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Heterotic performance of Morpho-Physiological Traits for Heat Tolerance in Bread Wheat (*Triticum aestivum* L.)

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ABSTRACT: Globally, wheat (*Triticum aestivum* L.) is the most important cereal. There are several challenges of wheat crop production due to climatic change, and among them, heat stress is a major one. A complete set of thirty-nine F1s, thirteen lines and three testers and two standard checks were evaluated in the RBD with three replications under two different environments, i.e., timely and late sown (E1 and E2). The different morpho-physiological characters like days to 75 per cent heading, days to maturity, plant height, spike length, relative injury (%) and grain yield per plantwere evaluated to estimate the heterosis level of different cross combinations.The standard heterosis over check UP2338, the highest negative significant heterosis was reflected in WH1124 × HD3059 (-6.96 %, -3.98 %) in E1 and E2, respectively, concerning days to 75 % heading. The highest negative significant heterosis over check DPW621-50 was observed in WH1124 × HD3059 (-5.58 %) and UP2843 × HD2967 (-3.52 %) in E1 and E2, respectively. The cross JOB666 × HD3059 (106.25 %) and WH1124 × HD2967 (42.86 %) was found significant positive heterosis over check parent (UP2338) in E1 and E2, respectively, for grain yield per plant. However, the cross JOB666 × HD3059 (93.05 %) and WH1124 × HD2967 (55.74 %) showed the highest significant positive heterosis over check parent (DBW621-50) in E1 and E2.These heterotic crosses can be extensively utilized to develop new superior heterotic segregants for grain yield in further breeding programmes. Heterosis estimation is important for varietal development.

Keywords: Heterosis, Heat tolerance, Wheat, Morpho-physiological traits, Wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.), the most important cereal, belongs to the grass family Poaceae worldwide and hexaploidy in nature, consisting of the three genome AABBDD (Kumar *et al.,* 2019). The total global production of wheat has been reached upto 757.6 million tonnes with an annual consumption of 734 million tonnes (FAO, 2018). In India, the cultivated wheat area is 31.45 mha with production and productivity of 107.59 mt and34.21 q/ha, respectively (Indian Institute of Wheat and Barley Research Annual Report, 2019-20). The stability in the production is essential to feed the growing population, and it depends on the genetic potential of a genotype and its interaction with the environment (Kumar *et al*., 2015a). The primary threat of wheat production is global climate changes heat stress, particularly during the different growth stages. In India, the main concerns of heat stress are at the reproductive stage due to climate change. Since, in Gangetic plain, winter is short, heat stress induction is early; therefore, high temperature at the time of grain filling stage hampered the yield. During the flowering and grain filling stage, wheat is generally exposed to short periods of high temperature (33–40˚C) (Talukder *et al*., 2014). After anthesis, it was observed that after more than 3-days of exposure to high temperature (max. 40˚C), there is a reduction in grain numbers and weight and an increased number of deformed grains (Stones *et al*., 1995). There is a need to identify the heat-tolerant and susceptible genotype with either morphological or physiological markers. Terminal heat stress-tolerant or susceptible genotype can be determined based on physiological responses of different wheat traits (Kumar *et al*., 2016).

In the present situation, the population growth is very high, and the resources are very limited. Due to the narrow genetic base of wheat cultivars, production and productivity are stagnant. There is an urgent need to create variability so that heterosis can be exploited. Heterosis breeding provides us with a way to break the yield barriers. The total wheat production can be increased only when the new cultivars have a broader genetic base and promising productivity potential under different climatic conditions. In the hybridization program for yield and its attributes of wheat, extraction of systematic information regarding the nature of parents combining ability(Kumar *et al*., 2015c and 2015d) and the nature of gene action involved in expression for different morpho-physiological traits affected by heat stress. The genetic dissection of quantitative traits, especially those related to yield and stress tolerance, is required to enhance yields. Keep these things in view; there is a need to determine superior heterotic crosses for yield and yield contributing traits. Therefore, our present hypothesis is to study the heterotic performance of different cross combinations and estimate the extent of heterosis for different morpho-physiological traits under normal and heat stress conditions.

MATERIALS AND METHODS

The present experiment was conducted at N. E. Borlaug, Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar. India. The experimental materials were generated through line x tester mating during *Rabi* 2013-14, and their progenies were evaluated in the Rabi season 2014-15. Thirteen genetically diverse wheat varieties for heat tolerance *viz*. HD3091, DBW90, UP2843, WH1124, HPW211, WH1021, CBW12, MASC6272, JOB666, HD2329, WAXWING, HD2891, HD2961 and three testers HD2967, WH1105, HD3059 were crossed in line x tester mating design excluding reciprocals. A complete set of thirty-nine F_1s, thirteen lines and three testers along with two standard checks (DPW 621-50, UP 2338) were evaluated in the Randomized Block Design (RBD) with three replications during rabi 2014-15 under two different conditions, i.e., timely (E1) and late sown (E2). Each plot consisted of 2 rows of 1 m length with plant geometry (row to row and plant to plant) 20 cm x 10 cm, respectively. To estimate the heterotic performance of different genotypes of wheat for morpho-physiological traits like days to 75 per heading, days to maturity, plant height (cm), spike length(cm), grain yield per plant(g) and relative injury (%) paying to heat tolerance. The procedure and formula of Blum and Ebercon (1981) were followed for the estimation of relative injury (%):

RI (%) = {1- [1-(T1/T2)/1-(C1/C2)]} X 100

T and C refer to treatment and control, respectively, and 1 and 2 refer to initial and final conductance reading.

Heterosis is expressed as a per cent increase or decrease in the performance of F_1 hybrid over the mid-parent (average or relative heterosis), better parent (heterobeltiosis) and check parent (standard heterosis). It was computed for each character using the following formula:

$$\text{Relative heterosis} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis} = \frac{\overline{F_1} - \overline{CP}}{\overline{CP}} \times 100$$

Where, $\overline{F_1}$ =Mean performance of F_1 hybrid, $\overline{P_1}$ =Mean performance of parent one, $\overline{P_2}$ =Mean performance of parent two, $\overline{BP}$ =Mean performance of better parent, $\overline{CP}$ =Mean performance of check parent, $\overline{MP}$ =Mean mid-parental value, i.e. $(P_1+P_2)/2$.

RESULTS AND DISCUSSION

The mean values of six characters of F_1 hybrids were compared with the mid-parent values, better parent and standard checks. Estimates of heterosis are defined as an increase or decrease in percentage over better parent (heterobeltiosis), mid parent (relative heterosis) and check variety (standard heterosis). It is listed herein, and tables provide data for different characters.

A. Days to 75% heading

The result for estimation of relative heterosis for the trait days to 75% heading, the highest significant positive heterosis over mid parent was found of the cross MACS6272 × HD3059 (3.23 %) in E1 and the cross WAXWING × HD3059 (3.27 %) in E2.The highest negative significant heterosis was observed in MACS6272 × HD2967 (-4.24 %) and HD2891 × HD2967 (-3.49 %) in E1 and E2, respectively. These findings follow the earlier observation of Esmail (2002), Akinici (2009) and Devi *et al*. (2013). However, the highest negative significant heterosis over a better parent was exhibited in UP2843 × HD2967 (-6.57 %) and UP2843 × HD2967 (-6.41%) in E1 and E2, respectively.

The cross WAXWING × HD3059 (4.87 %, 4.41 %) exhibited significant positive heterosis over check parent UP2338 and DPW621-50 in E2. However, the highest negative significant heterosis was reflected in WH1124 × HD3059 (-6.96 %, -3.98 %) in E1 and E2, respectively. Similar results were supported by Mahantashivayogayya (2002). The highest negative significant heterosis was observed in WH1124 × HD3059 (-5.58 %) and UP2843 × HD2967 (-3.52 %) in E1 and E2, respectively.

The key emphasis is on developing short-term genotypes in high-intensity crop rotation areas in northern India's Gangetic region, where most wheat areas are under guaranteed irrigation. The importance of negative heterosis for days to 75% heading has been highlighted. The highest negative heterosis for days to 75 per cent heading in E1 and E2 exhibited by the cross MACS6272 × HD2967 for relative heterosis, UP2843 × HD2967 for heterobeltiosis and WH1124 × HD3059 for standard heterosis over check UP2338 exhibited. WH1124 × HD3059 for standard heterosis over control DPW621-50 in both E1 and E2 showed the highest negative heterosis for the trait (Table 1). These cross combinations can be utilized to develop a new cultivar as per the need of hours.

B. Days to maturity

The highest significant positive relative heterosis was found in the cross MACS6272 × WH1105 (3.81 %) in E1, and the cross DBW90 × HD3059 (2.60%) was exhibited in E2 environment for days to maturity. The cross MACS6272 × WH1105 (3.67 %) was found the highest significant positive heterobeltiosis for days to maturity in E1, whereas, in E2, CBW12 × HD2967 (-2.99 %) showed the highest negative significant heterosis over the better parent.

Table 1: Estimation of heterosis for days to 75 % heading in timely sown and late sown condition.

Crosses	Days to 75% heading							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	0.77	0.97	-4.40**	-2.97*	-2.21	-1.34	-2.21	-2.64
HD3091 × WH1105	0.00	0.58	-4.03**	-2.60*	-1.35	-1.35	-3.10*	-3.52*
DBW90 × HD3059	0.39	1.17	-5.13**	-3.72**	-1.77	0.23	-1.77	-2.20
DBW90 × WH1105	-0.38	1.16	-4.40**	-2.97*	-0.90	0.23	-2.65	-3.08*
DBW90 × HD2967	-5.84**	-2.27*	-5.49**	-4.09**	-5.13**	-1.55	-1.77	-2.20
UP2843 × HD3059	0.00	1.78	-5.49**	-4.09**	-1.77	0.45	-1.77	-2.20
UP2843 × WH1105	-1.53	0.98	-5.49**	-4.09**	1.80	3.20*	0.00	-0.44
UP2843 × HD2967	-6.57**	-2.10	-6.23**	-4.83**	-6.41**	-2.67*	-3.10*	-3.52*
WH1124 × HD3059	-1.55	-0.59	-6.96**	-5.58**	-3.98**	-2.25	-3.98**	-4.41**
WH1124 × WH1105	-1.53	0.19	-5.49**	-4.09**	0.45	1.36	-1.33	-1.76
WH1124 × HD2967	-5.84**	-2.09	-5.49**	-4.09**	-4.70**	-1.33	-1.33	-1.76
HPW211 × HD3059	0.00	0.58	-4.40**	-2.97*	-1.33	0.00	-1.33	-1.76
HPW211 × WH1105	-1.91	-1.72	-5.86**	-4.46**	0.45	0.90	-1.33	-1.76
HPW211xHD2967	-3.65**	-1.31	-3.30*	-1.86	-4.70**	-1.76	-1.33	-1.76
WH1021 × HD3059	0.39	0.58	-5.13**	-3.72**	-2.65	-2.00	-2.65	-3.08*
WH1021 × WH1105	-2.67*	-1.73	-6.59**	-5.20**	-0.90	-0.67	-2.21	-2.64
CBW12 × HD3059	-3.30*	-0.56	-3.30*	-1.86	-1.32	-1.10	-0.88	-1.32
CBW12 × WH1105	-5.86**	-3.93**	-5.86**	-4.46**	-1.76	-0.67	-1.33	-1.76
CBW12 × HD2967	-1.46	-1.28	-1.10	0.37	-2.56	-1.08	0.88	0.44
MACS6272× HD3059	1.12	3.23**	-0.37	1.12	-2.17	-1.32	-0.44	-0.88
MACS6272× WH1105	1.12	2.45*	-0.37	1.12	-0.43	1.33	1.33	0.88
MACS6272× HD2967	-5.11**	-4.24**	-4.76**	-3.35*	-0.43	0.43	3.10*	2.64
JOB666 × HD3059	1.15	1.73	-3.30*	-1.86	1.32	1.76	2.21	1.76
JOB666 × WH1105	-0.38	-0.19	-4.40**	-2.97*	0.00	1.33	0.88	0.44
HD2329 × HD3059	-4.76**	-2.07	-4.76**	-3.35*	-2.17	-1.32	-0.44	-0.88
HD2329 × WH1105	-5.86**	-3.93**	-5.86**	-4.46**	-2.17	-0.44	-0.44	-0.88
HD2329 × HD2967	-2.19	-2.01	-1.83	-0.37	-0.43	0.43	3.10*	2.64
WAXWING× HD3059	0.00	2.82*	0.00	1.49	1.72	3.27*	4.87**	4.41**
WAXWING× WH1105	-2.20	-0.19	-2.20	-0.74	-3.00*	-0.66	0.00	-0.44
WAXWING× HD2967	0.00	0.18	0.37	1.86	0.00	0.21	3.54*	3.08*
HD2891 × HD3059	-0.38	0.77	-3.66**	-2.23	-1.77	-1.33	-1.77	-2.20
HD2891 × WH1105	-1.14	-0.76	-4.40**	-2.97*	-1.34	-0.90	-2.21	-2.64
HD2891 × HD2967	-1.82	0.00	-1.47	0.00	-5.56**	-3.49**	-2.21	-2.64
HD2961 × HD3059	-2.95*	-0.57	-3.66**	-2.23	0.00	0.44	0.88	0.44
HD2961 × WH1105	-3.69**	-2.06	-4.40**	-2.97*	-2.19	-0.89	-1.33	-1.76
HD2961 × HD2967	-1.82	-1.28	-1.47	0.00	-2.14	-0.87	1.33	0.88

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

The significant positive standard heterosis for check parent UP2338 was estimated in crosses WAXWING × HD3059, WAXWING × WH1105 (3.99 %) and UP2843 × WH1105 (3.37 %) in E2. At the same time, cross DBW90 × HD2967 (-3.32 %) showed the highest negative significant heterosis over check parent UP2338 in E2 only for days to maturity. Standard heterosis did not observe over the pooled environment. The present findings are in close agreement with the results obtained by Singh and Singh (2003) and Khatun *et al.* (2010). The best heterotic cross over check parent DPW621-50 in the desired direction over the environment was the cross WH1124 × HD3059 (-2.22 per cent) for days to maturity.

Early and extra-early varieties development seems to prioritise the wheat varieties in an intensive cropping system (sugarcane-wheat, potato-wheat, rice-wheat, cotton-wheat). In this context, negative heterotic response for maturity traits is desirable. The maturity is forced by temperature during March-April in northern India. The onset of high temperature during late February may result in shrivelling of grains and consequently reduce wheat production. Therefore, earliness is essentially a mandate for maturity. There were no significant negative estimates of relative heterosis observed in E1 and E2.The cross CBW12 × HD2967 in E2 for Heterobeltiosis; DBW90 × HD2967 for standard heterosis over check DBW 17 in E2 (Table 2). Similar results had been reported by Singh and Singh (2003), Sayed (2004) and Inamullah *et al.* (2006), which supports the present findings.

C. Plant height (cm)

The relative heterosis was calculated, and the highest significant positive was observed over mid parent in the cross CBW12 × WH1105 (7.60 %) and HD2891 × HD3059 (9.22 %) in E1 in E2, respectively for plant height. However, the highest negative significant relative heterosis in the cross HD2329 × HD2967 (-10.89 %) in E2. The desirable heterosis in plant height is in the negative direction. Hence, the best desirable heterotic cross was HD2329 × HD2967. Heterobeltiosis for plant height was computed, and none of the crosses had significant positive heterosis over better parents in E1 and E2. However, the highest negative significant heterosis was observed in crosses HPW211 × HD2967 (-10.15 %) and HD2329 × HD2967 (-13.64 %) in E1 and E2, respectively. The most desirable heterotic crosses (HPW211 × HD2967 and HD2329 × HD2967) were found in E1 and E2.

Table 2: Estimation of heterosis for days to maturity in timely sown and late sown condition.

Crosses	Days to maturity							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	2.36	2.63	-0.26	0.52	0.60	0.60	2.15	0.00
HD3091 × WH1105	0.00	0.26	-2.56	-1.80	-0.60	-0.60	0.92	-1.20
DBW90 × HD3059	0.00	0.53	-2.56	-1.80	1.51	2.60*	3.07*	0.90
DBW90 × WH1105	0.00	0.53	-2.56	-1.80	-1.21	-0.15	0.31	-1.80
DBW90 × HD2967	-2.58	-1.18	-3.32*	-2.58	-1.80	-0.30	0.61	-1.50
UP2843 × HD3059	1.84	1.84	-0.77	0.00	-2.40	-2.11	-0.31	-2.40
UP2843 × WH1105	1.84	1.84	-0.77	0.00	1.20	1.51	3.37*	1.20
UP2843 × HD2967	-2.06	-1.17	-2.81	-2.06	0.00	0.15	2.45	0.30
WH1124 × HD3059	-0.52	-0.39	-2.81	-2.06	-1.81	-0.76	-0.31	-2.40
WH1124 × WH1105	-0.79	-0.66	-3.07	-2.32	0.91	1.98	2.45	0.30
WH1124 × HD2967	-2.32	-1.56	-3.07	-2.32	-2.10	-0.61	0.31	-1.80
HPW211 × HD3059	0.00	0.13	-2.56	-1.80	0.30	0.45	2.15	0.00
HPW211 × WH1105	2.10	2.23	-0.51	0.26	-1.20	-1.06	0.61	-1.50
HPW211xHD2967	-1.29	-0.26	-2.05	-1.29	-2.10	-1.80	0.31	-1.80
WH1021 × HD3059	-0.26	0.53	-2.81	-2.06	1.21	1.52	2.76	0.60
WH1021 × WH1105	-0.52	0.26	-3.07	-2.32	-0.30	0.00	1.23	-0.90
CBW12 × HD3059	-0.26	0.13	-2.05	-1.29	-0.60	0.61	0.92	-1.20
CBW12 × WH1105	0.26	0.65	-1.53	-0.77	-2.11	-0.92	-0.61	-2.70
CBW12 × HD2967	-0.77	-0.26	-1.53	-0.77	-2.99*	-1.37	-0.61	-2.70
MACS6272× HD3059	1.31	1.45	-1.28	-0.52	0.00	0.30	2.15	0.00
MACS6272× WH1105	3.67*	3.81**	1.02	1.80	0.60	0.90	2.76	0.60
MACS6272× HD2967	-0.52	0.52	-1.28	-0.52	-0.60	-0.45	1.84	-0.30
JOB666 × HD3059	2.31	3.50*	2.05	2.84	1.21	2.13	2.76	0.60
JOB666 × WH1105	0.00	1.17	-0.26	0.52	1.21	2.13	2.76	0.60
HD2329 × HD3059	1.84	1.97	-0.77	0.00	-0.60	-0.30	1.53	-0.60
HD2329 × WH1105	-0.52	-0.39	-3.07	-2.32	-2.70	-2.41	-0.61	-2.70
HD2329 × HD2967	-0.77	0.26	-1.53	-0.77	-2.10	-1.95	0.31	-1.80
WAXWING× HD3059	2.05	3.37*	2.05	2.84	0.59	1.50	3.99**	1.80
WAXWING× WH1105	-0.51	0.78	-0.51	0.26	0.59	1.50	3.99**	1.80
WAXWING× HD2967	-1.28	-0.90	-1.28	-0.52	0.00	0.45	3.37*	1.20
HD2891 × HD3059	-0.52	-0.26	-3.07	-2.32	0.00	0.91	1.53	-0.60
HD2891 × WH1105	-0.26	0.00	-2.81	-2.06	-1.51	-0.61	0.00	-2.10
HD2891 × HD2967	-1.55	-0.39	-2.30	-1.55	-2.69	-1.37	-0.31	-2.40
HD2961 × HD3059	-0.52	0.39	-1.28	-0.52	-1.51	-0.91	0.00	-2.10
HD2961 × WH1105	-0.26	0.65	-1.02	-0.26	-0.30	0.30	1.23	-0.90
HD2961 × HD2967	0.52	0.52	-0.26	0.52	-0.60	0.45	1.84	-0.30

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

The highest negative significant standard heterosis (UP2338) for plant height was observed in the crosses WAXWING × HD2967 (-9.53 %) and HD3091 × HD3059 in E1 and E2, respectively. Whereas, over check parent DPW621-50, the crosses HPW211 × HD3059 (12.26 %) and MACS6272 × WH1105 (13.30 %) were significant with positive heterosis in E1 and E2, respectively.

The prime objective is to develop dwarf varieties with logging resistance, high fertilizer responsiveness, and short and stiff strawed. Thus, significant negative heterosis for plant height is desirable in a high yielding modern variety. The highest negative relative heterosis was observed with cross HD2329 × HD2967 in E2. The highest negative heterobeltiosis was found with cross HPW211 × HD2967 and HD2329 × HD2967, standard heterosis for check parent UP2338 with cross WAXWING × HD2967 and HD2329 × HD2967 in E1 and E2, respectively for plant height (Table 3). Similar results were reported by Afiah and Sattar (1998), Afiah *et al.* (2000), Budak (2001), Mahantashivayogayya (2002), Esmail (2002), Zhao *et al.* (2009) and Singh *et al.* (2012) that supports the present findings.

D. Spike length (cm)

The relative heterosis was calculated for spike length,and the highest significance with positive heterosis over mid parent was shown in cross HD2891 × HD2967 (22.51 %) and CBW12 × HD2967 (23.27 %) in E1 and E2, respectively. However, in cross HD2961× HD2967 (-17.56 per cent), the highest negative significant heterosis in E1 was observed. For spike length, the desirable heterotic performance was found in cross HD2891 × HD2967 and CBW12 × HD2967 in E1 and E2. The cross HD2891 × HD2967 (19.62 %) was found with the highest significant positive heterosis over better parents in E1. However, the highest negative significant heterobeltios is observed in HD2961 × HD2967 (-24.54 %) in E1 and E2, negatively significant crosses were not found.

The highest significant positive standard heterosis over check parent UP2338 for spike length was found in the cross HD2891 × HD2967 (9.42 %) in E1. There was not a positive significant heterotic cross in E2. However, the highest negative significant heterosis was observed in HD2891 × WH1105 (-14.69 %) and MACS6272 × HD2967 (-28.04 %) in E1 E2, respectively. Bao *et al*. (2009) also observed similar results in their previous work. The cross HD2891 × HD2967 (18.11 %) reflected the highest significant positive heterosis over check parent (DPW621-50) in E1 for spike length. However, the highest negative significant heterosis was observed in HD2891 × WH1105 (-15.63 %) in E1 only.

Table 3: Estimation of heterosis for plant height in timely sown and late sown condition.

Crosses	Plant height (cm)							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	1.11	2.15	-6.48	-0.39	1.06	1.67	-9.69*	-4.00
HD3091 × WH1105	4.03	5.15	-3.68	2.59	5.03	7.57	-1.48	4.73
DBW90 × HD3059	-2.40	0.27	-4.64	1.57	2.19	7.65	0.40	6.73
DBW90 × WH1105	-0.32	2.36	-2.60	3.74	0.00	2.31	-1.75	4.43
DBW90 × HD2967	4.02	6.03	1.63	8.26	1.64	1.71	-0.14	6.15
UP2843 × HD3059	-3.52	-1.69	-7.32	-1.28	-0.95	4.54	-2.29	3.87
UP2843 × WH1105	-1.86	-0.05	-5.72	0.42	-6.68	-4.33	-7.94	-2.14
UP2843 × HD2967	-1.15	-0.08	-5.04	1.15	0.14	0.41	-1.22	5.00
WH1124 × HD3059	-0.84	2.47	-1.96	4.43	1.14	4.50	-4.58	1.43
WH1124 × WH1105	-5.77	-2.68	-6.84	-0.76	3.29	3.58	-2.56	3.58
WH1124 × HD2967	-1.57	0.91	-2.69	3.65	3.29	5.32	1.34	7.73
HPW211 × HD3059	-3.71	4.38	5.39	12.26**	-5.36	4.18	2.29	8.73
HPW211 × WH1105	-5.41	2.48	3.53	10.28*	-1.99	4.93	5.92	12.59*
HPW211xHD2967	-10.15**	-3.32	-1.65	4.76	-5.85	-1.31	1.75	8.15
WH1021 × HD3059	1.46	4.66	-0.05	6.46	-3.23	4.82	0.94	7.29
WH1021 × WH1105	3.87	7.09	2.32	8.99*	-2.45	2.72	1.75	8.15
CBW12 × HD3059	1.74	3.11	-3.33	2.97	-3.25	0.44	-7.80	-2.00
CBW12 × WH1105	6.22	7.60*	0.93	7.51	2.83	3.63	-2.02	4.15
CBW12 × HD2967	2.00	2.54	-3.09	3.23	5.35	6.89	3.36	9.87
MACS6272× HD3059	-5.24	-1.83	-5.81	0.33	-6.49	2.82	0.81	7.15
MACS6272× WH1105	-7.82	-4.56	-8.38*	-2.41	-1.12	5.74	6.59	13.30*
MACS6272× HD2967	0.16	2.95	-0.45	6.04	-2.62	1.96	4.98	11.59*
JOB666 × HD3059	-5.84	-0.86	-3.19	3.12	-4.94	-0.65	-8.14	-2.36
JOB666 × WH1105	-2.11	3.01	0.64	7.20	2.65	4.17	-0.81	5.44
HD2329 × HD3059	0.62	3.66	-1.15	5.30	-3.22	4.95	1.21	7.58
HD2329 × WH1105	1.90	4.92	0.11	6.64	-3.35	1.90	1.07	7.44
HD2329 × HD2967	-1.19	0.99	-2.92	3.41	-13.64**	-10.89**	-9.69*	-4.00
WAXWING× HD3059	-5.32	-2.50	-7.05	-0.99	-7.42	-2.67	-9.42	-3.72
WAXWING× WH1105	-7.57	-4.86	-9.26*	-3.34	0.00	2.11	-2.15	4.01
WAXWING× HD2967	-7.85	-5.85	-9.53*	-3.63	-5.42	-5.29	-7.20	-1.36
HD2891 × HD3059	6.50	7.33	-1.50	4.92	2.12	9.22*	3.63	10.16*
HD2891 × WH1105	4.84	5.71	-2.94	3.39	-3.84	-0.07	-2.42	3.72
HD2891 × HD2967	5.05	6.71	-1.26	5.18	1.73	3.44	3.23	9.73
HD2961 × HD3059	0.03	0.09	-7.48	-1.45	-7.51	-2.38	-8.75	-3.00
HD2961 × WH1105	7.21	7.32	-0.74	5.73	4.91	7.55	3.50	10.01
HD2961 × HD2967	3.59	4.49	-2.62	3.72	1.77	2.05	0.40	6.73

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

Spike length is one of the most crucial yield components contributing to productivity and should be considered during selection. Thus, positive heterosis for spike length is desirable. The highest positive relative heterosis was shown by cross HD2891 × HD2967 and CBW12 × HD2967, heterobeltiosis by cross HD2891 × HD2967 in E1. Standard heterosis over the check (UP2338) by cross HD2891 × HD2967 in E1 and standard heterosis over the check (DPW621-50) by cross HD2891 × HD2967 in E1 (Table 4). Singh and Singh (2003), Inamullah *et al.* (2006), Mahmood *et al.* (2006), Ribadia *et al.* (2007) and Bao *et al.* (2009) had reported the same results, which support the present findings (Table 4).

E. Relative injury (%)

The crosses HD3091 × WH1105 (22.57 %) andHD2329 × WH1105 (10.72 %) had found the highest significant positive heterosis over mid parent in E1 and E2 for relative injury (%). The highest negative significant heterosis over mid parent was estimated in MACS6272 × WH1105 (-79.74 %) in E1. While, among E2 crosses, the highest negative significance was found in WAXWING × WH1105 (-73.54 %). The highest positive significant heterobeltiosis was exhibited in the cross HD3091 × WH1105 (7.97 %) in E1. In the cross MACS6272 × WH1105 (-81.34 %) were reflected the highest negative significant heterobeltiosis observed in E1 and WAXWING × WH1105 (-74.34 %) in E2 for relative injury (%).Standard heterosis for relative injury (%) ranged from -44.51 to 221.03 and-23.98 to 169.05 in E1 and E2. In the crosses, HD3091 × WH1105 (221.03 %) and HD3091 × WH1105 (169.05 %) estimated the highest significant positive standard heterosis over check parent (UP2338) in E1 and E2, respectively.

Table 4: Estimation of heterosis for spike length in timely sown and late sown condition.

Crosses	Spike length (cm)							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	-1.72	2.17	-1.82	-2.91	-7.45	-1.47	-23.75**	-10.85
HD3091 × WH1105	-7.87	-4.10	-7.70	-8.72	-8.75	-1.64	-22.79**	-9.72
DBW90 × HD3059	-14.22*	-13.59*	-14.31*	-15.25*	-8.88	-2.15	-24.93**	-12.23
DBW90 × WH1105	-0.27	0.60	-0.08	-1.18	-6.43	1.72	-20.83**	-7.43
DBW90 × HD2967	-3.56	-1.91	-5.06	-6.11	-10.63	-4.52	-27.18**	-14.86
UP2843 × HD3059	-2.51	1.43	-2.61	-3.69	-6.41	-0.95	-22.90**	-9.84
UP2843 × WH1105	-5.05	-1.07	-4.87	-5.92	-13.09	-6.86	-26.46**	-14.01
UP2843 × HD2967	-4.52	-2.99	-9.17	-10.17	-9.94	-5.18	-26.62**	-14.20
WH1124 × HD3059	2.73	6.12	9.63	8.42	-5.21	1.46	-21.90**	-8.68
WH1124 × WH1105	-4.77	-1.76	1.63	0.51	-4.82	3.14	-19.46**	-5.83
WH1124 × HD2967	-0.94	4.74	5.71	4.55	8.69	15.73	-11.45	3.54
HPW211 × HD3059	-1.17	0.05	1.20	0.08	7.84	12.97	-11.15	3.89
HPW211 × WH1105	-0.48	0.60	1.90	0.78	2.98	9.24	-12.87	1.88
HPW211xHD2967	11.40	15.49**	14.06*	12.81*	-9.51	-5.71	-26.27**	-13.79
WH1021 × HD3059	2.07	2.18	2.18	1.05	-7.09	-5.42	-20.64**	-7.21
WH1021 × WH1105	5.70	5.74	5.90	4.74	-1.76	-1.29	-16.09*	-1.88
CBW12 × HD3059	-13.87*	-10.81*	-7.62	-8.64	-6.61	-1.20	-23.06**	-10.03
CBW12 × WH1105	-8.29	-5.17	-1.63	-2.72	-9.60	-3.17	-23.51**	-10.56
CBW12 × HD2967	0.84	6.88	8.16	6.97	17.14	23.27**	-4.56	11.60
MACS6272× HD3059	-2.23	10.50	-2.34	-3.42	-6.70	1.50	-23.14**	-10.13
MACS6272× WH1105	-5.43	7.02	-5.25	-6.30	-12.45	-3.59	-25.92**	-13.39
MACS6272× HD2967	2.75	13.65*	-2.26	-3.34	-11.68	-4.40	-28.04**	-15.86
JOB666 × HD3059	17.92**	18.61**	17.79**	16.49**	-7.58	-0.92	-23.86**	-10.97
JOB666 × WH1105	7.68	8.48	7.89	6.70	-1.68	6.71	-16.81*	-2.73
HD2329 × HD3059	0.30	0.42	0.19	-0.91	-0.20	1.56	-17.77*	-3.86
HD2329 × WH1105	-0.65	-0.38	-0.46	-1.56	-7.60	-4.75	-21.82**	-8.59
HD2329 × HD2967	-7.26	-5.11	-7.59	-8.61	-3.13	-1.96	-21.07**	-7.71
WAXWING× HD3059	-12.04*	-11.16*	-10.36	-11.35	-2.39	-1.96	-18.87**	-5.14
WAXWING× WH1105	-1.17	-0.34	0.71	-0.40	-9.03	-8.22	-23.03**	-10.00
WAXWING× HD2967	-7.29	-4.10	-5.52	-6.56	-3.10	-2.13	-19.46**	-5.83
HD2891 × HD3059	-0.90	-0.87	-1.01	-2.10	-3.25	0.78	-20.29**	-6.80
HD2891 × WH1105	-14.85*	-14.70**	-14.69*	-15.63*	-13.81	-9.08	-27.08**	-14.73
HD2891 × HD2967	19.62**	22.51**	19.42**	18.11**	-4.71	-1.26	-22.36**	-9.22
HD2961 × HD3059	-17.27**	-11.62*	-5.25	-6.30	-9.21	-6.00	-25.20**	-12.54
HD2961 × WH1105	-9.67	-3.64	3.45	2.31	-4.31	0.35	-19.03**	-5.33
HD2961 × HD2967	-24.54**	-17.56**	-13.57*	-14.53*	4.08	7.18	-15.20*	-0.85

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

However, the highest negative significant heterosis over check parent (UP2338) estimated in MACS6272 × WH1105 (-44.51 %) and WAXWING × WH1105 (-23.98 %) in E1 and E2, respectively. In comparison, the highest significant positive standard heterosis over check parent (DBW621-50) was reflected by the cross HD3091 × WH1105 (181.08 %) and HD3091 × WH1105 (138.52 %) in E1 and E2, respectively. However, the highest negative significant heterosis was found in the cross MACS6272 × WH1105 (-51.42 %) and HD2329 × HD2967 (-46.33 %) E1 and E2, respectively.

Electrolyte leakage is a measure of cell membrane thermostability. This method is used in wheat as a modified method to develop heat-tolerant lines. Cellular membrane stability is one of the effective screening methods against heat tolerance on a physiological basis. The cross MACS6272 × WH1105 and WAXWING × WH1105 showed the highest positive relative heterosis and heterobeltiosisin the cross HD3091 × WH1105 in E1 only. However, the highest positive standard heterosis with MACS6272 × WH1105 and WAXWING × WH1105 crosses under environment E1 was estimated over check parent UP2338,and the crosses MACS6272 × WH1105 and HD2329 × HD2967 was found highest positive standard heterosis over the check (DPW621-50) in E2 (Table 5).

F. Grain yield per plant

The highest significant positive relative heterosis, 86.57 per cent, was found in the cross JOB666 × HD3059 in E1 andHPW211 × WH1105 (83.59 %) in E2 for grain yield per plant. The highest negative significant heterosis was observed in HD2891 × WH1105 (-36.78 %) and HD2329 × HD2967 (-58.26 %) in E1 and E2, respectively. The highest positive significant heterobeltiosis was exhibited by cross JOB666 × WH1105 (77.32 %) and HPW211 × WH1105 (59.82 %) in E1 and E2, respectively. However, the highest negative significant heterosis was observed in HD2891 × WH1105 (-42.38 %) and HD2329 × HD2967 (-63.80 %) in E1 and E2, respectively.

Table 5: Estimation of heterosis for relative injury (%) in timely sown and late sown condition.

Crosses	Relative injury (%)							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	-21.59**	-15.84**	105.74**	80.14**	-22.69**	-17.41**	95.21**	73.06**
HD3091 × WH1105	7.97**	22.57**	221.03**	181.08**	-3.30	7.96**	169.05**	138.52**
DBW90 × HD3059	-6.97*	4.27	144.08**	113.71**	-6.53*	3.72	136.02**	109.25**
DBW90 × WH1105	-72.02**	-66.93**	-16.80*	-27.15**	-69.49**	-64.70**	-15.12*	-24.75**
DBW90 × HD2967	-31.71**	-26.37**	40.54**	23.05**	-29.52**	-24.52**	42.79**	26.59**
UP2843 × HD3059	-68.38**	-65.42**	-17.04*	-27.36**	-66.47**	-63.55**	-15.34*	-24.95**
UP2843 × WH1105	-20.44**	-8.08**	136.56**	107.12**	-17.23**	-6.04**	130.30**	104.17**
UP2843 × HD2967	-46.30**	-40.65**	16.73*	2.20	-42.75**	-37.40**	21.35**	7.58
WH1124 × HD3059	-61.99**	-58.38**	-0.28	-12.69	-62.99**	-59.16**	-6.54	-17.14**
WH1124 × WH1105	-69.91**	-65.20**	-10.55	-21.68**	-69.73**	-65.16**	-15.78*	-25.34**
WH1124 × HD2967	-50.94**	-45.84**	6.38	-6.86	-44.90**	-40.63**	13.08*	0.25
HPW211 × HD3059	-60.62**	-60.57**	3.32	-9.54	-59.21**	-59.16**	2.99	-8.70
HPW211 × WH1105	-57.55**	-54.85**	26.21**	10.51	-52.94**	-50.60**	30.94**	16.08**
HPW211xHD2967	-62.27**	-54.88**	-1.26	-13.54	-60.75**	-53.76**	-1.13	-12.35*
WH1021 × HD3059	-63.58**	-62.23**	-4.43	-16.33*	-61.98**	-60.66**	-3.99	-14.89*
WH1021 × WH1105	-61.37**	-57.53**	14.86	0.57	-56.61**	-53.01**	20.72**	7.02
CBW12 × HD3059	-63.40**	-58.93**	-3.98	-15.93*	-61.82**	-56.89**	-3.58	-14.52*
CBW12 × WH1105	-48.97**	-39.62**	51.73**	32.85**	-52.01**	-43.54**	33.53**	18.38**
CBW12 × HD2967	-22.36**	-16.39**	59.36**	39.53**	-23.35**	-19.41**	49.29**	32.35**
MACS6272× HD3059	-58.92**	-57.97**	7.78	-5.64	-54.72**	-53.74**	14.34*	1.37
MACS6272×WH1105	-81.34**	-79.74**	-44.51**	-51.42**	-47.91**	-44.26**	44.93**	28.49**
MACS6272× HD2967	-43.91**	-34.11**	40.51**	23.02**	-40.96**	-31.62**	42.76**	26.57**
JOB666 × HD3059	-50.72**	-39.05**	29.30**	13.21	-49.95**	-39.18**	26.38**	12.04*
JOB666 × WH1105	-69.66**	-60.71**	-9.78	-21.00**	-67.98**	-59.62**	-10.90	-21.01**
HD2329 × HD3059	-35.61**	-25.95**	68.96**	47.93**	-39.96**	-31.77**	51.61**	34.41**
HD2329 × WH1105	-6.51*	13.17**	177.99**	143.40**	-6.46**	10.72**	160.27**	130.74**
HD2329 × HD2967	-65.63**	-63.96**	-33.35**	-41.64**	-68.45**	-67.07**	-39.46**	-46.33**
WAXWING×HD3059	-58.22**	-55.06**	27.55**	11.68	-57.88**	-54.52**	24.81**	10.65
WAXWING×WH1105	-80.16**	-79.90**	-39.44**	-46.97**	-74.34**	-73.54**	-23.98**	-32.61**
WAXWING×HD2967	-74.84**	-68.08**	-23.19**	-32.75**	-73.30**	-66.48**	-20.88**	-29.86**
HD2891 × HD3059	-65.41**	-63.85**	-0.70	-13.06	-64.59**	-63.10**	-2.73	-13.76*
HD2891 × WH1105	-75.85**	-75.42**	-28.18**	-37.12**	-70.92**	-70.73**	-19.09**	-28.27**
HD2891 × HD2967	-70.07**	-62.89**	-14.07	-24.77**	-68.21**	-61.23**	-12.67	-22.58**
HD2961 × HD3059	-55.94**	-55.44**	15.61	1.22	-56.91**	-56.01**	8.81	-3.53
HD2961 × WH1105	-70.78**	-68.63**	-13.13	-23.94**	-68.31**	-66.11**	-11.82	-21.83**
HD2961 × HD2967	-66.55**	-60.33**	-14.21	-24.89**	-63.99**	-58.27**	-12.80*	-22.69**

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

The cross JOB666 × HD3059 (106.25 %) and WH1124 × HD2967 (42.86 %) was found significant positive heterosis over check parent (UP2338)in E1 and E2, respectively, for grain yield per plant. However, the highest negative significant heterosis was observed in the cross HD2891 × WH1105 (-18.75 %) in E1 and the cross DBW90 × HD2967 (-48.87 %) in E2 condition.

The cross JOB666 × HD3059 (93.05 %) and WH1124 × HD2967 (55.74 %) showed the highest significant positive heterosis over check parent (DBW621-50) in E1 and E2. In comparison, the highest negative significant heterosis was found HD2891 × WH1105 (-23.95 %) in E1 and DBW90 × HD2967 (-44.26 %) in E2. Such type of finding is similarly responded by earlier workers viz. Khatun *et al.* (2010), Beche *et al.* (2013), Kalhoro *et al.* (2015) and Kumar *et al.* (2015a)

While selecting the plants in segregating generation, yield per plant receives the maximum attention of the plant breeder. Therefore, positive heterosis for this trait is desirable. The results (Table 6) revealed that the cross JOB666 × HD3059 showed high positive relative heterosis and the crosses JOB666 × WH1105 and HPW211 × WH1105 exhibited positive heterobeltiosis. The positive standard heterosis over the check (UP2338) was reported by cross JOB666 × HD3059, and WH1124 × HD2967 and JOB666 × HD3059 and WH1124 × HD2967 over check (DPW621-50) in E1 and E2, respectively. Similar results had been reported by Inamullah *et al.* (2006), Mahmood *et al.* (2006), Nawracaa *et al.* (2006), Akbar *et al.* (2009), Ribadia *et al.* (2007), Hussain *et al.* (2007) and Bao *et al.* (2009) which supports the present findings.

Table 6: Estimation of heterosis for grain yield per plant in timely sown and late sown condition.

Crosses	Grain yield/ plant (g)							
	Environment (E1)				Environment (E2)			
	BP	MP	CP1	CP2	BP	MP	CP1	CP2
HD3091 × HD3059	3.36	3.36	20.31*	12.61	35.58**	39.26**	6.02	15.57
HD3091 × WH1105	5.70	5.88	23.05**	15.17*	30.77*	45.45**	2.26	11.48
DBW90 × HD3059	23.83**	38.46**	44.14**	34.92**	13.04	31.92**	17.29	27.87*
DBW90 × WH1105	-9.09	1.50	5.47	-1.28	-15.94	4.98	-12.78	-4.92
DBW90 × HD2967	-34.52**	-16.86**	4.49	-2.19	-51.77**	-51.25**	-48.87**	-44.26**
UP2843 × HD3059	7.38	25.98**	25.00**	17.00*	49.04**	53.09**	16.54	27.05*
UP2843 × WH1105	32.32**	55.03**	53.52**	43.69**	-27.88*	-19.79	-43.61**	-38.52**
UP2843 × HD2967	-33.90**	-12.69*	5.47	-1.28	-2.84	11.84	3.01	12.30
WH1124 × HD3059	-26.66**	-20.31**	1.56	-4.94	27.03*	34.61**	6.02	15.57
WH1124 × WH1105	0.71	9.59	39.45**	30.53**	17.12	34.02**	-2.26	6.56
WH1124 × HD2967	-30.72**	-25.82**	10.55	3.47	34.75**	50.79**	42.86**	55.74**
HPW211 × HD3059	17.02**	22.81**	50.39**	40.77**	14.29	21.62	-3.76	4.92
HPW211 × WH1105	25.62**	32.04**	61.45**	51.12**	59.82**	83.59**	34.59**	46.72**
HPW211xHD2967	-39.29**	-32.75**	-3.13	-9.32	-12.77	-2.77	-7.52	0.82
WH1021 × HD3059	-16.44*	-7.95	-2.73	-8.96	1.52	2.83	-24.81*	-18.03
WH1021 × WH1105	18.18**	30.00**	37.11**	28.34**	2.29	9.72	-26.17*	-19.51
CBW12 × HD3059	-6.84	0.77	27.73**	19.56*	-5.45	-0.24	-21.80*	-14.75
CBW12 × WH1105	-7.69	0.00	26.56**	18.46*	16.36	32.64**	-3.76	4.92
CBW12 × HD2967	-7.71	-0.72	47.27**	37.84**	-21.99*	-12.35	-17.29	-9.84
MACS6272× HD3059	44.97**	44.97**	68.75**	57.95**	16.81	24.82*	-0.75	8.20
MACS6272×WH1105	6.04	6.22	23.44**	15.54*	41.59**	63.27**	20.30*	31.15**
MACS6272× HD2967	-38.56**	-28.95**	-1.95	-8.23	27.30**	41.34**	34.96**	47.13**
JOB666 × HD3059	77.18**	86.57**	106.25**	93.05**	-11.86	-3.93	-21.80*	-14.75
JOB666 × WH1105	77.32**	86.42**	105.72**	92.56**	-0.42	16.92	-11.65	-3.69
HD2329 × HD3059	22.79**	22.79**	42.93**	33.78**	-7.81	21.86**	33.08**	45.08**
HD2329 × WH1105	11.74	11.93*	30.08**	21.76**	-15.10*	18.55*	22.56*	33.61**
HD2329 × HD2967	-15.79**	-2.62	34.38**	25.78**	-63.80**	-58.26**	-47.74**	-43.03**
WAXWING×HD3059	20.30**	30.63**	66.35**	55.70**	14.29	28.29**	8.27	18.03
WAXWING×WH1105	-5.45	2.83	30.74**	22.38**	20.63	45.45**	14.29	24.59*
WAXWING×HD2967	19.62**	28.17**	90.88**	78.67**	-50.00**	-47.19**	-46.99**	-42.21**
HD2891 × HD3059	-8.03	0.76	29.69**	21.39**	31.22*	33.59**	-2.82	5.94
HD2891 × WH1105	-42.38**	-36.78**	-18.75*	-23.95**	25.58	34.04*	-10.30	-2.21
HD2891 × HD2967	-23.62**	-18.91**	21.88**	14.08	-6.74	11.44	-1.13	7.79
HD2961 × HD3059	5.20	12.77*	22.46**	14.63	-14.29	-8.79	-27.82**	-21.31
HD2961 × WH1105	11.11	18.92**	28.91**	20.66**	42.86**	64.10**	20.30*	31.15**
HD2961 × HD2967	-0.93	21.44**	58.09**	47.97**	21.28*	35.18**	28.57**	40.16**

*,** Significant at 5% and 1 % probability levels, respectively. BP = Better parent, MP = Mid parent, CP1&CP2 = Check parents

CONCLUSION

Wheat is a staple food crop across the world. The genetic background of wheat became narrow. Therefore, it is necessary to investigate the heterotic performance of different cross combinations for different morpho-physiological traits for heat stress in conventional plant breeding. The present study about heterosis estimation under normal and heat stress conditions will help select the parents to develop heat-tolerant varieties.

FUTURE SCOPE

Heat stress is the major constrain for the production of wheat. Production becomes stagnant of the majority of cereal crops. Therefore, it is necessary to find a heterotic cross combination to enhance the production and productivity of wheat. The present study will be helpful to identify the parents for the crossing program.

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