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COMBINING ABILITIES OF SPRING WHEAT (*Triticum aestivum* L.) FOR GRAIN YIELD AND RELATED TRAITS

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Abstract: An 8 x 8 F_2 spring wheat (*Triticum aestivum* L.) half diallel population with respective parents was assessed in a field trial at the field laboratory of the department of genetics and plant breeding at the Bangladesh Agricultural University, Mymensingh, during the period from November 2016 to April 2017, following a randomized complete block design (RCBD). The research objectives were to discover the combining abilities of grain yield and its associated traits. Significant variations among the genotypes were observed for different traits *viz*., number of spikes plant^{-1}, length of spike (cm), number of spikelets spike^{-1}, plant height (cm), straw grain weight (gm), number of grains spike^{-1}, 1000 grain weight (gm), yield plant^{-1} (gm), harvest index (%), and grain yield in hectare. The genetic analysis following Griffing's approach revealed significant additive and non-additive gene actions, with a preponderance of both additive and non-additive genetic components for regulating different traits. For grain yield plant^{-1} BARI Gom 27 and Kheri were observed as the best general combiners whereas BARI Gom 21 × BARI Gom 27 and Kheri × BARI Gom 30 exhibited as the best heterotic patterns. All of the traits investigated had a significant positive correlation with yield plant^{-1}. BARI Gom 21 × BARI Gom 27 and Kheri × BARI Gom 30 were the top yielding cross combinations on the basis of combining ability among the studied genotypes. Those cross combinations may be used for hybrid crop development or to extract transgressive segregants in developing high-yielding bread wheat cultivars.

Keywords: Spring wheat, half-diallel population, combining ability, general combiners, gene actions

Introduction

Wheat (*Triticum aestivum* L.) is a major cereal holding second position in Bangladesh after rice, on the basis of acreage and human consumption (BBS, 2019). The crop is commonly known as "Ghom" in Bangladesh and it belongs to the family Gramineae (Poaceae) of the genus *Triticum*. Wheat was cultivated in Bangladesh in an area of 395 thousand hectares during 2018-19 with production of 1250 thousand metric ton (USDA, 2020). China is the top most wheat producer of the world followed by India, Russia, USA, Canada, France, Ukraine, Pakistan, Germany, Australia (FAOSTAT, 2017). The socio-economic condition of the people uplifted that leads to better consumption habit particularly more wheat consumption. To meet up our annual consumption we were required 7.4 million metric tons of wheat in 2019; only one sixth portion of our demand had been filled up by our own production and the rest 5.5 million metric ton was imported and the trend is consistent in the previous five years (USDA, 2019). Nearly 80% of our current wheat demand is satisfying through import. Therefore, different steps for wheat improvement and crop production program should be undertaken to fulfill the current demand so that we can minimize our import through maximizing domestic production.

Hexaploid wheat (*Triticum aestivum* L., 2n=6x=42, AABBDD) has the largest genome of 16000 Mb about 8-fold larger than that of maize and 40-fold larger than that of rice (Arumuganathan and Earle, 1991, Yu et al., 2002, Schnable et al., 2009). So, studying the nature of gene action and genetic-environment interactions on important traits, e.g., yield, have become very challenging. Estimation of combining ability is useful in determining the breeding value of wheat genotypes by suggesting the appropriate use of breeding methods, and proper utilization of inbred lines and respective hybrids. The diallel cross technique is one of the quantitative genetic approaches which provides an effective means of obtaining rapid information about the genetic features of parental lines. Selection of parental lines based on combining ability in hybrids and subsequently uses them for developing pure lines or hybrid varieties depends on the nature of combining ability. The diallel analysis is proven quantitative genetic approaches (Griffing, 1956), that could reveal the major features of genetic system and predict the selection in early generation (Bari and Newaz, 2006). The main advantage of the diallel mating designs is their ability to carry out a necessary approach to test and analyze the progenies and to get information that could be rarely obtained otherwise (Christie and Shattuck, 1992). Thus, it helps in the selection of suitable parents for hybridization as well as in the choice of appropriate breeding procedures.

The ultimate goal of most breeding program in bread wheat is to increase yielding capacity of the crops and it needs knowledge of inheritance of yield and it’s contributing characters (Ehdaie and Waines, 1989). Usually, quantitative traits like yield shows the complex pattern of inheritance whereas some of yield contributing characters may show relatively simple pattern of inheritance. It has been observed that yield is controlled by both additive and non-additive gene action while the yield contributing characters are controlled by mainly additive gene action (Taleei and Beigi, 1996). Non-additive gene effects for yield were also reported to be significant in wheat (Dere and Yildirim, 2006).

The effects of general and specific combining abilities and their variances are very useful genetic parameters in the breeding program. The estimate of combining ability variances and effects provides an indication of relative magnitude of genetic variances and individual performance of inbred parents to govern a trait. In this context, combining ability results provide a guideline for selecting elite parents and desirable cross combinations to be used in formulation of a well-designed breeding project for rapid improvement of the genotypes. Yield is the final outcome attributed by a chain of interrelated effects of several traits (Islam and Khan, 1991). The degree of association between characters as indicated by the correlation coefficients has always been helpful for selecting desirable characters in a breeding program having the insight of interrelationship. Correlation coefficient analysis measures the mutual relationship between various plant characters. However, the estimates could be useful and informative in wheat breeding.

In wheat, several researchers have obtained information on the combining ability and gene action through diallel analysis and traits association (Ullah et al., 2010, Srivastava et al., 2012, and Kumar et al., 2017.

In a crop improvement program, the genetic advancement of cultivars could be driven by the detection and isolation of valuable gene combination through exploring favorable combining abilities. The lines which produce good progenies on crossing are of immense value to the plant breeders. The knowledge of gene action and combining ability helps in identifying the best combiners which may be hybridized either to exploit heterosis, or combining gene pools, or even can be advanced as potential lines. The research pursued to study combining abilities of F_2 half-diallel populations for obtaining general combining ability (GCA) and specific combining ability (SCA) variances as well as effects and to identify the top yielding cross combinations.

Materials and methods

The experiment was carried out at the field laboratory of the department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh during the period from November, 2016 to April, 2017. Eight spring wheat genotypes *viz*., BARI Gom 21, BARI Gom 22, Akbar, BARI Gom 27, Kheri, Kanchan, BARI Gom 28, BARI Gom 30, and their 28 F_2's, derived from F_1 diallel without reciprocals (Dhar, 2016) were included in the experiment. The experiment was set up in a randomized complete block design (RCBD) with three replications. Second filial generations of hybrids (F_2) along with parents were sown on November 2016. Plot size and inter-row distance were 3 m and 0.25 m respectively and plant to plant distances were maintained as continuous.

At maturity, data were recorded from five randomly selected plants from each experimental unit of each replication. The characters were number of spikes plant^{-1}, length of spike (cm), number of spikelets spike^{-1}, plant height (cm), straw grain weight (gm), number of grains spike^{-1}, 1000 grain weight (gm), yield plant^{-1} (gm), harvest index (%) and grain yield in hectare.

Minitab 17 statistical software package was used to carry out general ANOVA (Minitab Inc. State College, Pennsylvania, USA). For each trait, Griffing's method 2 model 1(fixed model) was followed to analyze combining ability by Plant Breeding tools. The general objectives of this model were comparing combining abilities of the parents and using parents as testers, particularly BARI Gom 27 and BARI Gom 30, to identify better cross combination (s).

Results

The analysis of variance (ANOVA) of different yield and yielding contributing traits of parental genotypes and their F_2 were presented in the Table 1.

Highly significant ($P<0.001$) difference due to genotypes were observed (Table 1) for most characters *viz*., number of spikelets spike^{-1}, plant height (gm), number of grains spike^{-1}, 1000 grain weight (gm), yield plant^{-1} (gm) and grain yield (t ha^{-1}). Number of spikes plant^{-1}, length of spike (cm), straw grain weight (gm) and harvest index (%) were found to be significant for 1% level of probabilities. Two characters out of ten characters *viz*., length of spike (cm) and number of spikelets spike^{-1} had showed to be significant for both sources of variances *i.e.* replications and genotypes.

Combining ability analysis following Griffing's approach

Analysis of variances for combining ability has been carried out for 8 × 8 half diallel populations for the evaluation of GCA and SCA variances involving ten characters are presented in Table 2.

In the ANOVA (2) revealed significant variation existed due to GCA and SCA.

Table 1. ANOVA (MS) for different yield and yield contributing characters in a diallel cross in wheat

Sources of variance	df	Number of spikes plant^{-1} (no.)	Length of spike (cm)	Number of spikelets spike^{-1} (no.)	Plant height (cm)	Straw grain weight (gm)
Replication	2	1.17	4.43**	8.24*	131.85	2456.30
Genotype	35	3.22**	1.51**	5.99***	249.45***	1758.30**
Error	70	1.44	0.86	2.41	79.69	796.10

Sources of variance	df	Number of grains spike^{-1} (no.)	1000 grain weight (gm)	Yield plant^{-1} (gm)	Harvest index (%)	Grain yield (t ha^{-1})
Replication	2	36.88	17.13	9.21	6.69	0.37
Genotype	35	57.82***	57.58***	14.85***	11.40**	0.59***
Error	70	19.70	19.34	2.19	5.45	0.09

*P<0.05, **P<0.01, ***P<0.001

Table 2. ANOVA (MS) for combining abilities according to Griffing's approach for 8 x 8 diallel populations

Items	DF	Number of spikes plant^{-1} (no.)	Length of spike (cm)	Number of spikelets spike^{-1} (no.)	Plant height (cm)	Straw grain weight (gm)
GCA	7	1.30	0.58	2.83	62.48	686.14
SCA	28	1.02**	0.48*	1.79**	88.31***	561.07**
Crosses	35	3.22**	1.51**	5.99***	249.44***	1758.25**
Error	70	0.48	0.25	0.80	26.56	265.35

Items	DF	Number of grains spike^{-1} (no.)	1000 grain weight (gm)	Yield plant^{-1} (gm)	Harvest index (%)	Grain yield (t ha^{-1})
GCA	7	23.61*	31.09	5.31*	3.06	0.21*
SCA	28	18.19***	16.22***	4.20***	3.99**	0.17***
Crosses	35	57.82***	57.58***	13.27***	11.41**	0.53***
Error	70	6.57	6.43	0.71	1.77	0.03

*P<0.05, **P<0.01, ***P<0.001

Estimates of effects due to GCA and SCA

GCA effects

The GCA effects of parents F_2's population are presented in Table 3. For number of spikes plant^{-1}, three out of eight genotypes showed positive GCA. Kheri (0.55) and BARI Gom 27 (0.52) were the best general combiners for number of spikes plant^{-1}. Maximum GCA effects found in BARI Gom 27 (0.27), followed by BARI Gom 21 (0.19) and Kanchan (0.16) for length of spike. The GCA effects indicate BARI Gom 27 (0.65) and Kheri (0.55) were the best general combiner for number of spiklets spike^{-1}. Kheri and BARI Gom 28 were the best and poor general combiner for the character plant height respectively. Maximum positive GCA effect (13.25) was recorded in the parent BARI Gom 27 being the best general combiner for straw grain weight, BARI Gom 27 performed as a desirable general combiner for number of grains spike^{-1}. BARI Gom 21 was the only parents for 1000 grain weight showed favorable combining ability. Three out of eight genotypes showed positive GCA for yield plant^{-1} where BARI Gom 27 (1.21) was the best combiner. The GCA effects indicate Kanchan (0.72) could be regarded as good general. Parents BARI Gom 27 (0.24) and Kheri (0.14) were the best general combiner for grain yield (t ha^{-1}). In addition, parent BARI Gom 27 showed positive significant combining ability for number of spikes plant^{-1}, number of spikelets spike^{-1}, number of grains spike^{-1}, straw grain weight, yield plant^{-1} and grain yield (t ha^{-1}). Kheri displayed positive significant combining ability for number of spikes plant^{-1}, yield plant^{-1} and grain yield (t ha^{-1}). BARI Gom 21 also showed positive significant combining ability for 1000 grain weight. Parent BARI Gom

Table 3. Estimates of General Combining Ability (GCA) effects of the parents for different characters in wheat

Parents	SN (no.)	SpkLng (cm)	SpIN (no.)	PH (cm)	SGW (gm)	GrnSpk (no.)	TGW (gm)	YP (gm)	HI (%)	GRYLD (t ha^{-1})
P_1	0.06	0.19	0.05	2.32	2.35	-0.74	4.18**	0.46	0.39	0.09
P_2	-0.41	0.14	0.02	-1.71	-4.40	0.88	-0.15	-0.31	0.39	-0.06
P_3	-0.07	-0.21	0.05	-0.14	5.75	-0.40	-0.03	-0.06	-0.88	-0.01
P_4	0.52*	0.27	0.65*	1.70	13.25*	2.36**	-0.41	1.21**	0.11	0.24**
P_5	0.55*	0.01	0.55	3.10	7.15	1.13	-1.09	0.72*	-0.03	0.14*
P_6	-0.12	0.16	0.11	1.26	-7.28	0.08	-1.56	-0.47	0.72	-0.09
P_7	-0.32	-0.13	-0.33	-3.31	-9.00	-0.49	-0.62	-0.77*	0.16	-0.15*
P_8	-0.21	-0.43*	-1.07**	-3.22	-7.85	-2.82**	-0.32	-0.78*	-0.76	-0.16*
SE (Gi)	**0.21**	**0.15**	**0.27**	**1.52**	**4.82**	**0.76**	**0.75**	**0.25**	**0.39**	**0.05**
LSD (5%)	**0.49**	**0.35**	**0.64**	**3.60**	**11.37**	**1.79**	**1.77**	**0.59**	**0.93**	**0.12**
LSD (1%)	**0.72**	**0.52**	**0.94**	**5.33**	**16.86**	**2.65**	**2.62**	**0.88**	**1.38**	**0.17**

*P<0.05, **P<0.01; Here, P_1=BARI Gom 21; P_2= BARI Gom 22; P_3= Akbar; P_4= BARI Gom 27; P_5= Kheri; P_6= Kanchan; P_7= BARI Gom 28; P_8= BARI Gom 30and SN= Number of spikes plant^{-1}, Spklng= Length of spike, SpIN= Number of spikelets spike^{-1}, PH= Plant height, SGW= Straw grain weight, GrnSpk= Number of grains spike^{-1}, TGW= 1000 grain weight, YP= Yield plant^{-1}, HI= Harvest index, GRYLD= Grain yield (t ha^{-1})

30 showed negative significant GCA effect for length of spike, number of spikelets spike^{-1}, number of grains spike^{-1}, yield plant^{-1} and grain yield (t ha^{-1}).

SCA effect

The results of specific combining ability (SCA) effects of F_2's population are presented in Table 4. A critical evaluation of the results with respect to SCA effects showed that none of the crosses exhibited desirable significant SCA effects for all characters. However, cross Kheri × BARI Gom 30 (2.70), Akbar × BARI Gom 28 (1.77) and BARI Gom 27 × BARI Gom 28 (1.74) showed positive significant SCA effects and cross BARI Gom 27 × BARI Gom 30(-1.57) showed negative significant SCA effects for number of spikes plant^{-1}. For the trait length of spike, BARI Gom 21 × BARI Gom 27 (1.30), BARI Gom 27 × Kheri (1.11), BARI Gom 22 × Kheri (1.01) and BARI Gom 27 × BARI Gom 30 (-0.93) cross combination manifested significant SCA effects. From the results of SCA effects, BARI Gom 22 × BARI Gom 27(2.13), BARI Gom 21 × BARI Gom 27 (1.93), Akbar × BARI Gom 27 (1.79), Akbar × BARI Gom 28 (1.75), Akbar × Kheri (-2.29) and BARI Gom 27 × BARI Gom 30 (-2.08) cross displayed significant SCA effects for number of spiklets spike^{-1}. Six cross combinations *viz*., BARI Gom 27 × BARI Gom 28 (19.08), Akbar × Kanchan (18.16), BARI Gom 21 × Kheri (15.58), Kheri × BARI Gom 30 (14.39), BARI Gom 22 × BARI Gom 27 (11.03) and BARI Gom 27 × BARI Gom 30 (-9.58) showed significant SCA effects for plant height. For straw grain weight, Akbar × BARI Gom 27 (44.59), BARI Gom 21 × BARI Gom 27 (42.16), Kheri × Kanchan (40.22) and BARI Gom 27 × BARI Gom 30 (-30.64) exhibited significant SCA effects.

As yield is not an independent and isolated trait but relative combination of the performances of several parameters, in that case positive SCA effects for number of grains spike^{-1} is considered as desired positive effects for contributing yield potential. Among the cross combinations Akbar × BARI Gom 27 (8.77) and BARI Gom 22 × BARI Gom 27 (7.45) showed highly significant SCA effects for number of grains spike^{-1}. Good yield potential genotypes along with 1000 grain weight should be the prime concern for a breeding purpose to develop a commercial wheat genotype or variety. Kheri × BARI Gom 28 (6.33), BARI Gom 21 × Akbar (5.28) and BARI Gom 22 × Kanchan (4.93) exhibited positive significant SCA effects for the trait 1000 grain weight.

For the characters yield plant^{-1} and grain yield (t ha^{-1}), the cross combinations namely Kheri × BARI Gom 30 (4.32 and 0.86), Akbar × BARI Gom 28 (4.13 and 0.83), BARI Gom 21 × BARI Gom 27 (2.92 and 0.58), BARI Gom 22 × Kheri (2.76 and 0.55) and BARI

Table 4. Estimates of Specific Combining Ability (SCA) effects of the hybrids for different characters in wheat

Parents	SN (no.)	SpkLng (cm)	SplN (no.)	PH (cm)	SGW (gm)	GrnSpk (no.)	TGW (gm)	YP (gm)	HI (%)	GRYLD (t ha^{-1})
P_1 × P_2	0.92	-0.28	-0.53	2.27	1.14	-2.08	4.42	1.33	2.02	0.26
P_1 × P_3	-0.16	-0.50	-1.03	-5.29	-16.68	-2.09	5.28*	-0.33	2.43	-0.07
P_1 × P_4	0.99	1.30**	1.93*	5.57	42.16**	5.97*	2.39	2.92**	-0.82	0.58**
P_1 × P_5	-0.29	0.45	1.17	15.58**	-3.74	0.32	2.66	-0.19	0.36	-0.03
P_1 × P_6	-0.23	-0.02	0.85	-2.82	-6.31	2.59	-1.40	-0.25	0.57	-0.05
P_1 × P_7	-0.50	0.66	1.02	0.79	5.74	2.95	-2.67	-0.90	-0.15	-0.18
P_1 × P_8	-0.48	-0.01	0.57	-2.20	-1.08	1.55	1.86	0.19	0.49	0.04
P_2 × P_3	-0.75	0.27	0.47	8.05	5.41	1.39	0.20	-0.86	-1.88	-0.17
P_2 × P_4	0.28	-0.08	2.13*	11.03*	25.57	7.45**	1.85	2.25**	-0.50	0.45**
P_2 × P_5	0.58	1.01*	1.67	5.52	24.01	3.92	-0.04	2.76**	-0.55	0.55**
P_2 × P_6	0.04	-0.34	-1.06	-2.25	-10.23	-5.56*	4.93*	-0.73	0.77	-0.15
P_2 × P_7	0.27	-0.18	-0.68	-4.86	2.66	-2.40	1.62	-0.33	0.00	-0.06
P_2 × P_8	-0.34	-0.31	-0.61	-5.97	-14.99	-2.13	-1.68	-1.73*	0.99	-0.34*
P_3 × P_4	1.12	0.36	1.79*	0.79	44.59**	8.77**	-4.90*	2.01*	-0.40	0.40*
P_3 × P_5	-0.56	-0.67	-2.29**	-2.00	-30.14	-4.11	0.61	-1.62*	2.56*	-0.33*
P_3 × P_6	0.16	0.60	0.71	18.16**	14.46	3.14	-4.72*	0.39	-2.80*	0.08
P_3 × P_7	1.77**	-0.57	1.75*	-3.60	28.34	4.82*	-4.52	4.13**	-0.06	0.83**
P_3 × P_8	-0.08	0.73	0.63	4.56	4.52	1.08	-0.99	-0.74	-0.75	-0.15
P_4 × P_5	-0.99	1.11*	0.78	-7.61	-21.31	-0.14	-1.55	-1.61*	-0.19	-0.32*
P_4 × P_6	-0.25	0.01	-0.47	-4.03	-27.04	-3.60	-0.94	-1.63*	1.81	-0.33*
P_4 × P_7	1.74*	0.60	-0.47	19.08**	18.51	-0.65	-2.38	2.11*	-0.50	0.42**
P_4 × P_8	-1.57*	-0.93*	-2.08*	-9.58*	-30.64*	-6.07*	-5.68*	-3.31**	-1.69	-0.66**
P_5 × P_6	0.35	-0.10	-0.61	9.14	40.22*	-1.68	1.37	0.92	-4.15**	0.18
P_5 × P_7	-0.71	0.12	0.19	-1.50	-15.73	0.00	6.33*	-0.17	3.02*	-0.03
P_5 × P_8	2.70**	0.78	1.26	14.39**	25.46	4.62	-1.31	4.32**	2.36	0.86**
P_6 × P_7	-0.25	0.22	-0.67	-4.38	-2.96	-3.20	1.60	-0.79	-0.93	-0.16
P_6 × P_8	-1.15	-0.44	0.74	-9.37	-20.11	2.25	-3.40	-1.40	2.57*	-0.28
P_7 × P_8	0.54	0.36	0.55	1.60	9.94	1.43	-1.17	0.29	-4.27**	0.06
SE (Sij)	**0.64**	**0.46**	**0.83**	**4.67**	**14.77**	**2.32**	**2.30**	**0.77**	**1.21**	**0.15**
LSD (5%)	**1.30**	**0.93**	**1.69**	**9.57**	**30.25**	**4.76**	**4.71**	**1.57**	**2.47**	**0.31**
LSD (1%)	**1.76**	**1.26**	**2.28**	**12.91**	**40.81**	**6.42**	**6.35**	**2.12**	**3.33**	**0.42**

*P<0.05, **P<0.01; Here, P_1=BARI Gom 21; P_2= BARI Gom 22; P_3= Akbar; P_4= BARI Gom 27; P_5= Kheri; P_6= Kanchan; P_7= BARI Gom 28; P_8= BARI Gom 30,and SN= Number of spikes plant^{-1}, Spklng= Length of spike, SplN= Number of spikelets spike^{-1}, PH= Plant height, SGW= Straw grain weight, GrnSpk= Number of grains spike^{-1}, TGW= 1000 grain weight, YP= Yield plant^{-1}, HI= Harvest index, GRYLD= Grain yield (t ha^{-1})

Gom 22 × BARI Gom 27 (2.25 and 0.45) showed highly significant (P<0.01) and positive SCA effects while BARI Gom 27 × BARI Gom 30 (-3.31 and -0.66), BARI Gom 22 × BARI Gom 30 (-1.73 and -0.34), Akbar × Kheri (-1.62 and -0.33) and BARI Gom 27 × Kheri (-1.61 and -0.32) cross combination showed negative significant SCA effects for both traits. The results of SCA effects stated that cross kheri × BARI Gom 28 (3.02), Kanchan × BARI Gom 30 (2.57) and Akbar × Kheri (2.56) exhibited positive significant and cross BARI Gom 28 × BARI Gom 30 (-4.27), Kheri × Kanchan (-4.15) and Akbar × Kanchan (-2.80) exhibited negative significant SCA effects for the trait harvest index. Cross combination Kheri × BARI Gom 30 showed highly significant SCA effects for number of spikes plant^{-1}, plant height, yield plant^{-1} and grain yield (t ha^{-1}). Cross combination BARI Gom 21 × BARI Gom 27 exhibited desirable SCA effects for length of spike, number of spikelets spike^{-1}, number of grains spike^{-1}, straw grain weight, yield plant^{-1} and grain yield (t ha^{-1}). Cross combination BARI Gom 27 × BARI Gom 30 performed negative significant SCA effect for the traits number of spikes plant^{-1}, length of spike, number of spikelets spike^{-1}, plant height, number of grains spike^{-1}, straw grain weight, 1000 grain weight, yield plant^{-1} and grain yield (t ha^{-1}).

Discussion

Analysis of agronomic performance

Analysis of variance (ANOVA)

Agronomic performance of 36 genotypes was evaluated by using the analysis of the variances. The analysis of variance (ANOVA) table showed almost all the studied traits *viz*., number of spikes plant^{-1}, length of spike (cm), number of spikelets spike^{-1}, plant height (gm), straw grain weight (gm), number of grains spike^{-1}, 1000 grain weight (gm), yield plant^{-1}(gm), harvest index (%) and grain yield (t ha^{-1}) were significantly variable (Table 1). The findings were in agreement with Khan et al., (2016) where ANOVA revealed highly significant for eight genotypes under study. Mahpara et al., (2008) also reported similar results, in wheat, among genotypes for plant height, number of tillers plant^{-1}, peduncle length, spike length, spikelet spike^{-1}, spike density, grains spike^{-1}, 1000 grains weight and grain yield plant^{-1}. These data indicated that the genotypes were mostly different each other's in their mean performance.

Analysis of combining ability variances

Combining ability describes the breeding values of parental lines to produce hybrids. Knowledge on nature of gene actions in regulating various agronomic traits and yield is crucial for leading successful of breeding program with suitable breeding approaches. The analyses of variance for combining abilities (GCA and SCA) were presented in the Table 2. Highly significant mean square for SCA were found number of spikes plant^{-1}, length of spike (cm), number of spikelets spike^{-1}, plant height (gm), straw grain weight (gm), 1000 grain weight (gm) and harvest index (%) while non-significant mean square GCA were found for those traits. This indicates that only non-additive nature of gene action was involved for regulating those traits. Bayoumi (2004) reported non-additive gene actions were responsible for spike length, number of spikes plant^{-1}, plant height, number of grains spike^{-1} and 1000-kernel weight. Mean square value of GCA and SCA were found to be significant for the trait number of grains spike^{-1}, yield plant^{-1} (gm) and grain yield (t ha^{-1}) which states both additive and non-additive genetic components played a role in the expression of those character. Similar results were reported by Rajput and Kandalkar (2018) where days to heading, plant height, spike length, grains spike^{-1}, biological yield and harvest index showed highly significant GCA and SCA variation. On the other hand, GCA:SCA ratio states that preponderance of GCA variances was observed over SCA variances for the traits involved number of spikes plant^{-1}, length of spike, number of spikelets spike^{-1}, straw grain weight, number of grains spike^{-1}, 1000 grain weight, yield plant^{-1} and grain yield (t ha^{-1}) suggesting additive genetic action prevails for controlling those traits. El-dayem (2014), observed similar fashion of results where magnitude of GCA variances were higher that of SCA variances.

Analysis of combining ability effects

Analysis of diallel cross data using combining ability approach (Griffing, 1956) showed that total variation among the genotypes was partitioned into variation due to general and specific combining ability and reciprocal effects. Assessment of GCA effects for grain yield and its components offers an important mean in selecting parental genotypes to develop high yielding hybrids and assessment of SCA effect helps to evaluate those crosses and provides guidelines to discard any of the crosses or advance selection though recurrent, back cross or pedigree selection (Tariq et al., 2014). Both positive and negative GCA and SCA effects were recorded for all the genotypes under study.

The significant estimates of GCA effects revealed that a parent BARI Gom 27 was good general combiner for number of spikes plant^{-1}, number of spikelets spike^{-1}, number of grains spike^{-1}, straw grain weight, yield plant^{-1} and grain yield (t ha^{-1}). Kheri was good general combiner for number of spikes plant^{-1}, yield plant^{-1} and grain yield (t ha^{-1}). BARI Gom 21 was good general combiner for 1000 grain weight. Rests of the parents were poor combiner for grain yield plant^{-1} having negative or non-significant positive general combining ability effects (Table 3). Those results are consistence with Adel and Ali (2013) for number of spikes plant^{-1}, Ljubičić et al., (2017) for grains spike^{-1}, and Zeeshan et al., (2013) for number of spikelets spike^{-1} and Kumar et al., (2017) for 1000 grain weight, and Çifci and Yagdi (2010), and Kandil et al., (2016) for grain yield plant^{-1}.

Significant SCA effects revealed that the best specific combiners were Kheri × BARI Gom 30, Akbar × BARI Gom 28, BARI Gom 21 × BARI Gom 27, BARI Gom 22 × Kheri and BARI Gom 22 × BARI Gom 27 for grain yield plant^{-1}. Best specific combiners were Kheri × BARI Gom 30 and Akbar × BARI Gom 28 for for number of spikes plant^{-1}, BARI Gom 21 × BARI Gom 27 for length of spike, BARI Gom 22 × BARI Gom 27, BARI Gom 21 × BARI Gom 27 for number of spikelets spike^{-1}, BARI Gom 27 × BARI Gom 28 and Akbar × Kanchan for plant height, Akbar × BARI Gom 27 and BARI Gom 21 × BARI Gom 27 for straw grain weight, Akbar × BARI Gom 27 and BARI Gom 22 × BARI Gom 27 for number of grains spike^{-1}, Kheri × BARI Gom 28 and BARI Gom 21 × Akbar for 1000 grain weight and kheri × BARI Gom 28 for harvest index. Most of the crosses with high SCA for yield had at least one high GCA parent. However, some of the crosses with high SCA had one or both parent with average GCA. The superiority of average × average or average × low combination may be due to the presence of genetic diversity among the parent and there could be some complementation indicating importance of non-additive effects. The results were agreed with Iqbal and Chowdhry (2000) for number of spikes plant^{-1}, Srivastava et al., (2012) for spike length, Zare-Kohan and Heidari (2014), for number of spikelets spike^{-1}, El-Hosary et al., (2015) for 1000 grain weight, Ullah et al., (2010) for plant height, Kashif and Khan (2008) for grains spike^{-1}, Kumar et al., (2015) for harvest index, and Kumar and Kerkhi (2014), and Ishaq et al., (2018) for grain yield plant^{-1}.

Conclusion

Both the genetic components of variances *viz*., additive as well as non-additive variances were prevalent for the control of grain yield and its components with some exceptions. BARI Gom 27 and Kheri were identified as good general combining parents for grain yield plant^{-1} and various yield component traits. Best specific combiners were Kheri × BARI Gom 30, Akbar × BARI Gom 28, BARI Gom 21 × BARI Gom 27 and BARI Gom 22 × Kheri for grain yield plant^{-1} and various components traits. Yield plant^{-1} has positive and significant relationship with number of spikes plant^{-1}, length of spike, number of spikelets spike^{-1}, plant height, straw grain weight, number of grains spike^{-1}, 1000 grain weight.

Author contributions

Md. Jakir Mahmud, Md. Abdullah Al Bari conceived the idea and designed the experiment. Md. Jakir Mahmud and Hossain Shahariar Sifat executed the field trial with guidance from Md. Amir Hossain and Md. Abdullah Al Bari. Md. Jakir Mahmud and Hossain Shahariar Sifat collected data. Md. Jakir Mahmud compiled, cured and analyzed the data and Md. Abdullah Al Bari oversaw the analyses. Md. Abdullah Al Bari and Md. Amir Hossain instructed the plan of writing manuscript. Md. Jakir Mahmud wrote the manuscript. Hossain Shahariar Sifat, Md. Amir Hossain, Md. Abdullah Al Bariedited the overall manuscript. All authors reviewed, and approved the manuscript.

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