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Research Article

Heterosis and inbreeding depression in relation to heterotic parameters in bread wheat (*Triticum aestivum L.*) under late sown condition

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Abstract

The present investigation on heterosis and inbreeding depression was conducted on genetically diverse 10 parent diallel crosses of bread wheat. The experimental materials comprised 100 genotypes including 10 parents and their F_1s and F_2s progenies and trial was conducted in randomized complete block deign with three replication at Economic Botanical Research Farm, Nawabganj of C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India, during 2013-14 and 2014-15. The analysis of variance revealed that the all components of variances showed significant differences for almost the traits under studied over both generations. The result of economic heterosis revealed that the cross combinations, DBW 14/K 0424, K 9162/K 9423, K 9533/K 0307, K 1114/K 0424 and K 1114/NW 2036 were good for grain yield per plant along with range of -88.54 (K 0424/K 0911) to 28.52 per cent (DBW 14/K 0424) and other traits compared to 45 F_1s whereas, all these cross combinations also had significant grain yield demission in F_2s results of increase of homozygosity among the crosses in succeeding generations. The range of inbreeding depression varied from-50.36 (K 1114/K 9423) to 49.12 percent (K 0911/K 0307) in F_2s. Accordingly, these cross combinations may be utilized for improving grain yield as well as production of better transgressive segregants in advance generations for maintain of specific gene pool of bread wheat through breeding program in future.

Key words: Diallel, heterosis, inbreeding depression and grain yield

1. Introduction

Among cereals, wheat possesses second rank after rice and is the staple food especially in Northern part of the country, where the people are mostly vegetarian. The crop is grown successfully between the altitude of 300 and 600 north and 270 and 400 south globally. Wheat is extensively cultivated under diverse agro-climatic conditions in India covering most of the states, except Kerala. Last few decades, wheat production is decreased due to abiotic stress like high temperature at flowering time of crop (Kumar *et al.,* 2016). To overcome of abiotic stress under wheat cultivation is possible to develop specific gene pool as well as high yielding cultivars against rising temperature through heterosis breeding programme. Because the magnitude of heterosis help in determining genetic diversity and serves as a guide in the selection of desirable parents. Simultaneous studies of heterosis and inbreeding depression estimates give an idea about gene action involved and help in devising breeding methodology for further improvement (Deshpandey and Nayeem, 1999). Inbreeding is basic mechanism for providing the base material for selection because it produced better segregants in wheat crop (Gaur, 2014 and Kumar *et al.,* 2016). Knowledge on the expression levels of the heterosis and inbreeding depression are useful to help breeders choose the best hybrid combinations which will serve as the basis for the selection of superior genotypes. Thus, the present investigation was carried out to study the heterosis in F_1 over economic parent and inbreeding depression over F_2 generations for grain yield and its related traits in wheat under late sown condition.

2. Materials and methods

The present investigation was carried out at Economic Botanical Research Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh during *Rabi* 2014-15. Ten diverse wheat genotypes namely K 9533, K 9162, K 1114, DBW 14, K 0607, K 0424, K 0911, K 0307, NW 2036 and K 9423 were selected as parents on the basis of their vast diversity. Crosses were attempted during Rabi, 2013-14 to generate F_1's and F_1's were advanced into F_2's at ICAR-Indian Institute of Wheat and Barley Research, Regional Station, Dalang Maidan, Lahul Spiti (H.P.) during off season in year of 2014.Final experimental material comprising 10 parents along with their 45 F_1's and 45 F_2's were evaluated during *Rabi*, 2014-15 in randomized block design with three replications. Sowing was done by manually the seeds at a distance of 5 cm plant to plant in the rows of 4 m length with row to row spacing of 20 centimeter.During crop period, all recommended agronomic practices were adopted to raise the good crop. The observations were recorded from the five competitive plants in parents and theirF1s and ten plant from their F2s progenies, taken at randomly for the following traits viz.,number of effective tillers per plant, number of spikelets per spike, number of grains per spike, grain weight per spike (g), spike length (cm), biological yield per plant (g), harvest index (%), 1000-seed weight (g), spike density, protein content (%) and grain yield per plant (g). Analysis of variance, heterosis and inbreeding depression were calculated as per standard procedures (Fonseca and Patterson, 1968).

3. Result and discussion

The analysis of variance of treatments was computed for all the eleven characters and their mean sum of squares given in Table1 (a) and Table 1 (b). Based on Table1 (a) and Table 1 (b), analysis of variances among eleven characters in a 10 parents diallel crosses (excluding reciprocal cross) expressed highly vast of an appreciable amount of variability in the base material as well as in the material.Heterosis was calculated in per cent over economic parent for all eleven characters. Heterosis and inbreeding depression is given in Table 2. The widely adopted and released variety of K 0307 was considered as economic parent for the estimation of economic heterosis for all traits under studied and inbreeding depression of F_2 generation has also been studied (Meredith and Bridge, 1972 and Singh and Narayanam, 2009).The nature and magnitude of heterosis, some crosses exhibited significant and positive heterosis varied from character to character. The range of economic heterosis for number of effective tillers per plant varied from -33.24 in K 1114/K 9423 to 43.38 in K 1114/K 0911. Out of 45 cross combinations, only eighteen cross combinations showed positive and significant heterosis. Top two cross combinations namely, K 1114/K 0911 and K 1114/NW 2036 expressed more number of effective tillers per plant whereas, out of 45, only four cross combination had no inbreeding depression for the concern trait which can be used for maintain the specific gene pool for further utilization of improvement of wheat. For number of spikelets per spike, five cross combination displayed significant economic heterosis which ranged from -29.43 to 9.39. K 1114/K 424 expressed high number of spikelets indicates significant economic heterosis whereas, same cross reflect high positive significant value of inbreeding depression for number of spikelets per spike. Similar results were also reported by Singh, (2003) and Jahanzeb and Khaliq, (2004). Economic heterosis for number of grains per spike ranged from -48.63 to 13.29. Cross combinations, K 1114/K 0607 exhibited desirable number grains per spike whereas, eleven crosses out of 45, express negative and significant inbreeding depression. More desirable cross combination K 1114/K 424 showed negative and significant inbreeding depression for the number of grains per spike. The range of economic heterosis for grain weight per spike varied from -96.15 to 12.67. Only five cross combinations showed positive and significant heterosis. K 307/K 9423 had high weight of grain per spike. 12 cross combinations had no inbreeding depression and range of inbreeding depression varied from -29.23 to 33.21. The similar findings were reported by Nawracala *et al.*, (2006) and Singh *et al.*, (2008). In case of spike length, none of cross combination had significant value of heterosis which is ranged from -31.07 to -3.29 whereas, range of inbreeding depression varied from -14.65 to 16.98. Top two cross combination were K 1114/K 0607 and K 9162/K 1114 for inbreeding depression expressed more desirable transgressive segregants. For biological yield per plant, eighteen cross combinations exhibited positive and significant economic heterosis which ranged from -48.12 to 27.13. DBW 14/K 424 and K 0911/K 0307 had more biological yield.

Table 1(a): Analysis of variance among eleven characters in a diallel cross (without reciprocal) of 10 parents and their F1s in wheat

Source of variation	d.f.	No. of effective tillers per plant	No. of spikelets per spike	No. of grains per spike	Grain weight per-spike (g)	Spike length (cm)	Biological yield per Plant (g)	Harvest index (%)	1000 seed weight (g)	Spike density	Protein content (%)	Grain yield per plant (g)
Replications	2	0.068	0.031	34.19	0.020	0.120	0.548	0.057	1.234*	0.00059	0.045	0.107
Genotypes	54	2.39**	6.59**	135.60**	0.386**	1.83**	52.18**	100.41**	14.83**	0.03596**	5.54**	22.67**
Parents	9	0.96**	1.95*	32.19	0.19**	3.24**	10.01**	53.56**	11.13**	0.04342**	1.80**	6.52**
F1s	44	2.45**	7.61**	159.13**	0.433**	1.56**	53.04**	111.27**	15.92**	0.03516**	5.976**	24.93**
Parents vsF1s	1	12.75**	3.35*	30.95	0.014	1.21**	393.75**	44.32**	0.234	0.00417	20.63**	69.21**
Error	108	0.145	0.791	20.46	0.019	0.039	0.562	4.04	0.364	0.00627	0.039	0.37

Table 1(b): Analysis of variance among eleven characters in a diallel cross (without reciprocal) of 10 parents and their F2s in wheat

Source of variation	d.f.	No. of effective tillers per plant	No. of spikelets per spike	No. of grains per spike	Grain weight per-spike (g)	Spike length (cm)	Biological yield per Plant (g)	Harvest index (%)	1000 seed weight (g)	Spike density	Protein content (%)	Grain yield per plant (g)
Replications	2	0.26	0.60	41.69	0.03	0.062	0.25	32.82	1.51	0.01186	0.31	1.26
Genotypes	54	1.24**	2.65**	103.09**	0.21**	1.37**	23.62**	49.09**	10.02**	0.03389**	2.66**	5.42**
Parents	9	0.96**	1.95**	32.19	0.19**	3.24**	10.01**	53.56**	11.13**	0.04342**	1.80**	6.52**
F1s	44	1.31**	2.85**	109.55**	0.19**	1.02**	26.94**	47.27**	10.00**	0.03270**	2.88**	5.21**
Parents vsF1s	1	0.57*	0.035	457.29**	1.06**	0.12	0.04	89.01**	0.41	0.00031	0.75**	4.45**
Error	108	0.114	0.23	22.02	0.03	0.09	1.3	11.56	0.52	0.00440	0.11	0.55

Table 2. Estimates of heterosis over economic parent (per cent) and inbreeding depression (per cent) in a 10 parent diallel crosses fordefferent characters in bread wheat

Crosses	No. of effective tillers per plant		No. of spikelets per spike		No. of grains per spike	
	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression
1.K 9533/K 9162	9.40	4.00	3.05	6.35	-4.95	21.28*
2.K 9533/K 1114	15.01*	20.00 **	7.45*	5.15	-10.06	9.70
3. K 9533/DBW 14	-6.09	7.81	-3.51	2.03	-17.53*	16.45 *
4.K 9533/K 0607	23.61**	11.24 *	1.17	3.56	-2.46	12.75
5.K 9533/K 0424	-6.09	17.19 *	-29.43**	-25.00	-14.19	6.84
6.K 9533/K 0911	8.11	-2.70	4.28	3.76	-0.68	12.53
7. K 9533/ K 0307	24.50**	11.11	3.05	4.44	7.57	7.67
8. K 9533/NW 2036	-7.86	14.29	-2.16	2.68	-17.77**	13.16
9. K 9533/K 9423	17.18**	3.66	-3.51	2.71	-14.96*	-1.59
10. K 9162/K 1114	-4.62	9.23	-16.14**	-4.56 *	-28.58**	11.41
11.K 9162/DBW 14	-4.62	12.31 *	-19.76**	-2.35	-27.08**	-3.22
12. K 9162/K 0607	12.88*	3.85	-2.83	0.67	-17.43*	7.31
13. K 9162/K 0424	12.88*	15.38	-2.83	3.37	-2.83	17.06
14. K 9162/K 0911	8.11	6.76	-7.16**	-2.11	-15.10*	2.39
15. K9162/K 0307	20.94**	10.47	-2.16	4.35	-5.72	18.39
16. K 9162/NW 2036	-23.43**	-1.82	-8.30*	-4.26	-35.41**	-12.17
17. K 9162/K 9423	27.75**	15.96 **	1.78	5.47	10.43	26.73 *
18. K 1114/DBW 14	-4.62	4.62	-4.25	-4.10 *	-10.15	16.12
19. K 1114/K 0607	-2.95	-13.64	-28.86**	-32.91 **	13.29*	39.26 **
20. K 1114/K 0424	20.11**	23.53 **	9.39**	23.74 **	-48.63**	-38.87 *
21. K 1114/K 0 911	43.38**	14.17 **	-2.16	0.67	-26.14**	15.12
22. K 1114/K 0307	1.52	5.80	-8.30*	-3.19	-17.60*	-2.57
23. K 1114/NW 2036	33.38**	21.57 **	-5.66	0.00	-12.41	13.21
24. K 1114/K 9423	-33.24**	-9.80	-5.66	5.54 *	-36.46**	-1.73
25. DBW 14/K 0607	21.90**	13.79 **	7.75*	9.67 **	-5.07	4.36
26. DBW 14/K 0424	27.75	20.21	7.75*	6.04 *	10.43	14.86
27. DBW 14/ K 0911	-6.09	6.25	-2.83	2.02	-39.76**	9.98
28. DBW 14/K 0307	5.62	0.00	3.05	0.32	-10.84	18.39
29. DBW 14/NW 2036	-4.62	-7.69	3.05	0.63	-20.37**	-3.05
30. DBW 14/K 9423	14.04*	29.11 **	-0.15	2.62	4.41	18.61
31. K 0607/K 0424	14.04*	18.99 *	-0.79	0.00	-18.08**	-7.07
32. K 0607/K 0911	10.65	19.74 **	8.82**	12.54 **	11.43*	19.64 *
33. K 0607/K 0307	21.90**	34.48 **	-0.15	8.20 **	2.92	22.60
34. K 0607/NW 2036	11.70	18.18	-10.65**	9.06 *	-5.07	31.23 **
35. K 0607/K 9423	5.62	16.67 **	-0.15	5.25	-31.89**	19.00
36. K 0424/K 0911	-23.43**	-21.82	-22.65**	-17.67 **	-39.52**	-6.91
37. K 0424/K 0307	-4.62	9.23	-7.16	0.70	-6.50	4.29
38. K 0424/NW 2036	-30.55**	-19.23	-7.16	0.00	-19.05*	-2.88
39. K 0424/K 9423	-9.69	4.84	1.78	4.50	-10.69	7.40
40. K 0911/K 0307	20.11**	28.24 **	3.05	5.08	8.06	27.12 *
41. K 0911/NW 2036	18.08**	21.69 *	6.05	4.92	10.06	17.31
42. K 0911/K 9423	4.04*	5.06	-7.16	-5.61	-10.42	-15.39
43. K 0307/NW 2036	8.11	6.76	2.44	1.28	-3.93	-18.20
44. K 0307/K 9423	10.65	11.84	2.12	6.41 *	11.53*	24.36 *
45. NW 2036/ K 9423	-7.86	1 7.46	-10.23**	0.72	-13.74	16.25 *
SE±	**0.31**		**0.72**		**3.69**	
+(sig)	11(18)	22(16)	12(5)	27(8)	7(3)	24(9)
-(sig)	12(4)	7(0)	18(10)	6(4)	17(18)	11(1)

Table 2. Continued

Crosses	Grains weight per spike (g)		Spike length (cm)		Biological yield per plant (g)	
	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression
1.K 9533/K 9162	-14.86**	22.82 **	-14.12**	1.97	6.19*	15.28 **
2.K 9533/K 1114	-20.28**	23.27 *	-6.55**	5.53 *	14.05**	31.30 **
3. K 9533/DBW 14	-32.81**	13.57 **	-21.29**	-9.88 **	-25.37**	9.56 *
4.K 9533/K 0607	-9.44	21.29 **	-10.93**	14.79 **	17.83**	16.61 *
5.K 9533/K 0424	-28.79**	11.60	-20.21**	-6.82 *	-11.60**	21.75 *
6.K 9533/K 0911	-10.39*	14.57	-11.29**	13.46 **	5.85*	19.18
7. K 9533/ K 0307	5.20	15.59 *	-3.61**	6.65 *	20.70**	2.17
8. K 9533/NW 2036	-35.64**	8.67	-11.29**	3.57	-6.43*	12.40 **
9. K 9533/K 9423	-30.10**	-0.34	-20.86**	7.16 *	-5.41	-10.47
10. K 9162/K 1114	-39.34**	4.37	-31.07**	-11.00 *	-12.03*	18.35 **
11.K 9162/DBW 14	-45.71**	-2.86	-19.47**	-3.54 *	-23.56**	0.98
12. K 9162/K 0607	-21.43**	5.25	-9.49**	2.70	-5.89*	5.73
13. K 9162/K 0424	-13.84**	14.88	-14.41**	5.08 *	-2.34	14.22 *
14. K 9162/K 0911	-26.87**	1.16	-20.21**	-2.67	-0.87	2.09
15. K9162/K 0307	-2.41	26.94 **	-3.29**	2.81 *	18.47**	23.56 **
16. K 9162/NW 2036	-47.40**	-20.66	-27.00**	-3.13	-1.27	24.89 **
17. K 9162/K 9423	10.84**	29.75 *	-10.38**	2.45 *	22.21**	15.22 **
18. K 1114/DBW 14	-22.01**	11.34	-12.22**	4.16	-18.33**	8.37
19. K 1114/K 0607	-75.86**	-17.74	-28.94**	-14.65 **	-48.12**	-9.37
20. K 1114/K 0424	8.27*	31.06 **	-9.14**	16.98 **	18.55**	36.59 **
21. K 1114/K 0 911	-47.40**	11.20	-22.39**	-0.60	19.29**	29.54 **
22. K 1114/K 0307	-26.87**	-5.48	-20.54**	0.00	2.44	22.45 **
23. K 1114/NW 2036	-8.05	16.10 *	-20.54**	1.49	22.99**	26.08 **
24. K 1114/K 9423	-52.69**	-7.39	-13.73**	7.58 **	-17.49**	14.48 **
25. DBW 14/K 0607	-23.79**	1.94	-5.72**	6.53 *	5.89	14.50 **
26. DBW 14/K 0424	12.07**	15.07 **	-14.70**	1.42	27.13**	28.69 **
27. DBW 14/ K 0911	-49.12**	14.79 *	-23.06**	0.30	-10.28*	18.59 **
28. DBW 14/K 0307	-30.10**	7.50	-6.55**	4.47 **	-4.46	26.37 **
29. DBW 14/NW 2036	-27.50**	-5.83	-23.85**	-1.53	-19.92**	-12.67
30. DBW 14/K 9423	-13.84**	14.71 *	-15.09**	3.69	-9.96**	15.53 **
31. K 0607/K 0424	-32.81**	-17.22 *	-13.16**	0.00	1.99	8.53 **
32. K 0607/K 0911	12.07**	23.13 **	-4.41**	6.70 **	23.37**	31.17 **
33. K 0607/K 0307	-7.14	20.42 *	-6.55**	8.42 *	18.15**	41.00 **
34. K 0607/NW 2036	-25.00**	26.02 **	-8.26**	4.28 *	6.91**	41.41 **
35. K 0607/K 9423	-35.64**	24.11 *	-9.14**	7.01 *	-11.82**	16.09 *
36. K 0424/K 0911	-96.15**	-29.23 *	-17.39**	4.06	-38.31**	0.12
37. K 0424/K 0307	-11.35*	6.26	-22.73**	-3.33	-3.30	14.79 *
38. K 0424/NW 2036	-16.97**	-1.84	-22.39**	-1.81	-30.30**	-7.98 *
39. K 0424/K 9423	-13.33**	12.76	-7.14**	2.65	-29.42**	4.23
40. K 0911/K 0307	6.25	33.21 **	-14.41**	-1.41	24.17**	40.53 **
41. K 0911/NW 2036	-4.94	7.68	-7.74**	5.32 *	11.22**	15.55 **
42. K 0911/K 9423	-23.79**	-13.59	-12.78**	0.28	5.77*	-3.89
43. K 0307/NW 2036	-15.38**	-13.73	-10.02**	0.82	3.50	1.19
44. K 0307/K 9423	12.67**	32.95 *	-12.22**	0.83	15.59**	27.62 **
45. NW 2036/ K 9423	-23.79**	13.57	-21.95**	4.52	-23.49**	13.14 **
SE±	**0.11**		**0.16**		**0.61**	
+(sig)	2(5)	15(18)	0(0)	16(17)	4(18)	9(31)
-(sig)	5(33)	10(2)	0(45)	7(5)	6(17)	4(1)

Table 2. Continued

Crosses	Harvest index (%)		1000 seed weight (g)		Spike density	
	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression
1.K 9533/K 9162	-14.61**	12.02	-11.25**	0.80	14.69**	4.32
2.K 9533/K 1114	-28.14**	-7.45 *	-10.48**	1.01	13.22**	-0.57
3. K 9533/DBW 14	-13.35**	1.19	-13.07**	-5.56	14.69**	10.94 **
4.K 9533/K 0607	-13.04**	9.51	-10.20**	1.91	10.65*	-13.38
5.K 9533/K 0424	-26.20**	-9.74	-15.96**	-1.31	-8.63	-17.46
6.K 9533/K 0911	-7.68*	-4.59	-8.99**	-3.68	13.71*	-11.40
7. K 9533/ K 0307	2.79	23.15**	-2.40*	3.23	6.21	-2.27
8. K 9533/NW 2036	-38.44**	-10.62	-13.33**	-4.28 *	7.93*	-1.01
9. K 9533/K 9423	-11.88**	10.23 *	-11.87**	1.71	14.20**	-4.92
10. K 9162/K 1114	-27.21**	-7.35	-10.07**	-2.49	11.70**	5.85
11.K 9162/DBW 14	-24.53**	-3.02	-14.11**	-3.95	-0.67	1.10
12. K 9162/K 0607	-4.27	2.90	-0.77	-0.09	6.21	-2.07
13. K 9162/K 0424	-0.29	12.91	-10.67**	-2.20 *	10.12**	-1.58
14. K 9162/K 0911	-13.97**	12.91 *	-6.99**	-1.12	11.18**	0.78
15. K9162/K 0307	-2.14	14.69 **	-0.23	3.61	1.31	1.52
16. K 9162/NW 2036	-110.28**	-91.37 **	-6.96**	-0.39	14.69**	-0.94
17. K 9162/K 9423	5.02	22.99 **	-0.93	-0.05	10.65**	2.95
18. K 1114/DBW 14	-15.29**	7.26	-10.26**	0.32	6.79	-8.62 **
19. K 1114/K 0607	-23.73**	-7.84	-12.21**	-6.45	0.00	-15.89 **
20. K 1114/K 0424	5.25	17.51 **	-4.08**	13.36 **	16.57**	7.90 *
21. K 1114/K 0 911	-11.08**	-9.65	-10.07**	0.97	16.57**	0.92
22. K 1114/K 0307	-24.35**	-17.79	-0.75	5.01 *	10.12**	-6.34
23. K 1114/NW 2036	-1.88	11.14 *	3.29**	3.89 *	12.21**	-0.19
24. K 1114/K 9423	-60.07**	-75.63 **	-10.26**	3.06 **	6.79	-2.25
25. DBW 14/K 0607	-5.31	1.74	-13.47**	-3.62 **	12.72**	3.08
26. DBW 14/K 0424	1.90	7.58	0.02	3.25 **	19.68**	4.44
27. DBW 14/ K 0911	-40.92**	-53.89 **	-4.69**	7.51 **	16.11**	1.47
28. DBW 14/K 0307	-11.22**	-6.69	-17.84**	-14.59 **	9.04*	-4.62
29. DBW 14/NW 2036	-12.38**	-0.27	-3.55**	-0.70	21.76**	1.90
30. DBW 14/K 9423	7.38*	26.82 **	-14.91**	-5.94 **	13.22**	-0.96
31. K 0607/K 0424	-15.47**	-5.30 **	-7.02**	-2.80	10.65**	-4.13 **
32. K 0607/K 0911	-12.67**	6.50	1.18	3.12 *	12.72**	6.17 *
33. K 0607/K 0307	-14.12**	-1.93	-0.68	8.55 **	6.21	-0.41
34. K 0607/NW 2036	-9.59**	-3.00	-19.68**	-8.57 **	-2.03	5.19
35. K 0607/K 9423	-8.89*	16.71 *	-10.67**	-1.01	8.48*	-1.82
36. K 0424/K 0911	-36.64**	-25.19 *	-17.43**	-5.44 **	-4.86	-22.63 **
37. K 0424/K 0307	-13.60**	1.08	-7.09**	-7.55 **	12.72**	3.66
38. K 0424/NW 2036	-10.68**	0.46	2.22*	-0.76	12.21**	1.74
39. K 0424/K 9423	-5.59**	7.70	-2.19	0.45	8.48*	2.02
40. K 0911/K 0307	-7.38*	14.52	-0.70	7.22 **	15.17**	6.36 *
41. K 0911/NW 2036	-6.03	10.84 **	-5.41*	-3.59 *	12.72**	-0.38
42. K 0911/K 9423	-9.66**	5.86	-10.40**	-6.77 **	5.03	-6.09
43. K 0307/NW 2036	-3.55	2.47	-7.48**	-0.14	11.18**	0.58
44. K 0307/K 9423	0.89	12.42 **	1.47	11.82 **	12.72**	5.78 *
45. NW 2036/ K 9423	0.79	7.29	-5.51*	0.22	9.58*	-3.58
SE±	**1.64**		**0.49**		**0.064**	
+(sig)	6(1)	16(11)	3(2)	10(10)	8(33)	16(5)
-(sig)	7(31)	12(6)	7(33)	15(10)	4(0)	20(4)

Table 2. Continued

Crosses	Protein content (%)		Grain yield per plant (g)	
	Heterosis	Inbreeding depression	Heterosis	Inbreeding depression
1.K 9533/K 9162	-6.63**	1.42	-7.50	25.50 **
2.K 9533/K 1114	-4.58**	-1.11	-10.23*	26.12 **
3. K 9533/DBW 14	-18.06**	-5.33 *	-42.12**	10.70 *
4.K 9533/K 0607	-23.40**	-3.93	7.16	24.83 **
5.K 9533/K 0424	-22.20**	0.00	-40.97**	14.54 *
6.K 9533/K 0911	-15.88**	7.38 *	-1.16	16.05
7. K 9533/ K 0307	-17.29**	6.85 *	22.91**	24.83 **
8. K 9533/NW 2036	-22.20**	-8.44	-47.28**	2.86
9. K 9533/K 9423	-11.95**	11.96 **	-17.91**	0.71
10. K 9162/K 1114	-10.38**	-2.64	-42.46**	12.16
11.K 9162/DBW 14	-10.77**	-4.41	-53.79**	-1.09
12. K 9162/K 0607	-7.26**	6.27 *	-10.43*	9.15 *
13. K 9162/K 0424	-8.85**	-9.83 **	-2.53	25.59 *
14. K 9162/K 0911	-4.58**	9.72 **	-15.01**	14.60
15. K9162/K 0307	-2.28	5.98 *	16.75**	34.90 **
16. K 9162/NW 2036	3.46**	10.26 *	-11.31**	-45.16
17. K 9162/K 9423	-11.75**	5.64	26.14**	34.69 **
18. K 1114/DBW 14	-6.63**	3.68	-36.85**	14.71 *
19. K 1114/K 0607	-22.20**	-10.06 *	-83.16**	-18.20
20. K 1114/K 0424	-0.97	8.04 *	22.81**	47.79 **
21. K 1114/K 0 911	9.26**	1.20	10.38**	22.69 **
22. K 1114/K 0307	5.14**	12.09 **	-21.19**	8.49
23. K 1114/NW 2036	7.92**	11.74 **	21.57**	34.43 **
24. K 1114/K 9423	7.72**	0.00	-88.25**	-50.36 *
25. DBW 14/K 0607	10.55**	10.45 **	0.90	16.14 **
26. DBW 14/K 0424	13.03**	15.94 **	28.52**	34.21 **
27. DBW 14/ K 0911	8.19**	3.41	-55.36**	-25.21 *
28. DBW 14/K 0307	-5.20**	2.23	-16.11**	21.55 **
29. DBW 14/NW 2036	8.86**	6.78 **	-35.03**	-13.22
30. DBW 14/K 9423	12.85**	18.06 **	-1.84	38.18 **
31. K 0607/K 0424	5.14**	5.54 **	-13.20**	3.69
32. K 0607/K 0911	16.67**	17.02 **	13.68**	35.62 **
33. K 0607/K 0307	15.72**	3.49	6.52	39.80 **
34. K 0607/NW 2036	6.83**	5.47 **	-1.92	39.79 **
35. K 0607/K 9423	10.04**	8.72 **	-21.80**	29.97 **
36. K 0424/K 0911	11.68**	12.97 **	-88.54**	-24.77
37. K 0424/K 0307	9.97**	17.50 **	-17.00**	15.97
38. K 0424/NW 2036	7.52**	8.64 **	-44.14**	-7.45
39. K 0424/K 9423	13.80**	14.15 **	-36.55**	11.70
40. K 0911/K 0307	5.50**	-1.41	18.47**	49.12 **
41. K 0911/NW 2036	7.92**	9.05 *	5.87	24.68 **
42. K 0911/K 9423	9.45**	9.79 *	-3.05	2.43
43. K 0307/NW 2036	-1.37	0.65	0.25	3.85
44. K 0307/K 9423	-5.82**	-4.86	16.35**	36.74 **
45. NW 2036/ K 9423	6.41**	4.80 *	-22.54**	19.44 *
SE±	**0.16**		**0.49**	
+(sig)	0(23)	10(25)	5(10)	11(26)
-(sig)	3(19)	7(3)	6(24)	6(2)

Table 3. Potential heterotic combinations for grain yield and its attributing traits in bread wheat under late sown condition

Cross	Heterosis	Inbreeding depression	SCA effects	GCA effects		Desirable heterosis in grain yield attributing traits
				P1	P2	
DBW 14/K 0424	28.52**	34.21**	7.44**	-0.73**	-0.52**	Number of spikelets per spike (7.75**), grain weight per spike (12.07**), spike density (19.68**) and protein content (13.03**)
K 9162/K 9423	26.14**	34.69**	5.73**	-0.08	-0.01	Number of effective tillers per plant (27.75**), grain weight per spike (10.84**) and spike density (10.65**)
K 9533/K 0307	22.91**	24.83**	3.48**	-0.29**	1.76**	Number of effective tillers per plant (24.50**)
K 1114/K 0424	22.81**	47.79**	5.52**	-0.07	-0.52**	Number of effective tillers per plant (20.11**), number of spikelets per spike (9.39**), grain weight per spike (8.27**) and spike density (16.57**)
K 1114/NW 2036	21.57**	34.43**	5.52**	-0.07	-0.76**	Number of effective tillers per plant (33.38**), 1000 seed weight (3.29**), spike density (12.21**) and protein content (7.92**)
K 0911/K 0307	18.47**	49.12**	1.90**	0.43**	1.76**	Number of effective tillers per plant (20.11**), spike density (15.17**) and protein content (16.67**)
K 9162/K 0307	16.75**	34.90**	2.11**	-0.08	1.76**	Number of effective tillers per plant (20.94**)
K 0307/K 9423	16.35**	36.74**	0.56	1.76**	-0.01	Number of grains per spike (11.53**), grain weight per spike (12.67**) and spike density (12.72**),
K 0607/K 0911	13.68**	35.62**	2.54**	0.29**	0.43**	Number of grain per spike (11.43*), grain weight per spike (12.07**) and protein content (16.67**)
K 1114/K 0911	10.38**	22.69**	2.38**	-0.07	0.43**	Number of effective tillers per plant (43.38**), spike density (16.57**) and protein content (9.26**)

The range of inbreeding depression for biological yield is positioned from -12.67 to 41.41. Thirty one cross combinations had negative and significant value of inbreeding depression. For development of heat tolerant genotypes in bread wheat, genotypes which have more biological yield should be used further in breeding programme(Desale*et al*., 2013 and Kumar *et al*., 2016). The estimates of economic heterosis for harvest index varied from -110.28 to 7.38 percent. Only one cross combination DBW 14/K 9423 exhibited maximum positive and significant heterosis for harvest index indicated economic importance. These crosses could be of greater value if exploited in breeding programme. Positive heterosis for harvest index was reported by Singh *et al.* (2013). Whereas, range of inbreeding depression varied from -91.37 to 26.82 for harvest index. Six cross combination out of 45, expressed desirable inbreeding depression.Crosses K 9162/NW 2036, K 1114/K 9423, DBW 14/K 0911, K 0424/K 0911 and K 9533/K 1114 were also desirable for straw and showed negative and significant value of inbreeding depression in order to merit.

For 1000 grain weight, desirable amount of positive heterosis was observed and range varied from -19.68 to 3.29. Only two crosses exhibited heterosis in positive and significant direction namely K 1114/NW 2036 and K 0424/NW 2036. Heterosis for 1000-grain weight was earlier reported by Hassan and Saad (1996). In case of range of inbreeding depression of 1000-grain weight varied from -14.59 to 13.36. Out of 45, 25 crosses displayed desirable amount of inbreeding depression. DBW 14/K 0307 and K 0607/NW 2036 were top two crosses expressed super cross in segregating generation. The magnitude of economic heterosis for spike density ranged from -8.63 to 21.76. Significant positive heterosis was demonstrated by two hybrids, i.e. DBW 14/NW 2036 and DBW 14/K 0424. These crosses could be of high value if used in future breeding strategy. The range of inbreeding depression for spike density varied from -22.63 to 10.93. 24 crosses, out of 45 had negative and significant inbreeding depression indicate concerned trait controlled by additive gene and could be improve though subsequent selection scheme of plant breeding. Top two crosses K 0404/K 0911 and K 9533/K 0424 had more spike density. The magnitude of heterosis for protein content ranged from -23.40 to 16.67. Out of 45, twenty three crosses were positive and significant heterosis over economic parent for protein content whereas, nineteen crosses were negative and significant economic heterosis. Crosses K 0607/K 0911, K 0607/K 0307, K 0424/K 9423, DBW 14/K 0424 and DBW 14/K 9423 had positive and significant economic heterosis. Similar results for gluten content were reported by Krystkowiak *et al.* (2009), Singh and Sharma (2012) and Singh *et al.* (2014). Ten cross combinations had negative and significant inbreeding depression in protein content. Top two cross K 1114/K 0607 and K 9162/K 0424 showed themselves for more desirable of protein content based on inbreeding depression.The range of heterosis over economic parent for grain yield per plant varied from -88.54 to 28.52. While selecting the plants, grain yield received maximum attention of plant breeder. Therefore, positive heterosis for grain yield is desirable. In case of grain yield per plant, 10 crosses showed significant and positive over economic parent (Table 3). Top five crosses for positive and significant desirable heterosis found in DBW 14/K 0424, K 9162/K 9423, K 9533/K 0307, K 1114/K 0424 and K 1114/NW 2036. Similar result on positive heterosis for grain yield per plant has been reported by Devi *et al.* (2013), Desale *et al.* (2013) and Singh *et al.* (2014). Inbreeding depression for grain yield per plant ranged from -50.36 to 49.12 per cent. Only eight cross combination had negative and significant inbreeding depression. First five crosses were K1114/K 9423, K 9162/NW 2036, DBW 14/K 0911, K 0424/K 0911 and K 1114/K 0607.

The linearity among the per cent homozygosity of the parent and the performance indicates that economic increase in grain yield in most of the combinations is due to non additive genetic components, has been cited as a major factor for the manifestation of hybrid vigour. As far as, the heterosis for grain yield per plant is concerned, it was observed that out of 45, only ten cross combinations showed positive heterosis over economic parent. Accordingly crosses, heterosis respond by high SCA effect along with detonation in their performance in F_2 generation for most of crosses (Singh and Narayanam, 2009). Inbreeding depression based on genetic variability indicated the positive and negative expression of genes in the population which could not be fixed for heterosis breeding. The heterosis and inbreeding depression jointly implement the criteria for positive selection. As indicated in the present study the succeeding generations showed the significant amount of dominance in the population with accumulation of additive and epistatic genes. Therefore, based of results, it is suggested that the cross combinations should be used for further crop improvement through interest traits to breeder.

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