	-0.71	-6.61	-6.68	5.54	-7.55
P2 x P6	normal	2.5	-0.81	-7.45	-3.2	-6.14	-11.20 *	70.78 **	43.06 **
	stressed	-2.11	-4.92	-17.33	-17.67	-17.22 **	-21.28 **	68.08 **	64.79 **
P2 x P7	normal	-2.86	-4.03	37.88	31.6	0.32	0.32	27.75	9.64
	stressed	-10.37 *	-11.48 *	13.06	8.87	6.88	5.38	12.51	12.35
P2 x P8	normal	-8.87	-8.87	50.24	35.76	9.86 *	4.12	-26.28 *	-34.90 **
	stressed	-10.29 *	-10.66 *	-1.43	-8.33	-1.97	-2.94	-7.52	-20.47
P2 x P9	normal	-6.07	-6.45	36.09	35.04	2.73	2.72	-13.87	-17.49
	stressed	-12.40 **	-13.11 *	4.37	-3.07	6.65	5.33	8.76	-1.59
P2 x P10	normal	0	-1.61	-11.51	-11.55	-8	-8.17	-12.3	-21.96
	stressed	-12.13 *	-13.93 **	-7.31	-13.99	-10.02 *	-11.55 *	-18.02	-31.72 **
P3 x P4	normal	13.42 **	11.97 *	15.03	8.82	-0.32	-5.33	-7.06	-8.3
	stressed	-0.87	-2.56	9.85	-0.84	2.67	1.05	-16.63	-26.05 *
P3 x P5	normal	13.12 *	9.65	32	18.96	13.53 **	12.67 *	18.37	6.05
	stressed	-15.57 **	-21.37 **	15.46	12.48	2.6	2.04	-9.37	-21.16
P3 x P6	normal	13.91 **	12.93 *	-32.71	-31.74	3.5	3.1	66.50 **	41.95 **
	stressed	8.77*	7.83	-13.12	-20.71	7.72	1.98	42.78 **	41.12 *
P3 x P7	normal	-0.43	-3.31	-3.41	-14.55	0.04	-5.01	41.08 **	23.29
	stressed	-6.9	-9.24	4.25	-1.8	-5.84	-6.73	25.93	24.73
P3 x P8	normal	3.36	-0.81	38.63	16.68	16.14 **	15.91 **	-4.75	-17.43
	stressed	1.71	-1.65	11.27	8.58	-9.82 *	-11.13 *	-6.1	-19.8
P3 x P9	normal	0.42	-3.25	9.76	2.06	-10.01 *	-14.54 **	17.63	15.05
	stressed	-3.86	-6.67	7.73	-8.34	-18.66 **	-19.29 **	3.15	-7.34
P3 x P10	normal	0	-2.5	23.65	14.11	2.07	-2.9	9.17	-4.65
	stressed	0	-1.71	30.63	27.76	2.86	1.58	-0.41	-17.59
P4 x P5	normal	6.25	1.71	22.46	0.86	-9.24 *	-13.17 **	16.24	2.91
	stressed	-5.65	-10.69 *	22.93	13.66	-7.15	-9.11	-2.98	-5.12
P4 x P6	normal	4.72	4.27	15.76	8.07	-12.59 **	-17.29 **	7.96	-6.91
	stressed	-7.76	-8.55	-8.21	-9.31	-9.80 *	-15.88 **	-19.59	-29.39 *
P4 x P7	normal	10.08 *	8.26	32.68	7.14	-7.22	-7.24	10.97	-1.88
	stressed	-5.93	-6.72	10.6	5.68	-10.36 *	-10.94 *	-18.85	-27.41 *
P4 x P8	normal	0.41	-2.42	43.19	9.64	11.00 *	5.21	8.96	-6.61
	stressed	-11.76 *	-13.22 *	13.96	5.2	9.47 *	6.2	-1.49	-5.67
P4 x P9	normal	10.00 *	7.32	25.84	7.14	-3.31	-3.32	9.39	8.43
	stressed	-13.08 **	-14.17 **	-2.94	-9.18	-12.96 **	-13.68 **	-17.84	-19
P4 x P10	normal	1.27	0	28.88	8.86	-8.14	-8.3	-1.51	-14.97
	stressed	-6.84	-6.84	14.21	5.2	-8.26	-8.58	-18.27	-24.56 *
P5 x P6	normal	11.21 *	6.9	19.98	22.54	1.79	0.63	-14.92	-33.71 **
	stressed	-13.01 **	-18.32 **	2.55	-4.11	-8.88	-13.29 *	-26.65 *	-36.82 **
P5 x P7	normal	12.28 *	5.79	32.02	29.3	1.27	-3.14	-26.54	-41.52 **
	stressed	-4	-8.4	9.89	6.16	-5.93	-7.33	-38.34 **	-45.92 **
P5 x P8	normal	8.23	0.81	47.08	36.17	10.51 *	9.46	12.38	8.26
	stressed	-14.29 **	-17.56 **	9.83	9.63	-4.56	-5.43	3.25	1.04
P5 x P9	normal	-4.35	-10.57 *	32.63	28.21	4.56	0.02	11.44	-2.1
	stressed	-17.93 **	-21.37 **	8.99	-5.18	8.2	6.77	3.28	-0.39
P5 x P10	normal	5.73	0	30.9	27.54	4.18	-0.18	-26.37 *	-28.47 *
	stressed	-19.35 **	-23.66 **	-7.64	-8.02	0.74	-1.05	-36.06 **	-39.73 **
P6 x P7	normal	0.42	-1.65	19.33	19.67	4.53	-1.11	-11.68	-14.21
	stressed	-16.24 **	-17.65 **	-19.27	-21.95	-8.47	-14.12 **	-33.47 *	-34.87 *
P6 x P8	normal	-1.67	-4.84	4.81	0.08	14.93 **	14.72 **	-5.59	-28.37 *
	stressed	-2.54	-4.96	-7.11	-13.28	17.65*	12.96*	-16.51	-29.38 **
P6 x P9	normal	2.09	-0.81	-32.84	-29.26	3.08	-2.47	30.6	13.46
	stressed	-2.98	-5	-33.95	-38.89	-17.36 **	-22.33 **	-1.33	-12.29
P6 x P10	normal	0.85	-0.83	-10.47	-6.39	4.16	-1.28	24.77	-4.77
	stressed	-8.62	-9.4	-16.21	-21.95	-9.69 *	-15.51 **	2.19	-16.22
P7 x P8	normal	3.67	2.42	14.92	8.5	0.67	-4.59	27.85 *	-1
	stressed	-10.83 *	-11.57 *	11.45	7.49	-12.71 **	-14.78 **	11.55	-3.96
P7 x P9	normal	-0.82	-1.63	-3.02	-8.12	-23.37 **	-23.38 **	12.78	0.5
	stressed	-16.32 **	-16.67 **	-30.7	-37.84	-22.10 **	-22.24 **	-14.24	-22.31
P7 x P10	normal	1.24	0.83	24.66	19.03	1.94	1.74	14.52	-10.76
	stressed	-4.24	-5.04	24.12	19.43	5.93	5.6	-6.68	-22.19 *
P8 x P9	normal	-10.93 *	-11.29 *	7.43	-3.59	-1.29	-6.44	11.9	-4.79
	stressed	-9.54 *	-9.92	-22.38	-32.57	-23.96 **	-25.63 **	-2.51	-7.92
P8 x P10	normal	1.64	0	-17.06	-25.02	-8.46	-13.09 **	12.83	11.85
	stressed	-9.24	-10.74 *	-16.93	-17.13	-10.33 *	-12.72 *	9.38	5.26
P9 x P10	normal	-2.06	-3.25	-20.12	-20.77	-5.72	-5.89	-11.45	-24.12 *
	stressed	-7.17	-8.33	-29.51	-38.89	-9.92 *	-10.35 *	-27.88 **	-34.29 **

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