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Genetic Studies on Combining Ability for Grain Yield and its Attributes in Bread Wheat (*Triticum aestivum* L. em Thell)

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ABSTRACT

Background: Selecting suitable parent genotypes to create gene combinations that enhance yield and other advantageous characters is the key goal of wheat improvement programmes. This research investigated the general and specific combining ability and the gene actions associated with yield and yield-attributing traits.

Methods: Combining ability for ten parental bread wheat genotypes was analyzed using a 10×10 half-diallel fashion in a randomized block design (RBD) having three replications.

Result: The results disclosed that all genotypes differed significantly in yield and the factors contributing to it. GCA and SCA mean squares were highly significant for days to 75% heading, productive tillers per plant, plant height, grains per spike, 1000-grain weight, biological yield, grain yield and harvest index. Except for days to 75% heading, all traits had GCA: SCA ratios less than unity, suggesting that nonadditive factors were comparatively more significant in the inheritance of these traits. The parents, CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/…, DBW 189 and UP 2901 were good general combiners in terms of yield and a few of their component traits. Eleven crosses presented notable and favourable SCA impacts regarding grain yield. The cross CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/…× PBW 692 displayed the maximum SCA effect for grain yield per plant. To improve productivity components and increase yields in wheat breeding programmes, parental wheat genotypes and progenies from these crosses offer the possibility of commercial exploitation either as hybrid varieties or as a base material for selecting potential homozygous lines from transgressive segregants.

Key words: Combining ability, Diallel, GCA, SCA, Transgressive segregants, Wheat.

INTRODUCTION

The challenges breeders face in producing high yielding varieties in self pollinated crops like wheat are selecting the potential parents and elite cross combinations in early generations that would result in high-yielding isogenic lines following allele fixation (Arya *et al.,* 2017; Thapa *et al.,* 2019; Kumar *et al.,* 2021). Choosing the wrong parents at any point could ruin a carefully thought-out and well-run follow-up programme. Because phenotypically superior lines may result in poor cross combinations for yield, choosing appropriate parents based on phenotypic performance alone is futile, highlighting the significance of assessing the parental genotypes for their combining ability and the resulting hybrid's potential to exhibit hybrid vigour.

Frequently, the high yielding parents may not combine finely to produce a superior hybrid. While the portion of specific combining ability allows the breeder to select higher yielding crosses meant for the exploitation of heterosis and a nonadditive share of genetic variance, knowledge of general combining ability helps the breeder identify superior performing parents who will outperform the rest of the population when used in the hybridization program. The degree of additive and nonadditive gene action is revealed by evaluations of combining ability effects and the extent of variance components. A high SCA indicates a nonadditive form of gene influence, while an additive mode of gene activity is indicated by a high GCA (Sprague and Tatum, 1942). Diallel mating design is one of the most operative biometrical methods for assessing the GCA and SCA effects of different wheat genotypes. It also offers insights into the genetic mechanisms governing grain yield and other traits. Considering the above, our current study aimed to examine the general and specific combining ability effects and variances and the type and extent of gene-action related to yield and yield-attributing traits.

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MATERIALS AND METHODS

Ten parental distinct bread wheat genotypes [CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/… (P1), HD 3234 (P2), PBW 692(P3), HUW 640 (P4), DBW 189

(P5), VORB/SOKOLL (P6), UP 2762 (P7), UP 2901 (P8), QLD 73 (P9) and QLD 65 (P10)] were crossed in a half diallel manner to produce their 45 F_1 hybrids. In *Rabi* 2018-19, a total of 55 entries were assessed using three replications in randomized block design at N.E. Borlaug CRC, G.B. Pant University of Agriculture and Technology, Pantnagar, India. The parental genotypes and resulting hybrids were planted in two-row plots, each measuring 1 m in length, having an inter and intra-row distance of 20 cm and 10 cm, respectively. Standard agricultural procedures and cultural operations were closely adhered to to encourage the best possible growth and expression of the material. The following twelve specific traits were observed in five competitive plants chosen randomly from each of the three replications: Days to 75% heading, flag leaf area (cm^2), days to maturity, plant height (cm), productive tillers per plant, spike length (cm), spikelets per spike, grains per spike, biological and grain yield per plant (g), harvest index (%) and 1000-grain weight (g) and each plot's days to maturity and days to 75% heading were noted. Following the conventional protocols set by Panse and Sukhatme (1985), the average mean of the recorded observations was subjected to analysis of variance. Therefore, to assess the interactions of general and specific combining ability effects, a combining ability study was also conducted using Griffing's Method II (Griffing, 1956), which comprised the parents and one set of F_1 hybrids excluding reciprocals, in conjunction with Model I (fixed effect).

RESULTS AND DISCUSSION

The ANOVA demonstrated highly significant mean squares due to GCA for traits such as days to 75% heading, productive tillers, plant height, days to maturity, grains per spike, 1000-grain weight, biological yield, grain yield and harvest index (Table 1). Conversely, spike length showed significant mean squares and two traits (flag leaf area and

Table 1: ANOVA for general (GCA) and specific (SCA) combining ability for 12 traits in bread wheat.

Character	GCA	SCA	Error	σ^2g	σ^2s	σ^2g/σ^2s
	(9)	(45)	(108)	-	-	-
Days to 75% heading	9.244 **	0.565**	0.320	0.743	0.244	3.037
Days to maturity	4.788**	1.604*	0.990	0.316	0.613	0.515
Flag leaf area (cm^2)	6.196	16.173**	3.790	0.200	12.383	0.016
Productive tillers/ plant	13.995**	14.255**	2.636	0.946	11.618	0.081
Plant height (cm)	9.629**	19.366**	3.165	0.538	16.200	0.033
Spike length (cm)	0.218*	0.152	0.105	0.009	0.047	0.198
Spikelets/Spike	0.912	0.648	0.489	0.035	0.158	0.222
Grains/Spike	19.505**	10.314**	3.212	1.357	7.102	0.191
1000-grain weight (g)	42.124**	9.236**	2.000	3.343	7.235	0.462
Biological yield/plant (g)	242.133**	107.571**	17.235	18.741	90.336	0.207
Grain yield/plant (g)	20.288**	13.111**	0.410	1.656	12.700	0.130
Harvest index (%)	23.287**	18.824**	5.597	1.474	13.227	0.111

*, ** 5% and 1% level of significance levels, respectively.

Table 2: Summary of GCA of parents for various traits.

Parents	DH	FLA	DM	PH	PT	SL	S/S	G/S	1000-GW	BY/P	GY/P	HI
P1 (CAL/NH//H567.71/3/ SER1/4/CAL/NH/H56 7.71/5/2*KAU2/6/...)	+	0	+	+	-	0	-	0	+	+	+	-
P2 (HD 3234)	-	0	-	+	0	0	0	0	-	-	0	0
P3 (PBW 692)	-	0	0	0	0	+	0	-	-	-	-	0
P4 (HUW 640)	-	0	0	0	0	0	0	-	-	-	0	0
P5 (DBW 189)	-	0	0	0	0	0	0	+	+	+	+	-
P6 (VORB/SOKOLL)	-	0	-	-	+	0	0	-	0	-	-	+
P7 (UP 2762)	+	0	+	0	0	0	0	0	-	0	-	0
P8 (UP 2901)	+	0	+	0	0	0	0	+	0	0	+	0
P9 (QLD73)	0	0	0	0	0	-	0	+	+	0	-	0
P10 (QLD 65)	0	0	0	0	0	0	0	0	0	0	-	0

DH: Days to 75% heading, DM: Days to maturity, FLA: Flag leaf area, PT: Productive tillers/plant, PH: Plant height, SL: Spike length, S/S: Spikelets per spike, G/S: Grains per spike, 1000-GW: 1000-grain weight, BY/P: Biological yield per plant, GY/P: Grain yield per plant, HI: Harvest index, +: Good general combiner, 0: Average general combiner, -: Poor general combiner.

spikelets per spike) displayed non-significant mean squares. The mean squares resulting from SCA were highly significant for traits like days to 75% heading, flag leaf area, productive tillers per plant, plant height, grains per spike, 1000-grain weight, biological yield, grain yield per plant and harvest index. In contrast, it was significant for days to maturity and non-significant for spike length and spikelets per spike. The manifestation of these traits involved both additive and nonadditive effects, as demonstrated by the significance of both general and specific combining abilities.

Variance components of combining ability

The variance estimates for general (σ^2gca) and specific (σ^2sca) combining ability are provided in Table 1. The estimated value of σ^2g was higher than its σ^2s for days to 75% heading, indicating that additive gene action predominated. However, nonadditive gene activity was more prevalent in the remaining attributes. The prevalence of nonadditive variance contributed comparatively more to the expression of various traits in wheat, as testified by Ali *et al.* (2020) and Askander *et al.* (2021).

GCA and SCA effects

The parents having significant GCA effects in the desired direction were classified as good general combiners (+), those having non-significant GCA effects were average general combiners (0) and those with significant GCA effects in the undesired direction were poor general combiners (-) (Table 2). These estimates are shown in Table 3 and 4 for both general and specific combining ability effects.

In drought-prone conditions, breeding wheat for early maturity is a sensible drought-avoidance tactic that enables plants to avoid terminal drought stress. For days to 75% heading and days to maturity, three parental genotypes (UP 2762, UP 2901 and CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/…) displayed significant negative GCA effects. The crosses that had the potential to improve earliness in wheat were VORB/SOKOLL×QLD 73 and CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/…×QLD 65 for days to 75% heading and VORB/SOKOLL×QLD 65 and HD 3234×DBW 189 for days to maturity. These crosses had strong negative SCA effects. Usually, dwarf plants are more desirable because they are more lodging resistant; however, depending upon the requirement, tall plants can also be preferred as they can be utilized for straw purposes. Only two parents had significant negative GCA effects for plant height. HD 3234 was the top general combiner for reduced plant height, VORB/SOKOLL had the lowest general combining ability and seven crosses had significant negative SCA effects. No parent showed significant GCA effects for the flag leaf area; however, nine crosses showed significant positive SCA effects. VORB/SOKOLL had a significant positive GCA value for productive tillers per plant and eleven crosses displayed significant positive SCA effects. Only one parent, PBW 692, showed significant positive GCA effects on spike

Table 3: General combining ability effects of parents for different traits in bread wheat.

Parents	Days to 75% heading	Flag leaf area (cm^2)	Days to maturity	Plant height (cm)	Productive tillers per plant	Spike length (cm)	Spikelets pern spike	Grains per spike	1000-Grain weight (g)	Biological yield per plant (g)	Grain yield per plant (g)	Harvest index (%)
P1 (CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/…)	-1.328**	-0.871	-0.572 *	-1.229*	-2.579**	-0.063	-0.530**	-0.156	3.304**	7.860**	2.161**	-1.798**
P2 (HD 3234)	0.644**	0.829	0.844**	-1.230*	0.170	-0.078	0.146	0.622	-1.349**	-2.449*	-0.127	-0.155
P3 (PBW 692)	0.950**	-0.368	0.261	0.400	0.288	0.210*	0.091	-1.239*	-1.252**	-3.273**	-0.664**	0.482
P4 (HUW 640)	0.672**	-0.887	0.289	-0.081	0.613	-0.055	0.378	-1.544**	-2.544**	-3.174**	-0.227	0.947
P5 (DBW 189)	0.561**	-0.391	0.233	0.952	-0.297	0.175	-0.344	2.122**	1.164**	7.807**	1.429**	-2.720**
P6 (VORB/SOKOLL)	0.756**	-0.609	0.678*	1.658**	1.679**	-0.129	-0.067	-1.267*	-0.113	-5.413**	-2.200**	2.102**
P7 (UP 2762)	-0.717**	0.926	-1.072**	-0.522	0.467	-0.054	0.119	-0.239	-1.233**	0.685	-0.828**	-0.532
P8 (UP 2901)	-1.383**	0.859	-0.822**	0.156	0.026	0.037	-0.085	1.150*	0.405	-0.010	1.416**	0.712
P9 (QLD73)	0.117	0.377	0.233	0.139	-0.471	-0.186*	-0.001	1.428**	2.605**	-1.373	-0.523**	0.554
P10 (QLD 65)	-0.272	0.135	-0.072	-0.241	0.105	0.142	0.294	-0.878	-0.987*	-0.661	-0.437*	0.408
SE (+i)	0.155	0.533	0.272	0.487	0.444	0.088	0.191	0.490	0.387	1.136	0.175	0.647
SE (+i-+j)	0.231	0.794	0.406	0.726	0.662	0.132	0.285	0.731	0.577	1.694	0.261	0.965

*,** 5% and 1% level of significance levels, respectively.

Table 4: Specific combining ability effects of crosses for various traits in bread wheat.

Crosses	Days to 75% heading	Flag leaf area ($cm^{2)}$	Days to maturity	Plant height (cm)	Productive tillers per plant	Spike length (cm)	Spikelets pern spike	Grains per spike	1000-Grain weight (g)	Biological yield per plant (g)	Grain yield per plant (g)	Harvest index (%)
P1×P2	-0.159	-4.993**	-0.412	-1.716	2.638	0.069	0.686	2.333	-4.442**	1.785	3.160**	-1.179
P1×P3	-0.465	0.251	0.172	-1.563	-1.077	0.284	0.518	-4.472**	3.795**	20.606 **	7.216**	-4.073
P1×P4	-0.854	4.252*	0.144	5.951**	-1.515	-0.017	-0.216	-0.167	3.587**	1.440	-1.144	-2.284
P1×P5	0.258	-2.440	-0.134	-4.765**	-2.605	-0.092	-0.270	1.833	1.545	4.926	5.003**	-3.434
P1×P6	0.396	-1.085	-1.245	-6.328**	-0.802	0.370	-0.324	0.556	1.155	3.583	2.600**	-2.882
P1×P7	0.202	-4.670*	-0.162	-0.437	-4.703**	-0.642*	-0.843	2.528	4.276**	-15.546**	-1.139	7.198**
P1×P8	-0.131	2.077	-1.412	-4.363*	-0.519	0.254	-0.306	3.472*	-1.862	-12.768**	-1.680**	5.617*
P1×P9	-0.298	3.666*	-0.134	0.675	-0.875	0.160	0.163	1.861	-0.896	-14.824**	-5.997**	2.285
P1×P10	-1.242*	-2.420	2.505**	4.355*	1.659	-0.125	0.535	1.833	3.364*	-13.960**	-3.964**	6.709**
P2×P3	-0.770	5.837**	0.755	2.894	1.505	0.352	1.176	3.083	5.614**	12.724**	2.185**	-4.193
P2×P4	-0.826	-2.881	-0.939	5.389**	-0.820	0.078	-0.448	-1.278	-2.093	-1.151	-1.222*	-2.060
P2×P5	-0.048	1.766	-2.217*	0.932	-3.244*	-0.300	-0.392	-0.611	0.698	-4.795	-1.908**	-0.407
P2×P6	-0.242	1.341	0.338	-1.471	-0.444	-0.018	-0.556	1.111	-0.692	-3.292	0.491	3.644
P2×P7	0.230	0.386	0.422	1.553	5.218**	0.977**	1.591*	0.417	0.596	-9.330*	-5.024**	6.402**
P2×P8	-0.770	3.160	-1.495	-0.436	3.546*	-0.078	0.685	2.028	1.124	14.141**	0.425	-6.426**
P2×P9	0.396	-1.855	1.783	-7.661**	-0.294	-0.572	-0.065	-0.583	-0.410	-0.222	-1.329*	-2.748
P2×P10	1.119*	-4.387*	3.422**	-6.021**	1.244	0.403	-0.027	0.389	0.183	0.206	4.331**	4.652*
P3×P4	0.202	-5.124**	2.311*	-0.661	2.342	-0.134	-0.500	4.250*	-5.023**	1.003	-0.686	1.476
P3×P5	0.313	4.397*	0.366	-2.611	-2.028	-0.165	-0.001	1.917	-5.405**	-16.437**	-5.872**	1.226
P3×P6	0.119	1.758	0.588	8.076**	2.662	-0.427	-1.278	3.306	-5.289**	-0.388	-0.716	-0.313
P3×P7	1.258*	0.390	0.672	0.950	1.654	0.318	0.536	-2.389	-4.001**	-6.252	2.675**	2.558
P3×P8	1.591**	-0.473	-0.912	0.424	3.375*	-0.006	0.740	0.889	3.194 *	-0.515	0.712	-0.400
P3×P9	0.424	-0.134	-0.967	-0.914	-3.378*	0.187	0.100	-0.389	2.827*	-14.521**	-1.619**	7.728**
P3×P10	0.146	-2.966	-0.995	3.296	-0.874	0.382	-0.639	1.250	0.586	-7.397	-4.476**	4.351
P4×P5	0.591	-2.122	0.672	-7.997**	-1.793	0.414	2.159**	-6.778**	-1.106	9.127*	-2.993**	-2.492
P4×P6	0.063	-2.714	-0.439	-9.996**	4.227**	0.196	1.768**	2.278	1.844	1.133	2.631**	-1.237
P4×P7	0.869	-4.075*	0.311	0.738	-3.895*	-0.026	-0.194	-4.750**	3.341*	0.982	5.928**	3.250
P4×P8	-0.798	1.145	-0.606	4.529**	-0.867	-0.204	-1.100	2.528	-0.420	-9.051*	-4.745**	5.106*
P4×P9	0.702	4.138*	-0.662	-0.047	5.597**	0.359	-0.408	2.583	-1.881	-9.343*	0.187	3.297
P4×P10	0.424	8.299**	-0.023	5.550**	4.798**	0.077	0.740	3.556*	-0.121	-0.673	0.284	-2.213
P5×P6	-0.159	-2.520	-0.717	3.427*	2.360	0.342	-0.843	0.611	-1.045	-3.171	0.164	3.816
P5×P7	0.646	-0.001	-1.301	-2.036	2.682	-0.790*	-0.809	-0.750	-0.417	7.068	1.792**	-2.067
P5×P8	-0.687	2.306	2.449*	3.426*	2.233	0.085	-0.715	-3.472*	0.278	-2.097	0.605	0.076
P5×P9	0.813	3.555	-0.606	3.410*	2.124	0.288	0.315	0.250	0.744	11.676**	0.498	-5.730*

Table 4: Continue....

Table 4: Continue....

P5×P10	-0.465	3.993*	0.033	3.927*	4.265**	-0.363	-0.094	3.222	-0.996	-16.156**	-4.552**	6.117**
P6×P7	-0.215	3.434	0.588	-2.198	3.152*	0.661*	1.028	-5.028**	-5.307**	-3.869	1.052	3.772
P6×P8	1.119*	-0.719	2.005*	0.489	3.923*	-0.333	0.675	-4.083*	0.221	-7.544	-1.595**	2.927
P6×P9	-1.381*	-6.343**	0.283	3.411*	-3.026*	0.236	0.481	4.306*	4.188**	-7.517	0.484	6.232**
P6×P10	-0.326	3.324	-3.078**	3.101	1.178	0.461	-0.038	2.944	2.780*	21.773**	5.301**	-7.141**
P7×P8	0.258	7.620**	0.088	-0.813	-2.642	0.192	-0.624	0.222	-3.324*	-2.816	0.883	-0.492
P7×P9	-0.909	2.522	0.366	4.114*	6.079**	-0.109	-0.258	3.611*	1.975	-4.355	-5.025**	-1.671
P7×P10	-0.187	-5.457**	-0.328	3.058	2.393	-0.457	-0.557	1.583	-0.766	0.972	-4.642**	-4.848*
P8×P9	-0.576	0.172	-0.217	1.946	5.296**	0.090	0.499	0.222	-1.050	3.196	-2.019**	-0.945
P8×P10	-0.520	1.177	-0.245	1.902	-2.836	0.372	0.534	1.194	4.096**	-7.444	-1.357*	0.755
P9×P10	0.313	5.596**	0.699	0.127	1.108	-0.216	-0.990	-6.417**	-1.771	1.657	0.940	-1.327
SE (ij)	0.521	1.793	0.916	1.638	1.495	0.298	0.644	1.650	1.302	3.824	0.590	2.179

length and two crosses (VORB/SOKOLL×UP 2762 and HD 3234×UP 2762) exhibited notable positive SCA effects. These outcomes are consistent with those of Joshi *et al.* (2020), Dahiya *et al.* (2023) and Bhatt *et al.* (2024).

Selection for significant yield contributory traits, such as spikelets per spike, grains per spike and 1000-grain weight, is desirable. For spikelets per spike, none of the parents displayed statistically significant positive GCA effects; nevertheless, HUW 640, QLD 65, HD 3234, UP 2762 and PBW 692 were the parents with positive GCA effects. Out of 45 crosses, only three (HUW 640×DBW 189, HUW 640×VORB/SOKOLL and HD 3234×UP 2762) exhibited substantial positive SCA effects. Five crosses (VORB/SOKOLL×QLD 73, PBW 692×HUW 640, UP 2762×QLD 73, HUW 640×QLD 65 and CAL/NH//H567.71/ 3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/...×UP 2901) demonstrated significantly positive SCA effects, while the parents, DBW 189, QLD73 and UP 2901, demonstrated significant positive GCA effects for grains per spike. CAL/ NH//H567.71/ 3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/..., QLD 73 and DBW 189 were the parents exhibiting significant favourable GCA impacts for 1000-grain weight. SCA effects for 1000-grain weight were significantly positive in eleven crosses. Significantly positive GCA effects were noted for two parents, CAL/NH//H567.71/3/SER1/4/CAL/ NH/H567.71/5/2*KAU2/6/... and DBW 189, in terms of biological yield. Sixteen crosses unveiled significant SCA effects with six crosses (VORB/SOKOLL×QLD 65, CAL/NH/ /H567.71/3/SER1/4/ CAL/NH/ H567.71/5/2*KAU2/6/ ...×PBW 692, HD 3234×UP 2901, HD 3234×PBW 692, DBW 189×QLD 73 and HUW 640×DBW 189) showing significantly positive effects and ten crosses presenting significantly negative effects.

Three parents-CAL/NH//H567.71/3/SER1/4/CAL/NH/ H567.71/5/2*KAU2/6/..., DBW 189 and UP 2901-presented significantly positive GCA effects for grain yield, while VORB/ SOKOLL, UP 2762, PBW 692, QLD 73 and QLD 65 presented significantly negative GCA effects. Of these, eleven crosses displayed significantly positive SCA effects for grain yield. For harvest index, only one parent (VORB/SOKOLL) demonstrated significantly positive GCA effects and nine crosses displayed significant SCA effects. Similar types of results for these characters have been testified by Mahdy *et al.* (2022), Rind *et al.* (2023), Ahmad and Gupta (2024), Bhatt *et al.* (2024) and Singh and Shrivastav (2025).

Hence, to increase the overall GCA for yield in bread wheat, it is advised that the breeder ought to focus on the superior combining ability for each component trait. Selecting parent plants displaying strong GCA for multiple traits is essential for creating a dynamic population rich in favourable genes. Restricted recurrent selection by intermating the most desirable segregants following subsequent selection or multiple crossing/biparental mating in early segregating generations will improve traits exhibiting dominance or nonadditive gene effects. Another useful breeding technique for using nonadditive gene effects is heterosis breeding. The parental genotypes CAL/

Table 5: Parents and crosses possessing the highest GCA and SCA effects for different characters.

Characters	Parents possessing the highest GCA effects	Crosses possessing the highest SCA effects
Days to 75% heading	UP 2901 (P8)	VORB/SOKOLL×QLD 73 (P6×P9)
Days to maturity	UP 2762 (P7)	VORB/SOKOLL×QLD 65 (P6×P10)
Flag leaf area (cm^2)	UP 2762 (P7)	HUW 640×QLD 65 (P4×P10)
Productive tillers/plant	VORB/SOKOLL (P6)	UP 2762×QLD 73 (P7×P9)
Plant height (cm)	HD 3234 (P2)	HUW 640×VORB/SOKOLL (P4×P6)
Spike length (cm)	PBW 692 (P3)	HD 3234×UP 2762 (P2×P7)
Spikelets/Spike	HUW 640 (P4)	HD 3234×UP 2762 (P2×P7)
Grains/Spike	DBW 189 (P5)	VORB/SOKOLL×QLD 73 (P6×P9)
1000-grain weight (g)	CAL/NH//H567.71/3/SER 1/4/CAL/NH/H567.71/5/2* KAU2/6/... (P1)	HD 3234×PBW 692 (P2×P3)
Biological yield/plant (g)	CAL/NH//H567.71/3/SER 1/4/CAL/NH/H567.71/5/2* KAU2/6/... (P1)	VORB/SOKOLL×QLD 65 (P6×P10)
Grain yield/plant (g)	CAL/NH//H567.71/3/SER 1/4/CAL/NH/H567.71/5/2* KAU2/6/... (P1)	CAL/NH//H567.71/3/SER1/4/CAL/NH/ H567.71/5/2*KAU2/6/...×PBW 692 (P1×P3)
Harvest index (%)	VORB/SOKOLL (P6)	PBW 692×QLD 73 (P3×P9)

NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/..., DBW 189 and UP 2901 confirmed sound GCA effects for grain yield along with its attributing components and can be valuable in the hybridization programmes (Table 5). Incorporating the parents with good GCA and F_1 hybrids with high SCA into multiple crosses may also be a beneficial strategy for the noticeable increase in wheat grain yield.

CONCLUSION

The study found substantial variation across parental lines and crosses for most characters, except spike length, where GCA and SCA were negligible. This showed that improvements can be made for all traits, except spike length, by selecting superior genotypes or isolating transgressive segregants. UP 2762 was the best general combiner for days to maturity, making it appropriate for creating lines with early maturity. CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/... can be utilized as one of the parents in hybridization programs to increase 1000-grain weight and grain yield. The crosses, *viz.,* CAL/NH//H567.71/3/SER1/4/CAL/NH/H567.71/5/2*KAU2/6/...×PBW 692 and HD 3234×UP 2762 were determined to be good crosses due to them having significant SCA effects for yield and two yield attributing traits, respectively. As such, they offered a chance for commercial exploitation either as hybrid varieties or as a base material for choosing potential homozygous lines from transgressive segregants to increase bread wheat yield levels.

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Disclaimers

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Conflict of interest

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