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Research Article

Deciphering combining behaviour and magnitude of heterosis in bread wheat cross combinations under sub-tropical region

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Abstract
The purpose of this research was to examine the extent of heterosis in 21crosses of bread wheat (*Triticum aestivum* L.). These hybrids originated from a line x tester mating scheme in which seven lines were crossed with three testers. Combining ability analysis revealed that the parental lines HP-25 and HD-3086 performed well for grain yield, while HP-24, HP-22, and HP-06 were observed to be better for other qualities that contribute to yield. Significantly higher positive Specific Combining Ability (SCA) for grain yield per plant was observed for the crosses HP-22 x JAUW-683, HP-44 x HD-3086, and HP-45 x RSP-561 suggesting the role of non-additive gene action. The ratio of variances was observed to be less than unity indicating the presence of non-additive genetic effects in these cross combinations. In terms of heterotic impacts on grain yield, yield contributors, and morpho-physiological features, HP-06 x RSP-561 was shown to be the best combination.

Keywords: Combining ability, heterosis, *Triticum aestivum,* gene action

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple food crop that provides a significant proportion of the world's calorie intake. To meet the growing demand for food, there is a need to improve wheat yields and enhance the genetic potential of this crop. In terms of output, wheat is far and away the leader, and for good reason: almost 36% of the global population relies on wheat as a primary source of nutrition. According to estimates, global wheat output is 784.91 million metric tonnes, with a yield of 3.50 metric tonnes per hectare across an area of 221.82 million hectares (wheat Production, 1990). In 2022-23, India harvested 108Mmt of wheat from an area of about 31.9 M ha with an average yield of 32.42q/ha. When it comes to world wheat output, India is second only to China (USDA, 2022-230). Wheat consumption is predicted to surpass 140 million tonnes by 2050, around 40% more than the present production scenario (Erenstein *et al*., 2022 and Singh *et al*., 2019), due to the country's rising population. To increase yields even more, improved high-yielding cultivars must be developed. However, effective hybridization programs require the identification of superior parents and their combining behaviour to produce desirable segregants, as hybridization is the fundamental mechanism for breaking yield barriers. To create superior, high-yielding varieties, it is necessary to first identify superior parents (Prasad, 2014; Sheera *et al*., 2022). The ability to comprehend the genetic mechanism governing the inheritance of characteristics is also crucial (Ismail, 2015). Heritability gives information on genetic diversity and is helpful in forecasting the response to selection in future generations, whereas heterosis estimates are often ascribed to both additive and non-additive gene effects. Heterosis, also known as hybrid vigour, is a phenomenon where the progeny of genetically diverse parents exhibits superior performance compared to their parents. The phenomenon of heterosis has been widely used in plant breeding to improve yield potential in crops, including wheat. Combining ability, on the other hand, refers to the ability of a particular parent to contribute desirable traits to their offspring when crossed with another parent. In wheat, combining ability is an important consideration in selecting the best parental combinations for hybridization. The purpose of this research was to identify lines with good combining ability for yield and yield contributing traits and also to identify cross combinations with better combining ability for exploitation in wheat heterosis breeding.

MATERIALS AND METHODS

This study was done at Sher-e-Kashmir University of Agricultural Sciences and Technology's Main Campus in Chatha, Jammu, during the *Rabi* season of 2020-21 at the laboratory of the Division of Plant Breeding and Genetics in the Faculty of Agriculture. The coordinates for the experimental site are 32°40N, 78°48E, and 336 meters above sea level. Seven lines (HP-6, HP-22, HP-24, HP-25, HP-33, HP-44, and HP-45), all of which were chosen for their high Zn or Fe content, or both were crossed with three locally adopted cultivars namely JAUW 683, RSP-561, and HD 3086 (**Table 1**), in Line x Tester mating fashion (Kempthorne, 1957) during Summer, 2019-2020. The hybrids thus generated were raised along with their parentsin a Randomized Complete Block Design with three replicates during *rabi*, 2020-21. Ten plants were planted 30 centimetres apart in four rows across each plot that was 1 meter in length. During the growing season, standard farming methods were employed for good crop stand. Observations on eight morphological traits namelyplant height (cm), number of tillers per plant, days to 50% flowering, flag leaf area $(cm)^2$, spikelet per spike, days to maturity, 1000 grain weight (g), and grain yield per plant (g), were recorded. Statistical analyseswere done using R (version 4) statistical software.

RESULTS AND DISCUSSION

The analysis of variance revealed significant mean squares attributable to genotypes for the eight yield and yield-contributing variables in F_1s (**Table 2**), suggesting the presence of sufficient genetic variation. These results are in line with similar findings reported by Raihan *et al*. (2023), Gul *et al*. (2015), Ram *et al*. (2014). Estimating GCA and SCA variances allows for the assessment of the genetic components of variations, as these parameters provide an indication of the presence of additive genetic variance.In the current study, additive components of variances were found to be larger than dominant components of variances for most characteristics. Both the number of tillers and days to maturity exhibited additive variations, with the ratio of genetic components variance of GCA / variance SCA being greater than one (**Table 3**). The results align with those of Kandil *et al*. (2016), Singh *et al*. (2019), Barot *et al*. (2018) who investigated the same attributes and observed a predominance of additive variances. Apart from plant height, spikelets per spike, 1000 grain weight, and grain yield per plant, the F_1 generation exhibited a higher proportional contribution from the lines for the number of tillers per plant, days to 50% flowering, flag leaf area, and days to maturity (**Table 4**).Considering this, it is evident that selecting lines based on factors other than plant height, spikelets per spike, 1000-grain weight, and plant output is crucial. High-yielding, strip rust-resistant cultivars have been selected for breeding, and lines with the optimal combination of these traits are anticipated to exhibit superior performance.All traits exhibited greater contributions from the testers, indicating weaker paternal influences. Akbar *et al*. (2009), Rauf *et al*. (2023) reported similar findings, highlighting that testers had the least impact on overall variation. For all traits except days to maturity in F_1, the line x tester interaction had more significant relative

Table 1. Description of lines and testers utilized for generating cross combinations

Lines/Testers	Pedigree	Description
HP-06	DANPHE#1*2/SOLALA//BORL14	High Zn & Fe
HP-22	SHAKTI/5/WHEAR/KIRITATI/3/C8001/3*BATAVIA//2*WBLL1*2/4/…	High Zn & Fe
HP-24	KATERE/MUCUY/7/TRAP#1/BOW/3/VEE/PJN//2*TVI/4/BAV92/...	High Zn & Fe
HP-25	KATERE//ONIX/KBIRD/6/C80.1/3*BATAVIA//2*WBLL1/3/ATTILA/….	High Zn & Fe
HP-33	KIRITATI/4/2*SERI.IB*2/3/KAUZ*2/BOW//KAU2/5/CMH81.530/…	High Zn & Fe
HP-44	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/…	High Zn & Fe
HP-45	KOKILA/2*VALI	High Zn & Fe
JAUW 683	Adapted variety /advanced line	Timely sown, irrigated
RSP 561	Adapted variety /advanced line	Timely sown and late sown irrigated
HD3086	Adapted variety /advanced line	Timely sown, irrigated

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Table 2. Analysis of variance for morpho-physiological traits in F_1 generation of wheat

Source of variation	df	Mean Sum of Square							
		Plant height	No. of tillers per plant	Days to 50 percent Flowering	Flag leaf area	Spikelets per spike	Days to maturity	1000 grain weight	Grain yield per plant
Replication	2	2.548	0.419	5.258	4.148	2.882	32.075 **	1.342	5.168
Genotype	30	194.736 **	34.291 **	44.402 **	249.634 **	15.055 **	91.193 **	55.238 **	166.235 **
Parents	9	166.385 **	4.004	18.963	37.765	20.607 **	8.756 **	51.424 **	36.568 **
Line	6	65.524 *	2.825	20.762	52.777 *	7.635 *	4.413	58.232 **	22.036
Testers	2	310.333 **	1.444	13.444	5.281	66.778 **	12.333 *	11.414	74.830 **
Line vs Tester	1	483.657 **	16.192	19.206	12.658	6.102	27.657 **	90.592 **	47.232
Parents vs Crosses	1	2219.614 **	447.714 **	384.414 **	1982.311 **	152.539 **	177.906 **	208.578 **	2149.781 **
Crosses	20	106.249 **	27.249 **	38.849 **	258.341 **	5.683 *	123.954 **	49.287 **	125.408 **
Line Effect	6	18.72	24.905	29.201	302.187	0.831	207.032 **	9.953	18.469
Tester Effect	2	520.587 *	105.540 *	0.968	65.075	5.921	581.635 **	36.081	211.581
Line x Tester	12	80.958 **	15.373 **	49.987 **	268.630 **	8.069 **	6.135 *	71.155 **	164.516 **
Error	60	21.482	5.542	10.425	19.736	2.893	2.886	3.79	12.449
Total	92	77.566	14.805	21.392	94.364	6.859	32.317	20.513	62.439

*, ** significant at 5% and 1% level, respectively.

Table 3. Estimates of components of genetic variances for different quantitative traits in F_1 generations in wheat

Components	Plant height	No. of tillers per plant	Days to 50 per cent flowering	Flag leaf area	Spikelets per spike	Days to Maturity	1000 grain weight	Grain yield per plant
σ^2 GCA	16.545	3.979	0.311	10.926	0.032	26.097	1.282	6.838
σ^2 SCA	19.825	3.277	13.187	82.964	1.725	1.083	22.455	50.689
σ^2 SCA/σ^2 GCA	1.198	0.824	42.444	7.593	53.581	0.041	17.518	7.412
σ^2 GCA/σ^2 SCA	0.835	1.214	0.024	0.132	0.019	24.101	0.057	0.135
σ^2 Line HS	-0.307	2.152	2.086	31.383	-0.229	22.683	0.685	0.669
σ^2 Tester HS	23.767	4.762	-0.45	2.159	0.144	27.56	1.538	9.483
σ^2A(F = 0)	66.179	15.915	1.243	43.705	0.129	104.39	5.127	27.354
σ^2D(F = 0)	79.301	13.109	52.749	331.86	6.901	4.331	89.821	202.76
σ^2A / Var.D	0.835	1.214	0.024	0.132	0.019	24.1	0.057	0.135

Table 4. Proportional (per cent) contribution of lines, testers and their interactions to total variance for different quantitative traits in F_1 generations in wheat

Traits	Contributions of lines	Contributions of testers	Contributions of L X T
Plant height	5.286	48.997	45.718
Number tillers per plant	27.419	38.731	33.850
Days to 50 percent flowering	22.550	0.249	77.201
Flag leaf area	35.039	2.524	62.436
Spikelets per spike	4.385	10.419	85.196
Days to maturity	50.107	46.923	2.970
1000 grain weight	6.061	7.327	86.612
Grain yield per plant	4.420	16.871	78.709

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Table 5. Estimates of general combining ability (GCA) effects for different quantitative traits in F_1 generations in wheat

Accessions	Plant height	Number of tillers per plant	Days to 50 percent flowering	Flag leaf area	Spikelets per spike	Days to maturity	1000 grain weight	Grain yield per plant
HP-06	0.905	-0.571	1.429	7.860 **	0.349	-5.841 **	-0.083	0.316
HP-22	-0.429	-1.905 *	-2.683 *	4.171 **	-0.317	1.270 *	0.362	-1.644
HP-24	1.016	3.429 **	-1.571	3.949 *	-0.095	-3.063 **	0.717	-0.943
HP-25	-2.206	0.429	-1.127	0.071	0.127	-1.175 *	-2.205 **	2.444 *
HP-33	-0.873	-0.349	1.54	-9.062 **	0.349	-2.619 **	0.129	0.248
HP-44	2.127	-0.683	1.984	-3.740 *	-0.429	2.603 **	0.029	0.907
HP-45	-0.54	-0.349	0.429	-3.251 *	0.016	8.825 **	1.051	-1.328
JAUW-683	5.730 **	-1.365 *	0.222	-0.73	-0.397	-5.317 **	-0.194	-2.542 **
RSP 561	-3.270 **	-1.222 *	-0.016	2.008 *	-0.206	0.111	1.397 **	-1.016
HD3086	-2.460 *	2.587 **	-0.206	-1.278	0.603	5.206 **	-1.203 **	3.558 **
CD 95% GCA(Line)	3.122	1.586	2.175	2.993	1.146	1.145	1.311	2.377
CD 95% GCA(Tester)	2.044	1.038	1.424	1.959	0.75	0.749	0.859	1.556

*, ** significant at 5% and 1% level, respectively.

Table 6. Estimates of specific combining ability (SCA) effects for different quantitative traits in F_1 generations in wheat

Crosses	Plant height	No. tillers per plant	Days to 50 per cent flowering	Flag leaf area	Spikelets per spike	Days to maturity	1000 grain weight	Grain yield per plant
HP-06 x JAUW-683	1.381	0.143	-4.667 *	6.763 *	-1.159	-0.349	2.516 *	-1.193
HP-06 x RSP-561	-4.619	-0.667	2.571	-4.241	0.984	0.222	-0.108	0.602
HP-06 x HD-3086	3.238	0.524	2.095	-2.522	0.175	0.127	-2.408 *	0.591
HP-22 x JAUW-683	5.048	1.143	4.111 *	6.752 *	2.508 *	-0.46	3.271 **	10.284 **
HP-22 x RSP-561	-5.286	-3.333 *	1.016	-16.486 **	-2.349 *	0.111	-0.019	-12.865 **
HP-22 x HD-3086	0.238	2.19	-5.127 **	9.733 **	-0.159	0.349	-3.252 **	2.581
HP-24 x JAUW-683	-1.73	3.143 *	4.667 *	-2.725	1.952	-1.46	1.549	3.42
HP-24 x RSP-561	2.27	0.333	-4.762 *	1.603	0.095	0.111	-0.741	-2.396
HP-24 x HD-3086	-0.54	-3.476 *	0.095	1.122	-2.048 *	1.349	-0.808	-1.023
HP-25 x JAUW-683	3.492	0.143	-0.111	-2.348	0.73	3.317 **	2.738 *	2.403
HP-25 x RSP-561	-2.175	0.333	1.794	1.814	-0.46	-0.778	-4.019 **	-0.04
HP-25 x HD-3086	-1.317	-0.476	-1.683	0.533	-0.27	-2.540 *	1.281	-2.363
HP-33 x JAUW-683	-1.841	-1.413	2.222	4.652	-1.492	-0.905	-6.629 **	-2.242
HP-33 x RSP-561	-0.508	-0.556	-2.873	4.814	0.651	0.00	5.748 **	1.903
HP-33 x HD-3086	2.349	1.968	0.651	-9.467 **	0.841	0.905	0.881	0.339
HP-44 x JAUW-683	-4.508	-1.079	-0.222	-1.17	-1.381	0.206	-1.495	-3.884
HP-44 x RSP-561	11.159 **	1.111	0.683	-3.275	1.095	0.111	-6.219 **	-1.136
HP-44 x HD-3086	-6.651 *	-0.032	-0.46	4.444	0.286	-0.317	7.714 **	5.020 *
HP-45 x JAUW-683	-1.841	-2.079	-6.000 **	-11.925 **	-1.159	-0.349	-1.951	-8.788 **
HP-45 x RSP-561	-0.841	2.778 *	1.571	15.770 **	-0.016	0.222	5.359 **	13.933 **
HP-45 x HD-3086	2.683	-0.698	4.429 *	-3.844	1.175	0.127	-3.408 **	-5.144 *
CD 95% SCA	5.408	2.747	3.768	5.184	1.985	1.982	2.272	4.117

*, ** significant at 5% and 1% level, respectively.

effect than the lines and testers, indicating substantial variation across the crosses. Heterosis can be attributed to this interaction, with a stronger relationship resulting in larger heterotic effects across all the traits.Similar findings were reported by Dere & Birkan Yildirim (2006) and Sudesh *et al*. (2002), emphasizing the significance of interactions in elucidating the complete genetic variation for various wheat traits. The assessment of inbreds based on their breeding qualities, which can help in determining the most effective breeding approach for subsequent generations, heavily relies on combining ability. Through additive genetic diversity, it facilitates the identification of the most suitable hybridization parents. The parental line HP-25 was identified to be an outstanding general combiner for grain yield (**Table 5**), exhibiting the most substantial and favorable GCA effect among the seven lines evaluated.The tester HD-3086 demonstrated strong performance across various parameters, including grain yield and tiller density. Utilizing pedigree selection in conjunction with progeny selection or mass selection in successive generations of segregating wheat populations can further enhance the development of high-yielding varieties. These findings align with previous research Aslam *et al*. (2014), Gul S *et al*. (2015), Kalhoro *et al*. (2015), Kandil *et al*. (2016), Kapoor *et al*. (2011) and Kumar *et al*. (2011). To effectively capitalize on heterosis for commercial purposes, identifying superior cross combinations is essential, highlighting the importance of combining ability. Since SCA effects are primarily linked to non-additive gene effects excluding those resulting from complementary gene action or linkage effects that cannot be fixed in pure lines they hold less relevance in self-pollinated crops like wheat. SCA would be a suitable criterion since the superiority of hybrids does not always indicate their ability to produce transgressive segregants. However, if a cross combination exhibits high SCA and high *per se* performance, and at least one parent is a good general combiner for a specific trait, desirable transgressive segregants are expected to be generated in subsequent generations. A total of 21 of the tested crosses had a statistically significant SCA effect (**Table 6**), highlighting effective trait-specific breeding for enhanced grain yield. Top specific combiners for grain yield were observed in the crosses HP-22 x JAUW-683, HP-44 x HD3086, and HP-45 x RSP-561. Similar findings were reported by Aslam *et al*. (2014), Kalhoro *et al*. (2015), Kandil *et al*. (2016), Kapoor *et al*. (2011), Raj *et al*. (2013) and Singh *et al*. (2019).

Table 7. Heterosis over the mid and better parent for different quantitative traits in F_1 generation in wheat

Crosses	Plant height		Number of tillers per plant		Days to 50 percent flowering		Flag leaf area	
	Mid arent	Better Parent	Mid Parent	Better Parent	Mid Parent	Better Parent	Mid Parent	Better Parent
HP-06 x JAUW 683	10.29 **	3.81	51.35	33.33	1.17	1	78.01 **	70.45 **
HP-06 x RSP-561	-2.25	-5.69	36.84	18.18	8.18 **	8.00 **	43.11 **	43.11 **
HP-06 x HD 3086	15.36 **	10.79 *	100.00 **	64.00 **	9.52 **	7.33 **	42.32 **	37.93 **
HP-22 x JAUW 683	15.77 **	6.03	28.57	28.57	6.20 *	6.02 *	76.40 **	72.89 **
HP-22 x RSP-561	-1.6	-7.69 *	-34.88	-36.36	2.85	2.68	-3.76	-9.59
HP-22 x HD 3086	13.90 **	12.60 **	82.61 **	68.00 **	-1.71	-3.36	83.01 **	77.20 **
HP-24 x JAUW 683	13.37 **	0.95	164.86 **	133.33 **	4.72 *	1.9	57.58 **	37.83 **
HP-24 x RSP-561	11.19 **	1.34	115.79 **	86.36 **	-4.72 *	-7.28 **	77.37 **	49.50 **
HP-24 x HD 3086	18.33 **	16.02 **	100.00 **	64.00 **	1.66	-2.85	68.77 **	46.06 **
HP-25 x JAUW 683	15.51 **	2.86	82.35 **	47.62	3.17	3	37.25 **	25.18
HP-25 x RSP-561	2.75	-6.35	82.86 **	45.45	4.84 *	4.67	56.63 **	37.38 **
HP-25 x HD 3086	13.55 **	11.33 *	115.79 **	64.00 **	3.06	1	44.50 **	30.32 *
HP-33 x JAUW 683	7.40 *	-0.95	17.07	14.29	9.64 **	8.36 **	15.73	14.04
HP-33 x RSP-561	2.3	-3.34	28.57	22.73	4.23	3.01	20.54	17.09
HP-33 x HD 3086	14.94 **	12.78 **	104.44 **	84.00 **	9.66 **	8.90 **	-37.28 **	-37.43 **
HP-44 x JAUW 683	4.86	-0.63	17.07	14.29	7.25 **	6.35 *	9.09	3.23
HP-44 x RSP-561	14.63 **	11.37 **	47.62	40.91	7.93 **	7.02 *	6.59	5.27
HP-44 x HD 3086	4.83	0	73.33 **	56.00 *	8.59 **	7.48 **	24.87 *	19.57
HP-45 x JAUW 683	7.75 *	-0.63	10	4.76	-1.82	-2.63	-26.58 *	-31.08 *
HP-45 x RSP-561	2.3	-3.34	80.49 **	68.18 *	5.47 *	4.61	68.92 **	65.43 **
HP-45 x HD 3086	15.71 **	13.53 **	72.73 **	52.00 *	10.14 **	7.24 **	-2.28	-7.19

*, ** significant at 5% and 1% level, respectively.

Table 7 (Continued). Heterosis over the mid and better parent for different quantitative traits in F_1 generation in wheat

Crosses	spikelets per spike		Days to maturity		1000 grain weight		grain yield per plant	
	Mid Parent	Better Parent	Mid Parent	Better Parent	Mid Parent	Better Parent	Mid Parent	Better Parent
HP-06 x JAUW-683	5.36	-1.67	-11.30 **	-12.14 **	6.06	2.29	36.55 *	14.84
HP-06 x RSP-561	50.00 **	26.92 **	-5.72 **	-7.86 **	5.94	4.72	108.36 **	92.33 **
HP-06 x HD-3086	16.81 *	8.2	-3.25 **	-4.29 **	-5.11	-6.72	144.97 **	125.24 **
HP-22 x JAUW-683	19.30 **	13.33	-6.14 **	-6.92 **	20.56 **	5.45	89.80 **	61.64 **
HP-22 x RSP-561	20.00 *	0	-0.49	-2.63 *	18.78 **	6.2	-13.62	-21.38
HP-22 x HD-3086	9.57	3.28	2.17 *	1.19	3.95	-4.61	141.11 **	118.62 **
HP-24 x JAUW-683	22.94 **	11.67	-9.11 **	-9.22 **	7.67	1.85	38.72 **	31.33 *
HP-24 x RSP-561	45.88 **	26.53 **	-2.71 **	-3.89 **	8.54 *	5.18	49.92 **	23.38
HP-24 x HD-3086	5.45	-4.92	0.73	0.73	3.93	3.63	90.34 **	56.11 **
HP-25 x JAUW-683	14.29 *	6.67	-4.37 **	-4.37 **	5.94	-2.73	41.71 **	40.45 **
HP-25 x RSP-561	38.64 **	17.31 *	-2.09 *	-3.40 **	-6.4	-12.03 **	73.63 **	36.02 *
HP-25 x HD-3086	13.27 *	4.92	-0.85	-0.97	4.72	1.18	88.08 **	46.89 **
HP-33 x JAUW-683	-3.33	-3.33	-8.50 **	-8.50 **	-6.67	-21.28 **	10.71	9.34
HP-33 x RSP-561	35.42 **	8.33	-2.58 **	-3.88 **	41.14 **	21.55 **	76.79 **	40.69 **
HP-33 x HD-3086	12.40 *	11.48	0.61	0.49	21.04 **	6.86	96.48 **	55.87 **
HP-44 x JAUW-683	-8.2	-9.68	-4.00 **	-4.12 **	1.41	-8	9.07	4.51
HP-44 x RSP-561	30.61 **	3.23	1.23	-0.24	-5.13	-11.93 **	68.10 **	36.98 *
HP-44 x HD-3086	4.07	3.23	3.40 **	3.15 **	32.79 **	26.67 **	139.56 **	94.56 **
HP-45 x JAUW-683	-1.69	-3.33	0.12	0	-8.20 *	-9.84 *	-21.54	-30.61 *
HP-45 x RSP-561	31.91 **	6.9	5.90 **	4.36 **	17.70 **	12.81 **	180.32 **	145.35 **
HP-45 x HD-3086	14.29 *	11.48	8.25 **	7.99 **	-10.05 *	-16.12 **	74.96 **	52.58 **

*, ** significant at 5% and 1% level, respectively.

Heterosis, also known as hybrid vigour, plays a crucial role in breeding programs as it often results in superior performance in hybrid offspring compared to their parents. Significant heterosis was observed over both the better parent (heterobeltiosis) and the mid parent (relative heterosis) across all traits. These findings are consistent with previous studies (Raj *et al*., 2013), confirming their reliability. Statistically significant positive heterobeltiosis and relative heterosis for most of the traits was observed in the crosses HP-06 x RSP-561 , HP-06 x HD-3086, HP-22 x JAUW-683 and HP-24 x HD-3086 (**Table 7**). This finding is supported by similar outcomes reported by Al-Daej (2022), Ismail (2015), Barot *et al*. (2014). To enhance both yield and micronutrient (Zn & Fe) content, it is essential to select stable lines in advanced segregating generations, with cross combinations like HP-06 x RSP-561 standing out as the best combiners with heterotic effects for grain yield and yield-contributing traits. Some of the wheat lines used as parental lines, surpassing their superior parents in the evaluated traits, hold promise for the future commercial production of hybrid wheat.

The study underscores the significance of leveraging genotypic combining abilities for breeding. HP-25, HP-24, HP-22, and HP-06 are strong general combiners for grain production and maturity. HD-3086 and RSP-561 are recommended general combiners, particularly for grain production. Crosses like HP-22 x JAUW-683, HP-44 x HD-3086, and HP-45 x RSP-561 show promising specific combining ability for grain yield. Notably, HP-06 x RSP-561 exhibits optimal heterotic impacts on grain yield and other traits. Additionally, various other effective combiners offer potential for selecting stable elite lines with enhanced yield in subsequent breeding.

REFERENCES

Akbar, M., Anwar, J., Hussain, M., Qureshi, M.H. and Khan, S. 2009. Line × tester analysis in bread wheat (*Triticum aestivum* L.). *J. Agri. Res. Pak.*,**47**: 21-30.

Al-Daej, M. I. 2022 Estimation of heterosis, heritability and genetic parameters for some agronomic traits of rice using the line × tester method. *J. King Saud Uni. Sci.*,**34**:101906. [Cross Ref]

Aslam, R., Munawar, M. and Salam, A. 2014. Genetic architecture of yield components accessed through line × tester analysis in wheat (*Triticum aestivum* L.). *Univ. J. Plant Sci.,***2**:93–96. [Cross Ref]

Barot, H.G., Patel, M.S. and Joshi, D.J. 2018. Study of combining ability for yield and its contributing traits in bread wheat (*Triticum aestivum* L.). *Electron. J. Plant Breed.,***9** (3), 899-907. [Cross Ref]

Barot, H.G., Patel, M.S., Sheikh, W.A., Patel, L.P. and Allam, C.R. 2014. Heterosis and combining ability analysis for yield and its component traits in wheat (*Triticum aestivum* L.). *Electron. J. Plant Breed.,***5** (3): 350-359.

Dere, Ş. and Birkan Yildirim, M. 2006. Inheritance of grain yield per plant, flag leaf width, and length in an 8 x 8 diallel cross population of bread wheat (*Triticum aestivum* L.). *Turk. J. Agri.-Forestry,***30:** 339-345.

Erenstein, O., Jaleta, M., Mottaleb, K.A., Sonder, K., Donovan, J. and Braun, H.J. 2022. Global trends in wheat production, consumption and trade. In: Reynolds M.P., Braun H.J. (eds) Wheat Improvement. Springer, Cham.

Gul, S., Aziz, M.K., Ahmad, R.I., Liaqat, S., Rafiq, M., Hussain, F., Rafiq, M. and Manzoor. 2015. Estimation of heterosis and heterobeltiosis in wheat (*Triticum aestivum* L.) crosses. *Basic Res. J. Agric. Sci.,***4:** 151-157.

Ismail, S.K.A. 2015. Heterosis and combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L.). *Int. J. Curr. Microbiol. Appl. Sci.,***4**: 1-9 [Cross Ref]

Kalhoro, F.A., Rajpar, A.A., Kalhoro, S.A., Mahar, A., Ali, A., Otho, S.A., Soomro, R.N., Ali, F. and Baloch, Z.A. 2015. Heterosis and combining ability in F1 population of hexaploid wheat (*Triticum aestivum* L.). *Am. J. Plant Sci.,***6:** 1011-1026. [Cross Ref]

Kandil, A.A., Sharief, A.E., Hasnaa, S.M. and Gomaa. 2016. Estimation of general and specific combining in bread wheat. *Int. J. Agric.,***8**: 37-44. [Cross Ref]

Kapoor, E., Mondal, S.K. and Dey, T. 2011. Combining ability analysis for yield and yield contributing traits in winter and spring wheat combinations. *J. Wheat Res.,***3:** 52-58. [Cross Ref]

Kempthorne, O. 1957. An Introduction to Genetic Statistics.

Kumar, V., Bai, R L., Maloo, S R. and Malool, S R. 2011. Heterosis and combining ability studies for yield components and grain protein content in bread wheat *Triticum aestivum* (L.). *J. Genet.,***71**: 363-366.

Manivannan, N., Muralidharan, V. and Mothilal, A. 2008. Combining ability analysis in groundnut (*Arachis hypogaea* L.). *Madras Agric. J.,***95** (1-6): 14-17. [Cross Ref]

Prasad, B. 2014. Heterotic vigour studies in forage sorghum hybrid by multiple criteria. *J. Hill Agric.,***5**: 182**.** [Cross Ref]

Raihan, H., Mithila N., Akhter S., Khan A. and Hoque M. 2023. Heterosis and combining ability analysis in maize using line x tester model. *Bangladesh J. Agric. Res.,***46** (3), 261–274. [Cross Ref]

Ram, M., Singh, R.M. and Agrawal, R.K. 2014. Genetic analysis for terminal heat stress in bread wheat (*Triticum aestivum* L.). *The Bioscan,* **9**: 771-776. [Cross Ref]

Rauf, A., Khan, M.A., Jan, F., Gul, S., Afridi, K., Khan, I., Bibi, H., Khan, R.W., Khan, W., and Kumar T. 2023. Genetic analysis for production traits in wheat using line x tester combining ability analysis. *SABRAO J. Breed. Genet.,***55** (2), 358-366. [Cross Ref]

Sheera, A., Dey, T., Pandey, M.K., Singh, T., Bhagat, T. and Shruthi, K. 2022. Genetic divergence in micronutrient-rich wheat – a tool to identify diverse parents. *Int. J. Environ. Clim. Change*, **1**: 150-156. [Cross Ref]

Singh, G.P., Sendhil, R. and Jasrotia, P. 2019. AICRP on Wheat and Barley: Salient Achievements and Future Directions. *Indian J. Fertil.,***15**: 80-90.

Sudesh, R., Yadava, K. and Rana, O.P. 2002. Combining ability effects in bread wheat involving gigas spike genotypes as testers. *Res. Crops,***3**: 426-431.

USDA, 2022-23. [Cross Ref]

Wheat Production, 1990. [Cross Ref]