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Research Article

Line × tester analysis and estimating combining abilities for the physiological and yield traits in bread wheat

Sadia Hakeem †[1], Zulfiqar Ali*[1], Muhammad Abu Bakar Saddique[1], Muhammad Habib-ur-Rahman[2,3], Sabah Merrium[1]
[1]*Institute of Plant Breeding and Biotechnology, MNS University of Agriculture, Multan, Pakistan*
[2]*Department of Agronomy, MNS University of Agriculture, Multan, Pakistan*
[3]*Institute of Crop Science and Resource Conservation (INRES), Crop Science Group, University of Bonn, Germany*
* *Corresponding author: zulfiqar.ali@mnsuam.edu.pk*

ABSTRACT

The present study focuses to determine the combining abilities for 12 wheat genotypes for the physiological and yield traits by using line × tester mating design. Eight lines and four testers, as parents, and resulting 32 cross combinations were evaluated in randomized complete block design during the 2018-19 cropping season. The analysis of variance (ANOVA) indicated that variability exists for all the traits under study. The parent 14 showed higher general combining ability (GCA) effects for the stomatal conductance (SC) and transpiration (T) while parent 19 and 6 have the highest GCA effects for the photosynthesis (P) and water use efficiency (WUE). Parent 14 was a good general combiner for the flag leaf area and spike weight while parent 19 for the seed weight and plant height. However, parent 18 showed the highest GCA effect for spike length. Overall, parents 14, 18, 19, and 6 were good general combiners for most of the traits. And the cross combination coded 32 was a potential hybrid for the spike weight, seed weight, and yield per row while 29 showed the highest specific combining ability (SCA) estimates for the physiological traits except for water use efficiency (WUE). Hybrid 28 showed superior SCA effects for spike length and plant height and hybrid 4 was a potential hybrid for flag leaf area (FLA). So, these parents and cross combinations can be used in the selection process of varietal improvement for ideal yield potential. This will also lead to the fixation of additive as well as non-additive genetic components for the improvement of the yield components in wheat.

Keywords: *Triticum aestivum*, general combining ability, specific combining ability, F1 hybrids, gene action

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1. INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is an important cereal grain crop that is a dominant food source for livestock and human all around the world. The global wheat demands have been increasing while wheat yield is facing a continuous threat by climate change. It is a staple food crop of Pakistan and is grown on an area of 8.7 million hectares with 25 million tons annual production (Anonymous, 2020). It accounts for 8.7 percent value-added to agriculture and 1.7 percent GDP of Pakistan according to the ministry of finance. The population is increasing and so is the food demand. The yield improvement can be achieved through improved agronomic practices and developing better adoptive high-yielding varieties (Fellahi *et al.*, 2013). So, there is a need to identify genotypes with better combining ability for the physiological and yield traits. The improvement of yield components is a crucial step towards developing high yielding cultivars. However, the selection of parents and crosses with higher combining abilities can be a problem for the development of varieties. The combining ability effects reveal the differences among genotypes and also depict the nature of gene action involved (Fasahat *et al.*, 2016). Plant breeders use general combining ability (GCA) for the selection of parents based on the progeny performance especially in F_1. It has been used in wheat for yield traits (Jain and Sastry, 2012; Khaled *et al.*, 2013), nutritional values (Singh, 2014), and pest resistance (Thompson *et al.*, 2012). A GCA value, positive or negative, indicates the variance of the parental mean from the general mean. The higher GCA value indicates predominantly additive gene action (Caixeta Franco *et al.*, 2001), high heritability, less gene interaction, and successful selection (Chigeza *et al.*, 2014). The specific combining ability (SCA) acts as masking effect as it is attributed to the non-additive gene action. The parental selection based only on SCA effects cannot be guaranteed. Thus, the SCA effect should be used in combination with the higher GCA estimates, higher hybrid performance involving at least one of the parents with higher GCA value (Makanda *et al.*, 2010).

The line × tester analysis by Kempthorne (1957) is a powerful tool for estimating the general and specific combining ability effects. It also provides a genetic background for the mechanisms controlling the traits (Akbar *et al.*, 2009). It aids in the selection of suited parents using GCA effects and crosses by SCA effects by applying the formula proposed by Singh and Chaudhary (1977) (Fasahat *et al.*, 2016).

The purpose of this study was to estimate the general and specific combing ability effects for the four physiological traits (stomatal conductance, photosynthesis, transpiration, and water use efficiency) and yield and its components to select the promising cross combination that shows better yield potential. The line × tester design was used for this purpose to assess the GCA and SCA effects of the traits under study.

2. MATERIAL AND METHODS

The research was conducted in the research farms of the Institute of Plant Breeding and Biotechnology, Faculty of Agriculture and environmental sciences, MNS university of agriculture in Multan during 2018-19 and 2019-20.

Eight wheat genotypes (coded as 2, 13, 14, 18, 19, 22, 23, and 25) were used as lines and four wheat genotypes (coded as 1, 5, 7, and 9) as testers and one local cultivar (Ujala-16) was used as a standard check variety. The testers were the genotypes with the best leaf architecture. On the other hand, the lines had the best physiological and yield-related traits. The 12 parents were crossed to produce 32 hybrids following the line × tester mating design as put forward by Kempthorne (1957) and adapted by Singh and Chaudhary (1977), during 2018-19.

The 32 crosses and 12 parents were evaluated during the 2019-20 growing season in Randomized Complete Block Design (RCBD) with two replications. In each replication, the parents and hybrids were sown in a single row of 1m length with 10 cm plant spacing and 25 cm row spacing. The 50 kg diammonium phosphate (DAP) and sulfate of potash (SOP) ha^{-1} was applied as a basal dose at the time of sowing. 50 kg Urea ha^{-1} was applied during the stem elongation period. All the recommended cultural practices were performed to raise a healthy crop (AARI, 2019). The physiological traits were measured using the 80018-3 CIRAS-3 portable photosynthesis System from PP Systems. The data were recorded from the first leaf of the plant. The middle portion of the leaf blade was considered for these measurements. Three readings were taken from each genotype and an average was calculated. The yield traits including flag leaf area (cm^2), spike length (cm), plant height (cm), ear weight (g), and seed weight (g) were recorded from three random plants. Grain yield (Y) was measured as grams per row. All the data recorded were subject to the line × tester analysis using statistical software R (version 3.6.1).

3. RESULTS

The present study was conducted to estimate the general and specific combining ability effects in a set of the line into tester crosses with eight lines and 4 testers of bread wheat. The parents and the cross combinations were evaluated for the physiological traits and yield components. The results obtained for each kind of traits are presented as under:

3.1. Physiological traits

The data for the four physiological traits including stomatal conductance (SC), photosynthesis (P), transpiration rate (T), and photosynthetic water use efficiency (WUE) is presented as Figure 1. Hybrid 11 followed by female 7 and hybrid 5 showed the highest score for the T (3.6 mmol H_2O m^{-2} s^{-1}) and SC (137.0 mmol H_2O m^{-2} s^{-1}) while hybrid 30 followed by hybrid 32 showed the lowest values (0.6 mmol H_2O m^{-2} s^{-1} and 22 mmol H_2O m^{-2} s^{-1}, respectively) for these traits. The hybrids 18, 8 followed by hybrid 29 had the highest values for the P (8.9 µmol CO_2 m^{-2} s^{-1}) while hybrids 32 followed by hybrid 30 had the lowest value for P (1.4 µmol CO_2 m^{-2} s^{-1}). For WUE, the hybrid 19 showed the highest value (13.0 mmol CO_2 mol^{-1} H_2O) while hybrid 11 followed by female 7 showed minimum values (0.5 mmol CO_2 mol^{-1} H_2O) for this trait.

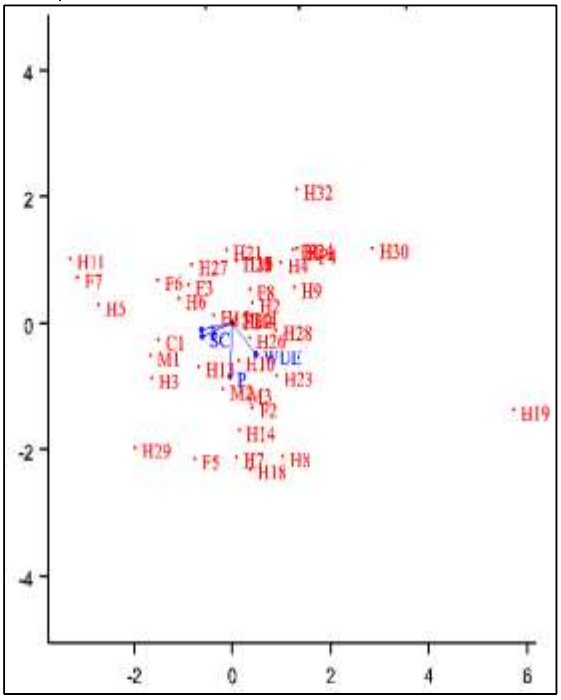

Figure 1. Biplot analysis of the physiological traits for the 32 wheat hybrids and their parents. SC: Stomatal conductance; WUE: Water use efficiency; T: Transpiration rate; P: Photosynthesis.

The ANOVA, GCA and SCA for the SC, P, T and WUE are presented in Table 1, 2 and 3.

The genotypes and hybrids showed significant variation for all the

Table 1. Mean squares for physiological traits

Sources of variation	DF	Stomatal Conductance (mmol H_2O m^{-2} s^{-1})	Photosynthesis (µmol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Water Use Efficiency (mmol CO_2 mol^{-1} H_2O)
Replication	1	763	2.7	1.34	1.62
Genotypes	44	1983.28**	9.71*	1.28**	6.05*
Parents	12	780	2.66	0.53	1.04
Parents and hybrids	1	16175.29**	31.85**	8.44**	4.51
Hybrids	31	1991.32**	11.72**	1.34**	8.18**
Lines	7	1596	10.29	1.07	4.81
Testers	3	2963	11.9	1.98	4.99
Lines × Testers	21	1984.3**	12.17**	1.33**	9.76**
Error	44	671	4.38	0.4	3.73

* Significant at 5% level, ** significant at 1% level

physiological traits (Table 1). The parents and hybrids showed significant variation for all traits except WUE. Hybrids and lines × testers were significant for all the traits.

The GCA effects of physiological traits for lines and testers are shown in Table 2. The GCA effects of all four physiological traits were negative for ≥50 percent of parents. Five parents including 1, 6, 14, 18, and 19 had positive GCA effects of SC, T, and WUE, while only four out of 12 parents showed positive GCA effects of P.

Table 2. General combining ability (GCA) effects of physiological traits for 12 parents used in cross combinations

Parents	Stomatal Conductance (mmol H_2O m^{-2} s^{-1})	Photosynthesis (μmol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Water Use Efficiency (mmol CO_2 mol^{-1} H_2O)
Lines				
2	-10.67	-0.85	-0.223	-0.516
13	-27.05	-0.962	-0.717	0.386
14	20.03	0.762	0.417	0.069
18	7.203	0.812	0.278	0.149
19	7.578	2.075	0.271	1.638
22	-1.547	-1.288	-0.033	-0.789
23	-1.172	-0.325	-0.069	-0.347
25	5.453	-0.225	0.021	-0.59
Testers				
6	11.016	1.113	0.211	0.633
1	10.266	-0.056	0.312	0.16
5	-3.484	-0.062	-0.045	-0.082
7	-17.97	-0.994	-0.478	-0.71

The GCA effects of SC for parents 14 and 6 were highest and positive while parents 13 and 7 had negative and lowest GCA effect, and of P highest GCA effect was shown by parent 19 and 6 while parents 22 has lowest and negative GCA effects. Parent 14 and 1 had the highest GCA effects of transpiration and parent 6 showed the highest GCA effects of WUE. Conversely, parent 13, and parent 22 have minimum GCA effects for these traits (Table 2).

The specific combining ability effects of physiological traits for all the wheat hybrids are presented in Table 3. The SCA of SC ranges from -56.851 (25) to 55.234 (29) and of P ranges from -3.500 (25) to 4.375 (29). Similarly, the ranges for SCA effects of T varies from -1.517 (31) to 1.505 (29) and of WUE ranges from -2.859 (17) to 4.799 (19).

Table 3. Specific combining ability (SCA) effects of physiological traits for 32 wheat hybrids

Hybrids	Stomatal Conductance (mmol H_2O m^{-2} s^{-1})	Photosynthesis (μmol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Water Use Efficiency (mmol CO_2 mol^{-1} H_2O)
1) 19×6	-22.016	2.85	-0.529	4.57
2) 19×1	4.484	-1.275	-0.155	-1.63
3) 19×5	9.734	-0.606	0.524	-2.327
4) 19×7	7.797	-0.456	0.16	-0.613
5) 14×6	-3.641	-2.037	0.206	-0.971
6) 14×1	-8.141	-2.563	-0.305	-1.521
7) 14×5	7.609	1.156	0.004	-0.148
8) 14×7	4.172	3.444	0.095	2.641
9) 22×6	23.109	1.212	0.51	0.486
10) 22×1	-2.891	0.737	0.094	0.041
11) 22×5	15.359	-0.444	0.313	0.529

12) 22×7	-35.953	-1.506	-0.917	-1.056
13) 23×6	11.734	0.6	0.266	0.35
14) 23×1	-3.766	0.975	-0.33	1.775
15) 23×5	27.984	0.894	0.944	-0.627
16) 23×7	-35.953	-2.469	-0.88	-1.498
17) 13×6	-24.391	-2.763	-0.667	-2.859
18) 13×1	30.109	3.012	0.873	0.291
19) 13×5	4.359	1.581	0.027	4.799
20) 13×7	-10.078	-1.831	-0.233	-2.231
21) 18×6	16.859	-0.737	0.113	-0.481
22) 18×1	-18.641	0.587	0.023	0.009
23) 18×5	-17.391	0.606	-0.475	0.407
24) 18×7	19.172	-0.456	0.337	0.066
25) 25×6	-56.891	-3.5	-1.404	-1.883
26) 25×1	32.109	0.075	0.605	0.393
27) 25×5	6.859	-0.306	0.179	-0.435
28) 25×7	17.992	3.731	0.62	2.71
29) 2×6	55.234	4.375	1.505	0.789
30) 2×1	-33.266	-1.55	-0.806	1.429
31) 2×5	-54.516	-2.881	-1.517	-2.198
32) 2×7	32.547	0.056	0.818	-0.019

The estimates of the co-variances of the lines and testers and the genetic components including additive and non-additive variances for the physiological traits are presented in Table 4. The male parent had higher covariance estimates for the SC and T as compared to the lines. The dominance genetic variance showed a major contribution for all the four physiological traits under study.

Table 4. Genetic components for the physiological traits

Genetic components	Stomatal conductance (mmol H_2O m^{-2} s^{-1})	Net photosynthesis (μmol CO_2 m^{-2} s^{-1})	Transpiration rate (mmol H_2O m^{-2} s^{-1})	Water Use Efficiency (mmol CO_2 mol^{-1} H_2O)
Cov H.S. (line)	-48.55	-0.23	-0.03	-0.62
Cov H.S. (tester)	61.18	-0.02	0.04	-0.30
Cov H.S. (average)	0.21	-0.01	0.00	-0.05
Cov F.S. (average)	755.14	3.54	0.53	1.39
Additive genetic variance when F = 0	0.84	-0.05	0.00	-0.19
Additive genetic variance when F = 1	0.42	-0.03	0.00	-0.09
Variance due to Dominance when F = 0	1313.45	7.79	0.93	6.03
Variance due to Dominance F = 1	656.73	3.89	0.46	3.01

3.2. Yield and yield components

The biplot for the 32 hybrids, their parents, and one local cultivar is presented as Figure 2. The female parent 5 followed by male parent 4 and hybrid 6 showed contrasting values for the flag leaf area (FLA) and plant height (PlH) i.e., highest for the FLA (53 cm^2) and lowest for the PlH (93 cm). The hybrid 6 followed by hybrid 8 showed the highest values for the seed weight per ear (SW) (5 g) and ear weight (EW) (6.4 g) while hybrid 19 followed by hybrid 2 showed the lowest values (1.9 g and 2.7 g, respectively) for these traits. The hybrid 15 showed the highest value for the grain yield per plot (Y) (186.2 g) while the female parent 5 followed by 3 had the lowest values for this trait (33.8 g). The lines 5, 3 followed by the tester 4 had the lowest ear length (EL) (10.9 cm) while the hybrid 30 has the highest value for this trait (14.7 cm).

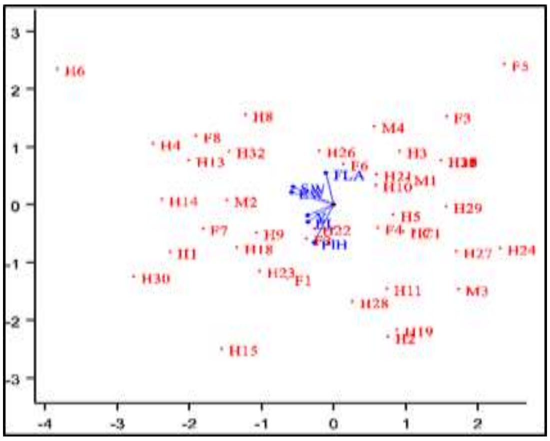

Figure 2. Biplot analysis of the yield and its components for wheat hybrids
Y: Grain yield per plot; EL: Spike length; EW: Spike weight; SW: Seed weight per spike; PlH: Plant height; FLA: Flag leaf area

Table 5. Mean squares for yield and yield components

Source of Variation	DF	Flag Leaf Area (cm^2)	Spike Length (cm)	Spike Weight (g)	Seed Weight (g)	Plant Height (cm)	Yield per Row (g)
Replication	1	4.1	105	0.15*	0.05	14.4	717.12
Genotypes	44	325.39**	181.4	4.70**	2.90**	3303.39**	1953.28**
Parents	12	153.94**	464.48**	1.19**	0.92**	169.45**	811.93
Parents vs hybrids	1	619.03**	802.69*	4.04**	2.62**	6570.18**	42.71
Hybrids	31	382.28**	51.76	6.08**	3.68**	4411.15**	2456.72**
Lines	7	479.5	33.1	6.35	3.97	2838.67	2110.37
Testers	3	704.1	80.8	8.81	4.37	6860.29	975.83
Lines × Testers	21	303.91**	53.83	5.60**	3.49**	4582.10**	2783.72**
Error	44	11.22	137.7	0.03	0.04	16.24	552.02

* Significant at 5% level, ** significant at 1% level

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The ANOVA among the lines, testers, hybrids, and line × tester interaction is presented in Table 5. The genotypes showed significant variation for the yield and yield components. A significant variation was observed among the parents except for Y. Similar results were shown by the hybrids. The interaction of lines and testers showed significant variation for all the traits except SL. While the SL was the only trait that showed significant variation for replication. The variation in the parents, hybrids, and line × tester interaction provided evidence for the further assessment of GCA and SCA effects.

Table 6. General combining ability (GCA) effects of yield and its components

Parents	Flag Leaf Area (cm^2)	Spike Length (cm)	Spike weight (g)	Seed Weight (g)	Plant Height (cm)	Yield per row (g)
Lines						
2	-3.895	-0.75	-0.061	-0.152	-8.688	9.553
13	-10.1	-3.582	-1.401	-1.145	-31.94	-27.04
14	12.963	1.921	1.349	0.828	15.438	-0.445
18	3.991	2.627	0.17	0.121	19.438	10.749
19	8.558	1.854	0.947	0.926	25.188	-5.855
22	-3.95	-0.961	-0.446	-0.29	-4.688	-2.889
23	-3.091	-0.473	0.219	0.336	-4.562	27.184
25	-4.478	-0.636	-0.777	-0.624	-10.19	-11.25
Testers						
6	8.861	2.611	1.084	0.774	22.5	2.206
1	-1.21	0.833	-0.395	-0.305	9.562	8.311
5	-0.452	-0.798	-0.139	-0.141	-6.688	-0.075
7	-7.199	-2.646	-0.55	-0.328	-25.38	-10.44

The GCA effects for the yield and yield components are presented in Table 6. The GCA effects of yield traits were negative for more than 60 percent of parents. The GCA effects of PlH and Y were comparatively higher than the other traits. The order of positive GCA effect of Y is 23 > 18 > 2 > 1 and 6. The parent 14 showed the highest GCA effect of FLA and EW while parent 19 has highest GCA for SW and PlH. The highest GCA effect of EL was shown by the parent 18.

The specific combing ability effects of yield and its components for 32 wheat hybrids are shown in Table 7. Like GCA, the SCA of PlH and Y had the highest values as compared to the other traits. The SCA effect of FLA ranges from -21.04 (2) to 14.756 (4), EL ranges from -10.410 (31) to 5.784 (28), EW ranges from -2.611 (31) to 2.283 (32), SW ranges from -2.252 (16) to 1.946 (32), PlH ranges from -95.600 (31) to 61.38 (28) and of Y ranges from from -65 (31) to 71 (32).

Table 7. Specific combining ability (SCA) effects of yield and yield components

Hybrids	Flag Leaf Area (cm^2)	Spike Length (cm)	Spike weight (g)	Seed Weight (g)	Plant Height (cm)	Yield per row (g)
1) 19×6	11.833	1.196	0.39	0.321	17.81	26
2) 19×1	-21.04	-2.038	-2.413	-2.079	-20.9	-5.4
3) 19×5	-5.546	-2.034	0.147	0.19	-23.4	-25
4) 19×7	14.756	2.866	1.876	1.568	26.5	4.4
5) 14×6	-13.97	-0.071	0.0688	-0.382	11.06	-4.1
6) 14×1	5.015	-1.78	0.63	0.838	-25.6	-0.9
7) 14×5	1.749	-0.702	-1.436	-1.198	-6.19	-20
8) 14×7	7.201	2.552	0.718	0.741	20.75	25
9) 22×6	13.755	4.686	1.408	1.232	40.69	37
10) 22×1	-4.342	-0.224	0.04	-0.173	1.5	-29
11) 22×5	3.149	2.254	0.624	0.566	22.43	26
12) 22×7	-12.56	-6.716	-2.072	-1.625	-64.6	-34
13) 23×6	11.047	3.848	1.608	1.211	28.56	36
14) 23×1	-1.356	0.914	0.69	0.896	1.375	-29
15) 23×5	3.729	2.442	0.439	0.145	34.81	57
16) 23×7	-13.42	-7.204	-2.737	-2.252	-64.8	-64
17) 13×6	-13.16	-5.943	-1.527	-0.958	-56.1	-20
18) 13×1	11.314	4.647	1.22	0.747	41.75	20
19) 13×5	8.26	5.392	1.424	0.981	51.69	9.5
20) 13×7	-6.413	-4.096	-1.117	-0.77	-37.4	-9.4
21) 18×6	1.467	1.548	0.382	0.291	0.062	-21
22) 18×1	2.755	-3.578	-1.092	-0.754	-22.1	23
23) 18×5	-1.986	0.284	1.068	0.95	-0.19	2.6
24) 18×7	-2.236	1.746	-0.358	-0.487	22.25	-5
25) 25×6	-18.78	-8.889	-2.151	-1.479	-77.8	-36
26) 25×1	2.251	0.326	0.401	0.466	0	9.3
27) 25×5	9.252	2.779	0.345	0.155	16.44	15
28) 25×7	7.279	5.784	1.405	0.878	61.38	11
29) 2×6	7.804	3.625	-0.197	-0.237	35.69	-18
30) 2×1	5.405	1.733	0.525	0.078	24	12
31) 2×5	-18.61	-10.41	-2.611	-1.788	-95.6	-65
32) 2×7	5.396	5.048	2.283	1.946	35.88	71

The estimates of the co-variances of the lines and testers and the genetic components including additive and non-additive variances for the yield-related traits is presented in Table 8. The male parent had comparatively higher covariance estimates for all the traits except grain yield per plot. The dominance genetic variance showed a major contribution for all the four physiological traits under study.

Table 8. Genetic components for the yield and its components

	Flag Leaf Area (cm^2)	Spike Length (cm)	Spike weight (g)	Seed Weight (g)	Plant Height (cm)	Grain yield per row (g)
Cov H.S. (line)	21.95	-2.59	-216.68	0.09	0.06	-84.17
Cov H.S. (tester)	25.01	1.69	142.39	0.20	0.05	-112.99
Cov H.S. (average)	2.34	-0.06	-5.10	0.01	0.01	-9.75
Cov F.S. (average)	242.31	-40.89	2373.73	3.44	1.95	702.31
Additive genetic variance when F = 0	9.34	-0.25	-20.38	0.06	0.02	-38.99
Additive genetic variance when F = 1	4.67	-0.12	-10.19	0.03	0.01	-19.49
Variance due to Dominance when F = 0	292.69	-83.87	4565.86	5.56	3.44	2231.70
Variance due to Dominance F = 1	146.34	-41.93	2282.93	2.78	1.72	1115.85

3.3. Proportional contribution of lines and testers

The proportional contribution of lines, testers, and interaction between both for all the traits under study (Table 9) revealed that the major proportion of total variance was contributed by the lines × testers interaction. The lines (females) contributed higher for all the traits except EL (spike length).

Table 9. Proportional contribution of lines, testers and their interactions to the total variance of NLTs, physiological and yield traits

Contribution of	Df	SC	P	T	WUE	FLA	EL	EW	SW	PH	Y
Lines	7	18.1	19.8	18.1	13.3	28.3	14.4	23.6	24.4	14.6	19.4
Testers	3	14.4	9.8	14.3	5.9	17.8	15.1	14.0	11.5	15.0	3.8
Lines × testers	21	67.5	70.3	67.6	80.8	53.9	70.5	62.4	64.2	70.4	76.8

LA: leaf angle; LR: leaf rolling; PH: prickle hairs; GT: groove type; SC: stomatal conductance; P: photosynthesis; T: transpiration; WUE: photosynthetic water use efficiency; FLA: flag leaf area; EL: spike length; EW: spike weight; SW: seed weight; PH; plant height; Y: yield per row

4. DISCUSSION

The line into tester analysis for the evaluation of hybrids was performed. The analysis of variance indicated that significant variation for the physiological traits, yield, and yield components was shown by the parents, hybrids, and line × tester interaction. Similar results have been reported by previous studies (Fellahi *et al.*, 2013). These evidence indicate the presence of sufficient variability among the parents and the hybrids to assess the general and specific combining ability of all the traits under study (Table 1 and 5 respectively).

The positive and higher GCA for the yield per row was shown by the genotypes 23, 18, 2, 1, and 6 indicating the higher potential for this trait. Genotype 14 (female parent) had the highest GCA values for the FLA and EW and SW indicating that this genotype had higher flag leaf area and more spike weight and seed weight These results are in agreement with the Abro *et al.* (2016). This genotype can be a good general combiner for the improvement of yield-related components. The female parent 18 followed by parent 14 showed the highest GCA for the spike length. The parent 18 followed by parent 2 were recorded as the best general combiners for the yield per row. The line 19 had the highest positive GCA for the plant height while the tester 7 had the highest negative GCA for the plant height as it had minimum plant height among hybrids which is desirable as short stature plants are lodging resistant and fertilizer responsive (Fellahi *et al.*, 2013).

However, wide variation exists for the superiority of different physiological traits among parents and crosses. The results indicated that the parent 6 (tester) has overall higher GCA effects of three out of four physiological traits and can be considered best while parents 22 and 13 (lines) can be considered contrasting. The parents 1 and 6 among testers and female parents 14 and 18 showed high positive general combining ability effects for the stomatal conductance, transpiration, and water use efficiency while parent 19 among lines and parent 6 among testers showed positive GCA for the photosynthesis.

The hybrid coded as 29 can be considered as the best cross combination for the physiological traits as it showed maximum positive SCA effects for three out of four physiological traits that are SC, P, and T. On the other hand, hybrid coded as 25 showed negative SCA effects for two out of four physiological traits under study i.e. SC and P, and can be considered as poor combination for these traits. The hybrid coded as 28 and 32 can be considered as the best cross combination for the yield and yield components as it showed the highest positive SCA for maximum of yield components including spike length, spike weight, plant height, and yield per row. Conversely, hybrid 31 can be considered as its contrast combination as it showed the lowest values of SCA for four out of six yield components.

However, all the traits under study showed higher values for the dominance variance indicating the preponderance of the non-additive gene action contrary to the results of (Rahul, 2017). Similar results were reported for the yield components and the associated quantitative traits in bread wheat (Srivastava *et al.*, 2012; Sattar *et al.*, 2018). Considering all these results, heterosis breeding is suggested for the improvement of these traits.

5. CONCLUSION

The cross combination 25×7 and 2×7 were excellent specific combiners for almost all the traits including grain yield per row. These hybrids will give transgressive segregants for the physiological and yield traits in the segregating populations. These crosses showed relatively lower SCA effects for the plant height that is a desirable character because poor SCA combiners for this trait will give dwarf plants in the successive segregating generations. Overall, hybrid breeding is recommended as a yield improvement strategy for future breeding programs

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7. AUTHORS' CONTRIBUTION

Conceived and designed the experiments: ZA SH. Performed the experiments: SH. Analyzed the data: SH SM. Contributed reagents/materials/analysis tools: ZA. Wrote the paper: SH. Critical review and editing: ZA MABS MHR. All authors read and approved the final manuscript.

8. CONFLICT OF INTEREST

The authors declare no conflict of interest

9. AVAILABILITY OF DATA AND MATERIALS

All relevant data are provided as tables within the paper. Excel files can be provided on demand.

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