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Heterosis and inbreeding depression for grain yield and yield component traits in bread wheat (*Triticum aestivum* L.)

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Abstract
The present investigation on heterosis and inbreeding depression was carried out for fourteen characters using genetically diverse 10 parent half diallel crosses of bread wheat (*Triticum aestivum* L.). The experimental materials comprised of 100 genotypes including 10 parents, their 45 F_1s and 45 F_2s progenies. The experiment was conducted during *Rabi* 2013-14 in randomized complete block design with three replications at Experimental Farm, BRDPG College, Deoria, India. Analysis of variance revealed that all components of variance showed significant differences among the parents, F_1s and F_2s for most of the characters indicating the presence of considerable genetic variability in the material under studied. The result of heterosis over economic parent for grain yield per plant revealed that the cross combination, UW510 × HUW468, HUW510 × HUW234, HUW510 × HD2329, HUW510 × UP2338 and HUW468 × RAJ1972, were good along with range of -13.21 (UP2338 × K65) to 53.42% (HUW510 × HUW468). All these cross combination had stable performance in both generations hence, can be exploited for development of high yielding stable lines and or isolation of desirable segregants. Negative estimates of heterotic effects were observed in some traits may be attributed to inter-allelic interactions.

Keywords: Diallel, Heterosis, Inbreeding depression, Grain yield

Introduction
Wheat (*Triticum aestivum* L.) is one of the leading cereals and staple food of peoples in many countries of the world. In India, wheat is the second most important food crop after rice which plays a remarkable role in meeting the food requirements of the country. It contains 70% carbohydrates, 22% crude fibers, 12% protein, 12% water, 2% fat and 1.8% minerals (Kumar *et al.* 2017) [10]. Being the staple food, grain yield of wheat needs to be increased continuously as it is expected that the grain requirement will be increased up to 70-110% globally by 2050 (Tilman *et al.* 2011). To feed burgeoning population of world, there is a terrible need to develop wheat genotypes having high yield potential. However, to keep continuous rise in future wheat production, we will have to have solutions for rigid challenges ahead as climate change, burgeoning population, depleting natural resources, biotic and abiotic stress etc. The success of any breeding programme depends primarily upon the proper selection of parents, mating system employed and finally the breeder's keen judgment in selecting superior genotypes from more abundant and less desirable plants within the segregating populations. The study of heterosis and inbreeding depression in most of the crops including wheat is an important tool in interpreting genetic parameters. The nature and magnitude of heterosis and inbreeding depression could play a vital role for the plant breeder in formulating the appropriate breeding procedures. Therefore, present study was carried out to delineate the magnitude of heterosis and inbreeding depression in bread wheat and identified superior parents and crosses would be gainfully utilized in future wheat improvement programmes.

Material and Methods
Present investigation comprised of ten genetically diverse bread wheat (*Triticum aestivum* L.) varieties, *viz.* HUW510, HUW234, HUW468, UP2338, HD2402, RAJ1972, HD2329, LOK1, SONALIKA and K65. These varieties were crossed in all possible combinations excluding reciprocals during *Rabi* 2012-13 to generate F_1s and the F_1s were advanced into F_2s during *Rabi* 2013-14 at Research Farm, BRDPG College, Deoria, Uttar Pradesh, India. Final experimental material comprising 10 parents along with 45 F_1s and 45 F_2s were evaluated during *Rabi* 2014-15. The genotypes under study were planted in a randomized complete block design (RCBD) with three replications per entry and one row (3m) per replication. Plant-to-plant spacing of 10cm and row-to-row spacing of 30 cm were maintained. Standard agronomic practices were used for raising and maintenance of the plants.

The observations were recorded randomly from the five competitive plants in parents and their F_1s and ten plant from their F_2s progenies for all the following traits *viz.* days to 50% flowering, number of tillers/plant, plant height, length of spike/plant, number of spikelet/spike, peduncle length/plant, leaf area index, days to maturity, grain yield/plant, 1000 seed weight, biological yield/plant, no. of grain/spike, protein content and gluten content. Pooled data were used for statistical and biometrical analyses using statistical package, Windostat version 9.2. Relative heterosis was estimated following methods suggested by Hays *et al.* (1955) [6]. Inbreeding depression was estimated by method suggested by Kempthorne (1957) [8].

Results and Discussion

Analysis of variance for fourteen characters in a 10 parents diallel crosses (excluding reciprocal cross) indicated significant differences among the parents, F_1s and F_2s for most of the characters indicating the presence of considerable genetic variability in the material studied (Table.1 and Table.2). Heterosis was calculated in per cent over economic parent for all fourteen characters. Heterosis and inbreeding depression for all fourteen characters are given in Table 3. The nature and magnitude of heterosis that most of the hybrids exhibited significant and negative relative heterosis for days to 50% flowering varied from -2.42-6.84%. Out of 45 cross combination, only one cross combinations (LOK1 × K65) showed negative and significant heterosis over economic parents for days to 50% flowering indicating early maturity. No inbreeding depression was observed in this cross for the concern trait which can be used for maintain the specific gene pool for further utilization of improvement of wheat. Out of 45 crosses combination, only one cross combination (HUW510 × HD2402) showed significant and negative inbreeding depression (-2.933%), while five cross combination showed positive and significant for this character. The range of heterosis over economic parent for number of tillers per plant varied from -10.07 to 5.14%. The negative and significant values of heterosis over economic parent were observed for most of the crosses except the cross combination, HUW468 × UP2338, which showed positive and significant heterosis indicating towards the high tillering. The fiindings of Akbar *et al.* (2010) [1] support the results for this trait. Inbreeding depression observed for this trait was positive and significant in all the crosses. The heterosis value for plant height varied from -10.09 to 12.80%. The superiority for plant height over economic parent was observed as desirable in six cross combination (HUW234 × SONALIKA, UP2338 × K65, HD2402 × SONALIKA, HD2402 × K65, RAJ1972 × SONALIKA and SONALIKA × K65) exhibiting significant and negative performance. The highest and desirable heterosis value (-10.09%) was expressed by the cross HD2402 × SONALIKA over economic parent. Dwarf stature is preferable as it is less prone to lodging. Similarly, in case of inbreeding depression, all the crosses also showed significant and negative value in support to heterosis. Thus, the selection must be based on shorter plant heights in the segregating generations. Similar results were obtained by Jaiswal *et al*. (2010) [7] and Gaur *et al.* (2014) [5]. The heterosis values over economic parent for spike length/plant varied from -7.51 to 17.67%. The increased percentage over economic parent for spike length/plant in two cross combinations (UP2338 × RAJ1972 and UP2338 × HD2329) were positive and highly significant, while negative and significant performance exhibited decreased heterosis for this trait. Inbreeding depression for this trait varied from -0.71-17.67%. Out of 45 crosses, eighteen cross combination showed positive and significant values over economic parent indicating increased percentage of spike length/plant. No inbreeding depression was observed for this trait in cross combination HUW510 × RAJ1972. For the trait, number of spikelets/plant, all cross combination displayed negative and significant economic heterosis ranged from -17.59 to 8.26. Positive and significant values of inbreeding depression for number of spikelets/plant were observed in four cross combination while one cross combination revealed negative and significant values. Dwarf stature of peduncle length per plant was considered as desirable trait. The heterosis for peduncle length/plant over economic parent varied from -20.55 - 11.23%. Out of 45 cross combination, seventeen cross combination were observed to be negative and significant, while two cross combination were found positive and significant. The inbreeding depression varied from -0.16 to 36.14% for this trait and 34 cross combination showed positive and highly significant value. Positive and negative expression of values indicated the presence of dominance and recessive genes. Similar findings were reported by Prasad *et al*. (1998) [11] and Gaur *et al.* (2014) [5]. The heterosis over economic parent in case of leaf area index (8.63-55.70%) was observed to be highly significant and positive for all cross combinations, while inbreeding depression were found to be positive and significant in only four cross combination. The two cross combination showed negative and significant values for inbreeding depression. The exploitation in leaf area will be a good precursor for high photosynthesis which will certainly increase the strengthening of seeds and carry over the increase in yield. Out of 45 cross combination, 44 combination showed positive and significant heterosis over economic parent (1.45-6.98%) for days to maturity. All there crosses showed the late maturity. Only three cross combination showed negative and significant inbreeding depression for this trait. The heterosis over economic parent for grain yield/plant (-13.21-53.42%) exhibited positive performance in fifteen cross combinations, except the three, HUW468 × K65, UP2338 × K65 and HD2402 × K65, which shows negative and significant heterosis over economic parent. Thus, the increased percentage of grain yield is assumed to be desirable for the consideration to enhance the yield. Inbreeding depression of this trait (-11.00-39.88%) exhibited positive and significant performance in all the combinations indicate the prevalence of non-additive gene effects due to genetic variability in the population (Budak and Yildirim, 1996; Gaur *et al*. 2014; Kumar *et al.* 2017) [3, 5, 10]. The extent of heterosis over economic parent for 1000-grain weight ranged from -18.31-8.32%. The estimate values of heterosis over economic parent should be positive and significant performance. Positive and significant heterosis over economic parent was observed in only one cross combination (HUW510 × RAJ1972). Inbreeding depression varied for this character from -20.21-14.82%. Positive and significant values for inbreeding depression were observed in eight crosses combination, while two cross combination showed negative and significant expression. For biological yield per plant, five cross combination were observed to exhibit positive and significant heterosis over economic parents ranged from -11.66-15.62%. HD2329 × K65, HUW468 × SONALIKA and LOK1 × SONALIKA had more biological yield. The range of inbreeding depression for biological yield is varied from -11.83 to 18.66%. Seven cross combinations had positive and significant value of inbreeding depression. The genotypes which have more biological yield should be used further in breeding programme (Desale *et al.* 2013; Kumar *et al.* 2016; Kumar *et al.* 2017) [4, 9, 10]. Only one cross combination *viz.* UP2338 × HD2402, exhibited positive and significant values of heterosis over economic parent for number of grains/spike while, eighteen cross combination showed significant and negative values of heterosis. Inbreeding depression observed for this character was significant and positive in all the crosses. Thus, the increased percentage of grain number in each spike is assumed to be desirable for the consideration to enhance the yield. Protein and gluten content are the most important characters among the quality traits in self-pollinated crops. The heterosis for protein content (-3.35-10.38%) over economic parent was positive and significant in 23 cross combinations. The positive and negative expressions indicated the role of dominant and recessive genes in inheritance of the characters. The value of inbreeding depression ranged from -6.43-8.27%. Among these, one cross combination showed significant and positive value, while one cross combination showed significant and negative values. Out of 45 crosses, four cross combinations (HUW510 × K65, HUW234 × LOK1, HUW468 × RAJ1972 and LOK1 × K65 showed positive and significant heterosis over economic parent for gluten content (-12.24-37.71%). Inbreeding depression for this trait varied from -11.24-11.93%. Inbreeding depression was observed to be non significant for this trait. 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. Bailey *et al*. (1980) [2] observed that F_2 progenies performance for inbreeding depression might be a good indicator of predicting heterosis performance in F_1 hybrid of wheat.

Table 1: Analysis of variance among fourteen characters in a diallel cross (without reciprocal) of 10 parents and their F_1s

		Days to 50% Flowering	Tillers/ Plant	Plant Height (cm)	Length of spike /Plant	Spikelets/ Plant	Peduncle length /Plant	Leaf Area Index (cm)	Day to Maturity 50%	Grain Yield/ Plant (gm)	1000 Seed Weight (gm)	Biological Yield/ Plant (gm)	Grains/ Spike	Protein Content (%)	Gluten Content (%)
Replications	2	0.61	0.06	20.81	0.10	0.06	10.00	4.74	5.38	4.62	2.92	77.00	2.30	0.01	0.09
Treatments	54	5.4***3	0.19***	45.56***	0.53***	1.40***	42.37***	18.04***	15.21***	43.95***	20.33***	100.84***	3.11***	0.46***	0.39*
Parents	9	5.05**	0.15*	96.37***	0.28	1.00	9.39	1.62	4.42	57.83***	8.25	68.67*	1.04	0.14	0.27
F_1s	44	2.32*	0.18***	34.56***	0.60***	1.12**	44.20***	5.54***	5.90***	38.58***	21.85***	109.04***	3.00***	0.30	0.39*
Parent Vs.F_1s	1	145.51***	1.22***	72.46**	0.00	16.82***	258.60***	715.64***	522.15***	155.46	62.34***	29.69	26.72***	10.32***	1.33*
Error	108	1.50	0.06	8.58	0.17	0.60	11.91	2.24	2.66	9.10	5.12	32.71	0.90	0.22	0.26

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01); *** Significant at 0.1% level (P = 0.001)

Table 2: Analysis of variance among fourteen characters in a diallel cross (without reciprocal) of 10 parents and their F_2s

		Days to 50% Flowering	Tillers/ Plant	Plant Height (cm)	Length of spike /Plant	Spikelets/ Plant	Peduncle length /Plant	Leaf Area Index (cm)	Day to Maturity 50%	Grain Yield/ Plant (gm)	1000 Seed Weight (gm)	Biological Yield/ Plant (gm)	Grains/ Spike	Protein Content (%)	Gluten Content (%)
Replicates	2	0.12	0.04	23.99	0.11	2.01	3.21	1.89	3.50	13.65	3.24	16.58	0.71	0.57	0.06
Treatments	54	5.67***	0.81***	41.48***	0.43***	1.60**	79.27***	13.95***	23.84***	30.71***	10.50***	83.15***	2.85***	0.46***	0.58***
Parents	9	5.05**	0.15	96.37***	0.28*	1.00	9.39*	1.62	4.42	57.83***	8.25	68.67*	1.04	0.14	0.27
F_2s	44	3.10**	0.49*	26.53***	0.26***	0.83	10.76***	5.36***	10.19***	25.84***	6.51	77.84***	2.13***	0.36*	0.64***
Parent Vs. F_2s	1	124.29***	20.84***	205.37***	9.22***	40.92***	3722.34***	502.66***	799.24***	0.95	205.95***	447.07***	50.35***	7.57***	1.03*
Error	108	1.72	0.31	7.98	0.12	0.85	3.78	2.45	3.25	9.78	4.68	28.01	0.86	0.21	0.24

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01); *** Significant at 0.1% level (P = 0.001)

Table 3: Estimates of heterosis and inbreeding depression in ten parental half diallel set of 14 traits

S. No	Cross	Days to 50% Flowering		No. of tillers/plant		Plant height (cm)	
		Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression
1	HUW510×HUW234	3.96	-1.665	-3.97*	10.150*	4.46*	3.969
2	HUW510×HUW468	4.19**	0.867	2.94	9.646	7.14**	6.726*
3	HUW510×UP2338	5.39**	-0.433	-1.28	16.608**	3.32	4.109*
4	HUW510×HD2402	3.58**	-2.933**	-0.72	9.091*	2.77	1.822
5	HUW510×RAJ1972	6.84**	2.971*	-1.82	4.815	7.38**	8.129*
6	HUW510×HD2329	3.51**	0.522	-1.81	11.073	2.92	3.886
7	HUW510×LOK1	1.51	-1.839	-4.48*	5.639	1.30	1.794
8	HUW510×SONALIKA	5.15**	3.830*	-3.91*	10.370	-1.53	3.239
9	HUW510×K65	3.70**	-1.263	-10.07**	-4.796	2.92	7.419**
10	HUW234×HUW468	3.78**	-1.562	-0.38	20.076**	5.16*	6.698
11	HUW234×UP2338	5.10**	1.430	-3.55	12.403**	5.16*	6.588*
12	HUW234×HD2402	4.57**	3.245	-5.55**	9.020*	4.81*	-0.167
13	HUW234×RAJ1972	5.70**	1.627	-0.75	16.538**	6.30**	7.377*
14	HUW234×HD2329	2.83*	-1.836	-0.37	5.227	6.72**	4.090
15	HUW234×LOK1	2.48*	2.120*	-5.70**	0.395	7.87**	9.743*
16	HUW234×SONALIKA	2.68*	-2.957	-5.84**	5.814*	-5.69**	-4.536**
17	HUW234×K65	4.68**	1.893	-3.32	5.344	1.63	3.301*
18	HUW468×UP2338	5.46**	1.884*	5.14*	18.841*	5.40*	9.032*
19	HUW468×HD2402	2.06	-1.186	-2.26	13.514	1.98	-0.648
20	HUW468×RAJ1972	3.59**	-1.255	2.66	8.889	5.58*	7.400*
21	HUW468×HD2329	2.00	-0.568	-0.38	4.939	9.71**	9.071*
22	HUW468×LOK1	1.49	1.039	2.44	6.593	7.02**	5.273
23	HUW468×SONALIKA	1.24	0.022	-2.97	10.345**	-3.33	-2.365
24	HUW468×K65	4.91**	1.774	0.38	4.869	-2.44	3.041
25	UP2338×HD2402	5.48**	3.525	-1.68	15.589**	-1.80	2.244
26	UP2338×RAJ1972	5.12**	0.086	-3.20	8.949	3.65	5.093
27	UP2338×HD2329	2.70*	-2.412	-2.44	-1.923	4.76*	3.052
28	UP2338×LOK1	4.09**	2.135	1.49	9.890	7.18**	11.483**
29	UP2338×SONALIKA	1.48	-2.998	-6.44**	0.787	0.89	7.454
30	UP2338×K65	3.56**	-0.785	-3.54	4.633	-7.46**	-4.656**
31	HD2402×RAJ1972	3.60**	-1.304	-2.61	-0.766	8.42**	8.581*
32	HD2402×HD2329	4.97**	0.213	-2.97	5.747	-0.52	5.402*
33	HD2402×LOK1	1.46	-0.914	-2.03	8.647	-0.58	4.406*
34	HD2402×SONALIKA	3.02*	0.647	-7.66**	4.348	-10.09**	-3.694*
35	HD2402×K65	3.59**	0.866	2.58	12.227*	-6.22**	-2.151**
36	RAJ1972×HD2329	3.71**	-0.086	-5.99**	-0.004	12.80**	10.034**
37	RAJ1972×LOK1	1.90	1.300	0.19	12.593**	-0.81	5.571*
38	RAJ1972×SONALIKA	3.78**	0.814	-6.98	-2.367	-4.48*	-3.342*
39	RAJ1972×K65	4.89**	3.206*	0.37	10.000*	-0.12	5.036
40	HD2329×LOK1	0.96	0.695	-3.88	10.769*	-1.91	-1.146
41	HD2329×SONALIKA	2.60*	1.076	-3.30	9.091*	-4.04	-1.382
42	HD2329×K65	3.30**	0.388	-1.48	8.647	0.98	-0.517
43	LOK1×SONALIKA	-0.35	1.618	-4.54	6.844*	1.08	14.583***
44	LOK1×K65	-2.42*	-0.901	-4.95	9.266**	1.74	10.570*
45	SONALIKA×K65	-0.09	-2.746	-5.45	5.381	-5.89*	-6.743*
	SE±	0.867		0.178		2.071	

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01)

S. No	Cross	Length of spike/Plant		No. of Spikelets/Plant		Peduncle length/Plant	
		Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression
1	HUW510×HUW234	1.76	7.965*	8.26	17.797*	2.61	22.051***
2	HUW510×HUW468	-0.61	0.634*	-0.91	8.537	-6.10	23.588***
3	HUW510×UP2338	-2.51	4.609**	-6.61	0.943	2.54	31.127***
4	HUW510×HD2402	-0.75	2.481	3.48	12.538	-4.75	22.797**
5	HUW510×RAJ1972	1.24	0.000*	-3.36	6.433	-8.29	21.037*
6	HUW510×HD2329	4.01	5.407	-5.59	-4.673	-3.15	20.305*
7	HUW510×LOK1	0.87	9.068	-2.11	14.462	-5.02	22.058*
8	HUW510×SONALIKA	-2.35	7.009*	-1.83	11.526	-0.87	21.953*
9	HUW510×K65	-4.95	-0.705	2.71	14.076*	-0.33	25.430***
10	HUW234×HUW468	-7.51**	4.746	-4.41	7.077	-8.91	14.414
11	HUW234×UP2338	-6.83*	0.559	-13.02**	-0.987	-10.22*	11.521*
12	HUW234×HD2402	-6.03*	1.507	-5.23	-9.416	5.82	29.708**
13	HUW234×RAJ1972	2.32	4.010	2.60	13.988	-9.39	9.499

14	HUW234×HD2329	-2.17	0.940	-9.74*	4.762	-5.44	7.502
15	HUW234×LOK1	-1.06	0.000	-11.44*	3.311	10.30*	27.958
16	HUW234×SONALIKA	-4.02	5.782**	-14.88**	-3.497	11.23*	27.525**
17	HUW234×K65	2.27	7.626	-7.92	9.873	-9.28	15.075
18	HUW468×UP2338	1.25	11.740	1.56	13.928	-13.18**	9.724
19	HUW468×HD2402	2.27	8.116	2.74	15.680	-20.55**	11.591*
20	HUW468×RAJ1972	-3.71	1.523**	-8.60	-0.990	-1.08	28.949*
21	HUW468×HD2329	-0.58	10.914*	-14.16**	-10.891	-13.28**	13.553
22	HUW468×LOK1	-5.77*	0.790***	-5.22	4.281	-9.21	12.473
23	HUW468×SONALIKA	-1.11	1.903	-14.71**	-3.448	-6.84	24.353**
24	HUW468×K65	-1.39	0.474	-14.20**	5.068	-15.74**	6.977
25	UP2338×HD2402	-5.59*	7.010	-10.19*	-2.632	7.67	36.141**
26	UP2338×RAJ1972	9.40**	13.947	-2.05	16.766*	4.66	34.937**
27	UP2338×HD2329	17.67**	24.356***	-16.97**	-6.312	-14.61**	-0.158
28	UP2338×LOK1	0.65	8.397	-17.35**	-5.119	-2.43	17.331**
29	UP2338×SONALIKA	-2.19	2.955	-15.59**	-7.458	-11.12*	16.416**
30	UP2338×K65	-2.36	4.554	-13.12**	3.896	-0.34	28.154***
31	HD2402×RAJ1972	2.05	2.240	-1.42	10.256	-9.37*	16.341
32	HD2402×HD2329	1.33	10.477	1.48	13.411*	-14.81**	13.499*
33	HD2402×LOK1	-1.70	5.372	-5.45	3.205	-17.33**	14.109*
34	HD2402×SONALIKA	4.76	9.123*	0.92	8.232	-15.88**	11.702
35	HD2402×K65	-2.09	1.363**	-0.30	9.422	-10.78*	15.096*
36	RAJ1972×HD2329	1.87	4.884	-12.63*	10.924	-11.21*	15.350*
37	RAJ1972×LOK1	-2.04	1.116	-17.59**	-13.869*	-20.42**	6.551
38	RAJ1972×SONALIKA	5.11	3.777*	-12.37*	-5.226	-16.22**	14.140
39	RAJ1972×K65	4.75	9.966*	-9.17	0.000	-9.08	16.535**
40	HD2329×LOK1	1.80	8.062*	-12.99**	7.792	-4.49	21.193*
41	HD2329×SONALIKA	-0.93	2.339*	-12.32*	-4.248	-12.97**	12.058*
42	HD2329×K65	2.53	7.702*	-9.60*	6.875	5.55	21.603*
43	LOK1×SONALIKA	0.08	7.364**	-14.66**	1.375	4.67	25.414***
44	LOK1×K65	-2.25	6.847	-12.43*	3.960	-5.73	22.238**
45	SONALIKA×K65	1.18	8.702*	-7.92	1.592	-13.87**	22.137**
	SE±	0.289		0.547		2.441	

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01)

S. No	Cross	Leaf area index (cm)		Day to maturity		Grain yield per plant (g)	
		Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression
1	HUW510×HUW234	12.66	-0.158	3.40**	-2.090	41.63**	34.865**
2	HUW510×HUW468	25.31**	2.022	3.27**	-2.793	53.42**	39.879**
3	HUW510×UP2338	20.52**	-11.534*	2.84**	-1.992	27.21**	8.929
4	HUW510×HD2402	36.41**	16.389*	2.32*	-7.239***	9.86	-2.030
5	HUW510×RAJ1972	19.91**	-1.665	4.81**	-2.071	19.73**	4.913
6	HUW510×HD2329	8.63	-0.585	4.61**	-0.058	31.01**	19.712*
7	HUW510×LOK1	38.88**	3.127	4.83**	0.554	4.19	-11.004
8	HUW510×SONALIKA	35.05**	-1.530	5.23**	-2.035	9.73	1.406
9	HUW510×K65	25.85**	-15.942*	6.39**	-0.291	9.68	6.058
10	HUW234×HUW468	39.64**	1.061	4.92**	-0.585	13.23*	-3.328
11	HUW234×UP2338	36.96**	10.820	2.29*	-5.830*	13.56*	2.782
12	HUW234×HD2402	49.02**	9.538	5.12**	-2.339	-2.90	-7.009
13	HUW234×RAJ1972	37.89**	10.512	6.98**	1.739	14.36*	-4.160
14	HUW234×HD2329	38.32**	11.215	5.58**	1.156	15.00*	8.300
15	HUW234×LOK1	23.57**	4.154	5.41**	2.262	9.23	-4.457
16	HUW234×SONALIKA	34.10**	4.284	6.45**	2.299	10.66	6.897*
17	HUW234×K65	37.59**	-6.261	2.89**	-1.292	3.34	8.308
18	HUW468×UP2338	44.77**	9.345	2.90**	-2.806	-7.44	4.340
19	HUW468×HD2402	54.51**	6.160	3.42**	-1.920	-5.46	1.541
20	HUW468×RAJ1972	37.19**	8.683	3.99**	-1.956	18.20**	8.584
21	HUW468×HD2329	38.90**	-0.735	3.44**	-0.880	12.34*	0.000
22	HUW468×LOK1	32.86**	6.015	3.33**	-2.941	11.51*	0.691
23	HUW468×SONALIKA	55.70**	7.710*	5.82**	0.862	11.49*	5.660
24	HUW468×K65	46.85**	-1.067	6.39**	2.918	-12.30*	-7.611
25	UP2338×HD2402	28.58**	6.090	4.46**	-1.458	-6.07	5.405
26	UP2338×RAJ1972	30.67**	8.465	5.75**	-1.395	3.00	0.085
27	UP2338×HD2329	36.46**	13.836	3.36**	-0.936	3.68	1.252
28	UP2338×LOK1	18.19**	-6.942	3.06**	-2.587	9.26	8.129
29	UP2338×SONALIKA	42.35**	12.631*	1.45	-0.388	-4.52	-7.807
30	UP2338×K65	39.21**	4.732	2.90**	-2.740	-13.21**	-9.123
31	HD2402×RAJ1972	30.92**	-1.381	3.81**	-5.294**	4.37	4.499

32	HD2402×HD2329	27.51**	1.885	3.33**	-2.941	5.65	6.512
33	HD2402×LOK1	29.26**	5.808	4.43**	2.624	-6.43	2.292
34	HD2402×SONALIKA	42.17**	12.789	4.19**	2.924	-9.23	6.894
35	HD2402×K65	38.85**	1.746	4.19**	0.384	-10.59*	11.760
36	RAJ1972×HD2329	30.42**	11.695	2.30*	-2.487	10.73	7.980
37	RAJ1972×LOK1	35.04**	11.217	5.34**	-1.166	16.13**	5.405
38	RAJ1972×SONALIKA	48.35**	9.978*	4.79**	-2.053	-7.04	-0.620
39	RAJ1972×K65	38.01**	-1.103	4.21**	-0.179	1.03	2.344
40	HD2329×LOK1	23.20**	-0.613	3.39**	0.000	-1.21	11.404**
41	HD2329×SONALIKA	36.16**	15.493	3.15**	-0.880	-4.22	-5.128
42	HD2329×K65	36.22**	3.819	5.49**	0.290	16.17**	14.932
43	LOK1×SONALIKA	19.26**	-2.602	5.76**	1.146	0.83	7.874
44	LOK1×K65	30.57**	-9.700	4.15**	0.882	-5.26	12.309
45	SONALIKA×K65	40.72**	3.603	4.52**	-0.587	1.49	10.000
	SE±	1.058		1.154		2.133	

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01)

S. No	Cross	1000 grain weight (g)		Biological yield/ Plant (g)		No. of Grain/spike	
		Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression
1	HUW510×HUW234	-4.11	2.381	2.50	4.600	2.45	14.072*
2	HUW510×HUW468	4.03	7.748	6.60	7.093	1.20	10.978*
3	HUW510×UP2338	1.59	5.216**	2.02	-4.199	-7.35*	-0.663
4	HUW510×HD2402	-6.17	4.150	-9.08*	-2.491	-0.61	4.746
5	HUW510×RAJ1972	7.65*	13.999**	-7.06	-11.832*	-5.62	2.194
6	HUW510×HD2329	-3.32	5.551	0.45	-4.136	-8.25**	1.307
7	HUW510×LOK1	1.43	8.081	3.17	6.897	-0.38	12.273*
8	HUW510×SONALIKA	-7.20*	3.760	-8.84*	-9.141	-9.83**	0.000
9	HUW510×K65	2.31	9.842	6.07	10.952	-2.04	2.318
10	HUW234×HUW468	3.87	5.712	0.70	-1.230	-3.41	5.769
11	HUW234×UP2338	-4.15	0.551	5.16	6.727*	-3.95	1.972
12	HUW234×HD2402	-2.34	3.826	-6.91	-3.257	-8.95**	3.102
13	HUW234×RAJ1972	8.32*	10.526*	-8.42*	2.586	-4.27	0.320
14	HUW234×HD2329	-5.54	0.551	-1.42	4.107	-6.03	-0.660
15	HUW234×LOK1	-6.82	-4.699	-2.02	-2.012	-5.99	0.000
16	HUW234×SONALIKA	-3.40	3.372	-9.46*	-9.004	-6.78*	-6.208
17	HUW234×K65	3.60	3.402	1.05	12.764***	0.55	2.172
18	HUW468×UP2338	-2.43	5.130	0.61	5.605	-0.46	9.318*
19	HUW468×HD2402	-0.04	14.441**	-5.49	-3.656	-12.90**	-4.938
20	HUW468×RAJ1972	-1.79	4.037	0.35	-0.037	-7.46*	5.807
21	HUW468×HD2329	4.78	8.006*	1.35	4.025	-4.99	-1.589
22	HUW468×LOK1	-8.38*	7.650	9.98*	17.839**	-2.51	1.875
23	HUW468×SONALIKA	-0.40	10.449*	12.51**	18.597*	-10.51**	0.000
24	HUW468×K65	2.31	10.082	-0.22	1.383	-9.24**	-1.010
25	UP2338×HD2402	2.26	7.056	-9.89*	-7.336	6.58*	15.882*
26	UP2338×RAJ1972	1.92	6.617	-5.69	-2.451	-8.68**	-4.667
27	UP2338×HD2329	-1.66	3.759	-6.14	-4.908	-5.25	1.138
28	UP2338×LOK1	-10.56**	0.325	5.92	6.384	-10.33**	-10.920
29	UP2338×SONALIKA	2.87	14.817*	1.67	6.281	-10.57**	-5.442
30	UP2338×K65	-0.76	4.301	-6.20	0.486	0.86	-0.464
31	HD2402×RAJ1972	-0.74	5.693	-8.17*	3.795	-7.41*	0.000
32	HD2402×HD2329	0.04	13.137**	-1.90	5.590	-3.99	0.960
33	HD2402×LOK1	-9.91**	-1.644	-5.70	4.442	-3.01	-3.025
34	HD2402×SONALIKA	-8.87	-0.314	-5.52	-1.989	2.80	10.000
35	HD2402×K65	3.03	8.830	-6.52	5.452	-4.26	8.091
36	RAJ1972×HD2329	-9.17*	-4.651	-4.42	3.177	-3.13	-0.309
37	RAJ1972×LOK1	-8.18*	-3.468	9.45*	11.948***	-8.78**	-5.921
38	RAJ1972×SONALIKA	-13.75**	-7.927	-11.66**	1.835	-13.59**	-8.163
39	RAJ1972×K65	-12.61**	-20.214*	7.31	14.373	-8.50**	0.000
40	HD2329×LOK1	-12.45**	-6.944	-11.53**	-11.185	-9.66**	-5.051
41	HD2329×SONALIKA	-7.87*	-3.937	-1.82	6.786	-0.82	14.414***
42	HD2329×K65	-3.94	-5.469	15.12**	9.656*	-0.84	5.229
43	LOK1×SONALIKA	-15.21**	-7.647	10.12*	18.663**	-10.94**	-10.436
44	LOK1×K65	-17.05	-15.808	5.54	5.630	-0.46	8.026
45	SONALIKA×K65	-18.31	-14.364*	-7.59	-2.307	3.76	5.506
	SE±	1.600		4.044		0.670	

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01)

S. No	Cross	Protein Content (%)		Gluten Content (%)	
		Heterosis over EP	Inbreeding Depression	Heterosis over EP	Inbreeding Depression
1	HUW510×HUW234	3.46	0.084	5.21	-3.733
2	HUW510×HUW468	8.48**	3.594	3.19	-2.226
3	HUW510×UP2338	-3.35	0.000	-0.21	0.034
4	HUW510×HD2402	6.12*	-1.226	-1.19	-2.133
5	HUW510×RAJ1972	6.23*	3.000	-2.03	0.000
6	HUW510×HD2329	7.10*	-0.077	-2.53	0.000
7	HUW510×LOK1	5.64	0.308	2.20	0.000
8	HUW510×SONALIKA	7.90**	2.492	-1.29	0.000
9	HUW510×K65	6.62*	-0.844	10.62*	0.000
10	HUW234×HUW468	8.69**	0.000	0.29	0.000
11	HUW234×UP2338	3.49	0.000	8.12	0.035
12	HUW234×HD2402	3.19	-3.765	0.12	-6.529
13	HUW234×RAJ1972	8.05**	2.137	5.06	4.211
14	HUW234×HD2329	2.92	-3.406	-6.61	-11.242
15	HUW234×LOK1	4.87	1.150	11.24**	11.555
16	HUW234×SONALIKA	3.08	-0.905	4.47	-6.468
17	HUW234×K65	6.16*	2.675	5.61	-0.301
18	HUW468×UP2338	3.82	-0.556	6.51	-1.341
19	HUW468×HD2402	4.15	0.000	-2.17	0.000
20	HUW468×RAJ1972	2.78	0.000	12.16**	-0.486
21	HUW468×HD2329	1.86	-4.537	-3.22	-9.881
22	HUW468×LOK1	8.14**	3.087	4.73	3.177
23	HUW468×SONALIKA	9.46**	2.023	5.25	0.504
24	HUW468×K65	4.82	-2.879	1.71	-4.933
25	UP2338×HD2402	5.41	3.140	-1.99	3.990
26	UP2338×RAJ1972	2.64	-3.923	0.10	0.781
27	UP2338×HD2329	4.38	3.083	-5.77	-5.031
28	UP2338×LOK1	8.83**	3.441	6.62	9.549
29	UP2338×SONALIKA	9.03**	1.946	5.23	-1.310
30	UP2338×K65	4.43	-5.678*	1.76	-10.172
31	HD2402×RAJ1972	10.38**	0.247	6.05	6.525
32	HD2402×HD2329	8.46**	8.077	1.18	10.247
33	HD2402×LOK1	6.74*	4.263	2.97	-0.765
34	HD2402×SONALIKA	1.58	-0.115	0.86	-4.627
35	HD2402×K65	9.47**	8.272*	7.93	11.927
36	RAJ1972×HD2329	8.99**	6.127	1.26	7.236
37	RAJ1972×LOK1	7.01*	-1.395	-0.88	-0.170
38	RAJ1972×SONALIKA	2.64	-0.761	-1.43	-1.317
39	RAJ1972×K65	10.35**	4.754	7.16	2.958
40	HD2329×LOK1	4.87	3.573	2.15	-0.562
41	HD2329×SONALIKA	0.64	-6.432	2.91	1.601
42	HD2329×K65	3.85	-1.926	-2.40	-3.408
43	LOK1×SONALIKA	8.25**	2.075	5.30	2.571
44	LOK1×K65	6.46*	-3.785	9.96*	5.350*
45	SONALIKA×K65	8.03**	5.249	8.47	5.238
	SE±	0.331		0.359	

*Significant at 5% level (P = 0.05); ** Significant at 1% level (P = 0.01)

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