Combining ability and gene interaction study for yield, its attributing traits and quality in common wheat

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Abstract: Combining ability and nature of gene interactions that contribute to yield and its attributing traits were investigated using 21 wheat hybrids developed by crossing 7 varieties in a half diallel mating design. Estimate of GCA effects exhibited that the parents UP2672, UP2526 and WH542 were identified as good general combiners revealing their ability in transmitting additive genes in desirable direction to their progenies. Hybrid *viz.,* PBW 621 × UP 2425 (15.125) found to be the best specific crosses for grain yield plant[-1], whether, WH 542 × HD 2967 (22.587) and UP 2526 × UP 2425 (14.490) had the highest SCA for biological yield plant[-1] and harvest index, respectively. However, the best specific cross combinations for other characters were found for WH 542 × QLD 40 (-3.694) for days to maturity, PBW 621 × UP 2526 (-3.819) for plant height, HD 2967 × UP 2526 (7.527) for 1000 grain weight and WH 542 × UP 2672 (2.077) for sedimentation value. While crosses PBW 621 × UP 2425, UP 2526 × UP 2425 and QLD 40 × UP 2425 were found to be the best specific combiner for the characters number of productive tillers plant[-1], grain yield plant[-1], spike length, grain weight spike[-1], harvest index, days to 75 % heading and protein content.

Keywords: Combining ability, Common wheat, Diallel cross, Gene interaction, Quality, Yield

INTRODUCTION

India is one of the wheat producing countries of the world. It produced 94.88 million tonnes wheat on an area of 29.90 million hectare (3173.24 kg/ha) (Anonymous, 2013) but geometrical increase in India's population has been a challenge for agricultural scientists. Global demand for wheat is growing at approximately 2% per year, twice the current rate of gain in genetic yield potential (Skovmand and Reynolds, 2000). Advancement in the yield of wheat requires certain information regarding the nature of combining ability of parents available for use in the hybridization program, and also the nature of gene action involved in expression of quantitative and qualitative traits of economic importance (Hassan *et al*., 2007). For the development of genetically superior high yielding varieties, identification of superior parents is an important prerequisite (Prasad, 2014).

The combining ability analysis provides useful information regarding the selection of better parents for hybridization programme. A speedy improvement can be brought about by assembling the desirable genes, locating the best combiners and exploiting the heterosis (Prasad *et al.,* 2005). Combining ability analysis (Sprague and Tatum, 1942) is one of the powerful tools available which gives the estimates of combining ability effects and aids in selecting desirable parents and crosses for further exploitation. The combining ability analysis developed by Griffing (1956) provides useful information regarding the selection of parents in terms of the performance of their hybrids. This analysis further elucidates the nature and magnitude of various types of gene actions involved in the expression of quantitative characters which help in choosing the parents for hybridization programme (Prasad *et al.,* 2012). Since the development of new cultivars through hybridization is a continuous process, information on combining ability of new cultivars remains important. The choice of parents is a very important task in a breeding program.

Combining ability studies are used by plant breeders to select parents with maximum potential of transmitting desirable genes to the progenies. The estimates of general combining ability (GCA) are very useful because the variance due to general combining ability is attributable to additive gene action and A x A interaction which can be fixed in further generations, while the variance due to specific combining ability is attributable to non-additive gene action. Breeders should concentrate on development of productive wheat varieties by crossing good general combining lines for grain yield and selecting transgressive segregants from the resulting hybrids. Diallel mating design has been extensively used to analyze the combining ability effects of wheat genotypes and also to provide information regarding genetic mechanisms controlling grain yield and other traits (Rajesh *et al.,* 2012). Among the qual-

ity parameter in wheat, protein content and sedimentation values are most important desirable characters preferred for nutrition and chapatti quality (Kumar *et al.*, 2015a).The significance of present study was designed to find out the good general combining genotypes for sound breeding program and to select high yielding combiners for the development of productive wheat varieties and good specific combiners for selection of transgressive segregants.

MATERIALS AND METHODS

The present investigation was carried out at Norman. Ernest. Borlaug. Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India. The material for the present study was developed during *Rabi* 2012-13 and the progenies were evaluated in the next *Rabi* season of 2013-14.Seven genetical diverse wheat varieties i.e. WH 542, HD 2967, PBW 621, UP 2526, QLD 40, UP 2672 and UP 2425 was crossed in diallel mating design excluding reciprocals. The parents and F1 seeds of 21 crosses along with 2 checks i.e. DPW 621-50, UP 2526 were planted in a randomized complete block design with 3 replications. Parents and F1 were grown in two rows plot of 1 metre length in each replication during *Rabi* 2013-14. The plant to plant distance was maintained at 10 cm and row to row as 20 cm. The material was planted in mid-November, 2013-14 under high fertility timely sown conditions. Wheat varieties were crossed with each other in a half-diallel mating design, resulting in 21 hybrid combinations, equal to p (p - 1)/2, where p is the number of parents used. The parents, F1 hybrids and checks were grown in a randomized block design in three replications. Each plot in a replication comprised of parents and F1's having double row of 1m length. The rows were spaced in 20 cm apart and plant-to-plant distance was maintained at 10 cm by dibbling. Observations were recorded on the whole plot basis for days to 75% heading and days to maturity, whereas the character like plant height, number of effective tillers per plant, spike length, number of spikelet per spike, number of grains per spike, grain weight per spike, 1000 grain weight, grain yield per plant, biological yield and harvest index were taken over five randomly selected competitive plants from each plot. Harvest index was calculated in percentage by the proportion of total grain yield in comparison to biological yield. For estimation of quality parameter in terms of protein content and sedimentation value samples were analyzed with the help of Near Infrared Transmission based Whole Grain Analyzer (Infratech 1241 Grain Analyzer). Combining ability analysis was carried out according to Griffing's (1956) method 2 of model 1.

RESULTS AND DISCUSSION

Analysis of variance revealed highly significant differences among the parents and their F1 hybrids for all the characters days to 75% heading, days to maturity, plant height, number of effective tillers per plant, spike length, number of spikelet per spike, number of grains per spike, grain weight per spike, 1000 grain weight, grain yield per plant, biological yield and harvest index (Table 1). Significant genotypic variation for all the characters was further partitioned into variation due to general combining ability (GCA) and specific combining ability (SCA) The analysis of variance for combining ability was performed for yield, its contributing traits and quality traits. Mean squares due to general combining ability (GCA) and specific combining ability (SCA) were significant for all characters except for number of grains per spike and number of spikelets per spike. It showed that both additive as well as non-additive genetic variances were important for the expression of the characters studied. The estimates of general combining ability (GCA) and specific combining ability (SCA) effects for different characters are described character wise here under

Days to 75% heading: Among the parental lines WH 542 (-1.222), UP 2526 (-1.333) and UP 2672 (-0.481) were having significant negative GCA effects while HD 2967 (2.370) and PBW 621 (0.852) had significant positive GCA effects. Parent UP 2526 and HD 2967 were found as the best and poorest general combiners, respectively. Fifteen crosses showed significant SCA effects out of which seven exhibited effects in negative direction while eight in positive direction. The crosses viz. WH 542 × UP 2672 (-1.546), WH 542 × UP 2425 (-1.509), PBW 621 × QLD 40 (-1.435), PBW 621 × UP 2425 (-3.583), UP 2526 × UP 2672 (-2.102), QLD 40 × UP 2672 (-1.769) and QLD 40 × UP2425 (-2.398) exhibited significant values of SCA effects in negative direction. PBW 621 × UP 2425 found as the best cross combination for earliness. Earliness is a desirable feature for any variety so, negative GCA effects regarding this trait are desirable. Parent UP 2526 was identified as superior general combiner for early heading. While cross PBW 621 × UP 2425 has identified as best cross combination for this trait. Potentiality in general combining ability and specific combining ability had been reflected from low to high magnitude for various parents to days to 75% heading. Similar significant results for GCA and SCA effects have been reported by Hasan *et al.* (2010) exhibited combining ability in the F_1 generations of diallel cross for yield and yield components in Wheat and Inamullah *et al.* (2010) also reported combining ability analysis for important traits in bread wheat.

Days to maturity: For days to maturity five parents namely, WH 542 (-0.725), UP 2526 (-0.540), QLD 40 (-1.021), UP 2672 (-1.021) and UP 2425 (-0.688) showed negative GCA effects while HD 2967 (1.534) and PBW 621 (2.460) showed positive GCA effects. Parent QLD 40 and UP 2672 were found as the best and PBW 621as poorest general combiner for earliness. Differential in general combining ability had

Table 1. Analysis of variance for general combining ability and specific combining ability for different characters in wheat.

S. N.	Source of varia- tion	d.f.	Days to 75% heading	Days to maturity	Plant height	Productive tillers/ plant	Spike length	Number of spikelets/ spike	No.of grains/ spike
			Mean sum of squares of different characters						
1.	GCA	6	44.469**	53.023**	371.158**	59.784**	3.499**	1.929	16.652
2.	SCA	21	14.299**	28.598**	71.030**	33.996**	1.048*	1.783	15.545
3.	Error	40	0.675	1.814	6.402	5.285	0.485	1.053	9.589

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S. N.	Source of variation	d.f.	Grain weight / spike	1000- grain weight	Biological yield/ plant	Grain yield/ plant	Harvest Index	Protein content	Sedimenta- tion value
1.	GCA	6	0.719**	232.96**	2,781.363**	963.396**	481.707**	0.700*	8.508**
2.	SCA	21	0.367**	80.471**	1,451.021**	324.066**	230.693**	0.616**	5.057**
3.	Error	40	0.071	6.497	24.489	62.410	32.520	0.232	1.732

*, ** = Significant at 5% and 1% probability level, respectively,; GCA- General combining ability, SCA- Specific combining ability

Table 2. Estimates of general combining ability effects of parents for various characters in wheat.

S. N.	Parents	Days to 75% Head- ing	Days to maturity	Plant height	Productiv e tillers/ plant	Spike length	Number of spikelets/ spike	No. of grains/ spike	Grain weight / spike
1.	WH 542	-1.222**	-0.725**	-5.664**	-1.336*	-0.375**	0.080	-0.074	-0.248**
2.	HD 2967	2.370**	1.534**	-3.079**	-0.835	-0.343**	-0.149	0.141	-0.170**
3.	PBW 621	0.852**	2.460**	0.343	0.294	0.197	-0.310	-1.374*	-0.067
4.	UP 2526	-1.333**	-0.540*	4.958**	0.549	0.334*	-0.088	0.089	0.065
5.	QLD 40	0.000	-1.021**	-0.320	-1.340**	-0.286*	-0.158	-0.458	0.125*
6.	UP 2672	-0.481**	-1.021**	4.006**	2.924**	0.532**	0.506**	1.124*	0.118*
7.	UP 2425	-0.185	-0.688**	-0.245	-0.257	-0.060	0.119	0.552	0.177**
	SE (gi)	0.146	0.240	0.451	0.410	0.124	0.183	0.552	0.047
	SE(gi-gj)	0.224	0.367	0.689	0.626	0.190	0.279	0.843	0.072

*, ** = Significant at 5% and 1% probability level, respectively.

Contd….

S. N.	Parents	1000-grain weight	Biological yield/ plant	Grain yield/ plant	Harvest index	Protein Content	Sedimentation value
1.	WH 542	-3.935**	-6.197**	-8.349**	-5.092**	-0.074	-0.708**
2.	HD 2967	-3.964**	1.755	-4.954**	-5.387**	-0.080	0.155
3.	PBW 621	-0.088	-0.30	-0.574	-0.649	0.002	-0.324
4.	UP 2526	1.500**	7.368**	2.888	-0.755	0.197*	-0.435
5.	QLD 40	2.010**	-14.701**	-1.292*	5.165**	-0.186*	-0.135
6.	UP 2672	0.780	16.836**	10.269**	2.395*	0.244**	0.662*
7.	UP 2425	3.697**	-4.758**	2.013	4.323**	-0.103	0.785**
	SE (gi)	0.454	0.882	1.408	1.016	0.086	0.234
	SE(gi-gj)	0.694	1.347	2.150	1.552	0.131	0.358

*, ** = Significant at 5% and 1% probability level, respectively.

been depicted by different parents for days to maturity. Significant differences due to GCA for days to matur- ity have also been reported by Mavi *et al.* (2007) for yield and its components in bread wheat (*Triticum aestivum* L.) in two nitrogen regimes and Siddique *et al.* (2011) noticed combining ability estimates for yield and yield components in spring wheat. Out of twenty one crosses, thirteen crosses exhibited significant SCA effects for days to maturity. Crosses WH 542 × PBW 621 (-2.509), WH 542 × UP 2425 (-2.176), WH 542 × QLD 40 (-3.694), HD 2967 × PBW 621 (-2.102), UP 2526 × QLD 40 (- 2.213), UP 2526 × UP 2672 (- 1.546), QLD 40 × UP2672 (-3.398), QLD 40 × UP2425(-0.731), UP 2672 × UP 2425 (-1.731)

Table 3. Estimates of specific combining ability effects of crosses for different characters in wheat.

Crosses	Days to 75% heading	Days to maturity	Plant height	Productive tillers/plant	Spike length	Number of spikelets/spike	No. of Grains/spike	Grain weight/spike
WH 542 × HD 2967	1.602**	0.083	0.225	2.790*	0.363	0.584	0.521	0.037
WH 542 × PBW 621	0.454	-2.509**	-0.997	-4.889**	-0.278	0.145	-0.498	0.020
WH 542 × UP 2526	-0.361	-2.176**	0.955	-4.994**	0.366	0.523	1.206	0.119
WH 542 × QLD 40	0.306	-3.694***	1.932	-1.305**	-0.374	-1.407*	-4.614**	-0.184
WH 542 × UP 2672	-1.546**	0.639	-0.527	-1.879*	-0.432	-1.138*	-3.595*	-0.141
WH 542 × UP 2425	-1.509**	1.639*	4.058**	-0.438	0.406	-0.884	-2.757	0.060
HD 2967 × PBW 621	1.861**	-2.102**	6.551**	-1.207	-0.047	0.308	1.754	0.409**
HD 2967 × UP 2526	0.046	0.565	-0.097	2.271	-0.183	-0.181	-0.209	0.404**
HD 2967 × QLD 40	2.380**	0.713	8.447**	-1.872	0.420	0.690	1.571	-0.356*
HD 2967 × UP 2672	1.528**	1.046	0.755	1.063	0.015	-0.775	-1.743	0.141
HD 2967 × UP 2425	3.231**	3.380***	0.973	3.911**	0.211	-1.055	-2.472	-0.359*
PBW 621 × UP 2526	0.898*	1.306	-3.819**	-3.358**	-1.074**	0.533	2.103	-0.149
PBW 621 × QLD 40	-1.435**	4.787**	1.258	-0.268	0.340	-0.483	-0.280	0.171
PBW 621 × UP 2672	1.046*	6.454**	1.266	0.617	-0.072	0.319	1.338	0.135
PBW 621 × UP 2425	-3.583**	2.787**	1.684	5.365**	0.337	-0.294	-0.157	0.015
UP 2526 × QLD 40	-0.583	-2.213**	5.177**	3.944**	0.710	-0.572	-1.077	0.153
UP 2526 × UP 2672	-2.102**	-1.546*	1.951	-1.455	-0.175	-0.836	-1.025	-0.670**
UP 2526 × UP 2425	-0.731	0.120	2.769**	-1.083	1.044**	0.217	1.513	0.690**
QLD 40 × UP 2672	-1.769**	-3.398**	-2.271	-1.615	-0.258	0.467	1.798	0.423**
QLD 40 × UP 2425	-2.398**	-0.731	4.481**	-3.883**	-1.396**	0.574	0.863	0.147
UP 2672 × UP 2425	1.417**	-1.731*	2.955*	-2.672*	0.576	-0.110	0.012	0.431**
SE(ij)	0.426	0.698	1.311	1.191	0.361	0.532	1.605	0.138

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Crosses	1000-grain weight	Biological yield/plant	Grain yield/plant	Harvest Index	Protein content	Sedimentation value
WH 542 × HD 2967	1.579	22.587**	7.377	-1.113	-0.279	-0.639
WH 542 × PBW 621	0.435	-30.690**	-11.316**	1.002	-0.851**	-2.853**
WH 542 × UP 2526	0.414	-32.592**	-10.988*	2.528	0.197	-0.563
WH 542 × QLD 40	0.638	-6.457*	-5.861	-4.175	-0.333	0.031
WH542 × UP 2672	0.684	-10.361**	-7.612	-3.235	0.414	2.077**
WH542 × UP 2425	2.118	-10.966**	0.441	4.757	0.554*	0.674
HD 2967 × PBW 621	6.365**	-22.476**	3.882	13.907**	0.332	1.301*
HD 2967 × UP 2526	7.527**	3.723	13.450**	9.930**	0.397	0.995
HD 2967 × QLD 40	-5.332**	-15.242**	-11.200**	-5.830	-0.290	1.098
HD 2967 × UP 2672	4.731**	-7.446**	4.439	6.183*	-0.280	-0.559
HD 2967 × UP 2425	-1.619	20.249**	2.775	-5.875	-0.130	0.848
PBW 621 × UP 2526	0.800	-1.622	-11.149*	-8.948**	0.294	1.931**
PBW 621 × QLD 40	3.191*	-6.887*	1.667	5.792	0.438	0.171
PBW 621 × UP 2672	-1.613	7.843**	4.839	0.002	0.558*	-1.206
PBW 621 × UP 2425	-1.963	31.871**	15.125**	-0.986	-0.322	0.998
UP 2526 × QLD 40	3.386*	28.845**	14.692**	-0.212	-0.387	-1.589
UP 2526 × UP 2672	-8.434**	-3.659	-17.166**	-12.782**	-0.064	-0.762**
UP 2526 × UP 2425	6.749**	-13.181**	9.384*	14.490**	0.446	-0.308
QLD 40 × UP 2672	5.707**	-17.657**	3.467	11.838**	-0.114	-1.355
QLD 40 × UP 2425	2.690*	-22.363**	-9.760*	4.380	0.800**	0.182*
UP 2672 × UP 2425	6.120**	-24.000**	0.886	11.226**	-0.080	-0.238
SE(ij)	1.321	2.564	4.094	2.955	0.249	0.580

*, ** = Significant at 5% and 1% probability level, respectively.

showed significant SCA effects in negative direction while WH 542 × UP 2425 (1.639), HD 2967 × UP 2425 (3.380), PBW 621 × QLD 40 (4.787), PBW 621 × UP 2672 (6.454), PBW 621 × UP 2425 (2.787) appeared with significant SCA effects in positive direction. WH 542 × QLD 40 (-3.694) identified as best specific combination for earliness. Earliness in view of maturity is essentially a mandate in breeding programme of wheat crop. QLD 40 and UP 2672 emerged as good general combiners for earliness with significant negative GCA effects.

Plant height: Among the parental lines UP 2526 (4.958) and UP 2672 (4.006) showed significant positive GCA effects while HD 2967 (-3.079) and WH 542 (-5.664) showed significant negative GCA effects. WH 542 and UP 2526 were found as best and poor general combiners respectively. Potentiality in general combining ability had been depicted low to high by different parents for plant height.Such type of similar findings of combining ability for grain yield and its components in wheat has been suggested by Rajesh *et al.* (2002) and Dugustu (2008) also reported combining ability analysis in relation to heterosis for grain yield per spike and agronomic traits in bread wheat *(Triticum aestivum* L.*)*. Eight crosses were found with significant SCA effects, one of them namely, PBW 621 × UP 2526 (-3.819) showed significant negative SCA effects. PBW 621 × UP 2526 was found as best specific cross combination. Differential in specific combining ability had been exhibited by different parents for plant height. Results were also close confirmation with the findings of Shoran *et al.* (2003) for winter and spring wheat noticed combining ability. Tall plants are preferred for straw purpose, whereas, dwarfs are more lodging resistant thus depending upon the objective, preference should be given. HD 2967 showed highest significant negative effects and thus can be considered as good general combiner for dwarfness while UP 2526 emerged as good general combiner for tallness with significant positive GCA effects. HD 2967 × QLD 40 (8.447) was identified as the best cross for plant height on the basis of highest significant SCA in positive direction while PBW 621 × UP 2526 (-3.819) was the best cross combination for reduced plant height with highest SCA value in negative direction.

Productive tillers per plant: Among the parental lines WH 542 (-1.336)) and QLD 40 (-1.340) showed negative significant GCA effects while UP 2672 (2.924) showed positive significant GCA effects. UP 2672 and QLD 40 (-1.340) were found as best and poor general combiners, respectively. Potentiality in general combining ability had been shown to different level of magnitude by different parents for productive tillers per plant. Results were close confined with the earlier findings of Siddique *et al.* (2004) who reported combining ability for harvest index and its components in bread wheat. Inamullah *et al.* (2010**)** also depicted combining ability analysis for important traits in bread

wheat for GCA**,** however**,** eleven crosses were found significant for productive tillers per plant. With respect to SCA, four crosses i.e. WH 542 × HD 2967 (2.790), HD 2967 × UP 2425 (3.911), PBW 621× UP 2425 (5.365) and UP 2526 × QLD 40 (3.944) showed positive significant SCA effects while seven crosses WH 542 × PBW 621(-4.889), WH 542 × UP 2526 (-4.994), WH 542 ×QLD 40 (-1.305), WH 542 × UP 2672 (-1.879), PBW 621× UP 2526 (-3.358), and UP 2672 × UP 2425 (-2.672) showed negative significant SCA effects. PBW 621 × UP 2425 (5.365) was found to be the best specific combiner for productive tillers per plant. Difference in specific combining ability had been found for different parents with respect to productive tillers per plant. Similar significant results for SCA have been reported by Asif *et al.* (2001) for combining ability analysis in intraspecific crosses of spring wheat and Hasan *et al.* (2012) also found the close findings for combining ability in bread wheat *(Triticum aestivum* L.) under salinity and normal conditions . UP 2672 showed highest significant positive GCA effects and thus can be considered as good general combiner for increasing number of productive tillers per plant. PBW 621 × UP 2425 was identified as the best specific cross combination with highest positive SCA value.

Spike length: For spike length, WH 542 (-0.375), HD 2967 (-0.343) and QLD 40 (-0.286) showed negatively significant GCA effects while UP 2526 (0.334) and UP 2672 (0.532) showed positively significant GCA effects. UP 2672 and WH 542 were found to be the best and poor general combiners, respectively. Two crosses PBW 621× UP 2526 (-1.074) and QLD 40 × UP 2425 (-1.396) showed negative and significant SCA effects. UP 2526 × UP 2425 (1.044) was found to be the best specific cross for spike length. Potentiality in general combining ability and specific combining ability had been reflected from low to high magnitude for various parents to spike length. Observations were confined with the results of the same character for GCA and SCA have also been reported by Dugustu (2008) also reported combining ability analysis in relation to heterosis for grain yield per spike and other agronomic traits in bread wheat *(Triticum aestivum* L.)

Number of spikelets per spike: With regard to number of spikelets per spike only one parent UP 2672 (0.506) was found with positive and rest of the parents showed negative GCA effects. UP 2672 and PBW 621 found to be the best and poor general combiners, respectively. However, two crosses WH 542 × QLD 40 (-1.407) and WH 542 ×UP 2672 (-1.138) exhibited negative significant SCA values and rest crosses were found to be non- significant. Difference in general combining ability and specific combining ability had been reflected from low to high magnitude for various parents to number of spikelets per spike. Significantly negative and positive results for number of spikelets per spike for GCA and SCA were also reported by

Rajesh *et al.* (2012) exhibited combining ability for grain yield and its components in wheat. Spikelets per spike are a yield contributing trait. Selection for good general combiners for spikelets per spike will include parents with high positive GCA effects. Thus no parent was identified as good general combiners for the trait. And no cross appeared as the best specific cross for spikelets/spike on the basis of SCA effects.

Number of grains per spike: Among the parental lines UP 2672 (1.124) showed positively significant GCA effects while parent WH 542 (-1.374) showed highest negatively significant GCA effects. Out of 21, two crosses namely WH 542 × QLD 40 (-4.614) and WH 542 × UP 2672 (-3.595) were found to have significant negative SCA effects. No cross was having significant positive SCA effects for this trait. Positive SCA effects are desirable for the above trait. No parental line was identified as good general combiners for increasing number of grains per spike. Variation in general combining ability and specific combining ability had been shown from low to high magnitude for various parents to number of number of grains per spike. Such type of significant results for SCA and GCA has been also reported by Rajesh *et al.* (2008) for combining ability and gene action in inter varietal crosses in bread wheat.

Grain weight per spike: For grain weight per spike, two parents WH 542 (-0.248) and HD 2967 (-0.170) showed negatively significant GCA effects while QLD 40 (0.125), UP 2672 (0.118) and UP 2425 (0.177) showed positively significant GCA effects. UP 2425 and WH 542 were found to be the best and poor general combiners respectively. Among 21, five crosses namely HD 2967 × PBW 621 (0.409), HD 2967 × UP 2526 (0.404), UP 2526× UP 2425 (0.690), QLD 40 × UP 2672 (0.423) and UP 2672 × UP 2425 (0.431) were having positively significant SCA effects while three crosses HD 2967 × QLD 40 (-0.356), HD 2967 × UP 2425 (-0.359) and UP 2526× UP 2672 (-0.670) showed negatively significant SCA effects. UP 2526 × UP 2425 (0.690) cross was found to be the best specific cross for this trait. Differential in general combining ability and specific combining ability had been shown from low to high magnitude for various parents to number of grain weight per spike. Similar significant results for GCA and SCA have also been depicted by Tahmasebi *et al.* (2011) by estimating of genetic parameters for grain yield and related traits in wheat using diallel analysis under optimum and moisture stress conditions

1000-grain weight: Among the parents WH 542 (-3.935) and HD 2967 (-3.964) showed negatively significant GCA effects while UP 2526 (1.500), QLD 40 (2.010) and UP 2425 (3.697) showed positively significant GCA effects for 1000-grain weight. Parents UP 2425 (3.697) and HD 2967 (-3.964) were identified as best and poor general combiners, respectively. Potentiality in general combining ability had been shown

to different level of magnitude by different parents for1000-grain weight. Rajesh *et al.* (2012) depicted combining ability for grain yield and its components in wheat and Inamullah *et al.* (2010) also reported combining ability analysis for important traits in bread wheat for GCA in this character. Eleven crosses showed significant SCA effects out of which HD 2967 × QLD 40 (-5.332) and UP 2526 × UP 2672 (-8.434) exhibited negatively significant SCA effects while nine crosses exhibited positively significant SCA effects. HD 2967 × UP 2526 (7.527) was found to be the best specific cross for this trait. Difference in specific combining ability had been found for different parents with respect to productive tillers per plant. Similar significant results for SCA have been reported by Hasan *et al.* (2007) noticed combining ability for spike characteristics in wheat (*Triticum aestivum* L.) and Shoran *et al.* (2003) also exhibited in winter and spring wheat for combining ability.

Biological yield per plant: Result revealed that parents UP 2526 (7.368) and UP 2672 (16.836) exhibited significant positively GCA effects while WH 542 (-6.197), UP 2425 (-4.758) and QLD 40 (-14.701) showed negatively significant GCA effects. UP 2672 and QLD 40 were found to be the best and worst general combiner respectively. Out of 21 crosses 18 were found to have significant SCA effect. Five crosses namely, WH 542 × HD 2967 (22.587), HD 2967 × UP 2425 (20.249), PBW 621× UP 2672 (7.843), PBW 621 × UP 2425 (31.87) and UP 2526 × QLD 40 (28.845) showed positively significant SCA effects while fifteen crosses showed significant negative SCA effects. PBW 621 × UP 2425 was found to be the best specific cross. Variation in specific combining ability had been found for different parents with respect to biological yield per plant. Similar significant results for SCA have been reported by Shoran *et al.* (2003) exhibited in winter and spring wheat for combining ability**.** Positive SCA effects are desirable for biological yield, UP 2672 and UP 2526 emerged as good general combiners in the present investigation while**,** PBW 621× UP 2425 acted as super cross combination for this trait.

Grain yield per plant: Data explained for grain yield per plant, WH 542 (-8.349), HD 2967 (-4.954), and QLD 40 (- 1.292) exhibited negatively significant GCA effects while UP 2672 (10.269) showed positively significant GCA effects. Out of 21 crosses 10 were found to have significant SCA effects. Six crosses showed positively significant SCA effects while HD 2967 × UP 2526 (13.450), PBW 621 × UP 2425 (15.125), UP 2526 × QLD 40 (14.692) and UP 2526 × UP 2425 (9.384) showed positively significant SCA effect. PBW 621 × UP 2425 (15.125) was found to be the best specific cross combination. Differential in general combining ability and specific combining ability had been shown from low to high magnitude for various parents to number of grain yield per plant. Similar results for GCA and SCA have been reported

by Kumar *et al.*(2015b) and Kamaluddin *et al.* (2009) depicted combining ability analysis for grain filling duration and yield traits in spring wheat (*Triticum aestivum* L. em.Thell.) and Hasan *et al.* (2010) also reported combining ability in the F₁ generations of diallel cross for yield and yield components in Wheat. The yield is a complex and highly variable trait and is a result of cumulative effect of its component characters and therefore, direct selection of yield *per se* may not be effective (Kumar *et al.*,2015c)

Harvest index: Out of seven parents, the GCA effects for harvest index was found significantly negative for WH542 (-5.092) and HD 2967 (-5.387) and QLD 40 (5.165), UP 2672 (2.395) and UP 2425 (4.323) reflected positive. QLD 40 was found to be the best combiner for this trait. However, out of 21 crosses, PBW 621 × UP 2526 (-8.948) and UP 2526 × UP 2672 (- 12.782) were found negatively significant SCA effects while HD 2967 × PBW 621 (13.907), HD 2967 × UP 2526 (9.930), HD 2967 × UP 2672 (6.138), UP 2526 × UP 2425 (14.490), QLD 40 × UP 2672 (11.838) and UP 2672 × UP 2425 (11.221) showed positively significant SCA effects. UP 2526 × UP 2425 was found to be the best specific cross. Variation in specific combining ability had been found for different parents with respect to harvest index. The work has also been justified by the similar result of Rajesh *et al.* (2012) exhibited combining ability for grain yield and its components in wheat.

Protein content: With regard to quality parameter as a protein content in common wheat variety QLD 40 had significantly negative (-0.186) GCA effects while, UP 2672 (0.244) exhibited statistically positive and act as a best combiner. Difference in general combining ability had been reflected from low to high magnitude for various parents to protein content. Similar results have been reported by Ghimiray *et al.* (2000) noticed combining ability of wheat (*Triticum aestivum L.)* genotypes for quality parameters in tarai soil, Esmail (2007) detected genetic components through triple test cross and line x tester analysis in bread wheat and Esra and Kokasal (2010) reported combining ability in the F1 generations of diallel cross for yield and yield components in Wheat. However, for SCA out of 21 crosses WH 542 × PBW 621 (-0.851) was found negatively significant SCA effects while WH 542 × UP 2425 (0.554), PBW 621× UP 2672 (0.558), QLD 40 × UP 2425 (0.800) reflected positively significant SCA effects. QLD 40 × UP 2425 was found to be the best specific cross. Variation in specific combining ability had been reflected from low to high magnitude for various parents to number of spikelets per spike palve *et al.* (1987) noticed similar results for combining ability in wheat from line x tester analysis and Rajesh *et al.* (2008) exhibited combining ability and gene action in inter varietal crosses in bread wheat reported the similar findings for this trait. Protein content is an important selection criterion for yield. Significant positi-

ve value of GCA for UP 2672 exposed its good general combining ability for the trait. QLD 40 × UP 2425 was identified as the most superior combination on the basis of high SCA values.

Sedimentation value: Another important quality parameter of wheat grain i.e. sedimentation value WH 542 showed negatively significant GCA(-0.708) and UP 2425 had greatest value(0.785) for GCA and was found to be the best combiner for this trait followed by UP 2672 (0.244).However, out of 21 crosses, WH 542 × PBW 621(-2.853) and UP 2526 × UP 2672 (- 0.762) were found to be negatively significant SCA while, WH 542 × UP 2672 (2.077), HD 2967 × PBW 621 (1.301), PBW 621 × UP 2526 (1.931) and QLD 40 × UP 2425 (0.182) had positively significant SCA effects. Due to performed greater SCA, QLD 40 × UP 2425 was identified as the most superior combination for this trait. Difference in general combining ability and specific combining ability had been reflected from low to high magnitude for various parents to sedimentation value. Esra and Kokasal (2010) also reported the positive and negative GCA and SCA values for the different quality traits in wheat for combining ability in F1 generations of diallel cross for yield and yield components in wheat.

Conclusion

Present findings concluded that Parent UP 2526 was a good general combiner followed by UP2425 and UP2672 for most of the characters studied. However, the performance of crosses PBW 621 × UP 2425, UP 2526 × UP 2425 and QLD 40 × UP 2425 were found to be the best specific combiner for the characters number of productive tillers plant[-1], grain yield plant[-1], spike length, grain weight spike[-1], harvest index, days to 75 % heading and protein content.

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