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Evaluation of General and Specific Combining Ability for Yield and its Attributing Traits in Bread Wheat (*Triticum aestivum* L.)

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ABSTRACT

In order to investigate the general and specific combining ability (GCA and SCA) and gene action for yield and its contributing traits in common wheat, 10 lines and 4 testers were crossed using line × tester mating design at the Crop Research Center of SVP University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The experimental material was raised under Randomized Block Design with three repetitions during *rabi* season of 2019–20 and 2020–21. The variance due to cross vs parent was highly significant for all the traits. Estimates of SCA variance for harvest index, plant height, biological yield per plant, 1000 grain weight, days to 50% blooming, grain yield per plant, days to maturity and number of productive tillers per plant, were higher than those of GCA variance, depicting the prevalence of non-additive gene action. GCA variance was found to be higher than SCA variance for the remaining characteristics, reflecting additive gene action. Based on GCA four parents were found promising (UP1109, DBW187, HD3237, PBW226, RAJ3777). On the basis of SCA, 9 crosses (HD3237 × WR544, RAJ 3777 × HD3086, DBW187 × HD3086, DBW187 × PBW226, K9162 × WH1105, PBW373 × WH1105, K9162 × PBW226, UP2628 × WR544, UP1109 × PBW226) were identified good specific combiner for grain yield per plant. In present study non-additive type of gene action was more pronounced, which can be utilized by pedigree method, biparental mating and selection in later generation.

Keywords Wheat, Combining ability, Line × tester design, Yield.

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INTRODUCTION

Bread wheat (*Triticum aestivum* L.) belongs to the Triticeae tribe and Triticine subtribe of the grass family Poaceae. It is predominantly an autogamous species and called as common wheat. One third of the world's population relies on wheat for staple diet. Wheat was domesticated more than 10,000 years ago in the Fertile Crescent region of Middle East, which covers Israel, Lebanon into Syria, Turkey, Iraq and Iran (Charmet 2011). Later, its cultivation reached around the world and now it is grown as between 67° N (Norway, Finland Russia) and 45° in South (Argentina) (Feldman 2001). Globally, 760.93 million tonnes of wheat are produced (FAO statistical book 2022). Asia produces 44% of world's share of wheat and India occupies second place in wheat production. Wheat is an imperative industrial crop and it is used in feed mills, bread, cake, biscuit, pasta, spaghetti, semolina, macaroni. In the current era, maintaining wheat output is crucial due to abrupt climate change and a rapidly expanding worldwide population. Future world food grain supplies must be sustained by breeding for high yielding cultivars with desirable qualities and resilience to a variety of biotic and abiotic stressors. Therefore, efforts are needed to identify suitable genotypes with high yield potential and tolerance to various stresses. Combining ability is an important technique to determining suitable parents for hybridization and identifying the promising cross combinations. Identification of the best parents and their crossings, which are essential for producing superior offspring, depends on both GCA and SCA. A potent biometrical tool to assess the GCA and SCA, effects and kind of gene action involved is the line tester design. The line × tester design is a potent biometrical tool to assess the GCA and SCA, effects and kind of gene action involved. Keeping this in view, the current experiment was carried out to evaluate the combining ability, nature and magnitude of gene action using line × tester design.

MATERIALS AND METHODS

Ten wheat genotypes viz., K9162, HD3237, HD2177, UP1109, RAJ3777, UP2628, PBW373, DBW187, NW5054 and PBW175 were used as females and crossed with 4 testers viz., WR544, PBW226, HD3086 and WH1105 by using line × tester biometrical design. The parents (14 genotypes) and crosses (40 F_1s) were evaluated at the of Sardar Vallabh Bhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India during *rabi* season of 2019-20 and 2020-21. The experiment was carried out using Randomized Block Design with three replications. The experimental plot was 3 meter long and between rows 22.5 cm space was maintained by thinning. Standard agronomic and cultural practices were followed during entire crop cycle. The observations were recorded for twelve characters namely, days to 50% flowering (d), days to maturity (d), plant height (cm), number of productive tillers per plant, peduncle length (cm), spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight (g), biological yield per plant (g), harvest index (%) and grain yield per plant (g). Five uniform plants from each genotype were randomly selected for data recording. Mean value of each trait was used for statistical data analysis. For days to 50% flowering (d) and days to maturity (d) observations were recorded on whole plot basis. To method given by Kempthorne (1957), which was later modified by Arunachalam (1974) was used to calculate combining ability.

RESULTS AND DISCUSSION

Combining ability is an important method for determining the genetic worth of parents and their crosses for further exploitation in breeding program. In present investigation, using line × tester design to work out the combining ability variance and their effect.

Analysis of variance for parent and hybrid

Analysis of variance for parents and hybrids is presented in Table 1. The differences among genotypes were highly significant for all the morphological traits under study. The variance due to cross was highly significant for plant height, harvest index, days to 50% flowering, biological yield per plant and number of productive tillers per plant, while significant association observed with number of grains per spike and 1000 grain weight.

The variance due to parents was observed highly significant for days to 50% flowering, harvest index, biological yield per plant, days to maturity, grain yield per plant and number of productive tillers per plant, while significant association was found with 1000 grain weight. The variance due to line was detected

Table 1. Analysis of variance (ANOVA) for parents and F_1 for 12 quantitative characters. *, ** significant at 5% and 1% level, respectively.

Characters	Replication	Genotype	Crosses	Parent	Line	Tester	Line vs tester	Crosses vs parent	Error	Total
df	2	53	39	13	9	3	1	1	106	161
Days to 50% flowering	5.68	26.08**	15.74**	33.53**	40.84**	10.43*	36.96**	332.54**	4.93	11.9
Days to maturity	1.25	16.69**	8.7	12.69**	14.78**	4.56	18.33**	379.96**	4.95	8.77
Plant height (cm)	10.89	60.61**	40.29**	11.74	9.77	16.43	15.4	1488.62**	15.51	30.3
Number of productive tillers per plant	0.03	2.88**	0.68**	1.11**	0.39**	2.37**	3.78**	111.91**	0.19	1.07
Peduncle length (cm)	3.19	14.30**	3.03	4.56	5.48	2.33	2.94	580.20**	4.14	7.47
Spike length (cm)	0.14	2.03**	0.59	0.07	0.09	0.05	0	83.70**	0.35	0.9
Number of spikelets per spike	0.08	2.96**	1.19	1.22	1.66	0.05	0.68	94.69**	1.34	1.86
Number of grains per spike	9.05	25.73**	14.42*	7.65	10.09	0.83	6.2	701.51**	7.56	13.56
1000 grain weight (g)	0.03	22.46**	12.84*	16.42*	3.93	42.93**	49.29**	476.19**	6.29	11.54
Biological yield per plant (g)	5.09	20.14**	11.66**	19.52**	20.24**	21.20**	8.02**	359.32**	3.3	8.87
Harvest index (%)	7.41	27.86**	27.74**	24.31**	28.94**	3.03	46.55**	78.48**	6.13	13.3
Grain yield per plant (g)	0.54	8.49**	7.47**	5.38**	7.13**	1.15**	2.34**	88.68**	0.4	3.06

highly significant for days to 50% flowering, harvest index, biological yield per plant, days to maturity, grain yield per plant and number of productive tillers per plant. The variance because of tester was highly significant for 1000 grain weight, biological yield per plant, number of productive tillers per plant and grain yield per plant, while significant association found with days to 50% flowering. The variance because of line vs tester showed highly significant association for 1000 grain weight, harvest index, days to 50% flowering, days to maturity, biological yield per plant, number of productive tillers per plant, grain yield per plant. Cross vs parent variance was observed highly significant for all the character. Similar results were also reported by Pancholi *et al.* (2012) and Singh and Kumar (2014).

Analysis of variance for combining ability

Analysis of variance for combining ability was cal-

Table 2. Analysis of variance (ANOVA) for combing ability for 12 quantitative characters. *, ** significant at 5% and 1% level, respectively.

Characters	Replication	Crosses	Line	Tester	Line × tester	Error	Total
Degree of freedom	2	39	9	3	27	78	119
Days to 50% flowering	11.99	15.74**	27.05**	5.72	13.08**	4.64	8.4
Days to maturity	3	8.7	13.45**	10.21**	6.96	4.53	5.87
Plant height (cm)	30.37	40.29**	97.34**	35.25**	21.83**	10.55	20.63
Number of productive tillers per plant	0.09	0.68**	0.95**	0.40**	0.62**	0.19	0.35
Peduncle length(cm)	2.47	3.03	3.09	8.41*	2.42	4	3.66
Spike length (cm)	0	0.59	1.06**	0.2	0.47	0.44	0.48
Number of spikelets per spike	0.1	1.19	1.74	2.56**	0.86	1.33	1.27
Number of grains per spike	4.39	14.42**	14.88**	52.37**	10.05	8.07	10.09
1000grain weight (g)	1.04	12.84**	8.78	2.14	15.38**	6.71	8.62
Biological yield per plant (g)	9.39	11.66**	11.77**	5.42	12.31**	3.42	6.22
Harvest index (%)	19.83	27.74**	32.16**	41.77**	24.71**	6.12	13.44
Grain yield per plant (g)	0.9	7.47**	9.12**	5.49**	7.14**	0.41	2.73

Table 3. Estimate of genetic components and their magnitude for 12 quantitative characters. *, ** significant at 5% and 1% level, respectively.

Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tillers per plant	Peduncle length (cm)	Spike length (cm)	Number of spikelets per spike	Number of grains per spike	1000 grain weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
σ^2A	0.087	0.057	0.606	0.002	0.020	0.004	0.011	0.144	-0.083	-0.022	0.100	0.011
σ^2D	2.813	0.808	3.759	0.141	-0.526	0.009	-0.158	0.662	2.890	2.963	6.196	2.244
σ^2g (female)	1.16	0.54	6.29	0.03	0.06	0.05	0.07	0.40	-0.55	-0.05	0.62	0.16
σ^2g (male)	-0.25	0.11	0.45	-0.01	0.20	-0.01	0.06	1.41	-0.44	-0.23	0.57	-0.05
σ^2g (pooled)	0.16	0.23	2.12	0.00	0.16	0.01	0.06	1.12	-0.47	-0.18	0.58	0.01
σ^2s (sca)	2.81	0.81	3.76	0.14	-0.53	0.01	-0.16	0.66	2.89	2.96	6.20	2.24
Average degree of dominance	5.68	3.75	2.49	8.39	-	1.56	-	2.15	-	-	7.89	14.42
Predictability ratio	0.03	0.07	0.14	0.01	-0.04	0.29	-0.07	0.18	-0.03	-0.01	0.02	0.00
% Contribution (line)	39.67	35.66	55.76	32.43	23.47	41.63	33.73	23.81	15.79	23.30	26.75	28.17
% Contribution (tester)	2.80	9.02	6.73	4.56	21.31	2.68	16.50	27.93	1.28	3.57	11.58	5.66
% Contribution (Lines × Tester)	57.53	55.32	37.51	63.01	55.22	55.69	49.76	48.25	82.93	73.12	61.67	66.17
Narrow sense heritability h^2n (%)	1.16	1.06	4.06	0.60	0.58	0.83	0.93	1.62	-0.88	-0.34	0.80	0.41

culated for yield and its attributing traits. It revealed significant variations due to parent, parent vs crosses and crosses. Variance was further partitioned into lines (females), testers (males), line × tester and error sources. The analysis of variance for combining ability is presented in Table 2. The variance due to crosses was highly significant for plant height, harvest index, days to 50% flowering, number of grains per

Table 4. Estimates of GCA effects of parents for 12 quantitative characters. *, ** significant at 5% and 1% level, respectively.

Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tillers per plant	Peduncle length (cm)	Spike length (cm)	Number of spikelets per spike	Number of grains per spike	1000 grain weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
K9162	-1.64 **	-1.89 **	5.40 **	0.01	0.14	0.23	-0.11	-0.23	-0.18	-1.07 *	-2.35 **	-1.20 **
HD3237	1.57 *	0.65	-0.35	0.03	0.39	0.06	0.37	0.29	-0.89	0.73	1.27	0.71 **
HD2177	-2.31 **	1.20	3.29 **	-0.25 *	0.17	0.12	0.24	0.41	-0.46	0.29	-0.80	-0.24
UP1109	-0.64	0.33	1.74	0.31 *	-0.47	-0.05	-0.28	-0.41	-0.53	1.04	2.89 **	1.39 **
RAJ3777	-0.31	-1.18	-2.13 *	0.45 **	-0.01	0.43 *	0.39	0.99	0.32	-1.06 *	-1.93 **	-0.99 **
UP2628	2.39 **	1.09	-0.71	0.13	1.10	0.30	0.52*	1.14	-0.37	0.15	1.16	0.47 *
PBW373	1.34 *	-1.08	-2.48 **	-0.20	-0.54	-0.37	-0.26	-1.42	0.41	-1.43 **	-1.05	-0.83 **
DBW187	-0.87	0.70	-4.06 **	0.01	-0.07	-0.28	0.07	1.77 *	1.64 *	1.66 **	1.06	0.94 **
NW5054	-0.45	-0.29	-1.33	-0.54 **	-0.62	-0.48 *	-0.26	-1.22	-1.01	-0.08	0.47	0.11
PBW175	0.91	0.48	0.63	0.06	-0.09	0.05	-0.68 *	-1.32	1.07	-0.24	-0.72	-0.35
WR544	-0.61	0.31	1.40 *	-0.16 *	0.56	-0.03	-0.19	-0.87	0.12	-0.62	0.24	-0.08
PBW226	0.43	0.07	-0.30	0.11	0.11	-0.01	-0.31	-0.96	0.06	0.09	1.49 **	0.59 **

Table 4. Continued.

Parents	Days to 50% flow-ering	Days to ma-turity	Plant height (cm)	Num-ber of produc-tive ti-llers per pl-ant	Ped-uncle len-gth (cm)	Spike length (cm)	Num-ber of spike-lets per spike	Num-ber of grains per spike	1000 grain wei-ght (g)	Bio-logi-cal yield per plant (g)	Har-vest in-dex (%)	Grain yield per plant (g)
HD3086	0.08	-0.84 *	0.10	0.03	-0.72*	-0.08	0.22	1.89 **	-0.39	0.25	-0.43	-0.09
WH1105	0.10	0.46	-1.21 *	0.02	0.05	0.11	0.28	-0.05	0.21	0.28	-1.31 **	-0.43 **
SE (gca line)	0.62	0.61	0.94	0.13	0.58	0.19	0.33	0.82	0.75	0.53	0.71	0.18
SE (gca tester)	0.39	0.39	0.59	0.08	0.37	0.12	0.21	0.52	0.47	0.34	0.45	0.12
SE (bet gca line)	0.88	0.87	1.33	0.18	0.82	0.27	0.47	1.16	1.06	0.76	1.01	0.26
SE (bet gca tester)	0.56	0.55	0.84	0.11	0.52	0.17	0.30	0.73	0.67	0.48	0.64	0.16

spike, 1000 grain weight, grain yield per plant and number of productive tillers per plant. The variance due to lines was highly significant for plant height, number of productive tillers per plant, harvest index, days to 50% flowering, number of grains per spike, days to maturity, biological yield per plant, grain yield per plant and spike length. The variance due to tester was highly significant for number of grains per spike, harvest index, plant height, days to maturity, grain yield per plant, number of spikelets per spike and

Table 5. Estimates of SCA effects of crosses for 12 quantitative characters. *, ** significant at 5% and 1% level, respectively.

Sl. No.	Hybrids	Days to 50% flow-ering	Days to ma-turity	Plant height (cm)	Num-ber of produc-tive ti-llers per pl-ant	Ped-uncle len-gth (cm)	Spike length (cm)	Num-ber of spike-lets per spike	Num-ber of grains per spike	1000 grain wei-ght (g)	Bio-logi-cal yield per plant (g)	Har-vest in-dex (%)	Grain yield per plant (g)
1	K 9162 × WR 544	2.50 *	1.20	0.63	0.20	0.35	0.44	-0.52	-1.29	-0.41	-3.28 **	-1.80	-1.65 **
2	K 9162 × PBW 226	0.51	-0.90	1.65	-0.07	0.06	-0.62	-0.52	-0.98	0.59	2.41 *	0.90	1.08 **
3	K 9162 × HD 3086	-4.11 **	-0.78	2.29	0.11	0.16	0.26	0.61	1.57	0.17	-0.30	-2.35	-0.93 *
4	K9162 × WH 1105	1.09	0.48	-4.56 *	-0.25	-0.58	-0.07	0.42	0.71	-0.36	1.18	3.26 *	1.50 **
5	HD3237 × WR 544	0.96	0.85	-1.62	-0.09	0.43	-0.56	-0.80	-1.20	-0.57	2.09	4.90 **	2.54 **
6	HD 3237 × PBW 226	-0.74	-0.10	-0.65	0.11	-0.39	0.12	0.06	-0.17	0.50	-0.82	-2.31	-1.16 **
7	HD 3237 × HD 3086	0.23	-0.56	-2.25	0.05	-0.29	0.55	0.86	1.24**	-0.18	-1.25	-3.52 *	-1.74 **
8	HD3237 × WH 1105	-0.45	-0.19	4.52 *	-0.07	0.24	-0.11	-0.13	0.12	0.25	-0.01	0.93	0.36
9	HD 2177 × WR 544	-0.70	-1.56	-1.08	-0.14	-1.34	0.34	0.67	1.28	-1.13	0.46	-0.57	-0.11
10	HD2177 × PBW 226	-2.98 *	-0.66	-2.04	0.06	0.57	0.69	-0.27	-0.89	1.93	-0.19	-1.49	-0.61
11	HD2177 × HD 3086	4.04 **	0.59	-0.12	0.07	0.01	-0.57	0.06	1.13	-0.45	-0.76	0.87	0.11
12	HD2177 × WH 1105	-0.37	1.62	3.24	0.01	0.76	-0.46	-0.46	-1.53	-0.35	0.49	1.20	0.61

Table 5. Continued.

Sl. No.	Hybrids	Days to 50% flow-ering	Days to ma-turity	Plant height (cm)	Num-ber of produc-tive ti-llers per pl-ant	Ped-uncle len-gth (cm)	Spike length (cm)	Num-ber of spike-lets per spike	Num-ber of grains per spike	1000 grain wei-ght (g)	Bio-logi-cal yield per plant (g)	Har-vest in-dex (%)	Grain yield per plant (g)
13	UP 1109 × WR 544	2.17	0.73	0.63	-0.37	-0.41	-0.58	-0.21	-0.56	0.95	-0.29	1.91	0.60
14	UP 1109 × PBW 226	1.28	0.52	2.17	-0.24	-0.26	0.03	-0.22	-0.80	-0.69	-0.27	2.32	0.74 *
15	UP 1109 × HD 3086	-0.07	0.69	-0.28	0.04	0.70	0.11	-0.29	-1.65	-0.98	0.34	-2.98 *	-0.99 **
16	UP 1109 × WH 1105	-3.38 **	-1.94	-2.51	0.58 *	-0.03	0.44	0.73	3.02	0.72	0.23	-1.24	-0.35
17	RAJ 3777 × WR 544	-4.05 **	-1.59	-0.72	0.97 **	-1.03	-0.29	0.38	0.37	3.53 *	-4.66 **	-4.33 **	-2.89 **
18	RAJ 3777 × PBW 226	1.77	0.73	-0.62	-0.18	-0.58	0.11	0.45	2.53	-1.71	1.63	0.92	0.77 *
19	RAJ 3777 × HD 3086	0.49	0.64	-1.35	-0.16	1.13	0.06	-0.69	-2.25	-1.29	1.66	4.42 **	2.12 **
20	RAJ 3777 × WH 1105	1.80	0.22	2.69	-0.62 *	0.48	0.13	-0.14	-0.64	-0.52	1.37	-1.01	-0.01
21	UP 2628 × WR 544	-1.86	-0.44	-0.20	0.01	-0.61	0.04	0.59	1.09	-0.39	2.36 *	0.72	1.05 **
22	UP 2628 × PBW 226	0.44	-1.96	-1.96	0.01	0.91	0.08	-0.35	-0.35	1.21	-0.12	0.94	0.28
23	UP 2628 × HD 3086	0.57	0.33	3.51	-0.38	-0.47	-0.41	-0.02	0.00	-0.31	-1.67	-1.90	-1.26 **
24	UP 2628 × WH 1105	0.85	2.07	-1.35	0.36	0.16	0.29	-0.21	-0.73	-0.50	-0.57	0.24	-0.07
25	PBW 373 × WR 544	0.86	0.09	-0.97	0.25	-0.26	0.64	0.03	0.85	1.80	2.18 *	0.30	0.74 *
26	PBW373 × PBW 226	-1.51	-0.37	0.94	-0.23	0.02	-0.05	0.03	0.61	0.33	-4.81 **	-3.84 **	-2.86 **
27	PBW 373 × HD 3086	1.50	-0.96	-1.26	0.02	0.44	-0.18	0.23	-1.04	-1.02	1.70	0.55	0.73
28	PBW 373 × WH 1105	-0.85	1.24	1.29	-0.04	-0.20	-0.41	-0.29	-0.43	-1.12	0.94	2.99 *	1.39 **
29	DBW 187 × WR 544	0.84	-2.39**	-2.31	0.27	0.49	0.01	-0.17	-2.14	-3.47 *	-1.18	-1.54	-1.02 **
30	DBW 187 × PBW 226	-0.61	0.51	2.70	-0.07	-0.06	-0.21	-0.51	-1.55	2.20	1.78	2.59	1.67 **
31	DBW 187 × HD 3086	-0.70	1.42	0.26	-0.19	-0.90	0.26	0.43	4.98 **	4.58 **	0.35	4.32 **	1.73 **
32	DBW 187 × WH 1105	0.47	0.46	-0.64	-0.02	0.47	-0.06	0.24	-1.29	-3.31 *	-0.95	-5.38 **	-2.37 **
33	NW5054 × WR544	0.09	2.26	-0.78	-1.38 **	-0.16	-0.12	0.17	0.45	2.15	0.60	-0.69	-0.13
34	NW5054 × PBW 226	1.94	2.16	-1.41	0.34	0.36	-0.21	0.69	1.35	-1.22	-0.08	-0.63	-0.27
35	NW 5054 × HD 3086	-2.63 *	-2.36	2.20	0.69 **	0.85	0.13	-0.57	-1.44	-0.40	-0.31	0.05	-0.05
36	NW 5054 × WH 1105	0.60	-2.07	-0.01	0.36	-1.05	0.20	-0.29	-0.36	-0.53	-0.21	1.28	0.45
37	PBW 175 × WR 544	-0.82	0.83	6.43 **	0.28	2.52 *	0.09	-0.15	1.15	-2.46	1.73	1.10	0.87 *

Table 5. Continued.

Sl. No.	Hybrids	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tillers per plant	Peduncle length (cm)	Spike length (cm)	Number of spikelets per spike	Number of grains per spike	1000 grain weight (g)	Biological yield per plant (g)	Harvest index (%)	Grain yield per plant (g)
38	PBW 175 × PBW 226	-0.09	0.07	-0.77	0.27	-0.63	0.06	0.64	0.25	-3.14 *	0.48	0.60	0.36
39	PBW 175 × HD 3086	0.67	0.98	-2.98	-0.25	-1.64	-0.20	-0.62	-2.54	-0.12	0.25	0.55	0.28
40	PBW 175 × WH 1105	0.24	-1.88	-2.67	-0.31	-0.25	0.04	0.13	1.14	5.72 **	-2.45 *	-2.25	-1.52 **
	Se (sij)	1.24	1.23	1.88	0.25	1.15	0.38	0.67	1.64	1.50	1.07	1.43	0.37
	SE (sij-sik)	1.76	1.74	2.65	0.36	1.63	0.54	0.94	2.32	2.11	1.51	2.02	0.52

number of productive tillers per plant while, while significant variance was found with peduncle length.

The variance due to line × tester was highly significant for harvest index, plant height, 1000 grain weight, days to 50% flowering, biological yield per plant, grain yield per plant and number of productive tillers per plant. These findings are supported by results of Patel *et al.* (2020).

Estimates of genetic components and their magnitude

The estimates of GCA and SCA variance, predictability ratio, average degree of dominance heritability in narrow sense and proportional contribution of lines, testers and lines × testers are given in Table 3. Estimates of SCA variance was higher than GCA variance for harvest index, plant height, biological yield per plant, 1000 grain weight, days to 50% flowering, grain yield per plant, days to maturity and number of productive tillers per plant. It depicts preponderance of non-additive gene action. For remaining traits GCA variance was observed higher than SCA variance. It reflects additive gene action. The value of average degree of dominance was more than unity for traits like grain yield per plant, number of productive tillers per plant, harvest index, days to 50% flowering, days to maturity, plant height, number of grains per spike, spike length. The predictability ratio was observed less than unity for all traits. Narrow sense heritability was observed maximum for plant height (4.06%), followed by number of grains per spike (1.62%), days to 50% flowering (1.16%), days to maturity (1.06%), number of spikelets per spike (0.93%), spike length (0.83%), harvest index (0.80%), number of productive tillers per plant (0.60%), peduncle length (0.58%), grain yield per plant (0.41%), 1000 grain weight (-0.88%) and biological yield per plant (-0.34%). Proportional contribution of lines, testers and lines × testers for all the characters under study revealed that the proportional contribution of lines for all traits varied from 15.79% (1000 grain weight) to 55.76% (plant height). The maximum contribution of lines was recorded for 55.76% (plant height) followed by spike length (41.63%), days to 50% flowering (39.67%), days to maturity (35.66%), number of spikelets per spike (33.73%), number of productive tillers per plant (32.43%), grain yield per plant (28.17%), harvest index (26.75%), number of grains per spike (23.81%), peduncle length (23.47%), biological yield per plant (23.30%) and 1000 grain weight (15.79%).

The proportional contribution of testers for all traits varied from 1.28% (1000 grain weight) to 27.93% (number of grains per spike). The maximum contribution of testers was recorded for number of grains per spike (27.93%) followed by peduncle length (21.31%), number of spikelets per spike (16.50%), harvest index (11.58%), days to maturity (9.02%), Plant height (6.73%), grain yield per plant (5.66%), number of productive tillers per plant (4.56%), biological yield per plant (3.57%), days

Table 6. Promising parents and crosses identified as good general and specific combiners for various traits.

Character	General combiners	Specific combiners
Days to 50% flowering	HD2177, K9162, DBW187	K9162 × HD3086, RAJ 3777 × WR544, UP1109 × WH 1105, HD2177 × PBW226, NW5054 × HD 3086
Days to maturity	K9162, HD 3086	DBW187 × WR544
Plant height	DBW187, PBW373, RAJ3777	K9162 × WH1105
Number of productive tillers per plant	RAJ3777, UP1109	RAJ 3777 × WR544, NW5054 × HD 3086
Peduncle length	HD 3086	RAJ 3777 × WR544
Spike length (cm)	RAJ 3777	HD3237 × HD3086
Number of spikelets per spike	UP 2628	NW5054 × PBW226
Number of grains per spike	HD3086, DBW187	DBW 187×HD3086
1000 grain weight (g)	DBW 187	PBW 175× WH1105, DBW187×HD3086, RAJ3777×WR544
×Biological yield per plant (g)	DBW 187	K9162 × PBW226, UP2628 × WR544, PBW373 × WR544
Harvest index (%)	UP 1109, PBW 226	HD3237 × WR544, RAJ 3777 × HD3086, DBW187 × HD3086, K9162 × WH1105, PBW373 × WH1105
Grain yield per plant (g)	UP 1109, DBW 187, HD 3237, PBW226, RAJ 3777	HD3237 × WR544, RAJ 3777 × HD3086, DBW187 × HD3086, DBW187 × PBW226, K9162 × WH1105, PBW373 × WH1105, K9162×PBW226, UP2628 × WR544, UP1109 × PBW226

to 50% flowering (2.80%), spike length (2.68%) and 1000 grain weight (1.28%). The proportional contribution of line × testers for all traits ranged from 37.51% (plant height) to 82.93% (1000 grain weight). The maximum contribution of testers was recorded for 1000 grain weight (82.93%) followed by biological yield per plant (73.12%), grain yield per plant (66.17%), number of productive tillers per plant (63.01%), harvest index (61.67%), days to 50% flowering (57.53%), spike length (55.69%), days to maturity (55.32%), peduncle length (55.22%), number of spikelets per spike (49.76%), number of grains per spike (48.25%) and plant height (37.51%). Similar results were also reported by Burungale *et al.* (2011), Desale and Mehta (2013), Dholariya et al. (2014), Singh *et al.* (2014), Naseem *et al*. (2015), Verma *et al.* (2016), Tabassum *et al.* (2017), Kumar *et al.* (2017), Ingle *et al.* (2018), Shah *et al.* (2018), Dedaniya *et al.* (2019) and Roy *et al.* (2021).

General combining ability effects of parents

The GCA effects for all characters are given in Table 4. The GCA effects for grain yield per plant among the lines ranged from -1.20 (K9162) to 1.39 (UP1109) and from -0.43 (WH1105) to 0.59 (PBW 226) for the testers. Positive and significant GCA effect in lines were exhibited by UP1109 (1.39), DBW187 (0.94), HD3237 (0.71) and UP2628 (0.47), while negative and significant GCA effects were showed by lines namely K9162 (-1.20) and RAJ 3777 (-0.99). Among the testers, PBW 226 (0.59) showed positive and significant GCA effect, whereas negative and significant GCA effects was exhibited by tester WH1105 (-0.43) for grain yield per plant. Similar findings were also reported by Burungale *et al.* (2011), Kapoor *et al.* (2011), Naseem *et al.* (2015), Verma *et al.* (2016), Verma *et al.* (2016), Jatav *et al.* (2017), Tabassum *et al.* (2017), Kumar *et al.* (2017), Barot *et al.* (2018), Ingle *et al.* (2018), Dedaniya *et al.* (2019) and Roy *et al.* (2021).

Specific combining ability effects of hybrid

The SCA effects for yield and its attributing traits varied widely among hybrids (Table 5). The specific combining ability effect for grain yield per plant ranged from -2.89 (RAJ3777 × WR544) to 2.54 (HD3237 × WR544). Positive value of SCA effects were observed for 21 crosses, out of which 12 were significant in positive direction. Negative values of SCA effects were detected for 19 crosses, out of which 11 were significant in negative direction. Highly significant and positive specific combining ability effects were recorded for crosses, HD3237 × WR 544 (2.54), RAJ 3777 × HD 3086 (2.12), DBW 187 × HD 3086 (1.73), DBW 187 × PBW226 (1.67), K 9162 × WH 1105 (1.50), PBW 373 × WH 1105 (1.39), K9162 × PBW 226 (1.08), UP 2628 × WR 544 (1.05), PBW 175 × WR 544 (0.87), RAJ 3777 × PBW 226 (0.77), UP 1109 × PBW 226 (0.74) and PBW 373 × WR 544 (0.74). The crosses RAJ 3777 × WR 544 (-2.89), PBW 373 × PBW 226 (-2.86), DBW 187 × WH 1105 (-2.37), HD 3237 × HD 3086 (-1.74), K 9162 × WR544 (-1.65), PBW175 × WH 1105 (-1.52), UP 2628 × HD 3086 (-1.26), HD 3237 × PBW226 (-1.16), DBW 187 × WR 544 (-1.02), UP 1109 × HD 3086 (-0.99) and K 9162 × HD 3086 (-0.93) were exhibited negatively significant SCA effects. Similar results were also reported in previous studies like Kapoor *et al.* (2011), Dholariya *et al.* (2014), Naseem *et al.* (2015), Jatav *et al.* (2017), Tabassum *et al.* (2017), Kumar *et al*. (2017), Ingle *et al.* (2018), Shah *et al.* (2018), Dedaniya *et al.* (2019) and Roy *et al.* (2021).

Based on GCA and SCA effects promising parents and crosses were identified, which are given in Table 6. Parents HD 2177, K 9162, DBW 187 identified good general combiner for days to 50% flowering; K 9162, HD 3086 for days to maturity; UP 1109 for number of productive tillers per plant, DBW 187 for 1000 grain weight and biological yield per plant, UP1109, PBW 226 for harvest index and UP 1109, DBW 187, HD 3237, PBW 226, RAJ 3777 for grain yield per plant. On the basis of SCA effect promising crosses were, RAJ 3777 × WR 544, NW 5054 × HD 3086 for number of productive tillers per plant, NW 5054 × PBW 226 for number of spikelets per spike, DBW 187 × HD 3086 for number of grains per spike, PBW 175 × WH 1105, DBW 187 × HD 3086, RAJ 3777 × WR 544 for 1000 grain weight. For grain yield per plant HD 3237 × WR 544, RAJ 3777 × HD 3086, DBW 187 × HD 3086, DBW 187 × PBW 226, K 9162 × WH 1105, PBW 373 × WH 1105, K 9162 × PBW 226, UP 2628 × WR 544, UP 1109 × PBW 226 were found superior.

CONCLUSION

The general combining capacity is attributed to fixable additive and additive × additive gene actions in nature. Additive gene action was recorded for peduncle length (cm), spike length (cm), number of spikelets per spike and number of grains per spike. The presence of additive gene action could be utilized through pure line selection, mass selection, and progeny selection. In current study non-additive gene action was observed for harvest index, plant height, biological yield per plant, 1000 grain weight, days to 50% flowering, grain yield per plant, days to maturity and number of productive tillers per plant. The specific combining ability is due to non-additive gene actions, which are inherently unfixable. The non-additive gene actions can be exploited through developments of hybrid. The promising cross combinations could be used in breeding programs designed to create hybrid for various traits. Pedigree method, biparental mating and selection in later generation of segregating population could be used for exploitation of non-additive gene action. According to the aforementioned finding, both additive and non-additive gene action have significant implications for grain yield and the contributing features under investigation. This suggests that pure line and heterosis breeding are both viable options for enhancing these wheat genotype yields.

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