Combining Ability and Heterosis Analysis for Grain Yield and Yield Components in Bread Wheat (*Triticum aestivum* L.)

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Abstract

Bread wheat is the primary strategic crop relied upon for human food sustainability. Therefore, this study was conducted to produce superior hybrids with yield characteristics in different environments. Half-cross crosses were performed between six Bread wheat varieties (IPA 99, IPA 95, Abu Ghraib 3, Fateh, Tahadi, and Taka 1). These varieties and their hybrids were grown in four environments to study Heterosis and the nature of gene influence in the parents and their hybrids regarding yield characteristics and components. The results showed that additive gene effects were more pronounced in some traits and less so in others. Additive and dominant effects were equal for 1000-grain weight and grain yield per plant. The parents IPA 99 and Taka 1 showed the best overall combination for most traits. The hybrid (IPA 99 × Abu Ghraib 3) also showed the best results. The IPA 95 × Fateh hybrid showed relatively high performance and ability to combine types and effects of hybrid vigor in the desired directions for a wide range of traits. Heritability in the narrow sense was high for most traits; hybrids superior in yield traits could be used in most environments to increase bread wheat production.

Introduction

Wheat (*Triticum aestivum* L.) is grown in various environments and is a staple food for millions of people worldwide, demand for it is increasing by 2% annually, which does not allow for a corresponding increase in its production (FAO, 2024). One of the most important procedures followed in improving wheat production is the production of high-yielding varieties and hybrids, this allows for increasing the genetic base of wheat genetic makeup and testing it under the influence of different environments, given that most quantitative traits are affected by the environment (Panhwar *et al*, 2024). Therefore, studying the genetic content of wheat varieties under the influence of their growing environments is crucial. Wheat hybrids can be produced using various mating systems, culminating in genetic analysis of the resulting hybrids. Researchers have developed techniques for analyzing the genetic patterns of all potential hybrids. This is essential for producing high-yielding varieties under a wide range of environmental conditions (Sharma *et al.,* 2019).

One of the important strategies for increasing wheat production is to cross-breed existing varieties with those with high and desirable general combining ability supported by information about the nature of gene action that affects grain yield and then select for transgressive segregations

in the offspring generations. In addition, information on the effects of general and specific combining abilities of wheat genotypes helps in implementing an efficient breeding program for the crop (Panhwar *et al.,* 2024). Among the genetic designs, diallel cross is considered the appropriate method to obtain suitable information about different traits in a short period of time. Information about general and specific combining abilities is of great importance for plant breeders to select for suitable genotypes and develop new varieties with high productivity characteristics (Khoury *et al.,* 2023; Panhwar *et al.,* 2024). The effect of heterosis has also been used in the field of breeding open-pollinated plants such as maize, and at present, the focus is also on hybrid breeding in self-pollinated crops including wheat (AL-Mafarji *et al.,* 2024), and the development of hybrid wheat is based on the assumption that there is heterosis in this crop (Khoury *et al.,* 2023; Dahiya *et al.,* 2023).

Taking into consideration the importance of estimating genetic parameters through adopting an appropriate method of a breeding program, the objectives of this study were to estimate general combining ability (GCA) and specific combining ability (SCA) effects for yield and its components under multiple environments, identify superior parents and hybrids for wheat improvement, and assess key genetic parameters including heterosis and heritability.

Materials and Methods

Bread wheat varieties (1) IPA95, (2) IPA99, (3) Abu Ghraib3, (4) Fatih, (5) Tahady and (6) Takka1 were subjected to half-diallel crosses according to the second method proposed by Griffing (1956), when they were planted in the first week of November 2019 in a field in Baldroz district, Diyala province, then the seeds of the first generation hybrids, amounting to 15 single hybrids, were obtained. The six varieties and their 15 hybrids were planted in mid-November of the two agricultural seasons 2020-2021 and 2021-2022 in two locations in each season, the first in Baladruz district, which is 45 km away from the governorate center, and the second in Mandali, which is 95 km away from the governorate center, The experimental unit consisted of three lines, each 3 m in length, with a 0.20 m distance between them. Flood irrigation was applied as needed during the study. Data were recorded on individual plants (ten plants were randomly selected from each experimental unit) for the following traits:

1. Plant height (cm)

The height of the plant was measured at the 100% flowering stage, from the average height of ten plants using a metric ruler from the base of the plant to the end of the spike of the main branch (without the awns).

2. Spike length (cm)

The average length of ten main spikes was measured for each experimental unit using a metric ruler.

3. **Number of tillers per plant**

The number of tillers was calculated for ten wheat plants per experimental unit at 100% flowering. The average number of tillers per plant was then calculated.

4. Number of grains per spike

Calculate the average number of grains for ten main spikes from each experimental unit.

5. 1000 grain weight (g)

The average weight of 100 grains was taken randomly from the grain yield of ten plants from each experimental unit and then converted to the weight of 1000 grains.

6. Grain yield per plant (g)

The total grain yield of ten plants from the experimental unit was weighed and then divided by the number of plants present in it.

The combined analysis of genotypes (parents + hybrids) as well as both parents and hybrids were done for the data of the four environments (Baldroz Season 2021, Mendley Season 2021, Baldroz Season 2022, Mendley Season 2022) and for each trait according to the experimental design method used (Al-Zubaidy and Al-Falahy, 2016). Then the genotypes sum squares of deviation was divided into the general and specific combining abilities and their interactions with the environments (seasons and locations) according to the second method, first (fixed) model proposed by Griffing (1956), and the following estimates were made:

1. The effects of the general combining ability (GCA) of parents and the specific combining ability (SCA) of hybrids from the combining analysis and their significance were tested using a t-test, as reported in (Al-Zubidy and Al-Jubouri, 2016).
2. The phenotypic variance components (additive, dominant, and environmental) were determined based on the expected mean square from Griffing analysis (fixed model), and their significance from zero was tested by the method described by Kempthorne (1957).
3. The heritability in both broad and narrow senses and the limits of each were adopted (to identify its importance) according to Ali (1999); Al-Adari (1999), respectively.
4. The average degree of dominance for each trait is used to identify the type of dominance that controls its inheritance (Mather and Jinks, 1982).
5. The expected genetic advance from selection in the next generation as a percentage for each trait mean (GA%) from the equation:

$$GA\% = [(h^2 \times \sigma P \times i) / \text{character over all mean}] \times 100$$

Where h^2, σP and i mean narrow-sense heritability, phenotypic deviation and selection intensity (which is equal to 1.76 when 10% of the plants are selected) respectively.

The expected genetic advance ranges suggested by Agarwal and Ahmad (1982) were adopted.

The following available statistical programs were used to analyze the data statistically and genetically (Statistical Analysis System, Minitab and Microsoft Office Excel 2021).

Statistical analysis

The data were statistically analyzed using the program (SAS 9.4, 2013) Random Complete Block Design (RCBD) with three iterations. A pooled analysis was performed between sites, and means were compared using Duncan's multiscale test at a probability level of 0.05.

Results and Discussion

Table 1 shows the combined analysis of variance results across the four environments (two seasons and two locations in each season) for each of the parents, first-generation hybrids, or all genotypes. It is noted that the mean squares of the environments, genotypes, parents, and hybrids were highly significant for all traits except grain yield per plant (not significant in the case of parents). And the mean squares of the parents verse hybrids were highly significant for the traits of number of tillers per plant, 1000-grain weight, and grain yield per plant, and not significant for other traits.

Table 1. Combined analysis of variance results of genotypes, parents and hybrids for wheat traits

Source	df	Mean square for traits					
		Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
Environments	3	904.57**	27.69**	0.574**	896.04**	3102.22**	50.612**
Blocks/Env.	8	37.087	1.111	0.020	39.823	13.568	12.899
Genotypes	20	541.76**	18.254**	2.094**	381.75**	104.543**	57.385**
Parents	(5)	601.48**	26.768**	2.521**	285.83**	87.655**	67.431
Hybrids	(14)	567.43**	16.665**	1.998**	445.959**	95.987**	43.467**
ParentsvsHybrids	(1)	9.674	0.013	0.129**	49.339	83.073**	128.281**
Genot. × Env.	60	3.773	0.058	0.001	1.903	16.984**	0.433
Exp. Error — genotypes	160	6.151	0.236	0.002	3.886	3.999	1.373
Exp. Error — Parents	46	11.589	0.371	0.00004	1.771	1.335	1.075
Exp. Error — hybrids	112	4.088	0.189	0.0014	4.484	5.111	1.555

(**) and (*) are significant at 1% and 5% probability levels, respectively.

As for the interaction between genotypes and environments, it was significant at 1% probability level for the trait of 1000-grain weight, which indicates that the performance of some genotypes for this trait is unstable in different environmental conditions, and not significant for other traits. The high significance of the mean squares of the genotypes for all traits indicates the large genetic divergence in these populations. Similar findings were reported by UL-Haq et al. (2022); Khoury (2023). So, the subsequent genetic analysis of combining ability is necessary. Therefore, the total genetic changes were divided into general and specific combining abilities and their interactions with the environment (Table 2). It is noted that the mean squares of the general and specific combining abilities were highly significant for all traits, indicating the importance of additive and dominant genetic effects in their inheritance. However, the mean squares of the interaction of the general and specific combining abilities with environmental factors were not significant for all traits, indicating the stability of the gene action for all traits under different environmental conditions. It is noted that the ratio of the components of the general combining ability to those of the specific combining ability was greater than one for the traits of plant height, spike length, and number of grains per spike. This indicates that the additive genetic effects were more important than the dominant ones in controlling the inheritance of these traits, while the ratio was less than one for the other traits, indicating the greater importance of the dominant genetic effects in their inheritance.

Table 2. Combined analysis of variance results for GCA an SCA and their interactions with the environment for wheat traits

Source	df	Mean square for traits					
		Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
GCA	5	1770.2**	62.03**	4.901**	1169.14**	237.23**	142.801**
SCA	15	132.28**	3.66**	1.158**	119.287**	59.823**	28.913**
GCA × Environ.	5	1.470	0.108	0.001	0.657	0.772	0.513
GCA × Environ.	15	4.429	0.052	0.002	1.738	0.846	0.251
Error	160	6.151	0.236	0.002	3.886	3.999	1.373
GCA/SCA components		1.748	2.256	0.044	1.262	0.522	0.642

(**) Significant at 1% and probability levels, respectively.
- GCA: General combining ability, SCA: Specific combining ability.

Table 3 shows the means of the four environments in which cultivation was carried out for the studied traits, and the results of the comparison between them using Duncan's multiple range test method. It is noted that the Baladrooz location in 2022 gave the highest means for the traits of the plant. height, spike length, number of tillers per plant, number of grains per spike, and grain yield per plant (which were higher than the general means for the trait) with a non-significant difference from Baldroz in 2021 for spike length, number of tillers per plant, and number of grains per spike, and from Baldroz in 2021 and Mandali in 2022 for the trait of grain yield. As for the trait of 1000-grain weight, the highest mean reached 54.162 g in Mandali 2022 with a significant difference from the other three environments, the differences between which were non-significant.

Table 3. Environmental means for wheat traits

Parents	Traits					
	Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
Baldroz 2021	90.085 b	10.814 ab	4.409 ab	54.125 a	39.749 b	23.051 ab
Mandali 2021	84.120 c	9.537 c	4.234 c	48.827 b	41.042 b	21660 b
Baldroz 2022	92.618 a	11.042 a	4.455 a	56.244 a	39.749 b	23.818 a
Mandali 2022	86.357 c	10.428 b	4.369 b	48.827 b	54.162 a	22.999 ab
General mean	88.295	10.455	4.367	52.006	43.676	22.882

- Values followed by the same letter for each trait are not significantly different from each other.

Table 4 shows the means of the parents for the different traits and their general combining ability effects. It is noted that for the traits of plant height and spike length, the variety Takk1 gave the highest highly significant desired effect of the general combining ability (4.261 and 0.778, respectively) and at the same time it was distinguished by its mean performance for the two traits. Likewise, the varieties IPA95, IPA99 and AbuGhraib3 had significant and desirable effects for the two traits. For the trait of number of tillers per plant, there were highly significant effects of the general combining ability in the varieties AbuGhraib3, Fatih and Tahadi (0.191, 0.283 and 0.116, respectively). The cultivar Fatih was surpassed in the number of tillers by a significant difference

from all other varieties, and therefore it is the most efficient in improving the trait. The effects of general combining ability for number of grains per spike were significant at 1% probability level in the desired direction in the cultivars IPA99, Fatih and Takka1 (2.553, 1.055 and 4.482 respectively), and Takka1 variety, in addition to having the highest significant effect, gave the highest mean for the trait, reaching 58.586, with a significant difference from all other varieties, and thus was the most useful in improving this trait. The effects of general combining ability were highly significant and desirable for 1000-grain weight trait in the varieties IPA95, IPA99 and Takk1 (0.721, 1.631 and 1.413, respectively). While the mean performance of the three varieties was high and distinguished with a significant difference from the other varieties, reaching (43.766, 43.758 and 43.939, respectively).

Table 4. Parental means and their general combining ability effects for wheat traits

Parents		Traits					
		Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
1- IPA 95	Mean	91.029 b	10.932 b	3.634 f	48.374 c	43.766 a	21.596 b
	Effect	1.407**	0.247**	-0.211**	-1.159**	0.721**	-0.170
2- IPA 99	Mean	88.940 b	11.509 a	4.117 e	53.309 b	43.758 a	22.446 b
	Effect	1.749**	0.501**	-0.119**	2.553**	1.631**	0.829**
3- Abo Graib 3	Mean	89.378 b	10.102 c	4.715 b	48.160 c	37.967 d	21.689 b
	Effect	1.908**	0.447**	0.191**	-1.488**	-1.814**	0.473**
4-Fatih	Mean	75.706 d	9.140 d	4.884 a	52.546 b	42.081 b	19.586 c
	Effect	-7.971**	-0.696**	0.283**	1.055**	0.021	-0.714**
5- Tahaddy	Mean	82.848 c	7.890 e	4.618 c	45.624 d	39.414 c	18.154 d
	Effect	-1.353**	-1.277**	0.116**	-5.442**	-1.972**	-1.927**
6- Takka 1	Mean	94.638 a	11.463 a	4.449 d	58.586 a	43.939 a	24.508 a
	Effect	4.261**	0.778**	-0.259**	4.482**	1.413**	1.508**
Parents means		87.090	10.173	4.403	51.099	41.821	21.330

- Mean values followed by the same letter for each trait are not significantly different from each other.
(**) For general combining ability effects are significant at 1% probability level.

Finally, for the grain yield trait per plant, the varieties IPA99, Abu Ghraib3 and Takka1 showed highly significant and desirable effects of the general combining ability (0.829, 0.473 and 1.508, respectively). The variety Takka1, which was distinguished in its general combining ability, gave the highest grain yield per plant, reaching 24.508 g, with a significant difference from all other varieties. In general, it is noted that the two cultivars, IP99 and Takka1, showed a highly significant and desirable general effects for all traits except the number of tillers per plant, which encourages their adoption in breeding programs to improve these traits. They are followed in importance by the variety Abu Ghraib3 and then IPA99, which showed a significant and desirable effect for four and three traits, respectively. All the above results are consistent with what was found by Motawea (2017), Afridi *et al.* (2018), Sharma *et al.* (2019), Al-Abd Al-Wahid (2020), and Yassin *et al.* (2024), where they found different effects of the general ability to combine between wheat patterns on the grain yield of each plant and some of its other component traits.

Table 5 shows data on the means of hybrids, their heterosis based on the deviation of the mean of the hybrid from the mid parents' means, and their effects on the specific combining ability. It is noted that the highest means were in hybrids (3 × 6) for plant height and spike length (97.924 cm and 12.254 cm, respectively) and (1 × 4) for number of branches per plant (4.925 branches) and (2 × 6) for the number of grains per spike, the weight of 1000 grains, and the grain yield per plant (62.789 grains, 50.052 g, and 27.372 g, respectively). It appears that a limited number of single hybrids showed a significant effect of the specific combining ability in the desired direction for each trait, as the number of hybrids with desired significant effects was four for plant height, six for each of spike length, number of tillers per plant, 1000-grain weight, and grain yield per plant, and seven hybrids for number of grains per spike. It is noted that three hybrids were each characterized by significant and desirable effects for four traits, which are: (1 × 4) for the traits of number of tillers per plant, number of grains per spike, 1000 grains weight and grain yield per plant, and (2 × 3) for the traits of plant height, spike length, number of grains per spike and 1000 grains weight, and (5 × 6) for the traits of spike length, number of tillers per plant, number of grains per spike, and 1000 grains weight, followed by hybrids (1 × 2), (1 × 3), (2 × 4), (2 × 6), and (3 × 4), each of which had a significant and desirable effect for three traits, including grain yield per plant in hybrids (1 × 3), (2 × 4), and (2 × 6). In addition to giving good performance means for these traits, it is noted that most of the single hybrids with significant desirable effects for a trait had at least one of their parents give a significant desirable effect for that trait. From previous studies, Khoury *et al.* (2023) and Dahiya *et al.* (2023) obtained significant effects of the specific combining ability shown by some hybrids for the traits of grain yield and its components from other traits. As for heterosis, the number of hybrids that gave significant heterosis in the desired direction was six for each of the traits of plant height and number of tillers per plant, seven for each of the traits of spike length and number of grains per spike, ten for the trait of 1000-grain weight, and twelve for the trait of grain yield per plant.

The highest heterosis was 6.854 cm in the hybrid (1 × 5), 1.472 cm in the hybrid (3 × 6), 0.666 branches in the hybrid (1 × 4), 5.351 in the hybrid (4 × 6), 5.595 in the hybrid (2 × 3), and 3.837 in the hybrid (2 × 4) for the traits of plant height, spike length, number of tillers per plant, number of grains per spike, weight of 1000 grains, and grain yield per plant, respectively. It is noted that some hybrids were distinguished by a desirable significant heterosis for the largest number of traits, including the grain yield per plant. This number of traits reached five in hybrids (1 × 2), (1 × 3), (2 × 3), and (3 × 4), four in hybrids (1 × 4), (2 × 4), and (3 × 6). It is noted that some hybrids have combined the specifications of good performance, and significant of both specific combining ability and heterosis in the desired direction, which are: (1 × 2) and (2 × 3) for plant height, (1 × 6) and (2 × 3) for spike length, (1 × 3) and (1 × 4) for number of tillers per plant, (1 × 4), (2 × 3) and (4 × 6) for number of grains per spike, (1 × 4), (2 × 3) and (5 × 6) for 1000 grains weight, and (1 × 3) and (2 × 4) for grain yield per plant. It seems that the hybrid (2 × 3) has been distinguished by the values of the three components (average performance, specific combining ability and heterosis) for the traits of plant height, spike length, number of grains per spike and weight of 1000 grains, followed by the hybrid (1 × 4) for the number of tillers per plant, number of grains per spike and 1000 grains weight, These results indicate the possibility of benefiting from these distinguished hybrids in breeding and hybrid production programs.

Table 5. Hybrid means, heterosis and their specific combining ability effects for wheat traits

Hybrids		Traits					
		Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
1 × 2	mean	93.52bcd	11.432 cd	4.065 e	54.13 def	46.217 bc	23.418 ef
	Heterosis	3.529*	0.212	0.189**	3.289**	2.455*	1.397*
	Effect	2.063**	0.229*	0.027**	0.731	0.189	-0.123
1 × 3	mean	92.049 d	11.200 de	4.788 c	51.661 g	43.110 e	24.589 cd
	Heterosis	1.846	0.683*	0.614**	3.394**	2.244*	2.947**
	Effect	0.439	0.051	0.442**	2.302**	0.528	1.405**
1 × 4	mean	74.436 j	9.702 g	4.925 a	55.702 cd	46.923 b	23.306 f
	Heterosis	-8.932**	-0.334	0.666**	5.242**	3.999**	2.715**
	Effect	-7.295**	-0.305**	0.487**	3.800**	2.507**	1.308**
1 × 5	mean	93.79 bcd	9.185 h	4.002 j	43.044 j	44.25 cde	19.875 h
	Heterosis	6.854**	-0.226	-0.124**	-3.955**	2.664*	0.000
	Effect	5.443	-0.240*	-0.115**	-2.360**	1.829**	-0.910**
1 × 6	mean	93.47bcd	11.779 bc	3.679 o	53.481efg	43.458 de	24.44 cde
	Heterosis	0.638	0.582*	-0.363**	0.001	-0.395	1.385*
	Effect	-0.571	0.282*	-0.529**	-3.160**	-3.702**	-0.731*
2 × 3	mean	94.827 bc	11.628 bc	4.391 h	55.21 cde	46.457 b	24.556 cd
	Heterosis	5.668**	0.8223**	-0.025	4.478**	5.595**	2.489**
	Effect	2.876**	0.225*	-0.047**	2.141**	2.964**	0.372
2 × 4	mean	84.205 g	10.151 f	4.709 e	56.193 c	45.34 bcd	24.85 bc
	Heterosis	1.882	-0.174	0.209**	3.266**	2.425*	3.837**
	Effect	2.132**	-0.108	0.179**	0.579	0.017	1.855**
2 × 5	mean	86.464 f	9.088 h	4.428 f	49.517 h	-43.192 e	21.722 g
	Heterosis	0.570	-0.612*	0.061*	0.051	1.606	*1.422
	Effect	-2.227**	-0.591**	0.065**	0.401	-0.143	-0.064
2 × 6	mean	95.163 b	11.871 b	3.788 n	62.789 a	50.052 a	27.372 a
	Heterosis	3.374*	0.385	-0.495**	6.842**	6.204**	3.895**
	Effect	-1.993**	0.191	-0.212**	-0.052	0.152	0.056
3 × 4	mean	81.494 h	11.050 e	4.856 b	52.755 fg	43.129 e	22.083 g
	Heterosis	-1.048	1.429**	0.057*	2.402*	3.105*	1.446*
	Effect	-0.738	0.844**	0.016	1.182*	1.248**	-0.558*
3 × 5	mean	88.277 e	10.426 f	4.627 f	42.764 j	38.758 f	23.66 def
	Heterosis	2.164	1.430**	-0.039	-4.128**	0.068	3.735**
	Effect	-0.573	0.800**	-0.046**	-2.312**	-1.132*	2.227**
3 × 6	mean	97.924 a	12.254 a	4.002 l	53.309efg	43.830 de	25.695 b
	Heterosis	5.916**	1.472**	-0.850**	-0.064	2.877*	2.597**
	Effect	0.728	-0.673**	-0.331**	-2.444**	-1.526**	-1.307**
4 × 5	mean	79.723 i	8.175 i	4.743 d	41.819 j	39.721 f	21.265 g
	Heterosis	0.446	-0.340	-0.008	-7.266**	-1.027	2.395**
	Effect	0.752	-0.308**	-0.022*	-5.798**	-2.004**	1.023**
4 × 6	mean	83.026gh	10.262 f	3.828 m	60.917 b	46.614 b	23.784c-f
	Heterosis	-2.146	-0.039	-0.839**	5.351**	3.604**	*1.737
	Effect	1.759**	-0.199	-0.600**	1.806**	-0.131	**1.761-

5 × 6	mean	93.288cd	10.319 f	4.302 i	52.107	45.21 b-e	21.938 g
	Heterosis	4.545**	0.643*	-0.232**	0.002 g	3.528**.	0.607
	Effect	-0.656	0.350**	0.098**	5.565**	1.768**	-1.401**

- Means values followed by same letter for each trait are not significantly different from each other.

Table 6 shows the estimates of variance components and genetic parameters for the studied traits. It is clear from this that the additive and dominance genetic variances were significant from zero for all traits, indicating their importance in controlling the inheritance of these traits. It is noted that the values of the additive genetic variance were greater than those of the dominance for the traits of plant height, spike length, and number of grains per spike, indicating the greater importance of the additive genetic effect for these traits, while the opposite was true for the number of tillers per plant, and they were close for the traits of 1000-grain weight and grain yield per plant, which indicates that the additive and dominance genetic effects were equally important in their effect on these two traits. For this reason, it is noted that the values of narrow-sense heritability were different and less than the values of broad-sense heritability by different limits between the traits, as the values of narrow-sense heritability ranged between 8.09% for the number of tillers per plant and 71.18% for spike length, i.e. they were low for number of tillers per plant and moderate for the traits of 1000-grain weight and grain yield per plant, which means that selection in the early generations is not effective for the traits of number of tillers, 1000-grain weight and grain yield per plant, while the values of broad-sense heritability ranged between 70.40% for 1000-grain weight and 99.84% for number of tillers per plant, i.e. they were high for all traits. The values of average degree of dominance appeared greater than one for the traits of number of tillers per plant, 1000-grain weight and grain yield per plant indicating the presence of over dominance, and these over dominance values may be due to the distribution of linked genes between parents, and therefore partial dominance appears as over dominance (Hayman, 1954). However, for the other traits, they were less than one, indicating the presence of partial dominance. Finally, it is noted that the expected genetic advance in the next generation as a percentage was moderate for spike length and number of grains per spike and low for other traits, as it ranged between 0.033% for number of tillers per plant and 16.024% for spike length. It is noted that the narrow sense heritability is less associated with the traits of number of tillers per plant, 1000-grain weight and grain yield per plant with low expected genetic advance, which confirms that these traits are subject to the dominant genetic effect.

Table 6. Estimates of variance components and genetic parameters for wheat traits

Variance components and genetic parameters	Traits					
	Plant height (cm)	Spike length (cm)	Number of tillers per plant	Number of grains per spike	1000 grain weight (g)	Grain yield per plant (g)
Additive genetic variance	36.751 + 19.713	1.287 + 0.691	0.102 + 0.055	24.276 + 13.019	4.859 + 2.642	2.946 + 1.590
Dominant genetic variance	10.511 + 3.781	0.285 + 0.105	1.158 + 0.033	9.617 + 3.409	4.652 + 1.710	2.295 + 0.827
Environmental variance	6.151 +	0.236 +	0.002 +	3.886 +	3.999 +	1.373 +

	0.683	0.026	0.0002	0.432	0.444	0.153
Total genetic variance	47.262	1.573	1.260	33.893	9.511	5.241
Phenotypic variance	53.413	1.809	1.262	37.779	13.509	6.614
Average degree of dominance	0.756	0.666	4.764	0.890	1.384	1.248
Narrow sense heritability	0.8848	0.8695	0.9984	0.8972	0.7040	0.7924
Broad sense heritability	0.6881	0.7118	0.0809	0.6426	0.3597	0.4456
Expected genetic advance, GA	8.800	1.675	0.159	6.912	2.313	2.005
GA%	9.967	16.024	0.033	13.290	5.297	8.762

Conclusions

It can be concluded from the above that it is possible to benefit from the two wheat varieties IPA99 and Takka1 because they are distinguished by a significant general combining ability effects in the desired direction for all traits except number of tillers per plant, and the two hybrids (IPA99 × Abu Ghraib3) and (IPA95 × Fatih), because they are distinguished by their mean performance and significant SCA effects and heterosis in the desired direction for largest number of traits in developing high-yielding hybrid varieties as well as to exploit the phenomenon of heterosis.

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Conflict of interest

The researcher declares that there is no conflict of interest in preparing this research.

Funding Declaration

Author Contribution

The author writes the original draft, and edit and finalize the manuscript. and author read and the submission of the manuscript to the journal.

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