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Research Article

Heterosis and combining ability studies for grain yield and its components in wheat (*Triticum aestivum* L.)

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Abstract Six lines and three testers in bread wheat were evaluated for fifteen quantitative traits along with their 18 crosses. Significant differences were observed for both general combining ability and specific combining ability effects. RAJ-2184 found to be good general combiner for most of the traits. The cross combinations namely, DPW-621-50 × CPAN-1796 and RAJ-2184 × WL-410 were found to be most significant for yield traits. On the basis of *per se* performance and estimates of heterosis, the cross PBW-65×WL-410 was identified as most promising followed by PBW-65 × WH-416, PBW-65 × CPAN-1796, DPW-621× CPAN-1796 and DPW-621-50 × WH-416 for grain yield per plant. The above best parents and best crosses can be used in hybridization and heterosis breeding, respectively.

Key words: Yield, Heterosis, Combining ability, Bread wheat, Traits

Introduction

Wheat belongs to the genus *Triticum* of the family *Graminae* and its origin is believed to be the Middle East Region of Asia (Lupton, 1987). Three species of wheat *viz*., *Triticum aestivum* L. (bread wheat), *Triticum durum* Desf. (Macaroni wheat) and *Triticum dicoccum* Schulb. (Emmer wheat) are grown commercially in India, covering 86, 12, and 2 per cent of the total area under wheat, respectively (Ukani*et al.*2015). Wheat is one of the most important and widely cultivated crops in the world, used mainly for human consumption and support nearly 35% of the world population (Mohammadi-joo *et al.* 2015) and providing 20% of the total food calories.

The yield of wheat and the end-use quality is dependent upon the genotype, environment and their interaction (Randhawa *et al*. 2002). The area under wheat cultivation in world during 2016-17 was 221.56 million hectare, production 750.4 million metric tons and grain yield 3.39 metric tons per hectare (USDA, 2017). In India during 2017-18, wheat is grown on 31.86 million hectares with an average production of 95 million tons and average yield of 3.0 metric ton per hectare (Ministry of Agriculture, Food Corporation of India, 2018). India has second position in both area and production after China (Jaiswal *et al*. 2017).

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 heterosis in wheat (Singh *et al*., 2004; Kumar *et al*., 2011). According to Rauf *et al.* (2012) manipulation of heterosis is an important strategy for increasing the yield potential of wheat. The study of heterosis helps the breeders in eliminating less productive crosses in F_1 generation itself. The knowledge of combining ability is useful to assess differences among the genotypes and also, elucidate the nature and magnitude of gene actions involved. It has an important role to select parents and crosses and it helps to decide breeding methods to be followed to choose desirable individuals (Salgotra *et al*. 2009).

Plant breeders focus on development of high yielding wheat cultivars by crossing good general combining lines and selecting desirable transgressive segregants from resulting hybrids for grain yield and other traits. Some researchers determined that the general combining ability effects for yield and other characters have played a significant role in selecting parents for grain yield (Kant *et al*., 2001; Akbar *et al*., 2009).

Materials and Methods

The experimental material consisted of six lines (PBW-65, DPW-621-50, MLKS-11, KSML-3, PBW-291 and RAJ-2184) and three testers (WH-416, CPAN-1796 and WL-410) crossed in a Line × Tester mating design. The variety PBW-725 of Bread wheat is used as check variety. The resultant 18 hybrids along with their nine parents were evaluated in Randomized Block Design with three replications atResearch Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib during Rabi 2017-18. This place is situated between 30̊-27’ and 30̊-46’ latitudes and 76̊-04’ and 76̊-38’E longitude and a mean height of 247 meters above sea level. Row to row and plant to plant spacing of 22.5×5 cm was maintained by thinning, respectively. A sample of five representative plants were taken from each genotype for recording data on different yield characters.The data pertaining to various characters were analysed as per the procedure of RBD given by Panse and Sukhatme (1978). The combining ability analysis was performed for a Line × Tester mating design as per the method suggested by Kempthorne (1957).

Results and Discussion

Analysis of variance for combining ability

Analysis of variance for combining ability, for line effect showed significant variance only for number of grains per plant shown in table 1. None of the character exhibited significant variance for tester effect. Line × Tester effect showed positive significance for all the characters except number of productive tillers per plant, number of spikelets per spike, number of grains per plant and grain yield per plant. The similar results were reported by Rajput and Kandalkar (2018).

General Combining Ability (*gca*) and Specific Combining Ability (*sca*) analysis

The results of *gca* effects are given in table2. The parents namely, PBW-65 was significant for plant height and number of grains per plant, DPW-621-50 for days to booting, number of grains per spike and biological yield per plant, MLKS-11 for plant height, peduncle length, number of grain per spike and biological yield per plant, KSML-3 for days to heading, days to anthesis, number of grain per spike, test weight and biological yield per plant. PBW-291 for plant height, peduncle length and biological yield per plant, RAJ-2184 for biological yield per plant, WH-416 for number of grains per spike and biological yield per plant,CPAN-1796 for number of grains per spike and biological yield per plant, WL-410 for number of grains per spike. Similar finding were also reported by Aslam *et al*., 2014 and Ishaq *et al.* 2018.

The results of specific combining ability (sca) effects are presented in table3.The cross combinations namely, DPW-621-50 × CPAN-1796 and RAJ-2184 × WL-410 significant for most of the yield traits.The similar findings were reported by Lohithaswa *et al*.(2013) and Singh *et al*. (2019).

Estimation of Heterosis

Exploitation of hybrid vigour for yield characters content provides an additional opportunity to improve and develops hybrids for yield traits along with adaptability for specific production environments. Estimates of mean squares for all the characters studied were highly significant indicating wide genetic differences among the genotypes. The heterotic effect in F_1 generation over better parent and standard check are presented in table 4, 5, 6 and 7.

Minimum number of days to booting and days to heading show early maturity of crop plant. All 18 cross combinations exhibited early maturity over commercial check. These findings are in accordance with the Ribadia *et al*. (2007), Ismail (2015), Thomas *et al*. (2017) and Rajput and Kandalkar (2018).

For days to anthesis, eight cross combinations revealed heterobeltiosis in negative maximum by DPW 621-50 × WL 410 (-7.37), while all cross combinations showed significant negative heterosis over commercial check. Similar findings were also noted by Murugan and Kannan (2017).

For number of productive tillers per plant, PBW-65 × WL-410 expressed highest positive heterosis (39.67) and none of the cross showed significant negative heterosis over better parents. The commercial check revealed neither significant positive heterosis nor significant negative for number of productive tillers per plant.These results are in accordance with the Ilker *et al*. (2010), Desale and Mehta (2013).

Two cross combinations showed significant positive heterobeltiosis as PBW-65 × WL-410 (15.01) to MLKS 11 × CPAN 1796 (17.54). For standard heterosis fourteen crosses exhibited significant positive heterosis for spike length, as reported earlier byPatil*et al*. (2011) and Rajput and Kandalkar (2018).

Significant negative heterobeltiosis for peduncle length was exhibited by three crosses, out of eighteen crosses was MLKS-11 × WH-416 (-21.52) to MLKS-11 × WL-410 (-15.86). Significant negative heterosis over standard check was exhibited by eleven cross combinations ranged from KSML-3 × WL-410 (-16.02) to (-8.35). The present findings are similar with the findings by Farooq *et al.* (2014).

Heterobeltiosis for days to maturity observed six cross combinations exploited negative heterosis with maximum range of MLKS-11 × WH-416 (-2.64) whereas, useful heterosis to be significant negative for all cross combinations. The following findings showed similar results with Thomas *et al*. (2017), Prakash *et al*. (2006).

The plant height is an important trait by which growth and vigour of plants are measured. A significant and high degree of heterosis for plant height was observed in comparison to the better parent and the commercial variety as well. The highest significant positive heterosis over better parent is exhibited by MLKS-11 × CPAN-1796 (19.86). Four cross combinations over better parent exhibited negative significant heterobeltiosis ranging from MLKS-11 × WL-410 (-8.50)to DPW-621-50 × CPAN-1796 (-15.39). Useful heterosis observed significant positive for two cross combinations ranged from RAJ-2184 × WH-416 (5.92) to PBW-65 × CPAN-1796 (7.09) while, five cross combinations exhibited significant negative useful heterosis as PBW-291 × CPAN-1796 (-6.12) to MLKS-11 × WH-416 (-11.29) indicating the presence of both additive gene effects in these crosses for plant height. Similar findings are done by Kumar and Kerkhi (2015).

Eight cross combinations exhibited significant positive heterobeltiosis for number of spikelets per spike as PBW-291 × CPAN-1796 (9.10) and PBW-65 × WH-416 (19.81) while, none of cross combinations were found to be significant negative heterotic effect over better parent. For standard heterosis fourteen cross combinations exhibited significant positive while, none of cross combinations were found to be negatively significant useful heterosis varies from over commercial check for number of spikelets per spike. The present study agrees with findings of Zaazaa *et al*. (2012).

Five crosses exhibited both significant positive heterosis over better parent as well as all eighteen cross combinations exhibited significant positive heterosis over standard check RAJ-2184 × WL-410 (5.26) to MLKS-11 × CPAN-1796 (38.55) over commercial check for number of grains per spike. The present study corresponds with the findings reported with Shrief *et al*. (2017).

The number of grains per plant is an important trait. For heterobeltiosis, thirteen cross combinations expressed highest significant positive heterosis over better parent. Cross PBW-65×WL-410 (45.57) showed that among hybrids was at highest. All the eighteen cross combinations showed positive significant heterosis over standard check. Similar type of heterosis reported by Maluszynski *et al*. (2001).

Three F_1 hybrids exhibited significant positive heterosis over better parent were from PBW-65 × WH-416 (6.91) to PBW-291 × CPAN-1796 (11.44) for test weight. Thirteen cross combinations exhibited significant negative heterosis over standard check PBW-65 × CPAN-1796 (-13.90) to PBW-65 × WL-410 (-5.37). The present study agrees with reporting of Seboka *et al*. (2009), Thomas *et al*. (2017), Murugan and Kannan (2017).

RAJ-2184 × WH-410 (18.74) expressed highest significant positive heterosis over better parent. Fourteen cross combinations showed significant positive heterosis over standard check for biological yield. The results of this study are in agreement with Seboka *et al*. (2009), Shrief *et al*. (2017), Rajput and Kandalkar (2018).

In the present investigation the grain yield per plant increased mainly due to increase in average number of tillers per plant and number of spikelets per spike. Fourteen cross combinations showed significant positive heterobeltiosis ranged RAJ-2184 × WH-416 (26.77) to PBW-65 × WH-416 (47.92). Two cross combinations exhibited significant positive heterosis over standard check varied from KSML-3 × WL-410 (23.78) to MLKS-11 × WH-416 (34.19). These findings are in accordance with the results reported by Lal *et al*. (2013), Shrief *et al*. (2017), Thomas *et al*. (2017).

Conclusion

It may be concluded that RAJ-2184 is good general combiner andDPW-621-50 × CPAN-1796 and RAJ-2184 × WL-410 is a best specific combination for most of the yield contributing traits.On the basis of *per se* performance and estimates of heterosis, the PBW-65 × WH-416 followed by PBW-65 × CPAN-1796, DPW-621× CPAN-1796 and DPW-621-50 × WH-416for seed yield per plant, hence could be evaluated further to exploit the heterosis and utilized in future breeding programme to obtain desirable and superior genotypes.

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Table 1.ANOVA for combining ability of line × tester analysis in bread wheat (*Triticum aestivum* L.)

Source of variation	d.f.	Days to booting	Days to heading	Days to Anthesis	Number of productive tillers per plant	Spike length (cm)	Peduncle length (cm)	Days to maturity	Plant height (cm)
Replications	2.00	5.92	3.57	3.57	0.35	0.21	1.40	3.63	1.58
Crosses	17.00	14.31**	16.57**	16.57**	1.57	4.20**	16.04**	17.94**	101.82**
Line effect	5.00	9.97	10.72	10.72	2.33	1.97	16.18	12.96	84.07
Tester effect	2.00	2.42	5.60	5.60	0.19	0.71	15.47	3.89	31.69
Line × Tester Eff.	10.00	18.86**	21.69**	21.69**	1.47	6.01**	16.08**	23.24**	124.72**
Error	34.00	3.24	2.87	2.87	2.12	0.84	2.95	2.80	2.72
Total	53.00	6.89	7.29	7.29	1.88	1.89	7.09	7.68	34.46

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Source of variation	d.f.	Number of spikelets per spike	Number of grains per spike	Number of Grains per plant	Test weight	Biological yield per plant (g)	Grain yield per plant (g)
Replications	2.00	2.28	1.96	1243.73	1.02	3.85	4.63
Crosses	17.00	1.39	59.13**	10044.71	5.07**	32.20**	14.71
Line effect	5.00	1.75	129.91	20898.60*	4.19	33.32	22.19
Tester effect	2.00	1.39	42.74	8496.11	7.02	19.90	23.94
Line × Tester Eff.	10.00	1.22	27.02**	4927.49	5.13**	34.11**	9.12
Error	34.00	1.25	1.34	7442.58	1.47	3.20	17.34
Total	53.00	1.33	19.90	8043.30	2.61	12.53	16.02

Table 2.Estimates for general combining ability of line × tester analysis in bread wheat (*Triticum aestivum* L.)

Character / Genotype	Days to booting	Days to heading	Days to anthesis	No. of productive tillers per plant	Spike length (cm)	Peduncle length (cm)	Days to maturity	Plant height (cm)	No. of spikelets per spike	No. of grains per spike	No. of Grains per plant	Test weight	Biological yield per plant (g)	Grain yield per plant (g)
PBW 65	0.32	0.35	0.50	0.45	0.06	1.17	0.76	2.83*	0.18	1.98**	52.84	0.03	1.18*	2.03
DPW-621-50	1.21*	0.84	1.06	0.41	-0.29	-0.63	1.01	1.65	-0.10	-1.42**	-6.52	0.37	-0.72**	0.07
MLKS-11	-0.52	0.05	0.00	0.03	-0.25	-1.60*	-0.05	-4.21**	-0.30	3.50**	43.66	-0.17	2.06**	1.54
KSML-3	1.05	1.29*	1.19*	-0.65	0.61	0.01	1.14	-0.59	0.08	2.76**	22.24	-1.27**	1.73**	-0.27
PBW-291	-0.56	-0.90	-1.05	-0.61	0.47	1.96**	-1.10	-2.82*	-0.57	-0.02	-49.79	0.48	-1.73**	-1.51
Raj-2184	-1.51**	-1.63**	-1.71**	0.37	-0.60	-0.91*	-1.76*	3.15**	0.71*	-6.81**	-62.43**	0.56	-2.53**	-1.86
WH-416	-0.36	-0.55	-0.49	0.10	0.04	0.43	-0.44	1.27	-0.01	1.77**	24.97	0.30	1.05*	1.25
CPAN-1796	0.37	0.57	0.48	-0.10	0.17	0.63	0.48	0.11	0.28	-1.07**	-10.37	-0.72**	-1.05*	-1.03
WL-410	-0.01	-0.02	0.01	0.01	-0.22	-1.06	-0.04	-1.38	-0.27	-0.70**	-14.59	0.41	0.01	-0.22
CD 95% GCA(Line)	1.21	1.16	1.16	1.00	0.63	1.30	1.35	2.24	0.70	0.71	56.80	0.81	1.14	2.64
CD 95% GCA(Tester)	0.86	0.82	0.82	0.70	0.45	0.92	0.96	1.58	0.49	0.50	40.17	0.58	0.81	1.87

Table 3: Estimates for specific combining ability of line × tester analysis in bread wheat (*Triticum aestivum* L.)

Characters / Genotype	Days to booting	Days to heading	Days to anthesis	No. of productive tillers per plant	Spike length (cm)	Peduncle length (cm)	Days to maturity	Plant height (cm)	No. of Spikelets per spike	No. of grains per spike	No. of Grains per plant	Test weight	Biological yield per plant (g)	Grain yield per plant (g)
PBW 65×WH-416	-1.10	-0.76	-0.61	-0.51	0.39	0.04	-0.38	-1.99	0.56	-1.62*	-25.00	1.45*	1.01	0.41
PBW 65×CPAN-1796	1.68	1.46	1.55	0.40	-1.26*	-1.97	1.57	5.33**	0.23	-1.35*	18.84	-1.92**	-0.09	-1.13
PBW 65×WL-410	-0.58	-0.70	-0.94	0.11	0.87	1.93	-1.19	-3.33	-0.79	2.97**	6.16	0.47	-0.92	0.72
DPW-621-50×WH-416	1.78	1.80	1.89	0.44	-2.69**	-1.73	1.84	3.23	0.09	-0.01	40.38	-0.82	0.41	0.79
DPW-621-50×CPAN-1796	-2.56*	-2.41*	-2.84**	0.44	1.34*	1.40	-2.84**	-2.62	-0.70	-1.69**	2.62	0.45	4.62**	0.49
DPW-621-50×WL-410	0.78	0.61	0.95**	-0.88	1.35*	0.34	1.00	-0.61	0.60	1.70**	-43.00	0.37	-5.03**	-1.28
MLKS-11×WH-416	0.74	-0.45	-0.48**	0.96	-0.21	-1.51	-0.53	-6.91**	-0.42	1.22	37.17	1.04	2.40*	2.38
MLKS-11×CPAN-1796	2.41*	3.46**	3.49	-1.23	0.53	0.62	3.48**	10.85**	0.69	3.18**	-32.59	-0.13	0.41	-1.38
MLKS-11×WL-410	-3.15**	-3.01**	-3.00	0.27	-0.32	0.89	-2.95*	-3.94*	-0.28	-4.40**	-4.59	-0.91	-2.81**	-1.00
KSML-3×WH-416	-0.34	0.25	0.14	-0.33	0.23	-0.30	0.09	6.42**	0.05	-3.15**	-37.54	-0.39	-1.47	-1.83
KSML-3×CPAN-1796	-1.93	-2.49*	-2.06*	-0.06	-0.11	2.04	-2.06	-5.41**	0.01	0.84	-21.48	-0.07	-3.07**	-0.82
KSML-3×WH-410	2.27*	2.24*	1.92	0.39	-0.12	-1.74	1.97	-1.01	-0.06	2.31**	59.02	0.46	4.54**	2.65
PBW-291×WH-416	-0.82	-0.70	-0.92	-0.50	0.91	4.33**	-0.97	-3.44	-0.78	2.14**	7.77	-1.26	0.14	-0.72
PBW -291×CPAN-1796	2.68*	2.69*	2.89**	0.17	-0.78	-1.87	2.88*	-2.04	0.34	-2.52**	-16.84	2.19**	-1.29	1.14
PBW -291×WL-410	-1.85	-1.99	-1.96	0.33	-0.13	-2.46*	-1.91	5.48**	0.43	0.38	9.07	-0.93	1.16	-0.42
RAJ-2184×WH-416	-0.26	-0.15	-0.01	-0.06	1.38*	-0.83	-0.06	2.69	0.49	1.42*	-22.79	-0.02	-2.50*	-1.02
RAJ-2184×CPAN-1796	-2.28*	-2.70**	-3.03**	0.29	0.28	-0.21	-3.04*	-6.10**	-0.57	1.53*	49.45	-0.52	-0.57	1.70
RAJ-2184×WL-410	2.54*	2.85**	3.04**	-0.23	-1.66**	1.04	3.09*	3.41	0.08	-2.95**	-26.66	0.54	3.07**	-0.68
CD 95% SCA	2.10	2.01	2.01	1.73	1.10	2.25	2.34	3.87	1.21	1.23	98.39	1.41	1.98	4.58

Table 4: Mean performance of F_1 hybrids and extent of heterosis in bread wheat for days to booting, days to heading, days to anthesis, number of productive tillers per plant

Crosses	Days to booting			Days to heading			Days to anthesis			Number of productive tillers per plant		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
PBW 65 × WH-416	87.93	-2.41	-8.06**	94.88	-3[illegible]	-8.32**	101.54	-2.46	-9.43**	13.44	26.47*	-2.68
PBW 65 × CPAN-1796	91.44	6.91**	-4.39**	98.20	3.16**	-5.11**	104.67	2.39	-6.64**	14.14	28.73*	2.39
PBW 65 × WL-410	88.80	0.68	-7.16**	95.47	-2.32	-7.75**	101.71	-0.54	-9.28**	13.97	39.67**	1.11
DPW-621-50 × WH-416	91.70	-5.33**	-4.13*	97.93	-4.62**	-5.37**	104.60	-3.94**	-6.70**	14.36	18.98	3.93
DPW-621-50 × CPAN-1796	88.10	-9.05**	-7.89**	94.83	-7.64**	-8.37**	100.84	-7.39**	-10.05**	14.15	17.29	2.46
DPW-621-50 × WL-410	91.05	-6.00**	-4.81**	97.27	-5.25**	-6.00**	104.16	-4.34**	-7.09**	12.94	7.24	-6.32
MLKS-11 × WH-416	88.93	-1.31	-7.02**	94.88	-3.06*	-8.31**	101.17	-2.82*	-9.76**	14.49	20.88*	4.90
MLKS-11 × CPAN-1796	91.33	2.85	-4.52**	99.91	5.68**	-3.46*	106.10	5.96**	-5.36**	12.09	0.89	-12.45
MLKS-11 × WL-410	85.39	-3.83*	-10.72**	92.86	-4.99**	-10.27**	99.15	-3.05*	-11.57**	13.71	14.40	-0.72
KSML-3 × WH-416	89.42	-0.76	-6.51**	96.83	-1.07	-6.43**	102.98	-1.08	-8.15**	12.52	17.81	-9.34
KSML-3 × CPAN-1796	88.56	4.77**	-7.41**	95.20	0.11	-8.00**	101.75	-1.88	-9.24**	12.59	14.62	-8.83
KSML-3 × WL-410	92.37	4.73	-3.42*	99.35	1.66	-3.99**	105.26	1.50	-6.12**	13.16	25.49*	-4.73
PBW-291 × WH-416	87.32	-3.09	-8.71**	93.68	-9.51**	-9.47**	99.68	-5.84**	-11.09**	12.39	-0.85	-10.28
PBW -291 × CPAN-1796	91.55	2.49	-4.28**	98.19	-5.16**	-5.11**	104.46	-1.33	-6.83**	12.86	2.85	-6.93
PBW -291 × WL-410	86.64	-3.01	-9.41**	92.92	-10.25**	-10.21**	99.14	-6.35**	-11.57**	13.13	5.07	-4.92
RAJ-2184 × WH-416	86.94	-3.51*	-9.10**	93.51	-4.46**	-9.64**	99.93	-4.01**	-10.87**	13.81	25.13*	-0.02
RAJ-2184 × CPAN-1796	85.66	-0.55	-10.44**	92.07	-2.22	-11.03**	97.88	-0.53	-12.70**	13.96	26.49*	1.06
RAJ-2184 × WL-410	90.09	2.14	-5.81**	97.04	-0.71	-6.23**	103.48	1.19	-7.70**	13.55	22.80*	-1.88
S.E±		1.46	1.46		1.40	1.40		1.40	1.40		1.20	1.20
C.D at 5%		2.97	2.97		2.84	2.84		2.84	2.84		2.44	2.44
C.D at 1%		3.99	3.99		3.82	3.82		3.82	3.82		3.28	3.28

Table 5: Mean performance of F_1 hybrids and extent of heterosis in bread wheat for spike length (cm), peduncle length (cm), days to maturity, plant height

Crosses	Spike length			Peduncle length			Days to maturity			Plant height (cm)		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
PBW 65 × WH-416	12.72	-2.30	26.27**	36.61	4.50	-4.43	126.90	-1.42	-16.75**	99.36	2.06	0.84
PBW 65 × CPAN-1796	11.21	3.83	11.25	34.79	-4.01	-9.16*	129.78	1.18	-14.86**	105.53	8.40**	7.09*
PBW 65 × WL-410	12.95	15.01*	28.51**	37.00	5.31	-3.39	126.49	-1.79	-17.02**	95.38	-2.03	-3.21
DPW-621-50 × WH-416	9.30	-30.59**	-7.67	33.03	-8.72	-13.77**	129.38	-8.15**	-15.13**	103.41	-9.24**	4.94
DPW-621-50 × CPAN-1796	13.47	0.50	33.68**	36.36	0.31	-5.07	125.62	-10.82**	-17.59**	96.41	-15.39**	-2.16
DPW-621-50 × WL-410	13.09	-2.36	29.87**	33.61	-7.13	-12.26**	128.94	-8.46**	-15.41**	96.92	-14.94**	-1.64
MLKS-11 × WH-416	11.82	-9.21	17.33*	32.29	-21.52**	-15.70**	125.95	-2.64*	-17.38**	87.41	0.73	-11.29**
MLKS-11 × CPAN-1796	12.69	17.54*	25.93**	34.62	-15.86**	-9.62*	130.88	1.17	-14.14**	104.01	19.86**	5.55
MLKS-11 × WL-410	11.46	1.75	13.70	33.19	-19.33**	-13.34**	123.93	-4.21**	-18.70**	87.73	-8.50**	-10.97**
KSML-3 × WH-416	13.11	-1.75	30.14**	35.10	8.75	-8.35*	127.76	-1.24	-16.19**	104.36	11.81**	5.91*
KSML-3 × CPAN-1796	12.91	-3.27	28.12**	37.64	3.84	-1.73	126.53	-2.19	-17.00**	91.37	-2.10	-7.27*
KSML-3 × WL-410	12.51	-6.27	24.15**	32.17	-8.45	-16.02**	130.04	0.52	-14.69**	94.29	-1.66	-4.32
PBW-291 × WH-416	13.66	4.91	35.59**	41.69	42.94**	8.84*	124.46	-3.32*	-18.35**	92.26	-2.93	-6.37*
PBW -291 × CPAN-1796	12.11	8.42	20.18*	35.68	-1.55	-6.84	129.24	0.76	-15.22**	92.51	-2.67	-6.12*
PBW -291 × WL-410	12.37	9.83	22.73**	33.40	-4.95	-12.81**	123.92	-3.79**	-18.71**	98.54	2.77	0.00
RAJ-2184 × WH-416	13.06	-0.28	29.61**	33.65	-7.47	-12.14**	124.71	-3.13*	-18.19**	104.37	11.50**	5.92*
RAJ-2184 × CPAN-1796	12.09	-7.66	20.01*	34.47	-5.21	-10.00*	122.66	-4.37**	-19.54**	94.42	0.87	-4.18
RAJ-2184 × WL-410	9.77	-25.43**	-3.08	34.03	-6.44	-11.17**	128.26	-0.42	-15.86**	102.44	6.84	3.96
S.E±		0.76	0.76		1.57	1.57		1.63	1.63		2.70	2.70
C.D at 5%		1.55	1.55		3.18	3.18		3.31	3.31		5.48	5.48
C.D at 1%		2.09	2.09		4.27	4.27		4.44	4.44		7.35	7.35

Table 6: Mean performance of F_1 hybrids and extent of heterosis in bread wheat for number of spikelets per spike, number of grains per spike, number of grains per plant

Crosses	Number of spikelets per spike			Number of grains per spike			Number of grains per plant		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
PBW 65 × WH-416	22.17	19.81**	16.29**	66.17	3.77**	29.98**	929.25	38.48**	33.32**
PBW 65 × CPAN-1796	22.13	12.34**	16.07**	63.61	0.77	24.95**	937.74	35.23**	34.54**
PBW 65 × WL-410	20.56	4.54	7.85	68.29	6.48**	34.15**	920.85	45.57**	32.12**
DPW-621-50 × WH-416	21.43	7.01	12.40**	64.37	0.96	26.45**	935.27	39.37**	34.18**
DPW-621-50 × CPAN-1796	20.93	4.51	9.77*	59.86	-5.17**	17.59**	862.17	24.33*	23.70*
DPW-621-50 × WL-410	21.68	8.24	13.69**	63.62	-0.80	24.97**	812.33	28.42*	16.55
MLKS-11 × WH-416	20.71	11.16*	8.64	70.53	10.61**	38.55**	982.24	25.09**	40.92**
MLKS-11 × CPAN-1796	22.11	12.25**	15.98**	69.66	10.36**	36.84**	877.14	11.71	25.84*
MLKS-11 × WL-410	20.59	4.68	7.99	62.44	-2.64	22.66**	900.92	14.74	29.26**
KSML-3 × WH-416	21.56	4.07	13.08**	65.42	-2.65	28.51**	886.11	13.61	27.13**
KSML-3 × CPAN-1796	21.81	5.29	14.41**	66.57	-0.93	30.78**	866.82	11.14	24.36*
KSML-3 × WL-410	21.19	2.30	11.15*	68.41	1.80	34.38**	943.11	20.92*	35.31**
PBW-291 × WH-416	20.08	5.68	5.33	67.93	6.53**	33.43**	859.40	28.07**	23.30*
PBW -291 × CPAN-1796	21.49	9.10*	12.73**	60.43	-4.27**	18.71**	799.44	15.29	14.70
PBW -291 × WL-410	21.03	6.91	10.30*	63.70	-0.68	25.12**	821.13	28.68*	17.81
RAJ-2184 × WH-416	22.63	16.69**	18.71**	60.42	-5.25**	18.68**	816.19	21.63*	17.10
RAJ-2184 × CPAN-1796	21.86	10.96*	14.65**	57.70	-8.59**	13.34**	853.10	23.03*	22.39*
RAJ-2184 × WL-410	21.96	11.63*	15.16**	53.59	-16.44**	5.26**	772.76	22.16*	10.87
S.E±		0.84	0.84		0.86	0.86		68.47	68.47
C.D at 5%		1.71	1.71		1.74	1.74		139.14	139.14
C.D at 1%		2.30	2.30		2.34	2.34		186.81	186.81

Table 7: Mean performance of F_1 hybrids and extent of heterosis in bread wheat for test weight, biological yield per plant**,** grain yield per plant

Crosses	Test weight (g)			Biological yield per plant (g)			Grain yield per plant (g)		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
PBW 65 × WH-416	40.02	6.91*	-3.29	61.39	16.33**	17.56**	37.24	47.92**	29.07
PBW 65 × CPAN-1796	35.63	5.34	-13.90**	58.18	10.38**	11.42**	33.42	44.09**	15.85
PBW 65 × WL-410	39.16	2.72	-5.37*	58.41	18.57**	11.86**	36.08	55.97**	25.06
DPW-621-50 × WH-416	38.10	1.70	-7.94**	58.89	11.59**	12.77**	35.66	41.64**	23.59
DPW-621-50 × CPAN-1796	38.35	2.38	-7.33**	61.00	15.71**	16.81**	33.08	42.61**	14.66
DPW-621-50 × WL-410	39.40	3.34	-4.80	52.41	4.66	0.36	32.12	38.52**	11.35
MLKS-11 × WH-416	39.42	1.56	-4.75	63.66	4.92*	21.91**	38.71	26.92*	34.19**
MLKS-11 × CPAN-1796	37.23	-4.07	-10.04**	59.56	-1.83	14.06**	32.69	7.16	13.30
MLKS-11 × WL-410	37.58	-3.16	-9.18**	57.40	-5.39*	9.93**	33.87	11.04	17.40
KSML-3 × WH-416	36.89	-1.46	-10.86**	59.46	-0.01	13.86**	32.70	16.12	13.34
KSML-3 × CPAN-1796	36.18	0.39	-12.57**	55.75	-6.25*	6.75*	31.43	11.62	8.95
KSML-3 × WL-410	37.85	-0.73	-8.55**	64.42	8.34**	23.36**	35.71	26.81*	23.78*
PBW-291 × WH-416	37.78	0.91	-8.72**	57.61	7.74**	10.32**	32.56	29.34*	12.86
PBW -291 × CPAN-1796	40.20	11.44**	-2.87	54.07	1.13	3.55	32.15	38.58**	11.43
PBW -291 × WL-410	38.21	0.23	-7.67**	57.59	7.71**	10.28**	31.40	35.73*	8.84
RAJ-2184 × WH-416	39.08	4.40	-5.56*	54.17	2.65	3.73	31.91	26.77*	10.62
RAJ-2184 × CPAN-1796	37.57	10.63**	-9.22**	54.00	2.43	3.40	32.36	39.50**	12.17
RAJ-2184 × WL-410	39.75	4.27	-3.95	58.69	18.74**	12.39**	30.79	33.11**	6.74
S.E±		0.98	0.98		1.38	1.38		3.19	3.19
C.D at 5%		1.99	1.99		2.80	2.80		6.48*	6.48
C.D at 1%		2.68	2.68		3.76	3.76		8.70*	8.70