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DIALLEL ANALYSIS IN BREAD WHEAT (*TRITICUM AESTIVUM* L.) CULTIVATED IN UZBEKISTAN

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SUMMARY

Diallel analysis undertakes the adequate capture of the interaction of genes contributing to traits' variation by the general (GCA) and specific combining ability (SCA) effects. However, in reality, the genes' interaction can be more complex, involving epistatic interactions and pleiotropy, which are unaccounted for in the traditional diallel analysis. Therefore, the presented work sought to study the combining ability in wheat genotypes widely planted in Uzbekistan. The mode of inheritance as studied through combining ability included the vegetation period, plant height, vitreousity, grain weight per ear, 1000-kernel weight, grain yield, and productive accumulation in 4 × 4 F_1 diallel hybrids of wheat. The analysis of variance indicated significant differences among the parental genotypes and their F_1 hybrids in the GCA, SCA, and reciprocal effect of the previously mentioned characters on grain size. Consequently, it helped determine the grain and cultivar quality, as well as the genetic strength of the grain. For management of the grain yield, the GCA and reciprocal effects played major roles compared with the SCA effects. Significant variances due to GCA and SCA showed the predominance of additive, epistatic, and dominant gene effects in controlling the inheritance of the wheat's studied traits.

Keywords: Bread wheat (*T. aestivum* L.), F_1 hybrids, diallel analysis, combining ability, additive, epistatic, dominant gene effects, morphological and yield traits

Key findings: Significant variances due to GCA and SCA showed greater genetic variability in the F_1 populations and the predominance of additive, epistatic, and dominant gene effects in managing the inheritance of morphological and yield traits in bread wheat (*T. aestivum* L.).

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INTRODUCTION

Climate change and global warming affect the production of various crops, including wheat (*Triticum aestivum* L.), which ensures 20% of the calories and 25% of proteins for dietary consumption worldwide. Wheat is the most widely grown cereal crop globally and one of the central pillars of global food security. FAO's latest forecast for global cereal production in 2024 has gone up to 7.9 million tons (0.3%) in July, with predictions to reach 2854 million tons, up fractionally from 2023 and marking a new all-time high. The monthly increase reflects improved prospects for coarse grains, with the world production forecast lifted by 0.4% to 1530 million tons, and for wheat, with expected production up to 0.3% to 789 million tons compared with the June outlook (FAO, 2024). Several yield parameters acquire severe influences from high temperatures, such as the vegetative weight, grain number, and weight in wheat. The world's expanding population also demands more grains and grain products at present and in the future (Akter and Islam, 2017).

Currently, the precise requirement of wheat grains rises. The updated forecasts of the Statista showed that in 2022–2023, the global wheat production reached 781.31 million tons, which was 0.5% lower than last year's productions; however, it is still the highest level of crop production (Statista, 2023). In 2019, world wheat production was 761.51 million tons, with an increase of 3.9% over the year 2018 (www.Statista.com).

The productivity of hybrids relies on the compatibility of applied parental genotypes in the process of hybridization, with the appearance of the desirable genes controlling various traits in future generations of wheat (Topal *et al*., 2004). Genetic potential rarely appears in parental forms; therefore, its study is by analyzing F_1 hybrids. The parental genotypes producing F_1 hybrids with better performance mean these genotypes have a good combining ability (Bao *et al*., 2009). The seed index has a remarkable role in managing the grain yield in wheat and other cereals (Fethi and Mohamed, 2010; Jain and Sastry, 2012). Parental genotypes often have varied general combining abilities depending on the character for selection (Ignatieva, 2005). In addition to grain quality parameters, many quantitative indicators exist. Mostly, the traits are twisted in the polygenic fold, and the boundary of the phenotypic level is not obviously visible in F_2 generations. Therefore, the variations due to the combining ability in F_2 populations will disappear in a continuous state.

In the selection and development process of wheat cultivars, the combining ability has an integral role in choosing the parent cultivars for use in hybridization. The main advantage of the combining ability is to determine the breeding values of cultivars based on their performance in the first and second generations (Buronov *et al*., 2023). Combining ability is the capacity of parental genotypes to produce the hybrids with better genetic potential in crossbreeding. The diallel analysis also explores the additive and non-additive gene effects and their function and role in the inheritance and presentation of various traits (Grebennikova, 2010). In the hybridization program, the importance of gene effects and the dispersion of genetic components in the studied characters is dependent upon the specific parental combinations through hybridization and existing environmental conditions (Novoselovic *et al*., 2004).

Combining ability is a concept in genetics and plant breeding referring to the ability of a particular genotype to combine with other genotypes to produce an offspring with desirable traits. It is especially relevant in the context of hybridization and helps to evaluate the potential of parental lines for producing superior hybrids. Combining ability has two types: general (GCA) and specific combining ability (SCA). The GCA value shows the performance of a parental genotype in a series of crosses for a specific trait, while the SCA specifies the genetic potential of a specific cross for those traits (Dremlyuk, 1980). Moreover, SCA can mean the heterogeneity found in certain cross combinations.

In F_1 and F_2 generations, the effects of interspecific genes on the heritability of the grain traits appeared to be differentially expressed depending on the cross combinations. Some studies even showed significant epistatic effects in exploring the genetic variability of various traits in bread wheat (Ljubicic *et al*., 2015). In hybridization, the selection of positive parental genotypes with desirable genes is crucial for their appearance in future generations. In this way, it will be possible to pre-estimate the characteristics of the future. The heterozygosity in parental lines is also crucial in enhancing the genetic variability. Based on the above discussion, the presented study aimed to determine the combining ability effects in bread wheat genotypes widely grown in Uzbekistan (Juraev *et al*., 2024).

MATERIALS AND METHODS

Breeding material and procedure

Four bread wheat (*Triticum aestivum* L.) cultivars, i.e., Zarrin, Bunyodkor, Jaykhun, and Gozgon were preferences. The first year of the study (2018–2019) had the planting of parental genotypes in crossing block field conditions. All the four genotypes underwent crossing in a complete diallel fashion to generate 12 cross combinations at the Southern Research Institute of Agriculture, Kashkadarya Region, Uzbekistan (Table 1) (Dilmurodovich *et al*., 2021). In each specific cross combination, the crossing of 10 selected spikes ensued, with the resulting F_1 hybrids analyzed in the F_1 generation. Each parental genotype and F_1 hybrid proceeded planting in a single row with 20 cm spacing and five replications in a randomized complete block design (RCBD). Implementing uniform field practices continued throughout the experiment to eliminate experimental errors.

Statistical analysis

All the recorded data based on various parameters attained the analysis of variance (ANOVA). After getting the significant mean differences in 12 F_1 hybrids and their four parental genotypes for various traits, the data received further evaluation through the combining ability analysis, per Method-I based on Eisenhart's Model-II (Griffing, 1956).

RESULTS AND DISCUSSION

This analysis provides important insights for wheat breeders. Traits like plant height and grain weight per spike show strong additive effects (high GCA values), making those promising targets for selection. Grain yield and vitreousness had non-additive effects influencing them, suggesting they may benefit from hybrid breeding strategies. Environmental factors also appear to impact certain traits, such as 1000-kernel weight and vitreousness, which could be optimal through multienvironment testing (Khan *et al.,* 2005).

Table 1. Cultivars used in diallel analysis of wheat bread.

No.	Crosses
1	Zarrin x Bunyodkor
2	Zarrin x Jaykhun
3	Zarrin x Gozgon
4	Bunyodkor x Zarrin
5	Bunyodkor x Jaykhun
6	Bunyodkor x Gozgon
7	Jaykhun x Zarrin
8	Jaykhun x Bunyodkor
9	Jaykhun x Gozgon
10	Gozgon x Zarrin
11	Gozgon x Bunyodkor
12	Gozgon x Jaykhun

Table 2. Mean squares due to ANOVA and combining ability in a 4 × 4 F_1 diallel cross of the upland bread wheat.

Variables	Mean Squares						
	ANOVA			Combining ability			
	Reps.	Genotypes	Error	GCA	SCA	Rec.	Error
Vegetation period	5.4	11.26**	1.453	35.24**	10.5**	0.3 N.S	1.14
Plant height	12.3	34.67**	1.863	127.25**	23.03**	0.3 N.S	1. 63
Productive accumulation	1.8	7.51 N.S	1.182	28.96**	4.06 N.S	0.23 N.S	1. 80
Grain weight spike^{-1}	29.3	80.31**	12.909	295.00**	50.43**	2.83**	12.4
1000-kernel weight	1.4	6.04**	200.663	11.51**	6.76**	2.57**	142.3
Grain yield	22.5	79.81**	12.855	2.93**	4.9**	28.1**	9.5
Vitreousity	16.7	49.53**	13.765	1.80**	3.3**	3.4**	14.65

**, * = Significant at $P \leq 0.01$ and $P \leq 0.05$, respectively, NS = Non significant

The genotype mean square for the vegetation period is highly significant (11.26), indicating substantial genetic variability among genotypes (Table 2). The replication (5.4) and error (1.453) contributions are much lower, suggesting differences in the vegetation period are predominantly due to genotypic factors (Kumar *et al.*, 2011). Genotype effects on plant height are notable (34.67), showing considerable genetic variation among the plants, with minimal contributions from replication (12.3) and error (1.863).

GCA has a very high mean square value (127.25), pointing to a strong influence of additive genetic effects on plant height, while SCA (23.03) is also significant, indicating some degree of non-additive genetic effects. However, the dominant GCA contribution suggests the selection for plant height in a breeding program could be highly effective. The genotype effect (7.51) for productive accumulation is not statistically significant, implying little genetic variation among the genotypes for this trait. GCA is substantial (28.96), while SCA is non-significant (4.06). This indicates the additive effects are more important than non-additive effects for productive accumulation, though the lack of significant genotype effect implies this trait may not be ideal for selection in this population (Khan *et al.,* 2011).

The diallel analysis can better help in the selection and development of a heterozygous cultivar with a shorter growing period through transgressive segregation. The presented results revealed that for vegetation period, the wheat cultivars Zarrin (1.404) and Gozgon (3.276) were notable with positive GCA effects (Table 3). For the said trait, the cultivars Bunyodkor and Jaykhun appeared with negative GCA effects of -3.519 and -1.161, respectively. GCA reflects the average performance of a cultivar when it is crossed with several other cultivars. It also gives an idea of the additive gene effects that a parental genotype contributes to its hybrids. Cultivar Zarrin (1.404) has the highest positive GCA value, signifying it is a good general combiner for managing and enhancing the growing period. Therefore, cultivar Zarrin can be beneficial in a hybridization breeding program to develop the hybrids with a longer vegetation period. For growing period, cultivar Bunyodkor has the highest negative GCA value (-3.519), indicating it tends to shorten the vegetation period of its hybrids. This could be more useful in breeding to develop the early-maturing cultivars. Cultivar Gozgon has the topmost positive GCA value, implying it generally enhances the vegetation period by crossing with other cultivars, followed by cultivar Zarrin, which was still a good genotype for extending the vegetation period.

Plant breeders are looking for desirable gene complexes, and genes and the identification of promising individuals are highly essential in any breeding program. The diallel-mating design is one of the tools that helps the breeder to identify the promising recombinants produced by combining the parental individuals through the potential genotypes of GCA and SCA. In diallel mating,

Table 3. GCA effects for morpho-yield traits in a 4 × 4 F_1 diallel cross of the upland bread wheat.

F1 Hybrids	Vegetation period	Plant height	Productive accumulation	Grain weight spike^{-1}	1000-kernel weight	Grain yield	Vitreousity
Zarrin	1.404	6.848	-2.135	0.195	0.074	-3.476	-3.221
Bunyodkor	-3.519	-0.857	-1.362	0.085	-0.614	2.169	1.301
Jaykhun	-1.161	-6.860	-0.395	-0.135	-0.054	0.119	1.424
Gozgon	3.276	0.870	3.893	-0.145	0.594	1.189	0.496

Table 4. SCA effects for morpho-yield traits in a 4 × 4 F_1 diallel cross of the upland bread wheat.

F1 Hybrids	Vegetation period	Plant height	Productive accumulation	Grain weight spike^{-1}	1000-kernel weight	Grain yield	Vitreousity
Bunyodkor x Zarrin	-3.451	2.167	-1.365	-0.522	0.379	-2.436	-0.066
Jaykhun x Zarrin	3.161	5.490	-1.593	-0.322	2.509	-3.206	-3.149
Jaykhun x Bunyodkor	-3.546	-1.455	0.865	-0.063	-0.354	2.159	0.479
Gozgon x Zarrin	-0.516	2.910	2.860	0.268	0.631	5.214	-1.121
Gozgon x Bunyodkor	3.766	-0.435	1.088	0.148	0.339	-3.661	2.356
Gozgon x Jaykhun	0.729	2.298	0.410	0.087	-0.631	0.669	-0.676

the parents get crossed in all possible combinations to identify parents as best or poor general combiners through GCA and the specific cross combinations through SCA. It involves both direct and reciprocal crosses, through which maternal effects can also be ascertained. In combining ability, the entire genetic variability of each trait can become sections of GCA and SCA (Griffing, 1956).

The SCA measures the performance of specific crosses and indicates non-additive genetic effects, such as dominance and epistasis. The hybrid combination Bunyodkor x Zarrin (-3.451) has a significantly negative SCA value, which can be effective in developing the genotypes with early maturity. The F_1 hybrid Jaykhun x Zarrin (3.161) has the highest positive SCA value, indicating a considerable SCA value. This suggests a beneficial interaction between the parental genotypes Zarrin and Jaykhun for the vegetation period and may be highly favorable for extending the growing period (Table 4). The hybrid Gozgon x Bunyodkor (3.766) also showed the utmost positive SCA value, implying an excellent specific combining ability. Despite cultivar Bunyodkor having a negative GCA, however, its combination with cultivar Gozgon appears beneficial, highlighting the importance of evaluating specific crosses. The cross Gozgon x Jaykhun (0.729) manifested a moderately positive SCA value, suggesting some beneficial effects for the growing period. Often, smaller values of genetic variances according to GCA and SCA came from reciprocals. In F_2, GCA components of variances were greater than SCA and revealed the dominance of an additive gene action for the inheritance of all traits (Khan *et al*., 2005).

The small reciprocal effects suggest minimal impact, while larger values indicate significant influences. The reciprocal crosses Zarrin x Bunyodkor (-0.020), Zarrin x Gozgon (0.010), and Jaykhun x Gozgon (0.090) indicated nonsignificant negative and positive reciprocal effects, respectively, and have no considerable alterations on the growing period (Table 5). The reciprocal crosses Bunyodkor x Gozgon (0.330) and Zarrin x Jaykhun (0.130) showed a small positive reciprocal impact, which can propose a slight benefit through reverse crosses. However, these reciprocal effects are relatively minor and may not significantly influence the genetic potential of genotypes.

In wheat, the plant height is an indispensable trait, and if the genotype plants are taller than the crop, lodging could occur, affecting the pollination and fertility and eventually, the grain yield. However, plant

Table 5. Reciprocal effects for morpho-yield traits in a 4 × 4 F_1 diallel cross of the upland bread wheat.

F1 Hybrids	Vegetation period	Plant height	Productive accumulation	Grain weight spike^{-1}	1000-kernel weight	Grain yield	Vitreousity
Zarrin x Bunyodkor	-0.020	-0.230	0.170	-0.330	3.470	-0.380	1.860
Zarrin x Jaykhun	0.130	0.130	-0.090	0.010	-0.420	0.960	0.360
Zarrin x Gozgon	0.010	0.000	0.070	0.530	0.330	9.030	-0.780
Bunyodkor x Jaykhun	-0.300	-0.340	-1.120	-0.020	1.270	-7.090	-4.570
Bunyodkor x Gozgon	0.330	0.110	0.150	0.700	-0.250	6.640	0.880
Jaykhun x Gozgon	0.090	0.120	0.280	-0.660	-0.500	-5.480	2.930

height can be optimal by crossbreeding. In the presented study, the parental genotypes Zarrin (6.848) and Gozgon (0.870) showed positive GCA effects (Table 3). However, the cultivars Bunyodkor and Jaykhun emerged with negative GCA effects (-0.857 and -6.680, respectively). For plant height, the SCA was positive in the F_1 hybrids Jaykhun x Zarrin, Bunyodkor x Zarrin, and Gozgon x Zarrin (5.490, 2.167, and 2.910, respectively). However, the F_1 hybrid Jaykhun x Bunyodkor (-1.455) was evident with negative SCA effects in wheat. The quantitative traits of plant productivity, as determined by polymeric genes, are characteristic of a wide range of variability under the influence of environmental conditions. Therefore, it is vital to know how the economically valuable traits of the parental genotypes are inherited in wheat hybrids (Lukonge *et al*., 2007).

Productive accumulation is highly crucial in grain crops, and the highest level of productive accumulation leads to more grains and eventually, higher grain yield (Table 3). For the said trait, the positive GCA was visible in the parental cultivar Gozgon (3.893). However, the other three cultivars, viz., Zarrin, Bunyodkor, and Jaykhun, showed negative GCA effects. According to productive accumulation, the positive SCA effects resulted in the cross combination Gozgon x Zarrin (2.860) and Gozgon x Bunyodkor (1.088). Inversely, the F_1 hybrids Jaykhun x Zarrin (-1.593) and Bunyodkor x Zarrin (-1.365) exhibited negative SCA effects for production accumulation in wheat (Table 4). The effectiveness of breeding programs is largely distinguishable by the knowledge of the character of inheritance of quantitative traits associated with the productivity of an individual wheat plant (Ljubicic *et al*., 2017).

According to the combining ability analysis for grain weight per spike, the highest positive GCA effects were prominent for the wheat genotypes Zarrin and Bunyodkor (Table 3). However, the parental cultivars Jaykhun and Gozgon gave negative GCA values. By analyzing the SCA in bread wheat F_1 hybrids for grain weight per spike, the study found that all the F_1 hybrids involving the cultivar Gozgon displayed the maximum positive SCA effects for the said trait. Based on reciprocal combining ability (RCA), the three F_1 hybrids, Jaykhun x Zarrin, Gozgon x Zarrin, and Gozgon x Bunyodkor, manifested with slightly positive RCA effects, while the rest of the reciprocal combinations revealed negative RCA outcomes. The grains, grain weight per spike, and 1000-grain weight can play a vital role in managing the total grain yield in wheat because these traits have a significant positive correlation with the grain yield. The inheritance of the investigated traits gained control from the polymeric genes—in the recessive state of these genes, genotypes with lower indices than the parental genotypes occur, and in their dominant state, the genotypes with the highest indices appear. A higher coefficient of variation for the grain number and weight per spike was evident as compared with the parental genotypes. This phenomenon is important in wheat breeding and allows increasing productivity due to the grain number and weight per spike without increasing the plant density (Juraev *et al*., 2023).

In bread wheat, the 1000-grain weight is a widely used indicator in the selection of cultivars and lines, and the main reason for this is that the 1000-grain weight is a major yield component. The 1000-kernel weight is a multiplier that indicates the baking and fullness of the grain, affecting its quality gauges; therefore, it mainly depends upon the climatic conditions of the area. The size of the wheat grain depends on the length of the growing season and ripening period. In 8 × 8 diallel crosses of bread wheat, the relationship among the spike length, grain weight per spike, and 1000-kernel weight revealed a positive influence on grain yield. Wheat yield is a complex trait consisting of three main components: the spikes per area, grains per spike, and 1000-kernel weight. Among them, the 1000-kernel weight has a relatively high heritability, which is a quantitative trait. As one of the key components of grain yield, the 1000-grain weight has main influences from the grain size and grain filling (Simmonds *et al*., 2014). By using diallel analysis in the development of a new bread wheat cultivar, the 1000-kernel weight can play a remarkable role (Juraev *et al*., 2023).

For 1000-grain weight, the diallel analysis detailed that the parental cultivars, Zarrin (0.074) and Gozgon (0.594), were remarkable with the highest positive GCA effects (Table 3). However, the two other cultivars, Bunyodkor and Jaykhun, appeared with negative GCA effects (-0.614 and -0.054, respectively). GCA values reflect the additive gene effects, which are critical for selecting good general combiners in a breeding program. The cultivar Gozgon has a moderately positive GCA value, suggesting it generally contributes to an increase in the 1000-kernel weight in its hybrids. This makes Gozgon a good general combiner for increasing the kernel weight. This positive effect indicates the cultivar Gozgon could be a potential good parent in breeding programs targeting increased kernel weight. The cultivar Zarrin has a slightly positive GCA value, signifying a minor positive impact in increasing the 1000-kernel weight. Despite the small positive GCA, the cultivar Zarrin's impact might be more significant in specific cross combinations, as also observed in the SCA effects. The 1000-grain weight was distinctive of high values for the coefficient of heritability, being controlled in most cases by the dominance and overdominance types of gene action, and hence is of great interest in breeding for wheat productivity (Abdel-Lateif and Hewedy*,* 2018).

For 1000-grain weight, the SCA values indicate the performance of specific crosses and reflect non-additive gene effects, such as dominance and epistasis. The F_1 hybrid Jaykhun x Zarrin (2.509) showed the ultimate positive SCA value, implying an excellent SCA for the 1000-grain weight, which will enhance the kernel weight. The F_1 cross combination Gozgon x Zarrin (0.631) has a moderately positive SCA value, indicating a beneficial interaction that can enrich kernel weight to boost the 1000-grain weight. Both parents also have positive GCA values, and their combination further improved the said trait. The F_1 hybrid Bunyodkor x Zarrin (0.379) has the positive SCA value, suggesting the said specific cross between Zarrin and Bunyodkor will increase the kernel weight more than expected, based on the parents' GCA. The said cross combination was promising, even with the cultivar Bunyodkor showing negative GCA effects. The cross Gozgon x Bunyodkor (0.339) has the least positive SCA effects. Meanwhile, the two other F_1 hybrids, Jaykhun x Bunyodkor (-0.354) and Gozgon x Jaykhun (-0.631), have negative SCA effects, which implies these cross combinations may not play a better role in enhancing the kernel weight in wheat (Table 4). Genetic parameters like mean performance, genetic gain, variance, heritability, and correlation coefficient are helpful tools to evaluate the genetic potential of a particular wheat genotype. Furthermore, these determine the effectiveness of breeding a particular trait in a genotype under the existing environment (Salim *et al.,* 2003).

Reciprocal effects indicate the directional influence of the cross on which parent should serve as the female or male for the trait. The reciprocal crosses Zarrin x Bunyodkor (3.470), Bunyodkor x Jaykhun (1.270), and Zarrin x Gozgon (0.330) showed the highest positive reciprocal effects, and these genotypes provided a significant increase in kernel weight. The F_1 hybrids Zarrin x Jaykhun (-0.420) and Bunyodkor x Gozgon (-0.250) exhibited negative reciprocal effects, which suggests the direction of the concerned crosses was unfavorable for increasing the kernel weight. The results highlighted the importance of evaluating both GCA and SCA values, as well as reciprocal effects, to select the best parental combinations for raising the 1000-kernel weight in bread wheat F_1 hybrids. Specific cross combinations, such as Zarrin x Jaykhun and Bunyodkor x Zarrin, emerged particularly beneficial (Table 5). An increase in grain yield is fundamentally reliant on an enhancement and improvement in yield components, i.e., plant height, productive stems per unit area, spike length, the number of grains, and grain weight per spike in wheat (Abdel-Lateif and Hewedy, 2018).

For grain yield, the parental cultivars Bunyodkor (2.169), Gozgon (1.189), and Jaykhun (0.119) showed positive GCA effects, and these genotypes could better perform in F_1 hybrids through SCA to enhance the grain yield (Table 3). However, the wheat cultivar Zarrin gave negative GCA effects (-3.476). According to specific combining ability effects, with the F_1 hybrids Gozgon x Zarrin (5.214) and Jaykhun x Bunyodkor (2.169) displaying positive SCA effects, these genotypes will better respond in improving grain yield in bread wheat. However, the F_1 hybrid Gozgon x Bunyodkor (-3.661) was evident with negative SCA effects (Table 3). In case of reciprocal effects, the F_1 hybrids Zarrin x Gozgon and Bunyodkor x Gozgon showed the highest positive RCA effects (9.030 and 6.640, respectively) and could respond to enrich grain yield in bread wheat. Inversely, the reciprocal cross combinations, Jaykhun x Gozgon, Bunyodkor x Jaykhun, and Zarrin x Bunyodkor, have the supreme negative RCA effects (-5.480, -7.090, and -0.380, respectively). These genotypes may not be responsive to wheat grain yield improvement. Grain size gains fewer influences from environmental conditions and is essentially one of the most accessible structural features for individual selection in early generations of splitting hybrids (Harasim *et al*., 2016).

In common wheat, the grain size determines the quality of the grain as well as its genetic strength. The higher the vitreousity of the grain, the better the flour yield and quality level (Table 3). The diallel analysis revealed the three parental cultivars, Jaykhun, Bunyodkor, and Gozgon, appeared with the highest positive GCA effects (1.424, 1.301, and 0.494, respectively) for grain yield in bread wheat. However, the parental genotype Zarrin (-3.221) had the topmost negative GCA value for grain yield. For specific combination ability (SCA), Jaykhun x Zarrin and Gozgon x Zarrin combinations have high values of -3.149 and -1.121. For grain yield, the F_1 hybrids Gozgon x Bunyodkor and Jaykhun x Bunyodkor enunciated positive SCA effects (2.356 and 0.479, respectively) could better respond to vitreousity of the grain. In reciprocal effects, the F_1 hybrids, Jaykhun x Gozgon and Zarrin x Bunyodkor, were noticeable with the ultimate positive RCA effects (2.930 and 1.860). Although the F_1 hybrids, Zarrin x Gozgon (-0.780) and Bunyodkor x Jaykhun (-4.570), have the highest negative reciprocal combining ability for grain vitreousity. All these yield components succeeded determination genetically, confirming the genetic control of yield components can be well established in diallel crosses of bread wheat (Reynolds *et al*., 2007).

The diallel analysis is a biometrical method used in genetics and plant breeding to study the combining ability among parental lines and their crosses. It involves systematically crossing multiple parental lines in all possible combinations to develop a set of F_1 hybrids. These hybrids further undergo evaluation for various traits of interest to assess the genetic effects and their interactions. The main objective of diallel analysis is to estimate the genetic components contributing to the observed character variations. These components include general and specific combining ability effects. The GCA represents the additive genetic effects of parental genotypes and indicates their average performance in the F_1 hybrids, while the SCA represents the non-additive gene influences, resulting in specific cross combinations. By analyzing the performance of the F_1 hybrids and their parental lines, diallel analysis allows researchers to estimate the GCA and SCA effects and understand the importance of additive and non-additive gene action in determining the traits of interest. This information helps plant breeders identify superior parental genotypes and take decisions regarding cross-combinations for further breeding programs. Such type of inheritance and the effects of genes mainly depend upon the parental genotypes used for diallel crossing. For this reason, the choice of wheat parental cultivars for the breeding program is highly critical (Joshi *et al.,* 2004; Gorjanović and Kraljević-Balalić, 2004).

The study of heterozygous breeding is vital to improving the productivity of agricultural crops. Diallel analysis is the most commonly used method for assessing genetic components and heritability for various traits. In complete diallel analysis, the selection of parental genotypes can proceed with a white-pigmented gene (Barot *et al*., 2014). A non-additive genetic variation plays a dominant role in determining the gene interactions and their effects (Singh *et al*., 2012). Crop genetic resources carry distinctions useful for overcoming the challenges of modern agriculture. Molecular markers can facilitate the selection of important agronomic traits. The pervasiveness of genomics research has led to an overwhelming number of publications and databases, which are, nevertheless, scattered and hence, often difficult for plant breeders to access, particularly those in developing countries. This situation separates them from developed countries, which have better endowed programs for developing varieties. Crop genetic resources have the variability that is useful for meeting the challenges of modern agriculture. Widespread use of genomic research has resulted in numerous publications and databases. However, their fragmentation causes limited access for plant breeders, especially in developing countries. This situation distinguishes them from countries with well-developed variety development programs, and for doing the same, the breeders must know the best combination skills (Van-Damme *et al*., 2011).

The use of the 7 × 7 complete diallel three-way crosses evaluated the combining ability in 42 F_1 hybrids, which revealed significant variances due to GCA and SCA for plant height, 1000-kernel weight, spike length, and grain yield (Nazan, 2008). Using diallel analysis in the development of new transgressive cultivars and lines with the highest 1000-grain weight is advantageous in bread wheat. The presented results revealed that for 1000-grain weight, the parental cultivars Zarrin and Gozgon had the highest positive GCA effects (1.404 and 0.594, respectively). The F_1 hybrid Zarrin x Gozgon of these parental cultivars also showed the maximum positive SCA effects (5.214), in addition to one other hybrid, Bunyodkor x Jaykhun (2.169).

CONCLUSIONS

For the management of the grain yield in bread wheat, the GCA and reciprocal effects played major roles compared with SCA effects. Significant variances due to GCA and SCA showed the predominance of additive, epistatic, and dominant gene effects in controlling the inheritance of the studied traits of wheat. Knowledge of these traits is imperative in selection programs for wheat breeding.

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