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HETEROSIS STUDIES FOR GRAIN YIELD AND ITS COMPONENTS IN WHEAT (*TRITICUM AESTIVUM* L. EM. THELL) UNDER NORMAL AND DROUGHT CONDITIONS

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ABSTRACT

Heterosis for yield and its component traits were studied in 8 parents and their 28 F_1s in wheat (*Triticum aestivum* L.) under normal and drought condition. Highest magnitude of heterobeltiosis was observed in cross PBW 343 x WH 1080 for effective tillers/plant (53.00%) followed by the cross PBW 343 x HD 2967 for grains/spike (49.27%) under normal environment, while under stress environment, crosses WH 1080 x HD 2967 for biomass/plant (60.61%) followed by the hybrid WH 730 x PBW 343 for grain yield (52.38%). For grain yield the crosses PBW 343 x WH 1080 and WH 730 x PBW 343 in normal environment and crosses WH 1080 x HD 2967 and WH 730 x PBW 343 were identified as promising on the basis of their high *per se* performance, average heterosis and heterobeltiosis. The manifestation of heterosis for effective tillers/plant, grains/spike and biomass/plant seemed to be responsible for increased grain yield in these crosses. These crosses could be extensively used in breeding programme to develop superior segregants and or better pure lines could be derived in further breeding programmes.

INTRODUCTION

Drought is a major environmental stress threatening wheat productivity worldwide. Global climate models predict changed precipitation patterns with frequent episodes of drought. Although drought impedes wheat performance at all growth stages, it is more critical during the flowering and grain-filling phases (terminal drought) and results in substantial yield losses (Farooq, 2014). Wheat being a highly self-pollinated crop, scope for exploitation of hybrid vigour depends on the direction and magnitude of heterosis, biological feasibility of crop and nature of gene action. Drought is one of the most common environmental stresses that affect growth and development of plants. (Nezhadahmadi *et al.*, 2013) It is assumed that by the year 2025, around 1.8 billion people will face absolute water shortage and 65 per cent of the world's population will live under water stressed environments. Drought limits the agricultural production by preventing the crop plants from expressing their full genetic potential. In most of the breeding programmes, the genetic improvement for drought tolerance is accomplished through selection for yield. Improving drought tolerance and productivity is one of the most difficult tasks for cereal breeders (Devi *et al.*, 2011). The study of heterosis helps the plant breeders in eliminating the less productive crosses in early generations. For any successful breeding programme to improve grain yield and its component characters, it is essential to know precisely the genetic architecture of these characters under prevailing conditions. The studies on heterosis in wheat has also been done by Srivastava and Singh (2008), ZhaoPeng *et al.* (2009), Ashutosh *et al.* (2011), Batool *et al.* (2013), Beche *et al.* (2013) and Singh *et al.* (2013). Heterosis breeding is one of the strongest tool to take a quantum jump in production and productivity under various agro-climatic conditions Devi *et al.* (2013). In views of the above facts, the present study was, therefore, undertaken to estimate the magnitude of heterosis for yield and its component traits by crossing 8 parents using diallel mating design. These studies would be helpful for selecting suitable parents for hybrid development and to select potent transgressive segregants and or better pure lines which can be further evaluated for enhanced yield potential.

MATERIALS AND METHODS

Eight, diverse wheat genotypes namely WH 730, WH 283, PBW 343, Raj 3765, DBW 17, WH 1080, HD 2967 and KRL 210 were selected as parents on the basis of their origin, adaptability, diversity, yield potential and drought tolerance characters in the present investigation. Crosses were attempted during *rabi*, 2010-11 in a diallel fashion (excluding reciprocals). Each of the 8 genotypes selected as parent were crossed with each other. Thus, in all 28 F_1 hybrids were developed. Eight parents along with 28 F_1s were evaluated during *rabi,* 2011-12 in randomized block design with three replications under two environments (normal and drought) at Wheat Research Area, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. Parents and F_1s were grown in single row with two meter row length. Sowing was done by dibbling the seeds at a distance of 10cm in the rows of 2m length with row to row spacing of 25cm, so as to raise the plants under space planting conditions. The observations were recorded on five randomly selected competitive plants in parents and F_1s from each replication in both the environments for quantitative traits viz., days to heading, days to anthesis, days to maturity, plant height, effective tillers/plant, grains/spike, 1000-grain weight, grain yield/plant, biomass/plant, harvest index and physiological traits; coleoptile length, SPAD chlorophyll content and chlorophyll fluorescence. Data were subjected to heterosis and analysis of variance using Window Stat Statistical Analysis Package/software. Percent increase or decrease of F_1 over the mid parent referred as average heterosis, while heterobeltiosis (Fonseca and Patterson, 1968) denotes the increase or decrease of F_1 over the better parent. The following formulae were used for the estimation of heterosis (MP) and heterobeltiosis (BP) in each environment for all the characters.

Heterosis over mid parent(MP) = $[(F_1\text{-MP})/\text{MP}] \times 100, t = [(F_1\text{-MP})/(SE_{(F1\text{-}MP)})^{1/2}], SE_{(F1\text{-}MP)} = (3MSe/2r)^{1/2}$

Heterosis over better parent(BP) = $[(F_1\text{-BP})/\text{BP}] \times 100, t = [(F_1\text{-BP})/(SE_{(F1\text{-}BP)})^{1/2}], SE_{(F1\text{-}BP)} = (2MSe/r)^{1/2}$

Where, MSe = error mean squares for parents and F_1s data of individual environment;

These calculated 't' values were compared with Table 't' value at error degrees of freedom at P = 0.05 and P = 0.01 level of significance for relative heterosis and heterobeltiosis. The differences in the magnitudes of relative heterosis, heterosis over male and female parents were tested as per the method proposed by Panse and Sukhatme (1961).

RESULTS AND DISCUSSION

Mean squares due to genotypes and F_1s revealed significant differences for all the traits in both the environments (normal and late sown), indicating presence of adequate genetic variation among the genotypes and F_1s (Table 1). In the present study higher mean values of the hybrids over parents revealed superiority and presence of sufficient amount of heterosis in F_1s in both the environments. Superiority of F_1s in wheat was also reported by Vanpariya *et al.* (2006) and Singh *et al.* (2007). None of the cross combination was found to show significant heterosis for all the traits together. Heterobeltiosis for grain yield/plant ranged from -57.15 (PBW 343 x Raj 3765) to 30.14 (PBW 343 x WH 1080) in normal environment and -36.87 (WH 283 x KRL 210) to 52.38 (WH 730 x PBW 343) in stress environment (Table 2). However, crosses PBW 343 x WH 1080 and WH 1080 x KRL 210 had significant heterotic effects (over better parent) in both the environments for grain yield, grain/spike, 1000-grain weight and biomass/plant. While, crosses WH 730 x PBW 343, WH 1080 x HD 2967, Raj 3765 x HD 2967 and Raj 3765 x KRL 210 were found to show positive significant heterosis (over mid and better parent) for grain yield, effective tillers/plant, biomass/plant, 1000-grain weight and grains/spike in stress environment. Positive significant heterosis for grain yield along with other attributes in stress environment was also reported earlier by Hassan *et al.* (2006), Ulukan (2007), Ribadia *et al.* (2007), Jaiswal *et al.* (2010), and Bilgin *et al.* (2011). These crosses could throw desirable transgressive segregantes giving rise to new populations.

Heterobeltiosis for days to heading ranged from 1.44 (DBW 17 x WH 1080) to 23.42 (PBW 343 x Raj 3765) in normal

Table 1: Analysis of variance showing mean squares for thirteen traits in eight-parent diallel cross

Source	d.f.	Daysto heading (No.)	Daysto anthesis (No.)	Daysto maturity (No.)	Plant height (cm)	Effective tillers/plant (No.)	Grains/ spike (No.)	1000-grain weight(g)	Grain yield/ plant(g)	Biomass /plant(g)	Harvest index (%)	Coleoptile length(cm)	Chlorophyll content (%)	Chlorophyll fluorescence (Fv/Fm)
Normal environment														
Replications	2	173.783	121.340	17.856	236.003	12.739	19.022	2.774	5.592	14.154	1.381	0.094	3.133	0.001
Genotypes	35	110.247**	67.799**	6.623**	234.575**	18.118**	196.690**	22.788**	94.825**	327.652**	38.268**	0.644**	14.398**	0.005**
Parents	7	216.962**	145.585**	8.833**	189.836**	4.830	74.420*	14.371**	167.311**	580.149**	35.183**	0.446**	12.010	0.004*
Crosses	27	69.625**	41.155**	5.573**	254.158**	19.220**	162.981**	22.465**	79.460**	272.939**	40.483**	0.709**	13.707*	0.005**
Parents v/s crosses	1	460.024**	242.705**	19.507**	18.988	81.389**	1962.716**	90.396**	2.284	37.432	0.041	0.275	49.784**	0.009*
Error	70	12.632	9.582	0.918	28.079	4.243	30.744	1.049	10.647	36.873	6.066	0.105	6.829	0.002
Stress environment														
Replications	2	0.520	2.327	28.854	31.767	3.447	49.659	10.846	10.405	75.066	1.612	0.099	271.032	0.012
Genotypes	35	8.780**	10.326**	8.253**	70.993**	8.872**	70.761**	34.182**	18.071**	179.603**	15.862**	0.650**	20.792**	0.002**
Parents	7	13.453**	17.040**	18.851**	121.607**	5.762**	31.618*	12.015**	7.528*	43.310	20.271**	0.506**	32.860**	0.001
Crosses	27	7.777**	8.794**	5.810**	58.261**	10.006**	67.411**	30.807**	19.998**	206.646**	15.205**	0.697**	17.812**	0.001*
Parents v/s crosses	1	3.154	4.693	0.010	60.456**	0.023	435.215**	280.464**	39.829**	403.517**	2.742	0.386*	16.767	0.020**
Error	70	1.913	1.802	1.362	7.380	1.848	11.608	0.829	2.717	20.615	3.412	0.056	5.382	0.001

Table 2: Mean (%) and range of heterosis (MP) and heterobeltiosis (BP) for thirteen traits in wheat

Traits	Environment	MP Mean	MP Range	BP Mean	BP Range
Days to heading (No.)	Normal	4.83	-1.66-22.54	10.30	1.44-23.42
	Stress	0.46	-1.79-3.10	1.89	-1.19-5.35
Days to anthesis (No.)	Normal	3.33	-2.70-16.02	7.43	0.57-16.06
	Stress	-0.54	-3.00-1.34	0.98	-2.66-3.92
Days to maturity (No.)	Normal	0.69	-1.07-2.05	1.40	-0.22-2.67
	Stress	0.03	-1.88-2.09	1.28	-1.31-4.10
Plant height (cm)	Normal	-1.04	-24.21-7.12	3.43	-22.20-18.16
	Stress	-1.94	-7.69-3.74	2.00	-5.84-12.74
Effective tillers/plant (No.)	Normal	16.70	-42.81-63.50	10.86	-43.99-53.00
	Stress	0.35	-29.18-48.98	-7.07	-36.31-42.86
Grains/spike (No.)	Normal	21.79	-17.08-50.70	14.85	-18.53-50.38
	Stress	11.74	-16.60-42.31	6.88	-22.20-33.64
1000-grain weight (g)	Normal	5.02	-17.40-14.72	2.14	-21.31-13.39
	Stress	10.26	-3.51-36.32	7.04	-7.04-36.00
Grain yield/plant (g)	Normal	3.33	-45.25-56.67	-10.31	-57.15-30.14
	Stress	12.02	-25.34-57.98	5.33	-36.87-52.38
Biomass/plant (g)	Normal	3.00	-41.53-31.49	-6.88	-52.99-18.48
	Stress	13.56	-20.13-60.61	7.91	-30.58-59.72
Harvest index (%)	Normal	0.42	-18.83-20.81	-4.46	-26.87-17.31
	Stress	-0.90	-17.08-11.84	-4.88	-22.06-6.87
Coleoptile length (cm)	Normal	-2.67	-28.77-43.39	-9.11	-34.51-30.96
	Stress	-3.26	-28.26-38.71	-9.93	-33,41-25.15
Chlorophyll content (%)	Normal	3.80	-8.01-14.92	1.00	-10.98-13.06
	Stress	-1.98	-13.52-14.41	-6.18	-17.48-13.14
Chlorophyll fluorescence(Fv/Fm)	Normal	-2.96	-15.68-7.45	-5.75	-18.03-6.94
	Stress	-4.47	-16.34-3.26	-5.87	-16.96-2.53

Table 3a: Extent of hetrosis (%) for days to heading, days to anthesis, days to maturity, plant height, effective tillers/plant and grains/spike in wheat

Crosses	Environment	Dyas to heading Heterosis (%) over		Days to anthesis Heterosis (%) over		Days to maturity Heterosis (%) over		Plant height Heterosis (%) over		Effective tillers/ plantHeterosis (%) over		Grains/spike Heterosis (%) over	
		M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.
WH 730 x WH 283	Normal	5.63*	11.21**	3.28	7.94**	0.24	0.92	-3.73	3.19	-24.39*	-30.39**	4.56	-6.18
	Stress	2.47*	3.76**	0.35	2.81*	0.73	2.43**	-7.18**	-1.16	-9.07	-14.68	11.64*	0.43
WH 730 x PBW 343	Normal	5.42*	9.64**	3.35	6.02*	-1.07*	0.05	3.61	11.66**	25.62*	18.10	29.00**	26.64**
	Stress	0.12	2.39	-0.95	0.83	-0.55	1.69*	-0.07	6.34**	48.98**	42.86**	18.09**	13.38
WH 730 x Raj 3765	Normal	4.57	7.96**	4.60*	7.34**	-1.05*	0.30	4.75	16.10**	10.32	9.77	33.61**	26.98**
	Stress	-1.00	-0.67	-1.72	-1.01	0.69	1.97*	3.74	12.74**	5.58	3.35	12.64*	4.25
WH 730 x DBW 17	Normal	-1.66	5.19	-2.70	2.48	0.83	1.29*	2.73	18.16**	36.61**	35.92**	43.60**	39.12**
	Stress	0.68	0.98	-0.57	-0.31	0.56	1.42	-4.37*	8.98**	4.79	2.87	14.87*	6.83
WH 730 x WH 1080	Normal	6.15*	10.71**	3.89**	7.22**	1.27**	1.50**	2.09	9.24*	25.78*	25.15	16.13	13.75
	Stress	-0.18	0.22	-2.70	-2.66*	-0.64	0.34	-1.76	5.29*	-6.00	-8.47	7.87	3.49
WH 730 x HD 2967	Normal	4.81*	11.88**	3.02	8.51**	0.76	2.48**	3.21	9.68*	1.67	-4.57	17.02*	8.09
	Stress	1.72	2.29	0.78	1.51	-1.28	1.92*	-6.38**	1.61	-29.18**	-32.69**	42.31**	27.90**
WH 730 x KRL 210	Normal	5.83*	7.93**	3.90	5.38*	1.04*	2.07**	1.90	7.96*	19.51	16.39	12.76	5.88
	Stress	1.62	3.60**	0.30	1.63	0.62	0.91	-2.69	2.69	-3.83	-18.81	24.81**	19.40**
WH 283 x PBW 343	Normal	1.32	11.16**	-0.97	6.29*	0.30	0.74	5.22	5.75	-6.05	-18.24	18.38*	8.01
	Stress	-0.93	2.62*	-3.00**	1.20	-1.85*	-1.31	-2.45	-2.38	-19.12*	-27.03*	19.95**	12.07*
WH 283 x Raj 3765	Normal	1.62	10.63**	3.39	11.01**	-0.18	0.49	1.47	4.70	2.69	-5.03	20.51*	3.38
	Stress	-1.79	-0.22	0.14	1.84	-0.63	-0.22	0.61	2.55	15.43	10.54	2.01	-1.08
WH 283 x DBW 17	Normal	2.74	4.30	0.91	1.66	0.99*	1.21*	-9.09*	-2.87	18.37	9.48	-4.10	-11.41
	Stress	1.02	1.98	-0.25	1.94	0.50	1.33	-5.36*	0.89	-21.98*	-25.50*	-10.27	-13.44*
WH 283 x WH 1080	Normal	3.71	4.66	2.42	3.68	2.05**	2.51**	-9.30**	-9.16*	-12.86	-19.41	23.99**	13.35
	Stress	0.91	2.59*	-0.49	1.91	-0.14	0.83	-4.41*	-3.83	-24.85**	-27.66**	-16.60**	-22.02**
WH 283 x HD 2967	Normal	3.72	5.08	1.53	2.29	0.33	1.34*	-5.19	-4.41	-42.81**	-43.99**	-9.22	-12.05
	Stress	0.98	1.68	-1.12	0.56	-1.86**	-0.39	-4.24*	*-2.50*	-21.46*	-22.52*	2.43	2.31
WH 283 x KRL 210	Normal	4.32	7.63**	2.09	5.15*	0.29	0.62	2.97	4.10	31.36**	18.24	27.10**	21.06**
	Stress	0.12	3.37**	-0.21	3.63**	0.05	1.46	-4.15*	-3.32	-20.56	-36.31**	7.51	0.80
PBW 343 x Raj 3765	Normal	22.54**	23.42**	6.02**	16.06**	0.89*	1.11*	-24.21 **	-22.20**	8.26	1.31	14.87	7.27
	Stress	3.10**	5.08**	1.34	3.92**	0.95	1.93*	-7.69**	-5.84*	8.43	1.87	7.03	3.00
PBW 343 x DBW 17	Normal	2.55	14.37**	1.06	9.33**	0.72	1.40**	7.12	13.84**	44.10**	34.85**	26.90**	25.21**
	Stress	-0.49	2.08	-0.48	1.57	-0.98	0.39	-3.10	3.38	-19.71	-24.36*	3.23	-0.14
PBW 343 x WH 1080	Normal	6.98**	16.22**	3.42	9.58**	1.75**	2.67**	0.78	1.45	63.50**	53.00**	50.70**	50.38
	Stress	-0.15	1.70	-0.84	0.97	0.96	2.22**	0.56	1.24	10.42	3.21	33.74**	33.64**

*,**significant at = 0.05 and 0.01, respectively.

Table 3a: Cont...........................

Crosses	Environment	Dyas to heading Heterosis (%) over M.P.	B.P.	Days to anthesis Heterosis (%) over M.P.	B.P.	Days to maturity Heterosis (%) over M.P.	B.P.	Plant height Heterosis (%) over M.P.	B.P.	Effective tillers/plant Heterosis (%) over M.P.	B.P.	Grains/spike Heterosis (%) over M.P.	B.P.
PBW 343 x HD 2967	Normal	2.80	14.39**	1.07	9.34**	0.02	0.58	-2.00	-0.69	44.62**	28.15*	49.27**	40.29**
	Stress	2.43*	5.35**	1.09	3.66**	-0.35	0.60	-1.70	0.16	-6.54	-14.63	18.26**	10.38
PBW 343 x KRL 210	Normal	9.82**	16.56**	7.14**	11.52**	1.57**	1.69**	-1.03	0.57	30.64*	25.98	16.45*	11.29
	Stress	1.16	1.47	-0.07	0.38	2.09**	4.10**	-1.86	-1.08	18.11	3.36	17.03**	16.60*
Raj 3765 x DBW I7	Normal	-1.30	9.23**	3.13	11.62**	1.07*	1.98**	-3.71	-0.40	2.15	2.15	25.17**	15.44
	Stress	-0.25	0.38	-1.46	-1.00	-0.14	0.27	0.37	4.90	-12.44	-12.70	23.27**	22.62**
Raj 3765 x WH 1080	Normal	3.96	12.08**	3.59	9.80**	1.25**	2.39**	-1.64	1.66	23.08*	23.08	31.90**	22.93**
	Stress	-1.26	-1.19	-2.40*	-1.73	1.99**	2.28**	3.33	4.68	-1.13	-1.66	25.02**	20.40**
Raj 3765 x HD 2967	Normal	4.68	15.59**	3.39	11.89**	-0.55	-0.22	4.58	8.82*	9.65	3.41	37.46**	21.19**
	Stress	-0.13	0.76	0.44	0.44	0.04	1.97*	-0.21	-0.10	9.73	6.48	4.42	1.15
Raj 3765 x KRL 210	Normal	13.95**	20.05**	10.85**	15.42**	1.71**	2.05**	-2.77	1.47	23.02*	19.23	31.54**	17.78*
	Stress	-0.76	0.84	-1.97	0.07	0.41	1.40	-2.25	0.52	37.60**	14.17	21.39**	17.24**
DBW 17 x WH 1080	Normal	1.97	4.48	1.73	3.76	1.47**	1.70**	-2.34	4.53	35.85**	35.85**	3.35	2.18
	Stress	0.70	1.41	-0.73	-0.52	0.47	0.61	-1.06	4.81	-10.65	-11.39	2.41	-0.86
DBW 17x HD 2967	Normal	1.24	1.44	0.57	0.57	0.31	1.55**	-1.50	6.16	-3.58	-9.07	12.96	7.52
	Stress	-0.41	-0.15	-0.33	0.14	-1.88**	0.44	1.43	6.12*	-14.16	-16.94	-1.68	-5.26
DBW 17x KRL 210	Normal	5.52*	10.58**	4.11*	8.05**	1.48**	2.05**	-3.99	3.78	16.43	12.85	31.87**	27.68**
	Stress	1.26	3.55**	0.48	2.07	1.31	1.88*	-3.80	3.50	7.98	-10.20	2.91	-0.09
WH 1080 x HD 2967	Normal	0.05	2.31	-0.63	1.35	0.18	1.65**	3.77	4.46	32.06**	24.54*	15 87*	9.11
	Stress	-1.54	-0.59	-2.40*	-1.73	-1.36*	0.83	2.03	3.25	36.40**	33.06**	11.70*	4.33
WH 1080 x KRL 210	Normal	4.24	6.56*	2.45	4.22	1.23**	2.03**	3.13	4.10	24.21*	20.38	45.58**	39.43**
	Stress	2.11	3.67**	1.13	2.52*	1.53*	2.24**	0.87	2.36	29.76**	7.21	9.32	8.99
HD 2967 x KRL 210	Normal	8.17**	13.12**	6.65**	10.69**	0.30	0.97	-5.82	-5.56	27.58*	16.84	-17.08*	-18.53*
	Stress	1.42	3.98**	0.58	2.66*	-0.52	2.41**	-2.53	0.11	-2.86	-21.30*	13.56*	6.36
CD. at 5 %	Normal	4.93	5.69	4.29	4.95	1.33	1.53	7.34	8.48	2.86	3.30	7.69	8.87
	Stress	1.92	2.12	1.86	2.15	1.62	1.87	3.77	4.35	1.88	2.18	4.72	5.45
CD at 1 %	Normal	6.47	7.48	5.64	6.51	1.74	2.02	9.65	11.15	3.75	4.33	10.10	11.66
	Stress	2.52	2.91	2.45	2.83	2.13	2.46	4.95	5.71	2.48	2.86	6.21	7.17
C.V. (%)	Normal	3.25	-	2.72	-	0.64	-	5.05	-	13.92	-	9.88	-
	Stress	1.53	-	1.45	-	0.96	-	3.00	-	14.02	-	7.45	-

*,**significant at = 0.05 and 0.01, respectively.

environment and -1.19 (Raj 3765 x WH 1080) to 5.35 (PBW 343 x HD 2967) in stress environment (Table 2). For days to anthesis, cross WH 730 x WH 1080 in stress environment depicted negative and significant heterosis over better parent. Negative and significant heterosis over mid-parent displayed by the crosses viz., WH 730 x PBW 343 and WH 730 x Raj 3765 in normal environment and WH 1080 x HD 2967 in stress environment for days to maturity (Table 3a). For plant height, negative and significant heterosis over better parent expressed by only one cross combination PBW 343 x Raj 3765 in both the environments and cross WH 283 x WH 1080 showed negative and significant heterobeltiosis in normal environment. Negative heterosis for plant height has also been reported by ZhaoPeng *et al.* (2009) and Beche *et al.* (2013). Earlier, Kumar and Sharma (2005), Jaiswal *et al.* (2010) and Beche *et al.* (2013) also observed the significant heterosis over better parent for days to heading and days to maturity in wheat.

The cross combinations, namely, WH 730 x PBW 343, Raj 3765 x KRL 210 and WH 1080 x KRL 210 in both the environments and WH 730 x DBW 17, WH 730 x WH 1080, WH 283 x KRL 210, PBW 343 x DBW 17, PBW 343 x WH 1080, and HD 2967 x KRL 210 in normal environment manifested significant positive heterosis over mid-parent for effective tillers/plant. The cross PBW 343 x WH 1080 exhibited maximum significant positive heterobeltiosis (53.00%) followed by WH 730 x DBW 17 (35.92%), DBW 17 x WH 1080 (35.85%) in normal environment (Table 3a) and ranged from -43.99 (WH 283 x HD 2967) to 53.00 (PBW 343 x WH 1080) for tillers/plant (Table 2). The cross WH 730 x PBW 343 exhibited maximum significant positive heterobeltiosis (42.86%) followed by WH 1080 x HD 2967 (33.06%) in stress environment for effective tillers/plant (Table 3a). Chowdhry *et al.* (2005) also found heterosis and heterobeltiosis for tillers/plant in wheat.

The highest estimates of positive heterobeltiosis displayed by the cross PBW 343 x WH 1080 (50.38%) followed by PBW 343 x HD 2967 (40.29%) and WH 1080 x KRL 210 (39.43%) in normal environment for grains/spike and PBW 343 x WH 1080 (33.64%) followed by WH 730 x HD 2967 (27.90%) and Raj 3765 x DBW 17 (22.62%) in stress environment for grains/spike (Table 3a). Grains/spike directly determines the yield potential of a genotype (Inamullah *et al.* 2006). These results were also corroborated by Singh *et al.* (2007), Krystkowiak *et al.* (2009), ZhaoPeng *et al.* (2009), Amarah *et al.* (2013), Batool *et al.* (2013) and Devi *et al.* (2013) were for grains/spike. The highest better parent heterosis was exhibited by the hybrid WH 1080 x HD 2967 (13.39%) followed by DBW 17 x WH 1080 (11.71%) and Raj 3765 x HD 2967 (9.53%) in normal environment and hybrid Raj 3765 x HD 2967 (36.00%) followed by Raj 3765 x DBW 17 (19.20%) and WH 283 x Raj 3765 (18.98%) in stress environment for 1000-grain weight (Table 3b). Positive heterosis for 1000-grain weight has been reported by Ashutosh *et al.* (2011) and Devi *et al.* (2013). A perusal of Table 3b revealed that for grain yield significant and positive heterosis over better parent was manifested by two crosses namely, PBW 343 x WH 1080 and WH 1080 x KRL 210 in both the environments and the crosses, WH 730 x PBW 343, WH 730 x Raj 3765, WH 1080 x HD 2967, WH 1080 x KRL 210, PBW 343 x Raj 3765, PBW 343

Table 3b: Extent of hetrosis (%) for grains/spike, 1000-grain weight, grain yield/plant, biomass/plant, harvest index, coleoptile length, chlorophyll content and chlorophyll fluorescence in wheat

Crosses	Environment	1000-grain weight Heterosis (%) over		Grain yield/plant Heterosis (%) over		Biomass/plant Heterosis (%) over		Harvest index Heterosis (%) over		Coleoptile length Heterosis (%) over		Chlorophyll content Heterosis (%) over		Chlorophyll fluorescence Heterosis (%) over	
		M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.
WH 730 x WH 283	Normal	3.09*	2.43	-27.24*	-33.43**	-19.72**	-21.35**	-9.30*	-15.42**	17.46*	11.00	5.45	3.73	-9.48*	-13.61**
	Stress	-3.40*	-7.04**	-3.45	-13.60	1.40	-6.66	-4.41	-6.92	18.26**	12.58*	2.67	-2.83	-7.54**	-8.18**
WH 730 x PBW 343	Normal	3.94**	3.76*	31.05**	2.73	17.95**	-5.23	12.00	7.92	38.05**	5.38**	-0.39	-3.83	-0.65	-1.16
	Stress	1.38	0.49	54.63**	52.38**	55.45**	48.28**	-1.30	-6.88	36.98**	5.15**	14.41**	13.14**	0.35	-0.83
WH 730 x Raj 3765	Normal	10.81**	5.40**	5.85	5.62	-10.21*	-10.27	17.63*	17.31**	13.88	-0.83	7.81	7.12	3.65	0.26
	Stress	19.41**	12.31**	27.18**	27.03*	25.19**	25.01*	1.03	0.85	16.56**	1.63	7.27	3.91	0.14	-1.25
WH 730 x DBW 17	Normal	6.67**	1.88	13.10	9.89	3.01	2.90	9.82*	6.82	43.39**	0.96**	9.31*	7.24	-1.53	-9.24*
	Stress	19.61**	12.45**	7.92	7.17	26.31**	24.16*	-15.03**	-16.68**	38.71**	3.92**	-0.82	-7.39	-9.39**	-11.08**
WH 730 x WH 1080	Normal	0.70	-2.59	14.09	6.02	0.72	-6.99	13.23**	12.62*	23.49**	3.27	4.11	1.39	-2.64	-5.39
	Stress	8.01**	5.66**	25.82**	19.91	24.20**	23.63*	1.33	-3.34	22.11**	1.71	3.57	-0.33	-5.62*	-6.77*
WH 730 x HD 2967	Normal	2.45	-2.01	-16.97*	-21.33**	-16.88**	-15.91**	0.30	-3.90	20.92**	7.94	1.43	-0.27	-3.13	-6.68
	Stress	1.53	-4.30*	-0.85	-7.05	-8.68	-8.76	8.23*	1.90	18.78**	5.71	-8.58*	-17.48**	-5.28*	-6.37*
WH 730 x KRL 210	Normal	0.81	-0.06	22.63*	-1.21	4.55	-10.71	18.32**	10.74**	20.00**	8.11	0.12	-2.90	-11.41**	-14.25**
	Stress	11.38**	5.34**	-0.67	-6.87	-6.61	-15.24	5.47	2.37	12.21*	2.10	-10.53**	-15.48**	-3.44	-4.10
WH 283 x PBW 343	Normal	-3.61*	-4.39*	-3.76	-29.20**	8.36	-14.26*	-8.56	-17.61**	7.50	3.06	0.51	-4.49	1.15	-2.98
	Stress	13.02**	9.71**	-13.31	-21.40*	-15.72	-25.69**	2.54	-0.73	11.71*	6.97	0.54	-5.84	1.48	0.98
WH 283 x Raj 3765	Normal	8.64**	2.71	-15.65*	-22.66**	-9.52	-11.44*	-6.53	-12.62**	3.03	-5.56	1.18	-1.11	2.79	1.37
	Stress	21.85**	18.98**	28.41**	15.03	33.54**	22.76**	-3.54	-6.25	4.63	-4.63	11.24**	8.61*	3.26	2.53
WH 283 x DBW 17	Normal	8.35**	2.86	-18.22**	-23.13**	-9.35	-11.10*	-9.68*	-13.52**	-10.11	-13.31	10.73*	6.89	-3.59	-7.06
	Stress	4.07*	1.57	-16.52*	-24.83*	-20.13*	-27.63**	4.51	3.75	-14.64**	-20.17**	2.86	1.40	-6.30*	-8.68**
WH 283 x WH 1080	Normal	7.06**	2.92	-22.77**	-33.87**	-3.75	-12.77*	-18.83**	-23.92**	-9.04	-20.15**	4.10	3.05	-5.34	-7.07
	Stress	2.45	0.76	-7.42	-20.59	-14.54	-21.66*	8.91	1.29	-7.30	-19.51**	-7.62*	-9.20*	-5.52*	-7.31*
WH 283 x HD 2967	Normal	8.33**	2.98	-28.19**	-30.80**	-13.71**	-14.49*	-17.01**	-19.33**	-14.69*	-19.71*	5.67	5.62	-4.06	-4.99
	Stress	13.80**	11.36**	-16.79*	-20.84*	-9.71	-16.82	-8.33*	-11.44**	-17.79**	-23.43**	-10.86**	-15.24**	-4.62	-6.37
WH 283 x KRL 210	Normal	3.62*	2.71	11.05	-16.30*	10.07	-7.58	3.18	-9.50*	-2.05	-6.91	5.21	3.71	-7.59	-8.92
	Stress	-3.51*	-5.25**	-25.34**	-36.87**	-17.63*	-30.58**	-9.34	-9.64*	-1.42	-6.01	-5.24	-5.43	-4.16	-5.47
PBW 343 x Raj 3765	Normal	-17.40**	-21.31**	-45.25**	-57.15**	-41.53**	-52.99**	-5.03	-8.73	-12.66	-16.67*	0.23	-2.63	-15.68**	-18.03**
	Stress	18.35**	12.26**	28.49**	26.76**	33.60**	27.61**	-4.14	-9.71*	-11.05*	-15.53**	-5.79	-9.73*	-3.35	-3.55
PBW 343 x DBW 17	Normal	11.68**	6.84**	17.32*	-9.92	19.16**	-4.33	0.37	-5.83	13.85*	13.15	14.92**	13.06*	0.00	-7.39
	Stress	0.16	-5.04**	-7.11	-7.82	-2.51	-5.45	-4.31	-8.01*	10.19*	7.49	3.24	-4.59	-1.72	-4.67
PBW 343 x WH 1080	Normal	8.35**	4.98**	56.67**	30.14**	31.49**	12.87	20.81**	15.80**	-8.84	-16.88*	8.77**	2.37	-3.72	-5.97
	Stress	6.10**	4.69*	29.42**	21.63*	28.48**	23.09*	0.42	-9.36*	-11.62**	-20 24**	10.88**	5.56	-2.84	-5.14

*,**significant at =0.05 and 0.01, respectively

Table 3b: Cont..................................

Crosses	Environment	1000-grain weight Heterosis (%) over		Grain yield/plant Heterosis (%) over		Biomass/plant Heterosis (%) over		Harvest index Heterosis (%) over		Coleoptile length Heterosis (%) over		Chlorophyll content Heterosis (%) over		Chlorophyll fluorescence Heterosis (%) over	
		M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.
PBW 343 x HD 2967	Normal	2.02	-2.25	12.58	-15.11*	16.85**	-6.92	-1.23	-8.67	-1.05	-2.94	0.75	-4.31	-1.94	-5.06
	Stress	9.77**	4.35*	0.76	-4.22	13.81	8.46	-11.45**	-11.64**	-0.88	-3.71	-6.32	-16.29**	-6.66*	-8.81**
PBW 343 x KRL 210	Normal	6.86**	6.78**	6.68	2.89	17.69*	9.29	-9.57	-12.26*	-10.00	-10.81	9.68*	2.81	-0.67	-3.37
	Stress	2.93	-1.83	6.55	-146	12.96	7.20	-4.69	-7.43*	-9.50	-9.91	2.48	-4.21	-1.32	-3.15
Raj 3765 x DBW I7	Normal	7.90**	7.42**	-10.19	-12.55	-0.78	-0.95	-9.63*	-11.86*	-20.06**	-24.17**	-0.20	-1.47	6.43	1.24
	Stress	19.25**	19.20**	4.66	4.05	-0.75	-2.31	5.77	3.54	-15.97**	-18.26**	0.75	-2.99	-3.72	-6.81*
Raj 3765 x WH 1080	Normal	4.18*	2.38	14.79	6.46	15.06*	6.31	0.01	-0.26	-16.25**	-20.15**	-8.01	-10.98*	7.45	6.94
	Stress	19.68**	14.97**	23.01*	17.10	9.99	9.64	11.84**	6.87	-17.63**	-21.95**	2.80	2.10	-1.67	-4.19
Raj 3765 x HD 2967	Normal	10.18**	9.53**	-11.00	-15.50*	-8.26	-9.37	-2.93	-6.75	-13.43*	-15.83*	3.81	1.42	-2.76	-3.16
	Stress	36.32**	36.00**	32.18**	24.05**	59.24**	58.86**	-17.08**	-22.06**	-14.37**	-16.35**	-5.78	-12.42**	-2.99	-5.42
Raj 3765 x KRL 210	Normal	3.37*	-1.45	16.88	-5.99	13.32*	-3.16	4.00	-2.91	-19.19**	-22. 22**	-1.71	-5.27	-2.95	-3.02
	Stress	0.04	-0.54	52.12**	42.47**	52.99**	39.03**	-0.49	-3.60	-15.14**	-19.07**	-12.57**	-14.80**	-4.05	-6.02
DBW 17 x WH 1080	Normal	13.19**	11.71*	14.13	3.28	14.25**	5.40	0.27	-1.95	-21.39**	-28.72**	7.25	2.52	-3.30	-8.44
	Stress	12.86**	8.38**	0.86	-4.52	-3.79	-5.00	4.82	-1.85	-25.23**	-30.98**	-0.11	-3.19	-6.32*	-6.94*
DBW 17x HD 2967	Normal	7.09	6.93**	-20.55**	-22.58**	-20.52**	-21.34**	0.06	-1.48	-27.60**	-29.41**	0.85	-2.69	0.36	-4.16
	Stress	7.31**	7.02**	-5.09	-10.44	-6.76	-8.43	2.01	-2.15	-28.26**	-28.57**	-12.89**	-16.02**	-16.34**	-16.96**
DBW 17x KRL 210	Normal	-2.87	-7.01**	26.64**	-0.18	16.80**	-0.33	9.66*	0.02	-24. 70**	-25.83**	3.81	-1.16	-0.14	-5.08
	Stress	10.33**	9.64**	10.70	3.12	8.96	0.46	1.74	0.67	-26.47**	-27.95**	-13.52**	-14.57**	-10.95**	-12.02**
WH 1080 x HD 2967	Normal	14.72**	13.39**	13.91	0.72	8.80	-0.58	5.12	1.25	-16.69**	-22.67**	4.23	3.23	-3.77	-4.63
	Stress	14.22**	9.97**	57.98**	41.60**	60.61**	59.72**	-0.92	-10.74**	-17.63**	-23.66**	-3.55	-9.78*	-2.10	-2.17
WH 1080 x KRL 210	Normal	-0.74	-3.75*	46.80**	25.66*	29.05**	18.48**	14.02**	6.18	-28.77**	-34.51**	3.47	3.03	-14.48**	-14.83**
	Stress	10.42**	6.68**	36.05**	33.74**	29.69**	18.20	4.01	-3.57	-26.51**	-33.41**	-5.35	-7.16	-6.67*	-7.17*
HD 2967 x KRL 210	Normal	11.76**	7.16**	-11.04	-31.19**	11.25	-5.88	-18.69**	-26.87**	-19.76**	-20.59**	3.38	1.95	-6.00	-6.45
	Stress	9.84**	9.45**	6.22	-6.22	9.97	-0.28	-2.75	-5.75	-20.06**	-22.00**	-8.59*	-12.91**	-7.96**	-8.40**
CD. at 5 %	Normal	1.42	1.64	4.52	5.22	8.42	9.72	3.41	3.94	0.45	0.52	3.62	4.18	0.06	0.07
	Stress	1.26	1.46	2.28	2.64	6.29	7.27	2.56	2.96	0.33	0.38	3.22	3.71	0.04	0.04
CD at 1 %	Normal	1.87	2.15	5.94	6.86	11.06	12.77	4.49	5.18	0.59	0.68	4.76	5.50	0.08	0.09
	Stress	1.66	1.92	3.00	3.47	8.27	9.55	3.37	3.89	0.43	0.50	4.23	4.88	0.05	0.06
C.V. (%)	Normal	2.22	-	10.81	-	7.87	-	6.33	-	10.08	-	5.88	-	6.29	-
	Stress	2.21	-	11.63	-	11.61	-	5.07	-	7.22	-	5.51	-	3.97	-

*,**significant at = 0.05 and 0.01, respectively.

x WH 1080, Raj 3765 x HD 2967 and Raj 3765 x KRL 210 in stress environment (Table 3b). Our findings are in agreement with the earlier results reported by Vanpariya *et al.* (2006), Singh *et al.* (2007), Ribadia *et al.* (2007), Jaiswal *et al.* (2010), Ashutosh *et al.* (2011), Bilgin *et al.* (2011), Amarah *et al.* (2013) and Devi *et al.* (2013).

As depicted in Table 3b, for biomass/plant the cross WH 1080 x KRL 210 in normal environment showed positive and significant heterosis (18.48%) over the better parent. The cross combinations, WH 730 x PBW 343 followed by WH 730 x Raj 3765 and WH 730 x DBW 17 in stress environment had positive and significant heterosis over better parent. The highest estimates of positive heterobeltiosis was exhibited for harvest index by the cross WH 730 x Raj 3765 (17.31%) followed by PBW 343 x WH 1080 (15.80%) and WH 730 x WH 1080 (12.62%). In stress environment, none of the crosses was found to show significant and positive heterobeltiosis for harvest index, however, heterobeltiosis ranged from -22.06 (Raj 3765 x HD 2967) to 6.87 (Raj 3765 x WH 1080) (Table 2). Similar findings were reported earlier by Srivastava and Singh (2008), Jaiswal *et al.* (2010) and Bilgin *et al.* (2011).

For the trait coleoptile length, the cross WH 730 x DBW 17 (30.96%) exhibited maximum significant positive heterobeltiosis followed by WH 730 x PBW 343 (25.38%) in normal environment and WH 730 x PBW 343 (25.15%) followed by WH 730 x DBW 17 (23.92%) in stress environment (Table 3b). Sharma and Tondon (1998) and Deshpande and Nayeem (1999) observed similar results for coleoptile length. However, one cross, PBW 343 x DBW 17 depicted positive heterosis over better parent in normal environment and two cross combinations, WH 730 x PBW 343 and WH 283 x Raj 3765 depicted positive heterosis over better parent in stress environment for chlorophyll content (Table 3b). For grain yield the crosses PBW 343 x WH 1080 and WH 730 x PBW 343 in normal environment and crosses WH 1080 x HD 2967 and WH 730 x PBW 343 in stress environment were identified as promising on the basis of their high *per se* performance, average heterosis and heterobeltiosis.

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