Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences 58(2): 69-81 (2021)

ISSN (Print): 2518-4261; ISSN (Online): 2518-427X
http://doi.org/10.53560/PPASB(58-2)623

Pakistan Academy of Sciences

Research Article

Estimation of Combining Ability in F_2 Hybrids of Bread Wheat (*Triticum aestivum* L.) Genotypes

Tanweer Fatah Abro[1], Asim Ali Rajput[1], Jay Kumar Sootaher[1*], Piar Ali Shar[1], Muhammad Saleem Chang[2], Muhammad Naeem[3], Ayaz Latif Siyal[1], Farhana Hayat Siyal[4], Kirshan Kumar Menghwar[1], Amanullah Baloch[5], Azizullah Keerio[6], and Muneer Ahmed Vistro[1]

[1]Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Sindh, Pakistan
[2]Department of Agronomy, Sub campus Umerkot, Sindh Agriculture University, Tandojam, Sindh, Pakistan
[3]Directorate of Agriculture Research (Dates), Kech, Turbat, Balochistan, Pakistan
[4]Department of Biotechnology, Institute of Biotechnology and Genetic Engineering, University of Sindh, Jamshoro, Sindh, Pakistan
[5]National Key Laboratory of Crop Genetic Improvement, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, China
[6]Key Laboratory of Molecular Biology, Crop Pathogens and Insects, Institute of Biotechnology, Zhejiang University, Hangzhou, China

Abstract: The seed of 6 parental cultivars along with 15 F_2 Hybrids of hexaploid wheat was planted in randomized complete block design with three replications 6 x 6 half diallel during 2016-2017 sat Southern Wheat Research Station, ARI, Tandojam, Sindh, Pakistan. Mean squares due to General Combining Ability (GCA) and Specific Combining Ability (SCA) variances were highly significant and significant for all morphological traits. It was noticed that additive, as well as nonadditive genes, were there for GCA and SCA. SCA variances were observed greater than those of GCA variances for five traits (PH, TPP, SL, SPS, GYPP) displaying the predominance of nonadditive genes, for some of the characters, nonetheless, GCA variances were more for the rest of the characters (GPS, TGW). Parental cultivars such as Khirman displayed maximum positive and desirable GCA effects for spike length and grains spike^{-1}, Hamal for tillers plant^{-1} and spikelets spike^{-1} and Benazir and NIA-Sarang for grain yield plant^{-1} and seed index. On the other hand, Hamal and NIA-Sarang equally distributed negative, but desirable GCA effects for plant height. The SCA estimates revealed that Sindhu x Hamal manifested maximum positive estimates for spike length and grain yield plant^{-1}, whereas Benazir x Sindhu was found as the best specific combiner for spikelets spike^{-1} and seed index, Benazir x Khirman and Benazir x NIA-Sarang for tillers plant^{-1} and grains spike^{-1}. These F_2 hybrids may be the best choice as a breeding material for hybrid crop development to improve yield characters. Therefore, it may be possible to take advantage of better general and specific combiners to further selection for the development of a hybrid variety of wheat which can assist to enhance the total production in Pakistan.

Keywords: General Combining Ability, Specific Combining Ability, F_2 Hybrids, Bread Wheat, Genotypes.

1. INTRODUCTION

Sustainable increase in production is a demand of the present situation of increasing food and feed consuming living forms and requires such breeders who can explore the germplasm for the selection of stable high yielding cultivars [1]. With these considerations in mind, wheat production must be increased at all costs, either by increasing the area under cultivation or by employing a

Received: September 2020; Accepted: June 2021
*Corresponding Author: Jay Kumar Sootaher <jaykumar3030@gmail.com>

varietal approach that includes a variety or hybrid improvement, which is one of the most difficult tasks in achieving a quantum leap in production and productivity in agro-climatic environments. There are also many factors responsible for low yield, among those; varietal selection for yield potentials is considered as the major factor [2, 3]. For fulfilling this gap between yield and demand, wheat has extremely important in this world. This crop has not only been named 'King of Cereals' but also 'Stuff of Life' because of its most spread in the world in the form of high acreage, high productivity, and the most essential food [4]. It is nutritionally compulsory cereal for food security, poverty alleviation, and livelihoods [5]. Therefore, Wheat breeders throughout the world have been utilizing the existing resources to modify the wheat varieties to meet the requirements of a day-by-day increasing population [6]. An understanding of genetic yield and yield components governing factors is the fundamental step towards breeding attempts [7]. To develop superior and new varieties, plant breeders and geneticists have also utilized such straits which carry a bundle of variation in their genes. Owing to its greater genetic diversity, the crop provides several opportunities to create new and favourable genotypes with the aid of crossing and recombination between desirable genes [8].

Wheat breeders are aware of the phenomenon that in hybridization programmes, certain crosses pass on more favourable genes towards the progenies [9]. Analysis of combining ability provides information for the selection of parents as well as the nature and the magnitude of gene action involved in the manifestation of a wide range of characters [10]. In plant breeding, it is the most commonly utilized biometrical method. Estimates of general and specific combining ability are very useful genetic studies for making decisions in the breeding program's next phase.

In such achievement, a diallel mating design is constantly used for the evaluation of General Combining Ability (GCA) and Specific Combining Ability (SCA). The same group of parents is considered as males and females for this breeding method. When an average performance of a parent is tested in a series of crosses, the combining ability is said to be in general combining ability, but the hybrids which are observed based on the parents' performances, it is categorized as specific combining ability [11]. From a statistical point of view, the GCA is the main effect, however, the SCA is an interaction effect. The variance of GCA is owing to the genes which are largely based on additive and additive x additive gene interactions in their effects, whereas SCA is regarded as an indication of loci with nonadditive genetic portion and all the three types of epistatic interaction components if epistasis is present. They involve additive x nonadditive and dominance x dominance interactions. As a result, combining ability is critical in the creation of crop varieties, and it is frequently employed in crop hybridization to exploit heterosis or combine fixable beneficial genes. Many scientists have tried combining abilities, but the outcomes have been mixed due to differences in experimental material, environment, and breeding procedures. GCA and SCA data are believed to be a prerequisite for a successful wheat breeding effort. [12]. Xu (1998) stated that it has been proven that the combination of genetic information from multiple hybrids is a very powerful and useful procedure [13]. In this way, the method which has been practiced in the experiment will be a good framework for the analysis of data in the identification of hybrids expressing better segregants owing to transgressive separation of alleles in a somewhat short time [14].

For wheat scientists, the search for desirable germplasm is a continuous process and the development of new elite germplasm is an unending goal. Hence, wheat breeders strive to gain comprehensive information on the extent and genetic basis of the variability regarding vital parameters in the parental material. Thus, present studies were designed to determine GCA and SCA of parental cultivars and their F_2 hybrids, respectively to obtain information on the nature and magnitude of genetic components of variation controlling the expression of yield and the attributes of its component in hexaploid wheat.

2. MATERIALS AND METHODS

2.1 Experimental Materials and Site

The seed of six wheat cultivars as parents such as Benazir, Sindhu, Khirman, Hamal, NIA-Sarang, and NIA-Sundar along with their fifteen F_2 hybrids viz. Benazir x Sindhu, Benazir x Khirman, Benazir x Hamal, Benazir x NIA-Sarang, Benazir x NIA-Sundar, Sindhu x Khirman, Sindhu x Hamal, Sindhu x NIA-Sarang, Sindhu x NIA-Sundar, Khirman x Hamal, Khirman x NIA-Sarang, Khirman x NIA-Sundar, Hamal x NIA-Sarang, Hamal x NIA-Sundar and NIA-Sarang x NIA-Sundar were planted in randomized complete block design with three repeats at Southern Wheat Research Station, Tandojam during 2016-2017 crop season.

2.2 Experimental Method and Design

A diallel is a mating system having all possible crosses from parents. This design is used for the study of quantitative characters. The design is not only practiced for the estimation of genetic variance from parents in the form of individuals or inbred lines, but also for the evaluation of combining ability of good parents and its crosses. This design is also put into practice to study the genetic structure of a population. Several methods have been practiced to analyzed and interpret diallel hybrids [11]. The GCA and SCA variances and their effects were calculated according to Griffing's Method-2 and Model-1 = n (n-1)/2 = parents + F_2 hybrids.

2.3 Crop Sowing

Drill method was applied to sow seeds in December 2016. The distance was maintained at 6 cm between plant to plant, however, the row to row distance was sustained at 9 cm. Per hectare at the time of sowing, 50 kg of DAP were given, 50 kg of N_2 with one dose, and 50 kg N_2 with another dose were supplied to the crop.

2.4 Crop Harvesting

The crop was reaped in April 2017. Herbicide was also spread after first irrigation to save the plant from the damage of weeds. Ten plants were chosen at random for each replication from parents and hybrids to record the data for traits such as plant height, tillers plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, grain yield plant^{-1}, and 1000-grain weight.

2.5 Statistical analysis

Analysis of variance was calculated according to the statistical methods of [15] with software Statistix 8.1 version. Diallel analysis was determined according to Griffing's Method-II [16] and the Numerical approach as adopted by [17]. The analysis evaluated additive and nonadditive variances and effects for various characters.

3. RESULTS

3.1 Analysis of Variance

The mean square from the analysis of variance for genotypes including parents, hybrids, and parents vs. hybrid of GCA and SCA were significantly different for all the studied characteristics such as plant height, spike length, spikelets spike^{-1}, grains spike^{-1}, tillers plant^{-1}, grain yield plant^{-1}, and seed index as shown in Table 1. The parents showed significant and highly significant differences in all the traits except for spikelets spike^{-1}, grains spike^{-1}, and grain yield plant^{-1}. In the case of hybrids, all the crosses were highly significant for all the characters except plant height and spike length. Parents vs. hybrids also expressed significant and highly significant differences for all the attributes. Variances due to GCA were significant and highly significant for all the traits excluding plant height, whereas variances because of SCA estimates were observed significant and highly significant for all the characters. There were total of seven traits and in five characters, the variances due to GCA were greater than those of the variances of SCA.

3. 2 Mean Performance of Parents and F_2 Hybrids

The mean performance results of parents and F_2 hybrids for seven characters are presented in Table 2. Among parents, maximum plant height (106.67 cm) was measured in Khirman followed by NIA-Sarang (101.10). Among the F_2 hybrids, maximum plant height (109.10 cm) was produced by the cross Benazir x Hamal followed by Khirman x Hamal (108.87). Maximum spike length among parents was shaped by Benazir (9.92 cm) followed by Sindhu (9.40 cm) similarly, while among F_2 hybrids maximum spike length was noted for Sindhu x NIA-Sarang (9.71 cm) followed by Sindhu x Hamal (9.62 cm). As regards spikelets Spike^{-1}, higher number of spikelets spike^{1} (18.47) among the parents was equally shown by Khirman and NIA-Sundar. In the F_2 hybrids, higher number of spikelets spike[1] (19.17) was recorded in Benazir x Hamal followed by Benazir x Sindhu (18.77). For rains spike^{-1} from the parents, the most grains spike^{-1} (66.07) were determined by Hamal followed by Khirman (55.80), whereas in hybrids, maximum grains spike^{-1} (65.40) were recorded in Hamal x NIA Sundar followed by Hamal x NIA-Sundar (65.40). As far as results regarding tillers plant^{-1} indicated that among the parents, maximum tillers plant^{-1} were observed in Sindhu (7.40) followed by NIA-Sundar (7.10). However, among F_2 populations, more tillers plant^{-1} were formed by Benazir x Sindhu (9.93) followed by Sindhu x Hamal (8.30). In the case of grain yield plant^{-1} from six parents, maximum grain yield plant^{-1} (15.82 g) was produced by Benazir followed by NIA-Sundar (15.31 g). Despite the fact in F_2 hybrids, maximum grain yield plant^{-1} (17.63 g) was verified in Sindhu x Khirman followed by Benazir x Sindhu (16.87 g). For seed index, the highest seed index was articulated by the parent NIA-Sarang (52.33 g) followed by Sindhu (50.27 g). Among the F_2 hybrids, the maximum seed index (52.40 g) was disclosed by Sindhu x NIA-Sarang followed by Benazir x NIA-Sarang (51.30 g).

3.3. General Combining Ability (GCA) and Specific Combining Ability (SCA) Estimates

SCA effects of F2 hybrids for morphological traits in bread wheat are shown in Table 4.

Plant height (cm): In plant height, generally short stature behaviour is liked, because such plants do not lodge respond fertilizers very quickly. Hence, negative combining ability estimates are preferred for the height of plants in bread wheat. From six parents, the three parents such as Hamal, NIA-Sarang, and NIA-Sundar expressed higher desirable negative GCA effects (-3.90, -3.90, and -3.13) in which Hamal and NIA-Sarang equally contributed. From 15 crosses, seven hybrids manifested desirable negative SCA effects, however, eight hybrids articulated undesirable positive SCA effects. The hybrid-like Khirman x NIA-Sundar, Khirman x NIA-Sarang and Khirman x Hamal performed best of all in expressing desirable negative SCA effects of -4.32, -3.41, and -2.60.

Tillers plant^{-1}: The maximum positive GCA effects were shown by Hamal (3.75) and Khirman (1.98). Regarding SCA effects, from fifteen F_2 hybrids assessed, the eleven F_2 hybrids demonstrated desirable positive SCA effects, nevertheless, four cross combinations showed the undesirable negative SCA estimates. The three specific combiners were identified which were Benazir x Khirman (2.30), Hamal x NIA-Sundar (1.90), and Benazir x Hamal

Table 1. Mean squares for different morphological traits of bread wheat

Source of Variation	D. F.	Plant height (cm)	Tillers plant^{-1}	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1} (g)	Seed index (g)
Replications	2	13253.6	0.44	94.65	426.00	4669.21	318.13	13.89
Genotypes	20	13094.6**	2.10**	85.87*	563.39**	3914.88**	299.14**	20.33 **
Parents (P)	5	46053.6**	0.18*	296.25**	66.54.18*	1140.76**	111.00**	31.12 **
Hybrids (H)	14	1288.17*	2.74**	12.54*	780.747**	5443.73**	415.51**	17.23 **
P vs. H	1	30392.57**	2.69**	200.63**	2924.64**	1382.15**	160.78**	9.78*
GCA	5	6043.90**	3.95**	45.60**	265.89**	4120.20**	188.90**	10.90 *
SCA	14	8210.45**	4.74**	66.34**	330.34**	3111.45**	334.80**	8.80*
Error	24	1227.1	0.10	7.80	55.60	377.29	38.78	2.46

Table 2. Mean performance of parent and hybrids for different yield and yield related traits in bread wheat

Genotypes	Plant height (cm)	Tillers plant^{-1}	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1} (g)	Seed index
Benazir	88.80	7.07	9.92	16.97	51.57	15.82	48.83
Sindhu	99.23	7.40	9.40	17.27	52.17	14.68	50.27
Khirman	106.67	6.80	9.40	18.47	55.80	15.07	40.57
Hamal	95.37	6.77	9.20	17.73	66.07	15.04	44.27
NIA-Sarang	101.10	7.07	9.09	16.70	49.70	13.29	52.33
NIA-Sundar	101.07	7.10	8.78	18.47	48.57	15.31	46.63
F_2 Hybrids							
Benazir x Sindhu	99.17	9.93	9.51	17.87	61.33	16.87	50.30
Benazir x Khirman	99.70	7.57	9.30	18.50	52.83	14.92	45.47
Benazir x Hamal	109.10	6.43	8.87	19.17	53.87	14.53	47.53
Benazir x NIA-Sarang	92.60	6.87	9.21	18.54	55.30	14.93	51.30
Benazir x Sindhu	100.27	7.40	9.28	18.77	48.20	14.93	48.47
Sindhu x Khirman	95.50	8.07	9.52	18.13	57.80	17.63	46.67
Sindhu x Hamal	90.37	8.30	9.62	17.40	56.13	15.97	48.37
Sindhu x NIA-Sarang	92.60	7.47	9.71	17.47	54.77	14.57	52.40
Sindhu x NIA-Sunder	98.30	6.97	9.33	18.30	52.67	14.49	49.33
Khirman x Hamal	108.87	6.60	9.27	17.50	58.37	14.81	43.37
Khirman x NIA-Sarang	108.40	7.70	9.15	17.37	57.43	14.85	47.43
Khirman x NIA-Sunder	108.57	6.70	8.92	17.30	56.40	14.44	44.53
Hamal x NIA-Sarang	108.60	6.67	9.47	16.93	58.43	14.82	49.43
Hamal x NIA-Sunder	94.00	7.30	9.41	17.80	65.40	14.43	46.20
NIA-Sarang x NIA-Sundar	100.33	7.33	8.91	17.13	47.43	13.50	50.57
LSD (5%)	**5.08**	**0.81**	**0.33**	**0.87**	**4.81**	**0.90**	**4.02**

(1.78). Current results expressed that parental lines and hybrids which scored higher GCA and SCA may be the best general and specific combiners in hybrid wheat production.

Spike length (cm): Out of six parents, three parents expressed the desirable positive GCA effects, while the rest of the parents exhibited undesirable negative GCA estimates. The maximum positive GCA effects were shown by parents Khirman (2.14), Benazir (1.90) and Sindhu (0.90) which showed that these three parents were good general combiners. In the case of SCA effects, eleven hybrids exhibited the desirable positive SCA effects, while the rest of the four hybrids maintained undesirable negative SCA estimates. The higher positive SCA effects were demonstrated by hybrids such as Sindhu x Khirman (1.46), Sindhu x Khirman (1.45), and Benazir x Khirman (1.20) which indicated that these three hybrids became the best specific combiners for the wheat hybrid development programmes.

Spikelets spike^{-1}: According to results of GCA effects for spikelets spike^{-1}, the four parents from six demonstrated desirable positive GCA estimates. The parent Hamal and Khirman showed the maximum positive GCA effects of 1.86 and 1.85. According to result hybrids, twelve F_2 hybrids expressed desirable positive SCA effects, but the rest of the hybrids sustained undesirable negative SCA estimates. The higher positive SCA effects were demonstrated by the crosses Benazir x NIA-Sundar (1.90), Benazir x NIA-Sarang (0.90), and Sindhu and Khirman (0.88).

Grains spike^{-1}: From six parents, four parents articulated the desirable positive GCA estimates. Khirman and Hamal expressed maximum positive GCA effects of 2.44 and 2.19. Out of fifteen hybrids, ten hybrids articulated positive SCA effects and only five crosses took negative SCA estimates in which Benazir x NIA Sarang (5.45), Benazir x Khirman (4.88), and Sindhu x Khirman (4.67) recorded higher positive SCA effects and these cross combinations were the best specific combiners for the hybrid wheat programmes.

Grain yield plant^{-1} (g): Grain yield plant^{-1} has got unique importance among plant characters because it makes a better performance in uplifting the economy of growers and the country. According to the results of grain yield plant^{-1}, only three parents showed positive GCA effects. The parents such as Benazir and Khirman exhibited the highest positive GCA effects of 8.20 and 4.38. The SCA effects revealed that eight hybrids determined the desirable positive SCA effects, nonetheless, seven hybrids revealed undesirable negative SCA estimates. The maximum positive SCA effects were displayed by Sindhu x Hamal, Benazir x Sindhu and Sindhu x Khirman with the SCA estimates of 6.00, 5.60, and 5.00.

Seed index (g): Seed index and yield are positively correlated, which means a unit increase in seed index will simultaneously increase the seed yield. The results indicated that three parents out of six exposed positive GCA effects. The parents like NIA-Sarang (6.90) and NIA-Sundar (4.91) revealed the maximum positive GCA effects. Results with respect to SCA effects indicated that ten hybrids verified the desirable positive SCA effects, whilst five hybrids unveiled undesirable negative SCA estimates. The highest positive SCA effects were manifested by the crosses Benazir x Sindhu, Benazir x Hamal and Benazir x NIA-Sarang having the SCA estimates of 6.00, 5.60, and 4.50.

Table 3. GCA effects of parents for morphological traits in bread wheat

Parents	Plant height (cm)	Tillers plant^{-1}	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1} (g)	Seed index (g)
Benazir	3.45	-3.33	1.90	0.84	1.85	8.20	4.00
Sindhu	3.10	-0.73	0.90	0.90	2.00	3.45	-5.21
Khirman	4.38	1.98	2.14	1.85	2.44	4.38	-6.70
Hamal	-3.90	3.75	-1.90	1.86	2.19	-10.60	-3.90
NIA-Sarang	-3.90	-3.44	-1.34	-2.58	-4.67	-2.90	6.90
NIA-Sundar	-3.13	1.76	-1.70	-2.87	-3.90	-2.13	4.91
S. E. (gi)	0.65	0.89	0.22	0.35	0.11	2.10	1.45

Table 4. SCA effects of F_2 hybrids for morphological traits in bread wheat

F_2 hybrids	Plant height (cm)	Tillers plant^{-1}	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}	Grain yield plant^{-1} (g)	Seed index (g)
Benazir x Sindhu	3.90	1.20	0.90	0.34	3.45	5.60	1.90
Benazir x Khirman	2.81	2.30	1.20	0.20	4.88	4.34	3.56
Benazir x Hamal	2.60	1.78	0.45	0.10	3.89	-4.56	5.60
Benazir x NIA-Sarang	0.91	1.45	0.66	0.90	5.45	-3.33	4.50
Benazir x Sindhu	-1.85	0.89	0.88	1.90	3.44	3.45	6.00
Sindhu x Khirman	-1.60	-0.76	1.45	0.88	4.67	5.00	-7.00
Sindhu x Hamal	-2.55	-2.10	1.46	0.65	-6.90	6.00	3.42
Sindhu x NIA-Sarang	3.51	-0.90	-1.21	0.45	-5.90	-4.60	4.45
Sindhu x NIA-Sunder	3.44	-0.67	-1.20	0.34	-3.90	-2.60	3.33
Khirman x Hamal	-2.60	0.56	-0.24	-0.68	-1.89	-3-43	-3.45
Khirman x NIA-Sarang	-3.41	1.34	0.45	-0.65	-2.90	2.90	-2.13
Khirman x NIA-Sunder	-4.32	0.34	-1.65	-0.90	3.76	-4.55	-1.30
Hamal x NIA-Sarang	1.44	1.65	0.88	0.82	2.00	2.16	-4.45
Hamal x NIA-Sunder	2.80	1.90	0.34	0.34	3.31	3.00	2.10
NIA-Sarang x NIA-Sundar	-1.65	0.65	0.89	0.56	2.12	-5.00	3.21
S. E. (si)	1.18	0.34	0.95	0.44	0.98	2.60	0.87

4. DISCUSSION

Trait improvements such as higher yields have remained important objectives of wheat breeders for many decades. For the improvement of any character, plant breeders mostly count on the combining ability of parents determined by various mating designs [10]. But some crosses may be more superior to their parents for some economic attributes. Conventional breeding in this regard played a major role in the development of new varieties. Lots of developments have also been made by molecular genetics. Besides, the evolution of new varieties with increased yield and adaptation to new environments are just a few success stories. As a result, wheat varieties are currently enhanced by integrating single or multiple characteristics into the wheat genome, and the expression of these traits is also controlled for wheat hybrid development [18]. Mean squares due to GCA and SCA were highly significant and significant in parents and parents x hybrids for all the traits, respectively. In two traits, GCA was greater than SCA, while SCA was greater than GCA for the rest of the characters. Additive and dominant genes played a very vital character for most of the traits in GCA and SCA for their mean squares and the genotypes which show such excellent results can be used in different locations [19]. He also suggested that the existence of significant differences was possible because of the additive and nonadditive gene actions in the average values of parents and F_2 hybrids. The prominence of GCA variance for grain yield plant^{-1} and grains spike^{-1} was witnessed by Nour *et al*. (2011) who advocated that additive genes were the only genes accountable for these characters [20]. Anwar *et al*. (2011) and Tsenov and Tsenova (2011) assumed that nonadditive hereditary effects were higher for grain yield and number of grains, exposing the prevalence of SCA effects [21, 22]. Additive and nonadditive types of gene actions with high values of GCA and SCA for tillers plant-1 and spikelets spike^{-1} were studied by Cifci and Yagdi (2010) and Kutlu and Olgun (2015) [23, 24]. Contrary to these findings, GCA effects were rather higher than SCA for spike length and for seed index SCA were higher than GCA in the experiment of Sreelakshmi and Babu. (2018) and Brahim and Mohamed (2014) also became successful in seeing GCA and SCA because of the existence of additive and dominant genes for some traits in wheat, but dominant gene action was high in the experiment [25, 26].

When comparing the average performance of 21 genotypes, including parental lines and F_2 hybrids, it was discovered that for the majority of the characteristics, the crosses outperformed their parents. Medium size plants in height are regarded as enviable in cotton breeding because of motive that medium sized plants are reasonably tolerant to lodging. The averages of parents and hybrids performed best for plant height. Information of GCA and SCA for yield and its constituents has proved very useful in the selection of appropriate parents for the development of hybrids. Both desirable and undesirable GCA and SCA estimates were seen for plant height. However, parents' and hybrids' results suggested that Hamal, NIA-Sarang, and NIA-Sundar being good general combiners. Similar results were also obtained by Kalhoro *et al*. (2015) and Baloch *et al*. (2014) who articulated the same results as the present results determining Imdad and TD^{-1} as good general combiners for the height of plant and number of tillers in a single plant [27, 28]. On the other hand, Sharma and Jaiswal (2020) and Padhar *et al*. (2010) added that success in the enlargement of high-yielding and widely adapted hybrids nevertheless is governed by the specific combining ability of parent crosses [29, 30]. Khirman x NIA-Sundar, Khirman x NIA-Sarang and Khirman x Hamal being good specific combiners are suitable parents and hybrids for hybridization and selection programmes to develop breeding material with medium taller plant height for hybrid wheat development. Such results had also been confirmed by Hijam *et al*. (2019) and Akbar *et al*. (2009) in his experiment working with the crop of wheat [31 32].

The formation of more tillers rises the opportunity of more spikelets and grains produced by the individual plant. Sindhu, NIA-Sundar, Benazir x Sindhu, and Sindhu x Hamal were the best scorers among the parents and cross combinations for tillers per plant. For the evolution of this characteristic in breeding programmes, the results for tillers per plant showed that Hamal and Khirman may be chosen. The higher SCA effects of these hybrids such as Benazir x Khirman, Hamal x NIA-Sundar and Benazir x Hamal that they are appropriate for selection in later generations for hybrid crop development. Kushwaha *et al*. (2020) and Bano and Singh (2019) also reported good results for this trait in wheat [33, 34]. Similar to our findings, Singh and Yadav (2011) and Sharifi (2019) articulated that GCA and SCA with additive and nonadditive genes were regulating tillers per plant. Yet, SCA mean squares being greater than GCA displayed more influence of dominant genes [35, 36].

The wheat inflorescence is said to be a spike. It contains grains, the major constituents of the yield. Among yield contributing characters, spike length is as imperative as any other traits being considered from the economic point of view. For spike length, parents Benazir followed by Sindhu and crosses Sindhu x NIA-Sarang followed by Sindhu x Hamal were on the top in the increase of the lengths of spikes. In the case of GCA and SCA, three parents and three crosses became good general and specific combiners for this trait. Ramesh *et al*. (2018) noted that the variety TD^{-1} was a good general combiner due to the presence of additive genes for controlling spike length [37]. These results about spike length conform with [38, 39] as well. It was finalized that these parents and hybrids were noted as the best selection criteria for hybridization and selection programmes so that superior plants can be chosen from later segregating populations for the length of a spike or they may be considered for hybrid wheat development for the improvement of spike length. Our findings are similar to Ghidan *et al.* (2019) and Baloch *et al*. (2013) who succeeded in identifying some hybrid with positive and desirable GCA and SCA for spike length [40, 41].

As spikelets spike^{-1} increase, yield is also expected to increase simultaneously. Therefore, a high affirmative relationship between these two characters is mostly observed. On average as regards to spikelets Spike^{-1}, the higher number of spikelets spike1 was shown by Khirman, NIA-Sundar, Benazir x Hamal and Benazir x Sindhu. For GCA effects, Hamal and Khirman were the best general combiners indicating that these parents retain more additive genes, thus they may be utilized in hybridization programmes so that spikelets spike^{-1} can be improved form segregating populations. Analogous outcomes were also confirmed by Patel *et al*. (2019) and Yucel *et al*. (2009) who notified that not only additive genes but dominant genes were also regulating the articulation of spikelets spike^{-1} [42, 43]. The findings also indicated that Benazir x NIA-Sundar, Benazir x NIA-Sarang, Sindhu x Khirman had stronger SCA effects owing to dominant and overdominant genes, suggesting that they might be the most trustworthy crosses for hybrid wheat production. Our results are in conformity with [44, 45] who testified some of the hybrids expressed both negative GCA and SCA as well as positive GCA and SCA for this trait. Finally, such results gave the idea that if parents and hybrids are used in hybridization programmes, desirable segregants can be extracted to improve the spikelet spike^{-1} in bread wheat.

Grain is also one of the most essential traits for increasing the yield of cereals. If the number of grains is in the higher count, the yield will also be in a higher quantity. Grains per spike is strongly correlated with grain yield and holds plenty of importance for wheat breeders because it plays a central role in the development of high-yielding cultivars, thus benefits the economy of the growers as well as the country for its improvement. In the case of grains spike-1 from the parents, Hamal and Khirman, whereas from hybrids, Hamal x NIA Sundar and Hamal x NIA-Sundar were noted as the best performers. For the results of GCA and SCA, our results suggested that Khirman and Hamal as the best general combiners, while Benazir x NIA Sarang, Benazir x Khirman and Sindhu x Khirman as the best specific combiners may be exploited for hybridization and selection programmes to develop wheat crop. Comparable to our results, superior general combiners were also confirmed by [46, 47] for grains per spike in two cultivars of his research. Furthermore, they established three crosses as the best specific cross combinations for certain characteristics, such as spike length. Hexaploid wheat breeders should pay close attention to our and their findings to improve grain production and contribute through GCA of parents and SCA of cross combinations. Therefore, our findings of grains spike-1 are the same as Ghidan *et al*. (2019) and Rustamova *et al*. (2021) [48, 49]. The present results are also in consonance with Baloch *et al*. (2013) and Gharib *et al*. (2013) in both of these researchers notified additive, as well as dominant genes, were advocating grains per spike [50, 51]. Thus, our results suggested that the above-mentioned parents are the best general combiners for the hybridization and selection programmes for the evolution of wheat. In addition, such parents and hybrids may prove to be fruitful in creating variability upon which effective selection for the increasing number of grains per spike could be exercised.

Yield per plant possesses exceptional importance for wheat breeders because it plays a major role in boosting the finance of farmers and the country. On behalf of grain yield plant-1 in six parents, Benazir along with NIA-Sundar, despite the fact in F_2 hybrids, Sindhu x Khirman followed by Benazir x Sindhu were with higher grain yield. The largest GCA effects for grain yield per plant were found in Benazir and Khirman, implying that both parents are strong general combiners who can be relied on to improve and raise the production of wheat plants through hybridization and assortment programmes. These results are in accordance with those recounted by Patel *et al*. (2019) and Fleitas *et al*. (2020) [52, 53]. In the case of SCA, good specific combiners were Sindhu x Hamal, Benazir x Sindhu and Sindhu x Khirman presenting their suitability for hybrid crop improvement and development. The results are according to [54, 55] who also stated that hybrids having dominant and overdominant genes would more and more potential for the exploitation of combing ability in wheat. Present are also in paradox with those Patel *et al*. (2019) and Fleitas *et al*. (2020) of who described significant GCA and SCA variances stating predominance of additive and nonadditive gene action involved in the inheritance of grain yield of wheat [52, 53].

Furthermore, the highest seed index was articulated by the parents NIA-Sarang and Sindhu and among hybrids, by Sindhu x NIA-Sarang followed by Benazir x NIA-Sarang. Documentation of parents and hybrids are the chief concerns to the wheat breeders for improving in various yield and biomass traits. Therefore, such parents and hybrids will be very advantageous in hybridization to advance many of the yield and its components. Seed index and grain yield are often positively correlated, which means an increase in seed index, will at the same time increase grain yield [56, 57]. Bolder seeds, on the other hand, may provide a larger grain yield in crops. The cultivars NIA-Sarang and NIA-Sundar have good and desired GCA estimates on seed index among parents. Several hybrids had higher SCA estimations, but Benazir x Sindhu, Benazir x Hamal, and Benazir x NIA-Sarang had the most positive SCA estimates. Based on the results, these parents and hybrids can further be utilized to improve the seed index for the development of wheat hybridization breeding. These conclusions are in harmony with Sudeepthi *et al*. (2018) and Ali et al. (2014) who suggested that GCA and SCA variances were under additive and dominant genes for governing this trait [58, 59].

5. CONCLUSION

It was concluded that significant analysis of variance owing to genotypes, parents, F_2 hybrids, and parents vs. F_2 hybrids were noted for all the attributes which expressed the attendance of a large extent of genetic changeability among these all. The variances of general and specific combining ability were also unlike for all the characters pointing out the reputation of both additives as well as non-additive genes determining them. In parents and cross combinations, the most superior general and specific combiners can unfailingly be brought under the hybridization programmes to improve in the majority of the characteristics from the segregating populations in the hybrid wheat development to fill the gap of food shortage for the day by day increasing population of the globe.

6. ACKNOWLEDGEMENTS

The authors are very thankful to Southern Wheat Research Station, Tandojam and Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Sindh, Pakistan for their kind cooperation and guidance in the research.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

8. REFERENCES

1. M.M. Elshenawy, G.B. Anis, W.G. Elgamal, and A.E. Ramadan. Genetic basis of combining ability for various quantitative traits using CMS lines of rice (*Oryza sativa* L.). T*he Serbian Journal of Agricultural Sciences* 67: 125-135 (2018).
2. K. Jons, and Amos. Environmental effect on the quality of different wheat genotypes quantitative variation of storage proteins. *European Journal of Agriculture* 13: 47-64 (2010).
3. S. Suvathipriya, and T. Kalaimagal. Combining ability study in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding* 9: 753-758 (2018).
4. V. Sharma, N.S. Dodiya, R.B. Dubey, and R. Khan. Combining ability analysis in bread wheat under different environmental conditions. *Bangladesh Journal of Botany* 48: 85-93 (2019).
5. S.R. Rahul. Combining ability and heterosis for morpho-physiological characters on bread wheat (*Triticum aestivum* L.). *Agricultural Research and Technology* 13: 001-009 (2017).
6. M.J. Baloch, G.M. Channa, W.A. Jatoi, A.W. Baloch, I.H. Rind, M.A. Arain, and A.A. Keerio. Genetic characterization in 5 × 5 diallel crosses for yield traits in bread wheat. *Sarhad Journal of Agriculture* 32: 127-133 (2016).
7. M. Abbas, A.D. Sheikh, M.S. Hazor, and N. Shagufta. Factor responsible for low wheat yield productivity in Punjab. *Pakistan Journal of Agricultural Sciences* 42: 79-82 (2015).
8. G. Kiani. Analysis of combining ability in rice varieties for quantitative traits. *Notulae Scientia Biologiae* 11: 436-439 (2019).
9. D.K. Mandan, A.H. Solangi, G.M. Baloch, Z.A. Soomro, Q. Chachar, and W.A. Jatoi. Combining ability and heritability estimation for elite genotypes in hexaploid wheat (*Triticum aestivum* L.). *International Journal of Biosciences* 15: 570-585 (2019).
10. N. Solongi, W.A. Jatoi, M.J. Baloch, M. Siyal, A.H. Solangi, and S. Memon. Heterosis and combining ability estimates for assessing potential parents to develop F_1 hybrids in upland cotton. *The Journal of Animal & Plant Sciences* 29: 1362-1373 (2019).
11. G.F. Sprague, and L.A. Tatum. General versus specific combining ability in single crosses of corn. *Journal of American Society of Agronomy* 34: 923-

932 (1942).

12. P. Fasahat, A. Rajabi, J.M. Rad, and P. Derera. Principles and utilization of combining ability in plant breeding. *Biometrics & Biostatistics International Journal* 4: 1-24 (2016).
13. S. Xu. Mapping quantitative trait loci using multiple families of line crosses. *Genetics* 148: 517-524 (1998).
14. M. Reynolds, F. Dreccer, and R. Trethowan. Drought-adaptive traits derived from wheat wild relatives and landraces. *Journal of Experimental Botany* 58: 177-186 (2007).
15. K.A. Gomez, and A.A. Gomez. Statistical procedures for agricultural research. John Wiley & Sons Inc. 2nd (ed.) New York, U.S.A. Pp. 680 (1984).
16. B. Griffing. Concept of general versus specific combining ability in relation to diallel crossing system. *Australian Journal of Biological Sciences* 9: 463-493 (1956).
17. R.K. Singh, and B.D. Choudhary. Biometrical methods in quantitative genetic analysis. *Kalyani Publisher, New Delhi*. p. 191-200 (1979).
18. Akanksha, and H. K. Jaiswal. Combining ability studies for yield and quality parameters in basmati rice (Oryza sativa L.) genotypes using diallel approach. *Electronic Journal of Plant Breeding* 10: 9-17 (2019).
19. G. Hassan, F. Mohammad, S.S. Afridi, and I. Khalil. Combining ability in the F1 generations of diallel cross for yield and yield components in wheat. *Sarhad Journal of Agriculture* 23: 937-942 (2007).
20. A. Nour, A.R. Nadya, H.S.A. El–Fateh, and A.K. Mostafa. Line x tester analysis for yield and its traits in bread wheat. *Egyptian Journal of Agricultural Research* 89: 979-992 (2011).
21. J. Anwar, Akbar, M. Hussain, S. Asghar, J. Ahmad, and M. Owais. Combining ability estimates for grain yield in wheat. *Journal of Agricultural Research* 49: 437-445 (2011).
22. N. Tsenov, and E. Tsenova. Combining ability of common winter wheat cultivars (*Triticum aestivum* L.) by date to heading and date to physiological maturity. *Bulgarian Journal of Agricultural Science* 17: 277-287 (2011).
23. E.A. Cifci, and K. Yagdi. The research of the combining ability of agronomic traits of bread wheat in F_1 and F_2 generations. *Journal of Agricultural Faculty of Uludag University* 24: 85-92 (2010).
24. I. Kutlu, and M. Olgun. Determination of genetic parameters for yield components in bread wheat. *International Journal of Biosciences* 6: 61-70 (2015).
25. C. Sreelakshmi, and P.R. Babu. Identification of parents and hybrids for yield and its components using line x tester analysis in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding* 9: 220-225 (2018).
26. B. Brahim, and B. Mohamed (2014). Analysis of diallel crosses between six varieties of durum wheat in semi-arid area. *African Journal of Biotechnology* 13: 286-293.
27. F.A. Kalhoro, A.A. Rajpar, S.A. Kalhoro, A. Mahar, A. Ali, S.A. Otho, R.N. Soomro, F. Ali & Z.A. Baloch. Heterosis and combing ability in F_1 population of hexaploid wheat (*Triticum aestivum* L.). *American Journal of Plant Sciences* 6: 1011-1026 (2015).
28. M.J. Baloch, J.A. Solangi, W.A. Jatoi, I.H. Rind & F.M. Halo. Heterosis and specific combining ability estimates for assessing potential crosses to develop F1 hybrids in upland cotton. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences* 30: 8-18 (2014).
29. A. Sharma, and H.K. Jaiswal. Combining ability analysis for grain yield and quality traits in basmati rice (*Oryza sativa* L.). *Plant Archives* 20, 2367-2373 (2020).
30. P.R. Padhar, R.B. Madaria, J.H. Vachhani, and K.L. Dobariya. Combining ability analysis of grain yield and its contributing characters in bread wheat (*Triticum aestivum* L.) under late sown condition. *International Journal of Agricultural Sciences* 6: 267-272 (2010).
31. C. Hijam, N.B. Singh, and J.M. Laishram. Diallel analysis of yield and its important components in aromatic rice (*Oryza sativa* L.). *Indian Journal of Agricultural Research* 53: 67-72 (2019).
32. M. Akbar, M. Saleem, M.Y. Ashraf, A. Husain, F.M. Azhar, and R. Ahmad. Combining ability studies for physiological and grain yield traits in maize at two temperature regimes. *Pakistan Journal Botany* 41: 1817-1829 (2009).
33. U.K.S. Kushwaha, Indra Deo, P.S. Shukla, D.C. Baskheti and A.K. Tewari. Estimation of combining ability, heterosis, heritability, and generation mean in basmati rice (*Oryza sativa* L.) by line x tester design. *Azarian Journal of Agriculture* 6: 153-163 (2019).
34. M.M. Kamara, K.M. Ibrahim, E. Mansour, A.M.S. Kheir, M.O. Germoush, D. Abd El-Moneim, M. I. Motawei, A.Y. Alhusays, M.A. Farid, M. Rehan. Combining Ability and Gene Action Controlling

Grain Yield and Its Related Traits in Bread Wheat under Heat Stress and Normal Conditions. *Agronomy* 11: 1450-1477 (2021).
35. D.A. Bano, and S.P. Singh. Combining ability studies for yield & quality traits in aromatic genotypes of rice (*Oryza sativa.* L.). *Electronic Journal of Plant Breeding* 10: 341-352 (2019).
36. M. Djanaguiraman, S. Narayanan, E. Erdayani, P.V. Prasad. Effects of high temperature stress during anthesis and grain filling periods on photosynthesis, lipids and grain yield in wheat. *BMC Plant Biology* 20: 268 (2020).
37. M.W. Riaz, L. Yang, M.I. Yousaf, A. Sami, X.D. Mei, L. Shah, S. Rehman, L. Xue, H. Si, C. Ma. Effects of heat stress on growth, physiology of plants, yield and grain quality of different spring wheat (*Triticum aestivum* L.) genotypes. *Sustainability* 13: 2972 (2021).
38. S.V. Singh, and R.K. Yadav. Combining ability analysis under different locations of U.P. in wheat (*Triticum aestivum* L.). *Bhartiya Krishi Anusandhan Patrika* 26: 118-122 (2011).
39. A. Tariq, I. Ashraf, M. Ahmed, A. Muscolo, S. Basra, M. Reynolds. Evaluation of physiological and morphological traits for improving spring wheat adaptation to terminal heat stress. *Plants* 10: 455 (2021).
40. P. Sharifi. Genetic variation for grain yield, yield components and qualitative traits in rice (*Oryza sativa* L.) mutants. *Genetika* 51: 829-843 (2019).
41. G.M.S.M. Abaza, H.A. Awaad, Z.M. Attia, K.S. Abdel-lateif, M.A. Gomaa, S.M.S.M. Abaza, E. Mansour. Inducing potential mutants in bread wheat using different doses of certain physical and chemical mutagens. *Plant Breeding and Biotechnology* 8: 252–264 (2020).
42. C. Ramesh, C.D. Raju, C.S. Raju, and N.R.G. Varma. Combining ability and gene action in hybrid rice. *International Journal of Pure and Applied Bioscience* 6: 497-510 (2018).
43. E.S. Moustafa, M. Ali, M.M. Kamara, M.F. Awad, A.A. Hassanin, E. Mansour. Field screening of wheat advanced lines for salinity tolerance. *Agronomy* 11: 281 (2021).
44. A.A. Kandil, A.E. Sharief, and H.S.M. Gomaa. Estimation of general and specific combining ability in bread wheat (*Triticum aestivum* L.). *International Journal of Agricultural Research* 8: 37-44 (2016).
45. I. Al-Ashkar, M. Alotaibi, Y. Refay, A. Ghazy, A. Zakri, A. Al-Doss. Selection criteria for high-yielding and early-flowering bread wheat hybrids under heat stress. *PLoS ONE* 15: e0236351 (2020).
46. S. Nazir, A.S. Khan, and Z. Ali. Combining ability analysis for yield and yield contributing traits in bread wheat. *Journal of Agriculture and Social Sciences* 1: 129-132 (2005).
47. D. Sharma, J.P. Jaiswal, N.C. Gahtyari, A. Chauhan, N.K. Singh. Genetic dissection of physiological traits over trait-based breeding in bread wheat conferring terminal heat tolerance. *Cereal Research Communication* 1–9 (2021).
48. W.F. Ghidan, R.Y. El-Agoury, and F.A. Hussein. Utilization of combining ability and genetic components for yield and its contributing traits of some rice (*Oryza sativa* L.) genotypes. *Journal of Agricultural Chemistry and Biotechnology* 10: 257-267 (2019).
49. S. Rustamova, A. Shrestha, A.A. Naz, I. Huseynova. Expression profiling of DREB1 and evaluation of vegetation indices in contrasting wheat genotypes exposed to drought stress. *Plant Gene* 25: 100266 (2021).
50. M.J. Baloch, A.T. Rajper, W.A. Jatoi, and N.F. Veesar. Identification of superior parents and hybrids from diallel crosses of bread wheat (*Triticum aestivum* L.). *Pakistan Journal of Scientific and Industrial Research* 56: 59-64 (2013).
51. M.A.A.H. Gharib, N. Qabil, A.H. Salem, M.M.A. Ali, H.A. Awaad, E. Mansour. Characterization of wheat landraces and commercial cultivars based on morpho-phenological and agronomic traits. *Cereal Research Communication* 49: 149–159 (2021).
52. U.M. Patel, G.O. Faldu, P.B. Patel, and N.P. Savankumar. Combining ability analysis in rice (*Oryza sativa* L.). *International Journal of Pure and Applied Bioscience* 7: 362-368 (2019).
53. M.C. Fleitas, S. Mondal, G.S. Gerard, N. Hernández-Espinosa, R.P. Singh, J. Crossa, C. Guzmán. Identification of CIMMYT spring bread wheat germplasm maintaining superior grain yield and quality under heat-stress. *Journal of Cereal Science* 93: 102981 (2020).
54. C. Yücel, F.S. Baloch, and H. Özkan. Genetic analysis of some physical properties of bread wheat grain (*Triticum aestivum* L.). *Turkish Journal of Agriculture and Forestry* 33: 525-535 (2009).
55. S. Schittenhelm, T. Langkamp-Wedde, M. Kraft, L. Kottmann, K. Matschiner. Effect of two-week heat stress during grain filling on stem reserves, senescence, and grain yield of European winter wheat cultivars. *Journal of Agronomy and Crop Sciences* 206: 722–733 (2020).

56. M. Behera, D. Sharma, O.N. Singh, and R.L. Verma. Combining ability analysis for yield and quality related traits in non- basmati aromatic rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences* 7: 1908-1922 (2018).
57. M.N. Barakat, I.M. Al-Ashkar, A.A. Al-Doss, K.A. Moustafa, M.I. Motawei, M.S. Alamri, M. Mergoum, M.S. Sallam. Identification of genotyping-by-sequencing tags associated with bread-making quality traits in spring wheat under heat stress. *Cereal Research Communication* 48: 347–353 (2020).
58. K. Sudeepthi, D.P.B. Jyothula, and Y. Suneetha. Heterosis and combining ability studies for yield and yield component traits in rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences* 7: 1205-1211 (2018).
59. Q. Ali, A. Ali, M.F. Awan, M. Tariq, S. Ali, T.R. Samiullah, S. Azam, S. Din *et al*. Combining ability analysis for various physiological, grain yield and quality traits of Zea mays L. *Life Science Journal* 11: 540-551 (2014).