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Research article

Prediction of gene action and combining ability for yield and quality traits in F_1 and F_2 generations of wheat (*Triticum aestivum* L.)

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Abstract: Combining ability analysis was studied in a 10 x 10 diallele set of bread to understand the inheritance pattern of several yield and quality traits in bread wheat. Results showed that the GCA variances were higher than SCA variances for plant height, spike length, duration of reproductive phase, gluten content and grain yield per plant in both the generations. General predictability ratio (GPR) did not reach near to unity for any of the traits in both the generations except tryptophan content in F_1 generation. On the basis of overall performance, parents K8962, K9423, PBW343, GW373, HD2733 and Sonalika were best general combiners for grain yield and other important characters. Among the cross significant and desirable SCA effects in order of merit for yield and yield contributing traits were exhibited by GW373/K8962, K9107/K8027, GW373/Sonalika, K8027/K8962, K8962/Sonalika, K9107/K9423, K8020/K9423, K9107/K9351, K9107/K8962, K9107/Sonalika. These parents may be used for simultaneous improvement in grain yield and quality attributes through an intermating population involving all possible combinations among themselves.
Keywords: *Triticum aestivum* - GCA - SCA - Combining ability.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is the principal food grain of the world population belonging to the family Gramineae are well known for their containing various phytochemicals that function as antioxidants (Ghose *et al*. 2013) and its huge global consumption as human food. Wheat is the second most important staple food crops (Joshi *et al*. 2007) next to rice, consumed by nearly 35% of the world population and providing 20% of the total food calories (Desale & Mehta 2013). Wheat is a rich source of essential human diet ingredients like 70% carbohydrates, 12% protein, 22% crude fibers, 2% fat, 12% water and 1.8% minerals. Yield and Quality traits like grain protein-content (GPC) are primary importance in bread-wheat breeding programs. The success of any crop improvement program depends mainly on a judicious selection of promising parents from gene pools, a clear cut understanding of genetic mechanisms involved in the inheritance of characteristics which help the breeders in deciding the most appropriate breeding procedure to enhance the genetic potentialities. The identification of superior parents for hybridization is based on the ability of a particular line to combine with other lines and produce desirable segregants/recombinants are important pre-requisite for efficient breeding programme (Jaiswal *et al.* 2013). Hybridization is the most potent technique for breaking yield barriers and evolving varieties having a built in high yield potential (Jaiswal *et al*. 2013). Singh*et al.* (2013) suggested that heterosis play significant role in combining ability of parents and can be include in the breeding programme. Diallel analysis provides a systematic approach for the identification of appropriate parents and crosses superior to the traits investigated so far (Joshi *et al.* 2004).

The combining ability analysis is an important tool for the selection of desirable parents together with information regarding nature and magnitude of controlling quantitative traits (Masood *et al.* 2014). The term general combining ability (GCA) is associated with genes of additive effects, used to designate the average

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performance of a line in hybrid combinations and specific combining ability (SCA) caused by dominance and epistasis, to define those case in which certain combinations do relatively better or worse than expected on the basis of the average performance of the lines involved. The diallel analysis is an efficient method for the study of combining ability and gene action involved in the inheritance of traits. Kamaluddin *et al*. (2007) studies GCA and SCA effects for yield and yield components in wheat. In bread wheat grain yield and grain protein content are two very important traits (Groos *et al*. 2003). In a systematic breeding programme, selection of parents with desirable characteristics having good general combining ability (GCA) and specific combining ability (SCA) effects for yield and its trait components are essential (Gowda *et al*. 2012, Desale *et al*. 2014).The number of parental lines can be tested in all possible combinations through diallele crosses (Hassan *et al*. 2007).

Therefore, knowledge about combining ability is important in selecting suitable parents for hybridization, understanding of inheritance of quantitative traits and also in identifying the promising crosses is of paramount importance in formulating an efficient breeding programme. Keeping in view, present investigation was carried out to obtain more precise estimates of combining ability and genetic architecture for yield and quality traits in bread wheat.

MATERIALS AND METHODS

Plant material

The material used for the present study was comprised of 10 varieties of hexaploid wheat (*Triticun aestivum* L.), namely, K 9107, GW 373, PBW 343, HD 2733, K 8020, K 9423, K 9351, K 8027, K 8962 and Sonalika were selected on the basis of their differences in maturity, plant height, grain yield and other important quality traits at Section of Economic Botanist (Rabi Cereals), C.S. Azad University of Agriculture and Technology, Kanpur. The details of genotypes and their pedigree are presented in table 1. These genotypes were used to obtain hybrid combinations according to a diallel crossing scheme. In order to get F_2 seeds of for final experiment about 30 F_1 seeds were raised in Wellington, Nilgiri Hills (Tamil Nadu) nursery during the off–season of summer in 2009.

Table 1. Pedigree details and some distinguishing features of the parents used in 10 diallel analysis in wheat.

SI No	Parents	Pedigree	Diagnostic features
1	K 9107	K8107/K68	Single gene dwarf (d1), late in maturity, rusts tolerant, protein content over 14%
2	GW373	HW2008/J505	Double gene dwarf (d2), resistant to rusts.
3	PBW 343	ND/VG1944//KAL//BB/3/ YACO‘5’/4/VEE5‘S’	Double gene dwarf (d2), resistance to rusts, protein content over 12%.
4	HD2733	ATTILA/3/TUI/CARC/ CHEN/CHT014/ATTILA	Double gene dwarf (d2), high yielding resistance to rusts
5	K 802	K. Sona/ HD 1982	Double gene dwarf (d2), early in maturity, resistance to rusts,
6	K 9423	HP 1633/ K.Sona/UP262	Double gene dwarf (d2), resistance to rusts and heat tolerant, high protein content
7	K9351	K72/HD2160	Double gene dwarf (d2), medium in maturity, resistance to brown rust
8	K8027	HD1696/ K852	Single gene dwarf (d1), resistant to rusts
9	K8962	K7401/ HD2160	Double gene dwarf (d2), early maturity, highly tolerant to all the three rusts
10	Sonalika	II54-388/AN/3/YT54/ N10B//LR64	Single gene dwarf (d1), tolerant to rusts

Experimental design

The experiment for the present investigation was carried out with 10 parents and their resulting F_1 which were grown in a triplicate randomized block design during crop years 2007–2008. The seeds were dibbled in rows keeping within and between row distances at 10 and 25cm, respectively. Single row of 3 m length served as an experimental unit. Three seeds per hill were sown to ensure the crop stand, which were thinned to single seedling per site after germination. At maturity 5 randomly selected competitive plants in each test entry per replication in F_1 and F_2 were tagged before flowering and observations were recorded for 14 traits: days of 75% flowering, days of 75% maturity, duration of reproductive phase, number of ear bearing tillers/ plant, plant height (cm), spike length (cm), ear density (cm), number of grains/spike, seed hardness (by O.S.K. 201 grain hardness Tester), protein content (by Biuret method in %), tryptophan content (%), phenol colour reaction (score), gluten content (%), and grain yield/ plant (g).

Statistical analysis

The data of various traits were compiled and mean values of the replicated data were used for statistical analysis using WINDOSTAT software, Hyderabad, India. The mean data of each replication were tested for significance by the method of analysis of variance (ANOVA) suggested by Panse and Sukhatme (1967). The breeding values of the parental lines have been evaluated by analyzing the combining ability estimates according to Griffing's (1956) for both F_1 and F_2 generations.

RESULTS

Analysis of variance (ANOVA)

Analysis of variance for combining ability revealed that the variances due to GCA and SCA were significant for all the traits in both generations (Table 2). This indicated existence of genetic variability in the parental lines and involvement of both additive and non-additive gene effects in the inheritance of these traits. The magnitude of estimates of GCA variances were higher for plant height, spike length, duration of reproductive phase, gluten content and grain yield per plant than the respective estimates of SCA variances in both the generations. General predictability ratio (GPR) did not reach near to unity for any of the traits in both the generations except tryptophan content in F_1 generation indicated non-additive component played relatively greater role in the inheritance of traits.

Table 2. Analysis of variance (ANOVA) for combining ability of 14 characters in a 10 parent-diallel cross in F_1 and F_2 generations of wheat.

Source		GCA	SCA	Error	$δ^2_g$	$δ^2_s$	GPR
df		9	45	108			
DF 75%	F_1	6.03**	8.57**	0.32	0.47	8.25	0.10
	F_2	9.35**	12.33**	4.11	2.44	8.22	0.05
PH	F_1	144.71**	126.11**	0.92	11.98	25.19	0.32
	F_2	130.11**	123.99**	0.75	10.78	23.24	0.31
NEBT	F_1	1.42**	1.34**	0.39	0.09	0.95	0.80
	F_2	0.91**	1.88**	0.40	0.04	1.48	0.26
SL	F_1	0.65**	0.41**	0.12	0.04	0.29	0.12
	F_2	0.40**	0.30**	0.10	0.03	0.20	0.13
DM	F_1	157.21**	215.23**	0.46	13.06	14.47	0.47
	F_2	153.13**	116.70**	0.51	12.72	16.19	0.44
DRP	F_1	5.86**	3.42**	0.36	0.46	3.06	0.13
	F_2	8.06**	2.85**	0.27	0.67	2.58	0.20
ED	F_1	49.33**	33.55**	2.44	3.91	31.11	0.12
	F_2	41.12**	43.52**	4.50	3.05	39.02	0.07
NG	F_1	24.21**	31.73**	0.51	1.97	31.22	0.05
	F_2	14.00**	40.00**	6.65	0.62	33.85	0.02
PC	F_1	0.28**	0.53**	0.06	0.01	0.47	0.03
	F_2	0.31**	0.42**	0.04	0.02	0.38	0.05
TC	F_1	0.08**	0.08**	0.008	0.06	0.07	1.77
	F_2	0.06**	0.06**	0.004	0.004	0.05	0.07
PCR	F_1	0.79**	1.14**	0.41	0.03	0.73	0.03
	F_2	1.09**	0.95**	0.41	0.05	0.54	0.08
GC	F_1	0.07**	0.03**	0.002	0.005	0.02	0.2
	F_2	0.66**	0.04**	0.005	0.05	0.03	0.62
SH	F_1	0.54**	0.68**	0.19	0.02	0.49	0.007
	F_2	0.23**	0.67**	0.14	0.007	0.53	0.013
GY	F_1	24.37**	12.90**	0.94	1.95	11.96	0.14
	F_2	21.00**	16.24**	1.21	1.64	15.03	0.098

Note: *Significant at 5% level; ** significant at 1% level

GCA-General combining ability variance, SCA-Specific combining ability variance, $δ^2$g-Estimates of GCA variance, $δ^2_S$-Estimates of SCA variance, GPR - General predictability ratio.

Days to 75% flowering (DF 75%), Plant height (PH), Number of ear bearing tillers/plant (NEBT), Spike length (SL), Days to maturity (DM), Duration of reproductive phase (DRP), Ear density (ED), Number of grains / spike (NGS), Protein content (PC), Tryptophan content (TC), Phenol colour reaction (PCR), Gluten content (GC), Seed hardness (SH), Grain yield/Plant (GY).

General combining ability and performance of parents

Considering GCA effects of the parents for all the 14 characters in F_1 and F_2 progenies are presented in table 3. Lowest negative and significant values of GCA effects were considered to be desirable for number of days to 75% flowering, plant height, days to maturity, phenol colour reaction while for remaining characters positive and significant GCA effects were taken into account for sorting out the desirable general combiners. In F_1 generation, significant and desirable GCA effects were observed for days to 75% flowering in K8020, K9351 and K8962, for plant height in K9423, K9351 and K8962 for days to maturity in K8020, K9423, K9351 and K8962, for phenol colour reaction in K8027. In F_2 generation, significant and desirable GCA effects were found for days to 75% flowering in K8962, days to maturity in K8020, K9423, K9351 and K8962, for plant height in K9423, K9351 and K8962; for phenol colour reaction in K9107 and K8027.

Table 3. Estimates of GCA effects and corresponding mean performance of the parents for 14 characters in 10 parents of diallel cross in F_1 and F_2 generation of wheat.

Parent		K9107	GW373	PBW343	HD2733	K8020	K9423	K9351	K8027	K8962	Sonalika	SE(gi)	SE(gi - gj)
DF 75%	F_1	0.11	0.84**	0.79**	0.11	-0.38**	0.81**	-0.76**	0.01	-1.37**	0.63**	0.17	0.24
	F_2	0.59	1.43*	0.99	0.51	-0.05	0.2	-1.06	-0.86	-1.30*	1.07	0.57	0.86
PH	F_1	-0.2	3.76**	3.25**	0.48	4.76**	-6.86**	-2.11**	1.13**	-3.22**	2.25**	0.26	0.41
	F_2	0.44	3.61**	3.33**	-0.12	5.16**	-5.45**	-2.10**	0.66*	-4.09**	1.88**	0.24	0.37
NEBT	F_1	0.15	0.64**	0.82**	-0.33	0	-0.24	-0.39**	-0.33	0.2	0.39*	0.17	0.26
	F_2	0.07	0.43*	0.51**	-0.26	-0.23	-0.35	-0.23	0.22	0.18	0.27	0.18	0.27
SL	F_1	-0.07	0.46**	0.62**	-0.24*	-0.31**	-0.06	-0.04	0.26*	0.12	-0.12	0.1	0.14
	F_2	-0.07	0.40**	0.59**	-0.20*	-0.17	-0.04	-0.08	-0.04	0.22*	-0.02	0.09	0.14
DM	F_1	2.40**	4.09**	3.17**	0.64**	-1.50**	-4.91**	-5.66**	0.70**	-1.30**	5.55**	0.19	0.28
	F_2	2.55**	4.21**	4.33**	0.15	-1.55**	-4.73**	-5.76**	0.73**	-0.85**	5.33**	0.2	0.3
DRP	*F1*	0.13	1.38**	1.12**	-0.71**	-0.81**	0.85**	-0.50**	-0.29	-0.29	0.23	0.17	0.25
	F2	1.22**	1.30**	1.16**	0.2	-0.14	-1.22**	0.29	0.07	-1.02**	-0.11	0.15	0.22
ED	*F1*	1.72**	3.15**	2.95**	0.06	-0.81	0.12	-2.95**	-0.38	-3.02**	2.11**	0.44	0.66
	F2	-0.41	2.20**	2.32**	1.51*	-0.83	0.5	-1.14	0.08	-3.94**	2.20**	0.6	0.9
NG	*F1*	0.52*	0.89**	0.92**	0.95**	-2.84**	0.58*	1.58**	0.34	-2.14**	0.13	0.2	0.3
	F2	0.07	1.43*	1.61**	1.19	-2.29**	0.28	0.29	0.2	-1.11	-0.05	0.73	1.1
PC	*F1*	-0.07	-0.06	-0.12	0.09	0.02	0.18*	0.18*	-0.33**	-0.02	0.13	0.07	0.1
	F2	0.01	-0.20**	0.25**	0.09	0.02	0.19**	0.09	-0.35**	0.1	0.05	0.05	0.08
TC	*F1*	-0.08*	0.16**	0.19**	0.09**	0.02	-0.07*	0.03	-0.08*	-0.02	-0.05	0.03	0.04
	F2	-0.01	0.09**	0.09**	0.09**	0.01	0.001	-0.02	-0.12**	0.05*	-0.10**	0.02	0.03
PCR	F_1	-0.2	-0.08	-0.06	0.25	0.13	0.43*	0.01	-0.51*	-0.05	0.01	0.18	0.27
	F_2	-0.41*	-0.04	-0.05	0.14	0.17	0.65**	-0.04	-0.38*	-0.07	-0.01	0.18	0.27
GC	F_1	0.03**	0.07**	0.06**	0.05**	-0.12**	0.07**	-0.01	0.02	-0.16**	0.05**	0.01	0.02
	F_2	0.02	0.08**	0.09**	0.07**	-0.11**	0.01	-0.01	0.03	-0.12**	0.04	0.02	0.03
SH	F_1	-0.05	-0.25*	-0.27*	0.11	0.27	0.34*	0.11	-0.17	-0.08	-0.29*	0.12	0.18
	F_2	0.01	-0.28*	-0.31*	0.08	0.01	0.24*	0.04	0.01	0.02	-1.13**	0.1	0.16
GY	F_1	0.85**	2.76**	2.32**	0.78**	-1.05**	0.76**	-1.03**	-0.43	-1.61**	1.14**	0.26	0.41
	F_2	0.75*	2.19**	2.45**	0.81*	-0.47	0.78*	-0.84*	0.04	-2.62**	0.92*	0.31	0.47

Note: * Significant at 5% level; ** significant at 1% level.

Days to 75% flowering (DF 75%), Plant height (PH), Number of ear bearing tillers/plant (NOEBT), Spike length (SL), Days to maturity (DM), Ear density (ED), Number of grains / spike (NOGS), Protein content (PC), Tryptophan content (TC), Phenol colour reaction (PCR), Gluten content (GC), Seed hardness (SH), Grain yield (GY).

Specific combining ability effects

The specific combining ability (SCA) effects estimated for all the traits are presented in Appendix I. On the basis of SCA effects and *per se* performance of the hybrids (Table 4), it was noted that the crosses were not exactly in the same order of ranking. In the present findings, best combinations mostly involved high ×low and low × low general combiners for the characters under study high x low GCA effects played an important role in the expression of positive and significant SCA effects. The cross combinations GW373/K8962, K8027/K8962 and K9423/K8962 in F_1 generation and K9423/K8962 and K9107/K9423 in F_2 generation involved one parent with desirable and significant GCA effects and other with poor or negative effects.

Considering both the F_1 and F_2 generations simultaneously, for grain yield per plant GW373/K8962, K9107/K8027 and GW373/Sonalika for protein content K8027/K8962, for tryptophan content K8962/Sonalika, for gluten content K9107/K9423 and K8020/K9423, for seed hardness K9107/K9351, K9107/K8962 and K9107/Sonalika were most desirable and common cross combinations based on SCA and *per se* performance.

Table 4. Good specific combinations on the basis of *Per Se* performance and SCA effects for 14 Characters in a 10parents diallel cross in wheat.

Character	Cross combination with high *Per Se* performance	Good specific combinations F_1	Good specific combinations F_2	Common cross combination based on *sca* and *Per Se* performance
DF 75%	GW373 X K8027 K9107 X HD2733	K8027 X K8962 K8020 X K8962	PBW343 X K8020 K9107 X K8962	K8027 X K8962
PH	GW373 X PBW343 K9107 X HD2733	K9107 X K8027 K8020 X K9351	K9107 X K9423 K8020 X K9351	K9107 X K9423
NEBT	GW373 X K8962 GW373 X Sonalika	GW373 X K8962 GW373 X Sonalika	PBW343 X K8027 GW373 X K8962	K9107 X K8962
SL	K8020 X K9423 PBW343 X K8962	K8020 X K9423 GW373 X K9423	K8027 X Sonalika PBW343 X K8020	K8027 X Sonalika
DM	PBW343 X K8962 PBW343 X Sonalika	PBW343 X K8962 PBW343 X onalika	K9423 X K8962 K9423 X Sonalika	K9423 X K8962 K9423 X Sonalika
DRP	K9107 X K8027 GW373 X Sonalika	K9107 X K8027 GW373 X K8962	K8020 X K9423 PBW343 X K9351	K9107 X K8027
ED	GW373 X Sonalika GW373 X K8027	PBW343 X K8962 GW373 X K8027	K8020 X K9423 K9107 X K8027	GW373 X K8962 GW373 X Sonalika
NG	K8962 X Sonalika K8027 X K8962	GW373 X K8027 K8020 X K9423	K8020 X K9423 K8027 X K8962	GW373 X K8027 K8027 X K8962
PC	GW373 X PBW343 HD2733 X K8962	K8020 X K8027 GW373 X K8962	K8962 X Sonalika K8027 X K8962	K8027 X K8962
TC	K9351 X K8962 K9351 X Sonalika	K8962 X Sonalika K9351 X Sonalika	K8962 X Sonalika K9107 X K8962	K8962 X Sonlika
PCR	K8020 X K9351 K8020 X K8027	K8020 X K8027 K8020 X K9351	K9423 X Sonalika K9423 X K8962	-
GC	K9107 X K8027 K9107 X K9423	K9107 X K9423 K8020 X K9423	GW373 X Sonalika K8020 X K9423	K9107 X K9423 K8020 X K9423
SH	K9107 X K9351 GW373 X K9423	K9107 X K9351 K9107 X K8962	GW373 X K8020 K9107 X K8962	K9107 X K9351 K9107 X K8962
GY	GW373 X K8962 GW343 X HD2733	GW373 X K8962 K9107 X K8027	K8020 X K9423 K9107 X K8027	GW373 X K8962 K9107 X K8027

Note: Days to 75% flowering (DF 75%), Plant height (PH), Number of ear bearing tillers/plant (NEBT), Spike length (SL), Days to maturity (DM), Ear density (ED), Number of grains / spike (NOGS), Protein content (PC), Tryptophan content (TC), Phenol colour reaction (PCR), Gluten content (GC), Seed hardness (SH), Grain yield/Plant (GY)

DISCUSSION

The population of India is continuously growing and many times we face the problems of drought and heavy rains which decrease the production of wheat. The systematic breeding with improved quality of seed grains can fulfill the hungry problems in India. The development of wheat varieties possessing improved yield related characters has been the major objective of wheat breeders. Availability of genetically based variation for these traits *viz.* Plant height, Number of ear bearing tillers/plant, Spike length, Days to maturity, Duration of reproductive phase, Ear density, Number of grains / spike, Protein content, Tryptophan content, Phenol colour reaction, Gluten content, Seed hardness, Grain yield/Plant is a pre requisite for the selection of new cultivars. Present wheat material was studied to generate information on general and specific combining ability for these traits. Similar findings were also reported by Saeed *et al.* (2010) and Zahid *et al.* (2011). Combining ability describes the breeding value of parental lines to produce hybrids (Romanus *et al.* 2008). The general combining ability has been equated with additive gene action and specific combining ability with non-additive gene action (Griffing 1956). A basic requirement in any effective hybridization programme is to identify superior genotypes which could excel in their combining ability. General combining ability effects have successfully been used in making the choice of the parents and also for the isolation of the germplasm base for further improvement. This information on yield and other agronomic traits is important and greatly help in the proper classification of parental lines. Hassan *et al*. (2007) studied combining ability in the F_1 generations of diallele for yield and yield components in wheat found best general combiner for grain yield per plant and grain weight per spike. The crosses showing high SCA effects with at least one good general combiner could produce desirable transgressive segregants in subsequent generations. Nazir *et al*. (2005) studied combining ability analysis for yield and yield contributing traits using 5 x 5 diallele cross of wheat show similar finding. The crosses involving good general combiners and showing high SCA effects may be utilized for further breeding purposes.

CONCLUSION

In conclusion, it is clear the information on GCA effects should be supplemented by SCA effects and hybrid performance of cross combinations to predict the gene action for yield and quality related traits in segregating generations. The identified crosses hold great promise in improving the grain yield and quality attributes in future breeding programme of bread wheat.

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Appendix I: Estimates of SCA effects and corresponding mean performance for 14 characters in a 10 parent diallel cross in F_1 and F_2 generations of wheat.

Cross combination	Days to 75% flowering		Plant height		Number of ear bearing tillers/plant	
	F_1	F_2	F_1	F_2	F_1	F_2
K9107 X GW373	-0.93	-1.14	1.90*	2.20*	1.19*	0.87
K9107X PBW343	1.20	2.07	2.21*	7.31**	-0.30	-0.13
K9107 X HD2733	-3.86**	-3.33*	-4.27**	-5.85**	-3.08**	-2.25**
K9107X K8020	0.76	1.27	-1.28	-2.28*	-0.69	-1.01
K9107X K9423	3.55**	2.48	-6.57**	-7.62**	-1.69**	-2.70**
K9107X K9351	-2.36**	-1.94	-1.07	-1.51*	0.64	-0.37
K9107X K8027	3.23**	2.49	-11.45**	-8.57**	1.16*	1.90*
K9107X K8962	-2.86**	-7.28**	-4.92**	-5.74**	1.67**	1.87*
K9107X Sonalika	-1.96**	-3.85*	-1.93*	-2.35*	1.35	0.72
GW373 X PBW343	0.06	0.51	-4.02**	-4.22**	1.34	0.18
GW373X HD2733	3.18**	2.81	3.63**	0.12	-0.45	-0.61
GW373X K8020	-1.80**	-7.76	7.72**	4.68**	-0.72	-2.04**
GW373X K9423	0.87	0.45	1.79*	3.02**	0.61	1.93*
GW373X K9351	-2.66**	-2.97	-1.10	0.46	-1.72*	-1.40*
GW373X K8027	-1.26*	-2.19	2.92*	-3.94**	-0.21	0.79
GW373X K8962	-2.41**	-2.01	-6.39**	-6.94**	2.31**	2.18**
GW373X Sonalika	-2.20*	-1.00	-3.23**	-4.39**	2.22	1.19
PBW343 X HD2733	-0.60	-0.49	-2.32*	-3.36**	1.07	1.05
PBW343X K8020	2.12**	-9.02**	-4.03**	-4.80**	-0.54	-0.37
PBW343X K9423	-1.89**	-0.77	-1.99*	-2.80**	0.46	0.27
PBW343X K9351	-0.29	0.66	-2.05*	-3.86**	-0.21	0.93
PBW343X K8027	-1.46**	-0.38	3.13**	0.41	-0.02	4.46**
PBW343X K8962	-2.97**	-0.93	0.001	0.41	-2.18**	-1.82*
PBW343X Sonalika	-1.96*	-0.72	0.49	0.39	0.35	-1.16
HD2733 X K8020	-1.33*	0.45	-0.39	1.05	0.67	0.18
HD2733X K9423	-2.35**	-2.80	-2.52*	-1.62*	1.67**	0.81
HD2733X K9351	2.19**	0.86	1.59*	2.49*	1.01	1.81*
HD2733X K8027	2.79**	2.50	0.61	1.59*	-4.48**	-0.58
HD2733X K8962	-1.65**	-1.56	1.64*	-0.07	-0.96*	-2.28**
HD2733X Sonalika	0.89	2.25	1.35	0.03	-0.86*	-1.98
K8020 X K9423	-0.32	-0.06	-3.23**	-2.22*	0.07	2.05**
K8020 X K9351	-1.14*	-0.59	-7.29**	-7.12**	0.73	-0.23
K8020 X K8027	0.49	1.18	4.39**	3.49**	0.25	-0.01
K8020 X K8962	-4.19**	-3.06*	4.43**	3.99**	-1.24*	-0.70
K8020 X Sonalika	-3.35**	-0.60	3.89**	2.89*	0.39	-0.65
K9423 X K9351	0.47	0.30	4.75**	3.88**	0.40	0.02
K9423X K8027	2.28**	2.73	8.85**	8.33**	-0.08	-0.04
K9423X K8962	0.72	0.62	-2.36*	-2.51	-0.24	-0.40
K9423X Sonalika	0.89	0.96	-1.19	1.35	0.10	-0.45
K9351 X K8027	-0.78	-0.84	6.37**	5.09**	-0.08	0.63
K9351X K8962	-0.89	-1.03	6.41**	3.93**	-0.24	-0.07
K9351X Sonalika	0.90	1.00	2.29*	2..72*	0.32	-0.10
K8027X K8962	-5.54**	-5.50*	-0.74	2.53*	-0.72	-1.79*
K8027X Sonalika	-2.33**	-2.15	1.95*	2.12*	-0.86	-1.83*
K8962 X Sonalika	-1.63**	-1.17	2.12*	2.65**	-0.25	-0.95
SE(S ij) ±	0.52	1.86	0.88	0.79	0.57	0.58
SE (Sij – Sik)±	0.76	2.76	1.30	1.17	0.84	0.86

Continue....

Cross combination	Spike length		Days to maturity		Duration of reproductive phase	
	F_1	F_2	F_1	F_2	F_1	F_2
K9107 X GW373	0.46	0.24	-2.09**	-1.02	0.03	-0.19
K9107X PBW343	0.52	0.38	2.61**	3.88**	1.34*	-0.62
K9107X HD2733	0.03	-0.65	-2.94**	-3.21**	-3.07**	-1.48*
K9107X K8020	-0.35	-0.17	0.91	0.73	1.65*	-0.54
K9107X K9423	0.06	0.29	0.12	0.01	0.05	-0.29
K9107X K9351	-0.02	-0.17	-0.70	-0.69	1.76*	-0.42
K9107X K8027	-0.68*	-0.31	-1.79*	-2.33**	3.57**	2.04**
K9107X K8962	-0.05	-0.27	-3.15**	-5.08**	-1.04*	-2.68**
K9107X Sonalika	-0.12	-0.24	-2.85**	0.09**	0.83	-1.35
GW373 X PBW343	0.11	-0.04	7.67**	6.01**	0.34	-0.05
GW373X HD2733	0.44	-0.10	-2.21**	-2.75**	0.08	-0.70*
GW373X K8020	0.72*	0.66*	-0.70	1.19*	0.10	-1.21*
GW373X K9423	0.88*	0.96*	-0.48	0.46	1.16**	0.72**
GW373X K9351	-0.03	0.33	-0.64	-0.90	-0.96	-0.35
GW373X K8027	0.14	0.16	-2.06**	-2.87**	-2.16**	-0.60
GW373X K8962	-1.14**	-1.02**	-2.09**	-2.30	2.32**	0.16
GW373X Sonalika	0.14	-0.44	-2.10**	1.00	2.25**	0.17
PBW343 X HD2733	-0.41	-0.30	-4.18**	-5.84**	2.30**	0.04
PBW343X K8020	0.13	0.96*	-2.33**	-2.90**	-0.56	0.09
PBW343X K9423	0.04	0.17	0.88	0.40	1.01	0.32
PBW343X K9351	-0.45	-0.87*	1.06*	0.34	1.74*	2.10**
PBW343X K8027	0.22	-0.51	-4.03**	-4.30**	-0.16	-1.03*
PBW343X K8962	0.77*	0.27	-9.73**	-7.05**	-2.46**	-0.18
PBW343X Sonalika	0.78*	0.35	-8.60**	-5.35**	1.27	-0.39
HD2733 X K8020	-0.71**	-0.32	1.45**	2.34**	0.48	1.74**
HD2733X K9423	0.12	0.28	5.00**	4.28**	2.01**	0.71*
HD2733X K9351	-0.54	-0.26	4.85**	4.92**	0.87	-0.02
HD2733X K8027	0.21	0.35	0.76	0.95	-0.54	0.63
HD2733X K8962	0.01	-0.28	0.06	-0.15	-1.64*	-0.71*
HD2733X Sonalika	0.20	-0.29	0.39	-0.30	-0.85	0.89**
K8020 X K9423	1.74**	0.29	0.52	-0.12	1.05	3.41**
K8020X K9351	0.83	-0.34	-1.64**	-3.48**	1.50*	0.88*
K8020X K8027	0.01	-0.64*	-1.06*	-1.45*	0.93	0.02
K8020X K8962	-0.36	-0.44	1.76**	-2.21*	-1.67*	-0.27
K8020X Sonalika	-0.12	-0.514	0.86	-2.20*	0.87	0.21
K9423 X K9351	-0.34	-0.20	-0.42	0.13	-0.01	1.57*
K9423X K8027	-0.51	-0.01	-2.18**	-1.51*	-2.76**	-0.15
K9423X K8962	-0.96*	-0.97*	-6.88**	-8.27**	-1.96**	-3.38**
K9423X Sonalika	-0.86*	-0.87*	4.95**	-6.25**	-1.23	-2.25**
K9351 X K8027	0.75*	0.70*	-4.67**	-5.54**	-0.08	1.84**
K9351X K8962	0.30	0.65*	5.30**	5.04**	-1.02*	-1.86**
K9351X Sonalika	1.30**	0.89*	4.38**	4.92**	-1.00*	0.86**
K8027X K8962	0.64*	0.26	3.21**	4.07**	-2.02**	-1.18*
K8027X Sonalika	0.85	1.00*	3.38**	4.35**	-2.00**	-1.10*
K8962 X Sonalika	0.75*	0.71*	3.27**	1.20	1.25**	1.30*
SE(S ij) ±	0.47	0.29	0.55	0.65	0.55	0.42
SE (Sij – Sik)±	0.32	0.43	0.91	0.97	0.81	0.70

Continue....

Cross combination	Ear density		Number of grains / spike		Protein content	
	F_1	F_2	F_1	F_2	F_1	F_2
K9107 X GW373	-0.62	0.01	-0.16	-1.19	-0.23	-0.58*
K9107X PBW343	2.31	4.54*	2.11*	1.07	0.04	0.24
K9107X HD2733	-10.08**	-7.97**	4.90**	3.41	0.68*	0.69*
K9107X K8020	-0.59	-2.85	3.35**	1.83	-0.32	-0.41*
K9107X K9423	0.50	-6.77**	3.53**	3.66	0.02	-0.44*
K9107X K9351	4.47*	1.06	4.75**	4.84*	0.13	0.25
K9107X K8027	4.31*	10.98**	0.17	-0.37	0.64*	0.61*
K9107X K8962	-0.12	-5.46*	-6.86**	-6.07*	0.09	0.50*
K9107X Sonalika	-0.20	-3.83	-3.33*	3.79	0.52*	0.75*
GW373 X PBW343	6.00**	-2.68	-4.16**	-1.20	0.22	0.85*
GW373X HD2733	1.64	-5.20	-6.38**	-7.19*	0.26	0.13
GW373X K8020	-4.78*	-7.74**	-1.25*	3.89*	0.43*	0.40*
GW373X K9423	5.64**	6.67**	-0.07	1.28	0.46*	0.65*
GW373X K9351	-8.22**	-2.17	5.47**	5.90*	0.77*	-0.08
GW373X K8027	9.29**	2.25	9.90**	7.02*	-0.20	0.94*
GW373X K8962	7.35**	8.31**	5.53**	3.66	-0.80**	0.23
GW373X Sonalika	6.22**	6.25**	3.22**	2.35	0.79*	0.22
PBW343 X HD2733	1.65	5.51*	0.56	2.40	0.53*	0.42*
PBW343X K8020	-8.53**	-6.87**	-6.65**	-2.08*	0.44*	0.30*
PBW343X K9423	-1.60	-0.96	2.53**	2.65	0.18	-0.01
PBW343X K9351	3.70*	4.03*	1.75*	2.50	0.21	0.01
PBW343X K8027	2.44*	1.12	4.17**	4.62	0.17	-0.04
PBW343X K8962	11.06**	-10.74**	2.81**	2.59	0.55*	-0.24
PBW343X Sonalika	-10.60**	6.90**	3.12**	2.31	0.49*	-0.31*
HD2733 X K8020	5.75**	2.53	4.14**	3.83	0.27	0.32*
HD2733X K9423	4.17**	2.86	4.99**	4.66*	-0.19	-0.15
HD2733X K9351	0.98	4.02	-3.80**	-5.50*	0.06	0.13
HD2733X K8027	-8.01**	-5.89*	-6.71**	-7.04*	0.38*	-0.07
HD2733X K8962	-1.95	-9.50**	5.59**	2.60	0.63*	0.35*
HD2733X Sonalika	0.67	-6.25**	3.49**	-1.96	0.49*	0.32*
K8020 X K9423	7.33**	13.48**	9.11**	11.07**	0.39*	0.28
K8020X K9351	4.47**	2.14	3.99**	6.59*	-0.16	0.04
K8020X K8027	-0.19	-2.94	-1.92*	1.63	0.99**	0.51*
K8020X K8962	-1.62	-2.88	6.05**	7.34**	-0.14	-0.06
K8020X Sonalika	-1.22	2.30	5.85**	3.85*	0.10	-0.02
K9423 X K9351	6.23**	2.05	3.50**	2.41	-0.88**	-0.79*
K9423X K8027	2.24	-0.53	-3.41**	-3.80	0.33	0.12
K9423X K8962	-2.70*	-3.22	-4.77**	-5.16*	0.25	0.44*
K9423X Sonalika	-1.25	-1.97	-3.27**	-4.19*	0.22	0.12
K9351 X K8027	0.04	-4.90*	0.81	-1.95	-0.31	-0.30*
K9351X K8962	1.94	5.03*	1.44**	0.69	0.71*	0.82*
K9351X Sonalika	-0.12	3.25	1.00	0.39	0.65*	0.78*
K8027X K8962	-0.22	-6.88**	7.87**	8.81**	0.78*	0.88*
K8027X Sonalika	-0.33	-4.35	6.77**	6.35**	0.70*	0.75*
K8962 X Sonalika	-0.65	-3.32	7.12**	4.82*	0.55*	0.90*
SE(S ij) ±	1.43	1.94	0.66	2.36	0.23	0.18
SE (Sij – Sik)±	2.11	2.86	0.97	3.48	0.34	0.26

Continue....

Cross combination	Tryptophan content		Phenol colour reaction		Gluten content	
	F_1	F_2	F_1	F_2	F_1	F_2
K9107 X GW373	-0.24**	-0.20*	0.91	-0.29	-0.14**	-0.11*
K9107X PBW343	0.22**	0.21*	0.03	0.01	0.20**	0.13*
K9107X HD2733	-0.11*	-0.18*	0.03	-0.02	-0.04	-0.03
K9107X K8020	0.05	0.01	0.55	0.34	0.19**	0.07
K9107X K9423	-0.25**	-0.10*	-0.09	-0.54	0.36**	0.30**
K9107X K9351	-0.18*	-0.16*	-0.21	-0.17	0.06	0.08
K9107X K8027	0.19*	0.05	1.25*	1.04*	0.21**	0.15*
K9107X K8962	0.21**	0.43**	0.12	1.01	-0.42**	-0.60**
K9107X Sonalika	0.27**	0.33**	1.63**	0.22	0.01	-0.72**
GW373 X PBW343	0.08	0.06	0.52	-1.26	-0.13**	-0.07
GW373X HD2733	-0.14*	0.00	-1.48*	-1.29	0.01	-0.14*
GW373X K8020	-0.17*	0.27**	0.03	1.07*	-0.16**	0.04
GW373X K9423	0.43**	0.30**	0.40	0.52	0.07	0.01
GW373X K9351	0.10	0.30**	0.94	0.89	0.04	0.07
GW373X K8027	0.15*	0.41**	0.73	1.10*	0.30**	0.17*
GW373X K8962	0.29**	0.06	0.61	-0.26	0.09*	0.08
GW373X Sonalika	0.41**	0.31**	0.79	-0.22	0.15**	0.92**
PBW343 X HD2733	0.12*	0.20*	-0.21	0.01	0.01	0.01
PBW343X K8020	0.11*	0.18*	-1.03	0.04	-0.14**	-0.47**
PBW343X K9423	-0.04	-0.10*	0.34	0.49	0.01	0.01
PBW343X K9351	0.25**	0.13*	0.55	0.19	0.07*	0.13*
PBW343X K8027	0.01	0.01	-1.00	-0.93	0.10**	0.12*
PBW343X K8962	0.19*	-0.13*	-0.12	0.04	-0.03	0.01
PBW343X Sonalika	0.11	0.16*	-0.19	0.35	0.20**	0.31*
HD2733 X K8020	026*	0.31**	0.97	1.01*	0.11**	0.14*
HD2733X K9423	024*	0.10*	-0.66	-0.54	0.05	0.05
HD2733X K9351	0.26*	0.20*	-0.78	-1.17*	-0.06	-0.17*
HD2733X K8027	0.24*	0.15*	0.67	0.71	-0.14**	-0.15*
HD2733X K8962	0.30*	0.09	0.55	0.01	0.05	0.07
HD2733X Sonalika	0.35**	0.10*	0.65	0.02	0.10*	0.12*
K8020 X K9423	0.11**	0.15*	-1.15**	-1.17*	0.35**	0.36**
K8020X K9351	0.42**	0.05	1.73**	0.86	0.09*	0.16*
K8020X K8027	0.19*	0.20*	2.18**	1.40*	-0.04	-0.06
K8020X K8962	-0.17*	0.01	-0.94	-0.96	0.03	0.06
K8020X Sonalika	-0.19*	0.25*	-0.79	-0.81	0.10*	0.15
K9423 X K9351	-0.21*	-0.20*	-1.91*	-1.69*	0.13**	0.12
K9423X K8027	0.06	-0.04	0.55	-0.14	-0.04	0.001
K9423X K8962	-0.06	0.02	0.76	1.16*	-0.11*	-0.16*
K9423X Sonalika	-0.02	0.12*	0.81	1.19*	0.22*	-0.11*
K9351 X K8027	-0.37	-0.15*	-0.57	-0.11	0.01	-0.11*
K9351X K8962	0.29**	0.29**	0.31	0.52	0.04	0.02
K9351X Sonalika	1.00**	0.18*	0.65	0.65	0.12	0.15**
K8027X K8962	0.11*	0.10*	1.43**	1.07*	0.01	0.05
K8027X Sonalika	0.19**	0.35**	1.42**	0.65	0.11	0.18*
K8962 X Sonalika	1.10**	0.55**	1.39*	0.85	0.30**	0.10
SE(S ij) ±	0.08	0.06	0.59	0.59	0.04	0.06
SE (Sij – Sik)±	0.12	0.09	0.87	0.86	0.05	0.09

Continue....

Cross combination	**Seed hardness**		**Grain yield / plant**	
	F_1	**F_2**	**F_1**	**F_2**
K9107 X GW373	-0.26	-0.36	-0.31	-0.13
K9107X PBW343	-0.93*	-0.76*	1.99**	1.49
K9107X HD2733	-0.19	-0.17	-7.09**	4.73**
K9107X K8020	-0.45	-0.62*	1.11	-1.78*
K9107X K9423	-0.20	-0.18	0.24	-3.28*
K9107X K9351	1.80**	0.95*	3.61**	0.13
K9107X K8027	0.16	-0.09	5.34**	6.88**
K9107X K8962	1.15**	1.18**	-1.80*	-4.79**
K9107X Sonalika	1.10**	1.01*	0.35	-2.86*
GW373 X PBW343	0.15	-0.27	3.00**	-1.16
GW373 X HD2733	0.03	-0.06	0.77	-2.91*
GW373 X K8020	-0.47	1.89**	-2.12**	-4.38**
GW373 X K9423	0.93*	-0.39	3.49**	3.51**
GW373 X K9351	-0.40	-0.08	-4.42**	-1.25
GW373 X K8027	0.03	-0.25	2.29**	0.50
GW373 X K8962	-0.35	-0.45	5.39**	6.03**
GW373 X Sonalika	-0.42	0.65	5.15**	6.15**
PBW343 X HD2733	-0.61	-0.94*	2.68**	2.51*
PBW343X K8020	0.16	-0.05	-4.22**	-3.05*
PBW343X K9423	0.03	-0.36	0.14	-0.19
PBW343X K9351	-1.56**	-1.22**	0.18	3.68**
PBW343X K8027	-0.28	-5.24**	1.01	-0.28
PBW343X K8962	0.80*	0.60*	-7.12**	-5.27**
PBW343X Sonalika	0.75	0.71*	1.10	3.89**
HD2733 X K8020	-0.63	0.99*	3.07**	2.92*
HD2733X K9423	-1.07*	-0.92*	3.68**	1.81*
HD2733X K9351	0.09	0.11	1.17	1.81*
HD2733X K8027	-0.70*	-0.10	-4.11**	-3.27*
HD2733X K8962	-1.22*	-0.91*	-2.45*	-5.14**
HD2733X Sonalika	1.00*	-0.71*	1.16	-2.39
K8020 X K9423	0.48	0.07	4.22**	9.24**
K8020X K9351	0.97*	0.47	3.30**	1.69*
K8020X K8027	-0.48	-0.09	0.19	-1.42
K8020X K8962	0.07	-0.39	-2.35*	-1.79*
K8020X Sonalika	0.01	0.40	0.78	-1.35
K9423 X K9351	0.03	0.10	2.69*	2.19*
K9423X K8027	-0.21	-0.25	-1.47*	-0.41
K9423X K8962	-1.03*	-0.92*	-3.40**	-4.29**
K9423X Sonalika	1.00*	-0.75*	-3.40**	-1.87
K9351 X K8027	-0.32	-0.49	-0.04	-0.70
K9351X K8962	-0.45	-0.56*	-0.19	0.57
K9351X Sonalika	-0.42	-0.49	-0.35	0.81
K8027X K8962	-0.79*	-0.88*	-2.00*	-4.33**
K8027X Sonalika	-0.33	-0.12	-0.39	-2.83
K8962 X Sonalika	-0.49	-0.31	-1.12*	0.79
SE(S ij) ±	0.40	0.34	0.98	1.00
SE (Sij – Sik)±	0.59	0.50	1.31	1.41

Note: * Significant at 5% level; ** significant at 1% level

Days to 75% flowering (DOF 75%), Plant height (PH), Number of ear bearing tillers/plant (NOEBT), Spike length (SL), Days to maturity (DM), Days to maturity (DOM), Ear density (ED), Number of grains / spike (NOGS), Protein content (PC), Tryptophan content (TC), Phenol colour reaction (PCR), Gluten content (GC).