

Heterosis and Combining Ability Analysis for Various Yield Components in Bread Wheat (*Triticum aestivum* L.)

Ravi Kumar, S. A. Kerkhi, Pradeep Kumar, Neeraj Kumar

Received 23 January 2017; Accepted 25 February 2017; Published online 16 March 2017

Abstract A study was conducted for the analysis of heterosis and combining ability for yield and some quality traits involving 24 parents (20 Line \times 04 Tester) and their 80 F_1 s during 2009-10 and 2010-11. The five crosses (Selection 1 \times PBW 590, HUW 635 \times PBW 590, WCW 98–48 \times PBW 590, HUW 234 \times PBW 343 and PBW 550 \times DBW 17) expressed significant and positive SCA effect along with high significant heterotic response and good *per se* performance indicated that these individual crosses would be effective for development of heterotic population for

achieving higher yield in wheat. Among the 17 high yielding crosses, eight crosses namely (Election 1 \times PBW 590, WCW 98–48 \times PBW 590, PBW 502 \times PBW 590, PBW 502 \times DBW 17, HUW 234 \times DBW 17, HD 2733 \times DBW 17, PBW 435 \times DBW 17, Selection 1 \times DBW 17) were involved high \times high general combiners. The parents involved in these crosses namely (Selection 1, PBW 590, PBW 502, DBW 17, WCW 98–48, HUW 234 and PBW 435) had also been desirable general combiners for 4 to 8 characters in addition to grain yield. This may be due to the accumulation of favorable additive or additive \times additive effects. These crosses or parents involved in these F_1 s may be exploited in multiple cross breeding program to have a desirable breeding population with broad genetic base for yield improvement in wheat.

Keywords Heterobeltiosis, Yield components, Line \times Tester, Quality traits, Bread wheat.

R. Kumar*, S. A. Kerkhi
Sardar Vallabhbhai Patel University of
Agriculture and Technology,
Meerut 250110, UP, India

P. Kumar
Indian Institute of Wheat and Barley Research,
Karnal 132001, Haryana, India

N. Kumar
Department of Zoology,
Vardhman College, Bijnor 246701, UP, India
e-mail : pradeeptaliyan231@gmail.com

*Correspondence

Introduction

Wheat (*Triticum aestivum* L.) is an important cereal crop of India and it is grown over 30.23 million hectares area with total production amounting to 93.50 million tons and average productivity of 2.9 tons/ha. At global level, India ranks second largest wheat producing nation after China. India's share in world wheat area is about 12.5%, whereas it occupies 13.43% in total world wheat production [1]. Wheat is a highly self pollinated crop, scope for the exploitation of

Table 1. Extent of heterosis over better parent in 80 crosses for different yield components in bread wheat (*Triticum aestivum* L.).

Crosses	Days to ear emergence	Days to maturity	Productive tillers	Plant height	Flag leaf area	Spike length
UP 2338 × PBW 343	-7.44**	0.00	-16.67**	-0.48	24.02**	8.52
UP 2338 × PBW 226	-5.79**	-2.49**	7.78	-13.00**	2.62	5.88
UP 2338 × PBW 590	-0.41	5.87**	13.69*	-3.22**	12.67**	-1.27
UP 2338 × DBW 17	-5.37**	-3.15**	11.55*	-12.79**	46.34**	13.82*
PBW 550 × PBW 343	-2.62	-1.44*	-23.19**	8.47**	0.75	-2.10
PBW 550 × PBW 226	3.03*	0.72	1.80	-0.30	15.64**	-21.42**
PBW 550 × PBW 590	-0.43	-0.48	0.00	-8.24**	32.66**	-21.48**
PBW 550 × DBW 17	-2.55	-0.72	16.01**	8.26**	-13.13**	-1.46
HD 2967 × PBW 343	-1.31	5.57**	-13.77**	4.30**	23.90**	-4.62
HD 2967 × PBW 226	-1.30	-1.74**	-7.54	-5.41**	35.17**	-3.69
HD 2967 × PBW 590	2.56	6.39**	-2.66	14.60**	14.96**	-19.85**
HD 2967 × DBW 17	-4.26**	-5.08**	4.14	7.05**	3.53	-17.12**
PBW 502 × PBW 343	-2.12	0.76	-21.16**	-4.31**	-13.00**	5.50
PBW 502 × PBW 226	-3.39*	4.73**	8.53	8.42**	31.30**	10.22
PBW 502 × PBW 590	-1.27	5.04**	8.46	-3.81**	-15.38**	-9.18
PBW 502 × DBW 17	0.42	0.48	21.62**	-2.45*	-12.26**	12.47
WCW 98-4 × PBW 343	1.30	-6.04**	-20.29**	2.22*	11.34**	18.13**
WCW 98-4 × PBW 226	-3.03*	-5.80**	-1.95	-3.91**	26.22**	7.39
WCW 98-4 × PBW 590	3.85**	1.21	8.98	-6.81**	31.73**	-9.36
WCW 98-4 × DBW 17	4.26**	0.48	22.61**	-5.59**	-4.70	16.16*
WCW 98-48 × PBW 343	-1.65	-4.30**	-7.97	-10.50**	25.66**	7.87
WCW 98-48 × PBW 226	-3.29*	-3.58**	7.78	-3.59**	35.51**	13.70*
WCW 98-48 × PBW 590	-8.64**	-4.53**	9.23	-0.16	6.19	9.63
WCW 98-48 × DBW 17	-0.82	-0.48	18.81**	10.56**	18.03**	2.77
WCW 98-19 × PBW 343	-0.44	4.56**	-5.80	-3.97**	-18.88**	-5.48
WCW 98-19 × PBW 226	5.19**	4.73**	-1.20	7.40**	-27.41**	4.04
WCW 98-19 × PBW 590	4.70**	7.93**	9.23	0.67	-35.78**	-5.73
WCW 98-19 × DBW 17	-1.28	-5.81**	22.11**	3.90**	-10.72**	8.47
UP 2425 × PBW 343	0.43	6.33**	-5.80	-4.21**	-18.02**	-15.75**
UP 2425 × PBW 226	1.28	4.23**	1.80	-7.64**	1.05	-29.06**
UP 2425 × PBW 590	5.13**	7.16**	9.23	-14.35**	-14.63**	-15.97**
UP 2425 × DBW 17	0.85	-3.87**	23.09**	-3.74**	-4.65	-8.65
PBW 373 × PBW 343	-3.75**	-1.91**	-0.72	13.36**	6.27	4.49
PBW 373 × PBW 226	-1.67	-4.06**	6.29	-4.65**	5.96	-8.20
PBW 373 × PBW 590	-2.50	-0.24	1.54	-8.34**	26.23**	-11.07
PBW 373 × DBW 17	-5.83**	-6.68**	16.88**	0.89	-7.47	7.49
HUW 213 × PBW 343	4.80**	0.99	-7.39	-5.16**	-11.05**	-22.50**
HUW 213 × PBW 226	2.16	1.49*	7.04	-5.54**	3.01	-5.34
HUW 213 × PBW 590	1.28	4.47**	-3.08	-1.94	7.80	2.18
UP 2338 × PBW 343	-1.28	-3.15**	20.46**	-17.16**	28.29**	2.18
UP 2338 × PBW 226	3.06*	0.25	-3.62	-14.77**	-0.60	-2.95
UP 2338 × PBW 590	4.33**	-1.74*	-1.20	-8.93**	10.09*	-2.65
UP 2338 × DBW 17	5.98**	3.28**	-1.54	-6.28**	-15.71**	-20.13**
PBW 550 × PBW 343	-5.11**	0.97	13.86	-16.03**	17.64**	-0.45
PBW 550 × PBW 226	4.80**	-1.52*	-7.97	6.63**	2.91	12.57
PBW 550 × PBW 590	-1.73	1.24	-1.05	-8.35**	-0.40	-10.65
PBW 550 × DBW 17	1.28	6.91**	15.23**	8.16**	18.33**	11.50
HD 2967 × PBW 343	2.13	0.97	17.16**	3.70**	3.76	19.80**
HD 2967 × PBW 226	-2.11	2.27**	5.74	4.30**	15.45**	6.62
HD 2967 × PBW 590	-3.38*	4.23**	7.04	-5.55**	32.77**	-8.41
HD 2967 × DBW 17	3.38	6.06**	1.23	-3.21**	-4.41	2.72
PBW 502 × PBW 343	-2.95*	-1.21	14.82*	-2.92*	-0.09	2.40
PBW 502 × PBW 226	-6.05**	4.25**	5.97	-15.29**	-4.86	-15.63**

Table 1. Continued.

Crosses	Days to ear emergence	Days to maturity	Productive tillers	Plant height	Flag leaf area	Spike length
PBW 502 × PBW 590	-7.66**	-0.50	8.53	-6.77**	11.67**	-11.48
PBW 502 × DBW 17	1.61	5.25**	10.86	-16.86**	28.17**	-22.18**
WCW 98-4 × PBW 343	-7.26**	-3.39**	-1.38	-14.31**	-11.22**	6.58
WCW 98-4 × PBW 226	-7.14**	-6.18**	-4.35	-11.22**	13.81**	3.55
WCW 98-4 × PBW 590	-8.73**	-3.80**	6.29	-6.90**	21.56**	-2.17
WCW 98-4 × DBW 17	-1.19	1.43*	14.62**	-3.31**	21.85**	6.73
WCW 98-48 × PBW 343	-7.94**	-7.60**	20.46**	-8.63**	24.73**	14.27*
WCW 98-48 × PBW 226	2.60	1.27	-23.19**	-16.91**	-2.10	-6.47
WCW 98-48 × PBW 590	8.23**	2.49**	10.78*	-16.12**	8.43*	-13.14*
WCW 98-48 × DBW 17	2.99*	5.12**	10.62	-13.71**	11.63**	-7.91
WCW 98-19 × PBW 343	3.83**	1.21	14.84**	-10.43**	-25.45**	-5.89
WCW 98-19 × PBW 226	-2.47	-1.95**	3.62	-12.80**	22.06**	-13.41*
WCW 98-19 × PBW 590	-8.23**	-2.68**	-1.89	-2.93*	-11.61**	-3.25
WCW 98-19 × DBW 17	-3.29*	-5.11**	4.71	-9.77**	-1.88	3.44
UP 2425 × PBW 343	-7.82**	-2.42**	-1.16	-13.71**	-17.19**	-3.38
UP 2425 × PBW 226	6.55**	0.48	-5.07	2.32*	24.72**	4.12
UP 2425 × PBW 590	-4.76**	-1.92**	3.29	-8.60**	18.06**	10.15
UP 2425 × DBW 17	-0.43	-4.57**	12.31*	-8.71**	30.83**	21.41**
PBW 373 × PBW 343	4.68**	0.48	18.63**	2.99**	19.36**	16.50*
PBW 373 × PBW 226	6.99**	1.94**	-10.14	4.92**	16.27**	-3.16
PBW 373 × PBW 590	1.30	-5.10**	-3.44	3.57**	37.80**	11.67
PBW 373 × DBW 17	-0.43	-2.18**	10.61	4.73**	-12.77**	6.45
HUW 213 × PBW 343	-6.81**	-4.60**	3.15	-20.89**	-5.86	-6.91
HUW 213 × PBW 226	-0.84	0.25	-8.61	15.80**	-4.99	14.46*
HUW 213 × PBW 590	-2.11	3.48**	10.93*	-0.17	23.95**	2.92
UP 2338 × PBW 343	-3.80**	5.06**	8.83	-2.71*	8.61*	18.02**
UP 2338 × PBW 226	-0.84	-1.21	13.04*	-0.71	27.87**	-12.93*

Table 1. Continued.

Crosses	Grains per spike	Biological yield	Harvest index	Grain yield	Ash content
UP 2338 × PBW 343	9.57**	-20.98**	-1.41	-16.64**	-17.43**
UP 2338 × PBW 226	-5.21**	2.69	-7.99	-3.55	-24.72**
UP 2338 × PBW 590	-2.96	14.84**	-16.86**	-0.90	10.06*
UP 2338 × DBW 17	6.91**	7.87	-11.62*	-0.58	28.37**
PBW 550 × PBW 343	7.95**	-20.04**	-2.20	-21.82**	-31.09**
PBW 550 × PBW 226	-27.12**	0.26	-2.93	-2.39	31.46**
PBW 550 × PBW 590	-2.09	2.52	-12.93**	-0.80	23.37**
PBW 550 × DBW 17	-1.11	9.87	10.75*	23.73**	-16.44**
HD 2967 × PBW 343	0.53	-27.08**	-2.37	-28.91**	-6.05
HD 2967 × PBW 226	-21.13**	-22.04**	-10.52*	-30.19**	20.15**
HD 2967 × PBW 590	-4.07	2.10	-16.51**	-1.09	15.14**
HD 2967 × DBW 17	-13.12**	-0.56	-3.61	0.20	-31.22**
PBW 502 × PBW 343	3.32	-7.28	-12.80**	-7.53	-19.33**
PBW 502 × PBW 226	-7.02**	1.24	-8.62*	0.95	0.30
PBW 502 × PBW 590	-6.35**	38.68**	-9.53*	28.11**	6.83
PBW 502 × DBW 17	11.38**	38.59**	-12.37**	35.13**	-33.00**
WCW 98-4 × PBW 343	-10.51**	-20.48**	-13.16**	-24.23**	-32.47**
WCW 98-4 × PBW 226	-20.40**	-1.80	-14.30**	-11.97*	6.81
WCW 98-4 × PBW 590	-18.35**	41.18**	-18.90**	16.58*	-20.77**
WCW 98-4 × DBW 17	-3.54	22.47**	-5.86	23.25**	37.57**

Table 1. Continued.

Crosses	Grains per spike	Biological yield	Harvest index	Grain yield	Ash content
WCW 98-48 × PBW 343	-9.71**	-6.98	6.42	3.18	-5.08
WCW 98-48 × PBW 226	-14.95**	3.92	-7.75	-3.91	-18.29**
WCW 98-48 × PBW 590	17.89**	39.09**	-6.38	32.82**	-2.42
WCW 98-48 × DBW 17	2.58	18.24**	-2.23	17.17*	-43.80**
WCW 98-19 × PBW 343	-10.64**	-1.02	-17.30**	-4.10	-15.98**
WCW 98-19 × PBW 226	-18.40**	-4.10	-16.00**	-9.96	12.45**
WCW 98-19 × PBW 590	-7.61**	27.38**	-20.41**	5.99	8.55*
WCW 98-19 × DBW 17	0.27	16.99**	-3.84	28.25**	39.71**
UP 2425 × PBW 343	7.85**	7.22	-5.92	12.86*	-15.84**
UP 2425 × PBW 226	-18.55**	-6.85	-13.64**	-14.12*	4.07
UP 2425 × PBW 590	-3.65	35.25**	-11.20**	22.15**	3.45
UP 2425 × DBW 17	-8.47**	12.31	-7.14	13.56	24.32**
PBW 373 × PBW 343	2.13	0.24	-5.65	4.47	-20.46**
PBW 373 × PBW 226	-26.53**	-1.54	-12.55**	-9.13	-12.90**
PBW 373 × PBW 590	-14.93**	14.86**	-10.04*	6.79	-11.25**
PBW 373 × DBW 17	-15.27**	-5.21	-0.96	-6.00	-38.10**
HUW 213 × PBW 343	-15.57**	-15.98**	-11.94**	-18.40**	-48.49**
HUW 213 × PBW 226	-25.73**	-11.71**	0.00	-7.09	-3.04
HUW 213 × PBW 590	-0.28	27.04**	-11.07**	15.35*	10.60**
UP 2338 × PBW 343	-17.35**	4.06	-4.99	5.76	-3.95
UP 2338 × PBW 226	9.97**	-12.03**	-2.63	-13.67*	-41.81**
UP 2338 × PBW 590	-27.24**	-2.73	-1.63	-4.23	11.90**
UP 2338 × DBW 17	21.27**	15.24**	-15.70**	-1.09	9.14*
PBW 550 × PBW 343	-6.15**	11.75*	-1.90	9.42	1.75
PBW 550 × PBW 226	-14.10**	-18.59**	-7.17	-22.65**	-42.34**
PBW 550 × PBW 590	-13.62**	5.77	-3.07	2.94	-14.84**
PBW 550 × DBW 17	11.40**	38.52**	-17.07**	16.94*	-1.30
HD 2967 × PBW 343	10.61**	22.80**	3.14	26.96**	-49.81**
HD 2967 × PBW 226	-14.56**	0.61	-18.15**	-2.68	-13.93**
HD 2967 × PBW 590	-13.86**	-3.12	-13.15**	-5.27	-25.55**
HD 2967 × DBW 17	4.04*	16.00**	-14.50**	3.24	-33.57**
PBW 502 × PBW 343	-15.96**	2.61	-9.01*	4.24	-30.16**
PBW 502 × PBW 226	-10.70**	11.80**	-12.77**	12.01	-6.58
PBW 502 × PBW 590	-17.13**	-0.94	-11.68**	-4.01	-19.78**
PBW 502 × DBW 17	-20.25**	7.67	-10.47*	-3.91	14.11**
WCW 98-4 × PBW 343	2.73	16.62**	0.89	25.24**	96.20**
WCW 98-4 × PBW 226	-11.04**	-1.87	-14.26**	-2.70	-13.04**
WCW 98-4 × PBW 590	-13.20**	-6.30	-13.27**	-10.10	12.06**
WCW 98-4 × DBW 17	-3.99**	32.01**	1.06	38.04**	-31.70**
WCW 98-48 × PBW 343	-19.13**	33.05**	-15.05**	27.48**	13.45**
WCW 98-48 × PBW 226	-8.58**	-16.21**	-20.37**	-21.17**	-41.23**
WCW 98-48 × PBW 590	-11.14**	0.69	-19.82**	-9.23	15.00**
WCW 98-48 × DBW 17	4.27	43.39**	-10.45*	35.18**	-39.92**
WCW 98-19 × PBW 343	-10.46**	27.40**	-14.27**	23.86**	13.53**
WCW 98-19 × PBW 226	3.59	-6.42	22.82**	27.63**	-0.76
WCW 98-19 × PBW 590	-19.43**	-14.64**	-3.83	-12.80*	-15.33**
WCW 98-19 × DBW 17	5.96**	24.79**	-6.64	19.00**	-19.28**
UP 2425 × PBW 343	2.16	12.99*	15.82**	32.39**	-12.91**
UP 2425 × PBW 226	-19.02**	-16.15**	-9.58*	-19.43**	-24.89**
UP 2425 × PBW 590	-9.31**	10.02*	-3.42	7.75	12.79**
UP 2425 × DBW 17	23.87**	22.16**	-8.98*	13.31	-20.65**
PBW 373 × PBW 343	-0.63	24.58**	-0.03	29.08**	-31.53**
PBW 373 × PBW 226	8.88**	-2.51	-16.42**	-4.82	-1.23
PBW 373 × PBW 590	-12.58**	-2.65	-12.54**	-5.18	-47.23**
PBW 373 × DBW 17	7.96**	33.66**	-10.06*	20.27**	-47.14**

Table 1. Continued.

Crosses	Grains per spike	Biological yield	Harvest index	Grain yield	Ash content
HUW 213 × PBW 343	4.40*	17.70**	-9.12*	11.10	7.84*
HUW 213 × PBW 226	9.69**	8.19	-4.23	15.36*	5.73
HUW 213 × PBW 590	0.79	-3.04	-8.67*	-5.80	18.83**
UP 2338 × PBW 343	0.00	27.56**	-8.83*	19.68**	-4.92
UP 2338 × PBW 226	-13.27**	18.29**	1.38	27.09**	17.15**

hybrid vigor depends on the direction and magnitude of heterosis, biological feasibility of crop and nature of gene action. The use of heterosis for getting high yield with improved quality has been largely used in cross pollinated crops but now in self pollinated crops evidences are available to confirm the potential use of heterosis. Wheat production can be enhanced through the development of new cultivars having wide genetic base and better performance under various agro-climatic conditions. For any successful breeding program to improve grain yield with acceptable quality is the prime objective of any breeding program. Estimation of heterosis in wheat crop have also been reported earlier [2—4] for grain yield productive tillers, day to maturity, plant height, grains per spike, biological yield and several other component traits. The major objective of the present study was to estimate the heterosis over better parents (heterobeltiosis) and combing ability through Line × Tester mating design involving 20 lines and 04 testers for improvement in yield component and quality traits in bread wheat.

Materials and Methods

The experimental material comprising 20 lines (UP 2338, PBW 550, HD 2967, PBW 502, WCW 98-4, WCW 98-48, WCW 98-19, UP 2425, PBW 373, HUW 213, K 9162, K 712, K 8962, HUW 516, Selection 1, HUW 635, HUW 234, HD 2733, Raj 3765, PBW 435 and 4 Testers (PBW 343, PBW 226, PBW 590, DBW 17) was planted at Crop Research Center, SVBPU and T, Meerut during *rabi* 2009-2010 for attempting crossing in a Line × Tester mating design. In the next crop season (i.e. *rabi* 2010-2011), experimental material consisted total 104 genotypes (24 parents and their 80 F₁s) was sown

in a randomized block design with three replications. Seeds of each of the parental lines and also F₁s were dibbled in single row plot of 5 meter length maintaining spacing of 10 cm among plants within a row and 23 cm between rows. All the standard agronomical practices were followed to raise normal crop. Observations were recorded for days to ear emergence, days to maturity, number of productive tillers plant, plant height (cm), flag leaf area (cm²), spike length (cm), grains per spike, biological yield per plant (g), harvest Index (%), 1000-grain weight (g), ash content and phenol color reaction. Mean data on these traits were subjected to statistical and biometrical analysis. The magnitude of heterosis was estimated by commonly used statistical software (INDOSTAT 7.5). The data were first subjected to the usual analysis followed by a RBD [5]. The percent increase or decrease of F₁ hybrids over better parent was calculated by using the standard formula [6].

$$\text{Heterosis (\%)} = \frac{F_1 - PM}{PM} \times 100$$

F₁ = Mean performance of F₁ hybrid; PM = Mean performance of parent

Results and Discussion

Heterosis over better parent for days to ear emergence ranged from -0.41 (UP 2338 × PBW 590) to 8.23 (HUW 635 × PBW 226). The highest significant and negative heterosis (desirable) were recorded in Selection 1 × PBW 226 (-8.73) followed by WCW 98-48 × PBW 590 (-8.64). Heterosis over better parent for days to maturity ranged from -0.24 (PBW 373 × PBW

Table 2. Crosses showing maximum heterosis over better parents for grain yield and other yield components in bread wheat (*Triticum aestivum* L.).

Crosses	Heterosis	Other character exhibiting significant heterosis in desirable direction
Selection 1 × PBW 590	38.04**	Productive tillers, Plant height, Flag leaf area, Biological yield per plant
HUW 635 × PBW 590	35.18**	Plant height, Flag leaf area, Biological yield per plant
PBW 502 × DBW 17	35.13**	Productive tillers, Plant height, Grains per spike, Biological yield
WCW 98-48 × PBW 590	32.82**	Days to ear emergence, Days to maturity, Grains per spike, Biological yield
HUW 234 × DBW 17	32.39**	Days to ear emergence, Days to maturity, Plant height, Biological yield, Harvest index
HD 2733 × DBW 17	29.08**	Productive tillers, Flag leaf area, Spike length, Biological yield
WCW 98-19 × DBW 17	28.25**	Days to maturity, Productive tillers, Biological yield, Ash content
PBW 502 × PBW 590	28.11**	Plant height, Biological yield
HUW 234 × PBW 343	27.63**	Days to maturity, Plant height, Flag leaf area, Harvest index
Selection 1 × DBW 17	27.48**	Days to ear emergence, Days to maturity, Productive tillers, Plant height, Flag leaf area, Spike length, Biological yield, Ash content
PBW 435 × DBW 17	27.09**	Productive tillers, Flag leaf area, Biological yield, Ash content
K 712 × DBW 17	26.96**	Productive tillers, Spike length, Grains per spike, Biological yield
HUW 635 × DBW 17	23.86**	Productive tillers, Plant height, Biological yield, Ash content
PBW 550 × DBW 17	27.73**	Productive tillers, Harvest index
WCW 98-4 × DBW 17	23.25**	Productive tillers, Plant height, Spike length, Biological yield, Ash content
UP 2425 × PBW 590	22.15**	Plant height, Biological yield
Raj 3765 × PBW 590	20.27**	Days to maturity, Grains per spike, Biological yield

590) to 7.93 (WCW 98-4 × PBW 590). The highest negative (desirable) and significant value of heterosis were recorded in Selection 1 × DBW 17 (-7.60) followed by Selection 1 × PBW 343 (-6.18). Heterosis over better parent for plant height ranged from -0.16 (WCW 98-48 × PBW 590) to 15.80 (PBW 435 × PBW 343). The highest negative (desirable) and significant heterosis were recorded in Raj 3765 × DBW 17 (-20.89) and HUW 213 × DBW 17 (-17.16). Negative (desirable) and significant heterosis for days to maturity and plant height were earlier reported [3, 4, 7–10]. The negative and significant heterosis for days to maturity and plant height is desirable in case of wheat crop.

Heterobeltiosis for productive tillers ranged from -0.72 (PBW 373 × PBW 343) to 23.09 (UP 2425 × DBW 17). The highest positive (desirable) and significant value of heterosis was recorded in UP 2425 × DBW 17 (23.09) followed by WCW 98-4 × DBW 17 (22.61). Positive and significant heterosis for productive tillers has been reported earlier [3, 4, 7–9]. A range of heterobeltiosis for flag leaf area was recorded -0.09 (K 8962 × DBW 17) to 46.34 (UP 2338 × DBW 17). The highest positive and significant heterosis was observed in UP 2338 × DBW 17 (46.34) followed by Raj

3765 × PBW 226 (37.80). Such types of findings on heterosis for this trait were also reported earlier [4, 7–9]. Heterobeltiosis for spike length ranged from -0.45 (K 9162 × DBW 17) to 21.41 (HD 2733 × PBW 590). The highest positive and significant value of heterosis were observed in HD 2733 × PBW 590 (21.41) followed by K 712 × DBW 17 (19.08). Positive and significant value of heterosis for spike length has been reported earlier [7–9]. Heterosis over better parent for grains per spike ranged from -0.28 (HUW 213 × PBW 590) to 23.87 (HD 2733 × PBW 590). The desirable and significant value of heterobeltiosis was recorded in HD 2733 × PBW 590 (23.87) followed by K 9162 × PBW 590 (21.27). Similar findings for grain per spike were also reported by Singh et al. [7]. Heterosis over better parent ranged from -0.56 (HD 2967 × DBW 17) to 43.39 (HUW 635 × PBW 590) for biological yield. The highest and positively significant value of heterosis were observed for WCW 98-4 × PBW 590 (41.18) followed by WCW 98-48 × PBW 590 (39.09). Similar findings for biological yield were also reported earlier [7–9] in wheat crop.

Heterobeltiosis for harvest index ranged from -0.03 (HD 2733 × DBW 17) to 22.82 (HUW 234 × PBW 343). The highest positive and significant value of

Table 3. The crosses showing maximum SCA effects for grain yield and other yield components in bread wheat (*Triticum aestivum* L.).

Crosses	SCA		GCA of parents		Significant for other character
	value	<i>per se</i>	P ₁	P ₂	
HUW 234 × PBW 343	4.64**	29.037	3.16**	-1.76**	Productive tillers, Plant height, Flag leaf area, Grains per spike, Harvest index, Ash content
Selection 1 × PBW 590	2.98**	28.170	1.51**	0.69**	Grains per spike, Harvest index
HUW 635 × PBW 590	3.66**	27.64	0.30	0.69**	Days to ear emergence, Days maturity, Flag leaf area, Biological yield, Harvest index
UP 2425 × PBW 343	3.81**	25.677	0.64	-1.76**	Biological yield, Grains per spike
PBW 435 × PBW 343	2.95**	26.243	2.06**	-1.76**	Days maturity, Grains per spike, Biological yield, Ash content
HD 2733 × PBW 226	3.11**	26.430	0.47	-0.15	Days to ear emergence, Plant height, Grains per spike, Biological yield, Ash content
HUW 516 × PBW 343	3.29**	25.483	0.96	-1.76**	Productive tillers, Biological yield
K 712 × PBW 226	2.33**	25.250	0.07	-0.15	Days to ear emergence, Plant height, Ash content
WCW 98-48 × PBW 590	1.98*	27.103	1.44**	0.69**	Days to ear emergence, Days to maturity, Grains per spike, Ash content
PBW 550 × DBW 17	1.96*	24.903	-1.28**	1.22**	Grains per spike

heterosis were observed in HUW 234 × PBW 343 (22.82) followed by HUW 234 × DBW 17 (15.82). Desirable and significant heterosis for harvest index was also reported earlier [4, 7–9].

A range of heterosis over better parent for grain yield was recorded from -0.58 (UP 2338 × DBW 17) to 38.04 (Selection 1 × PBW 590). Total numbers of 26 crosses were identifying which showed positive (desirable) and significant heterosis for grain yield. The highest positive and significant value of heterosis were observed in Selection 1 × PBW 590 (38.04) followed by HUW 635 × PBW 590 (35.18), PBW 502 × DBW 17 (35.11), WCW 98-48 × PBW 590 (32.82) and HUW 234 × DBW 17 (32.39). Similar findings on positive heterosis for grain yield have been reported earlier [2, 3, 7–10]. Heterosis over better parent for ash content ranged from -0.76 (HUW 234 × PBW 226) to 96.20 (HUW 516 × DBW 17) (Table 1). The highest positive and significant heterosis were recorded for HUW 516 × DBW 17 (96.20) and WCW 98-19 × DBW 17 (39.17).

On the basis of high percentage of significant and desirable heterosis for grain yield, out of 26 crosses, 17 crosses were screened out where significant heterosis (%) was recorded in the range of 20.27% to 38.04%. These 17 crosses were also having good

mean yield (between 24.807 g to 29.037 g per plant) as compared to average yield of all the F₁ crosses (22.995 g per plant). Out of these 17 crosses, 13 (Table 2) crosses namely, WCW 98-4 × DBW 17 (24.807), PBW 550 × DBW 17 (24.903), UP 2425 × PBW 590 (24.927), K 712 × DBW 17 (25.553), Selection 1 × DBW 17 (25.657), WCW 98-19 × DBW 17 (25.813), HD 2733 × DBW 17 (25.980), PBW 502 × PBW 590 (26.143), PBW 435 × DBW 17 (26.197), WCW 98-48 × PBW 590 (27.103), PBW 502 × DBW 17 (27.197), Selection 1 × PBW 590 (28.170) and HUW 234 × PBW 343 (29.037) were observed as superior F₁s crosses where the heterosis over better parent was estimated and the better parents either DBW 17 or PBW 590 were involved in these cross combinations. By exploiting these crosses through heterosis breeding program will lead in development of a promising hybrid population for high productivity in wheat. High and significant heterosis over better parent were also reported earlier [4, 7–10], for grain yield in wheat. Perusal of the SCA data (Table 3) showed that five crosses namely, Selection 1 × PBW 590, HUW 635 × PBW 590, WCW 98-48 × PBW 590, HUW 234 × PBW 343 and PBW 550 × DBW 17 also expressed significant and positive SCA effect along with high significant heterotic response as well as good *per se* performance indicated that economic increase in grain yield was due to non additive genetic components. This indicated that these

individual crosses would be effective for development of heterotic population for achieving higher yield in wheat. Among the 17 high yielding crosses, eight crosses namely, Selection 1 × PBW 590 (20.407), WCW 98-48 × PBW 590 (20.407), PBW 502 × PBW 590 (20.407), PBW 502 × DBW 17 (20.127), HUW 234 × DBW 17 (20.127), HD 2733 × DBW 17 (20.127), PBW 435 × DBW 17 (20.127) Selection 1 × DBW 17 (20.127) were the involved high × high general combiners. The parents involved in these crosses such as Selection 1, PBW 590, PBW 502, DBW 17, WCW 98-48, HUW 234, PBW 435 had also been desirable general combiners for 4 to 8 characters in addition to grain yield. Hence, the increased vigor in F_1 s under such conditions could be attributed due to the accumulation of favorable additive or additive × additive effects. These crosses might also produce good recombinants/segregants in preceding generations. These crosses or parents involved in these F_1 s may be exploited in multiple cross breeding program to have a desirable breeding population with broad genetic base for yield improvement in wheat. Further, high heterotic response for ash content was observed in 10 F_1 s crosses (more than 20%) only. However, three crosses namely, HUW 516 × DBW 17, WCW 98-19 × DBW 17 and WCW 98-4 × DBW 17 showed high heterotic response for ash content along with grain yield. These crosses also showed better heterotic response for 3 to 5 yield contributing traits.

Conclusion

In the present study based on the above results it may be concluded that the superior performance for all the traits were not expressed in a single cross. However many crosses are superior for more than one traits with yield. The crosses namely, Selection 1 × PBW 590, HUW 635 × PBW 590, WCW 98-48 × PBW 590, HUW 234 × PBW 343 and PBW 550 × DBW

17 expressed significant and positive SCA effect along with high significant heterotic response and *per se* performance indicated the economics increase in grain yield was due to non additive genetic components. It means these individual crosses would be effective for development of heterotic population for achieving higher yield in wheat.

References

1. Anonymous (2016) Progress Report of all India Coordinated Wheat and Barley Improvement Project. Singh GP (ed). Indian Institute of Wheat and Barley Research, Karnal, pp 1—5.
2. Singh V, Krishna R, Singh S, Vikram P (2012) Combining ability and heterosis analysis for yield traits in bread wheat (*Triticum aestivum*). Ind J Agric Sci 82 : 916—921.
3. Singh MK, Sharma PK, Tyagi BS, Singh G (2014) Heterosis for yield component traits and protein content in bread wheat under normal and heat-stress environment. Cereal Res Commun 42 : 151—162.
4. Kumar Pradeep, Gyanendra Singh, Singh YP, Kumar S (2015) Identification of best heterotic cross combination from diallel crosses for grain yield and other agromorphological traits in bread wheat (*Triticum aestivum* L.). Elect J Pl Breed 6 : 938—949.
5. Panse VG, Sukhatme PV (1985) Statistical methods for agricultural workers. 3rd edn. ICAR, New Delhi, pp 547.
6. Fonseca S, Patterson EL (1968) Hybrid vigor in seven parent diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci 8 : 85—95.
7. Singh Jogendra, Garg DK, Raje RS (2007) Heterosis for yield and associated traits in bread wheat [*Triticum aestivum* (L.) em. Thell.]. Ind J Genet and Pl Breed 67 : 215—216.
8. Kumar D, Kerkhi SA (2014) Heterosis studies for yield component traits and quality in spring wheat (*Triticum aestivum* L.). The Bioscan 9 : 1725—1731.
9. Kumar Pradeep, Kumar Ravi, Nagar SS, Singh YP, Abhishek D (2016) Estimation of heterosis for grain yield and its contributing traits in bread wheat (*Triticum aestivum* L.). The Bioscan 11 : 1099—1105.
10. Kumar Jaydev, Singh SK, Singh L, Kumar M, Kumar A, Kumar S, Yadav RK (2016) Study of economic heterosis and inbreeding depression in bread wheat (*Triticum aestivum* L.) under late sown condition. Res in Environ and Life Sci 9 : 1882—1886.