Research Article

Combining Ability and Narrow-Sense Heritability in Wheat (*Triticum aestivum* L.) under Rainfed Environment

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Abstract | Six advance wheat lines namely B4N11, B6N5, B6N12, BRF1, BRF3 and BRF17 and four wheat cultivars namely Zam-04 (ZM04), Kohat-10 (KT10), Pirsabak-08 (PS08) and Janbaz (JZ) were crossed in line × tester mating to develop 24 F_1 hybrids. The resultant hybrids along with parents were evaluated during cropping season 2012-13 at Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera, Pakistan under rainfed environment, using RCB design with 3 replications. General combining ability (GCA), specific combining ability (SCA) and narrow sense heritability for maturity and yield components traits were determined. The main objective of the research was identification and proper selection of best performing wheat parental genotypes and best F_1 crosses, based on GCA and SCA estimates. Significant differences were observed among the wheat genotypes for all the studied traits. The estimates of σ^2gca and σ^2sca and its ratio (σ^2gca/σ^2sca) indicated that non-additive genetic expression were pre-dominant for most of traits studied. Line BRF3 and testers ZM04 were good general combiners for most of traits under consideration, while F_1 hybrids B4N11 × PS08, B4N11 × JZ, BRF1 × ZM04, BRF1 × KT10 were best specific combiners observed for several important traits including grain yield plant^{-1} which can be subsequently utilized in future wheat breeding to develop high yielding new wheat cultivars from transgressive segregants recovered in latter generations.

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Introduction

Wheat is the staple food crop for the many countries of world including Pakistan. The total cultivated area of wheat in Pakistan for the cropping year 2013-14 was 9.19 m hectares, with total wheat produce of 25.98 million tons and average grain yield of 2824 kg ha^{-1} (MINFSAR, 2015). The main focus is on to increase wheat production and to break the yield slight stagnancy from last decades. This has been in response to the pressure for an adequate food supply caused by constantly increasing population in Pakistan and the world in general. Therefore, development of new improved wheat cultivars with high genetic potential for yield under stress environment has become a major objective in the wheat breeding.

For improvement in wheat yield, study of the genetic structure and trend of combining ability and plant behaviour under water stress is of great importance for the wheat scientist, knowledge of general and specific combining ability along with mode of gene action in available breeding material is very important to start effective wheat breeding programme. Line × tester mating is effective strategy to evaluate genotypes used as parents for combining ability effects in order to select suitable parents for developing new cultivars (Majeed et al., 2011). Many researchers have studied the combining ability and genetic structure of bread wheat hybrid populations using line × tester method related to yield and yield components. Several researchers (Larik et al., 1995; Akbar et al., 1997; Masood and Kronstad, 2000; Ahmadi et al., 2003; Joshi et al., 2003; Sulayman and Akguni, 2007) have reported that majority of genetic variances of grain yield as well as yield components are under control of non-additive nature of genes. However, Akbar et al. (1997) have reported that numbers of tillers plant^{-1} is controlled by additive gene action.

This study was undertaken to find out good general combining lines and testers for important yield contributing traits, so that superior cross combinations are selected for development of new cultivars with desirable attributes.

Material and Methods

An experiment was conducted at Cereal Crops Research Institute (CCRI), Pirsabak Nowshera, Khyber Pakhtunkhwa, Pakistan. Six advance wheat lines (hereafter used as lines) namely B6N11, B6N5, B6N12, BRF1, BRF3 and BRF17 and four cultivars (hereafter used as testers) Pirsabak-08 (PS08), Janbaz (JZ), Zam-04 (ZM04) and Kohat-10 (KT10) were crossed in line × tester fashions to develop 24 F_1 hybrids. The F_1 hybrids along with their parents were evaluated during cropping year 2012-13 using RCB design with 3 replications. Experimental plot was of two rows, row length was of two meters. Row to Row space was thirty cm and plant to plant space was kept constant as 10 cm by sowing the seeds through dibbler. Data were taken on maturity, morphological and yield parameters namely, days to heading, maturity, leaf area, grain filling duration, plant height, productive tillers plant^{-1}, spike length, spikelets per spike, grains per spike, 1000-grains weight, grain yield plant^{-1}, biological yield plant^{-1} and harvest index. Analysis of variance was performed by the formula of Fisher (1918) to determine the significant differences among wheat genotypes. Combining ability analysis was carried out by method of Kempthorne (1957).

Table A: *Weather data about the experimental site (CCRI, Pirsabak) during 2012-13*

Month	Mean temp. °C		Average rainfall (mm)
	Min	Max	
October, 2012	7.2	22.1	0.1
November, 2012	6.0	21.6	0.2
December, 2012	2.5	18.3	3.2
January, 2013	3.9	17.8	0.6
February, 2013	4.4	18.2	13.2
March, 2013	8.7	21.0	19.4
April, 2013	11.7	25.3	13.3
May, 2013	15.5	28.2	17.9
Soil type	Sandy loam / alkaline with pH 8.0 to 8.1		

Table B: *List of six wheat lines and four cultivars crossed in line × tester fashion*

Genotypes	Parentage/Source	
Lines		
B4N11	KAUZ//ALTAR84/AOS3/PASTOR	
B6N5	KAUZ//ALTAR84/AOS/3MILAN/ KAUZ/4/HUITES	
B6N12	REH/HARE//2*BCN/CROC-I/…	
BRF1	PIRSABAK.85/SALEEM2000	
BRF3	KAGHAN. 093/4/T-ARST//KAL/ BB/3/ANA-75	
BRF17	KATILA-1	
Testers		
Zam-04 (ZM04)	KAUZ*2/OPATA//KAUZCRG732-11Y-010K-0Y	
Kohat-10 (KT10)	ALTAR84/AESQ//ARROSA219-01// SERI-CMBW91-…	
Pirsabak-08 (PS08)	KAUZ/PASTORCNSS93B00025S-48Y-010-M-01-Y-O	
Janbaz (JZ)	SERI*3//RL6010/4*YR/3/PASTOR/4/ BAV92	
F_1 hybrids		
B4N11 × ZM04	B6N12 × ZM04	BRF3 × ZM04
B4N11 × KT10	B6N12 × KT10	BRF3 × KT10
B4N11 × PS08	B6N12 × PS08	BRF3 × PS08
B4N11 × JZ	B6N12 × JZ	BRF3 × JZ
B6N5 × ZM04	BRF1 × ZM04	BRF17 × ZM04
B6N5 × KT10	BRF1 × KT10	BRF17 × KT10
B6N5 × PS08	BRF1 × PS08	BRF17 × PS08
B6N5 × JZ	BRF1 × JZ	BRF17 × JZ

Results and Discussions

Statistical data revealed highly significant ($P \geq 0.01$) differences among genotypes for all studied parameters, indicated enough genetic variation in wheat genotypes (Table 1). The GCA and SCA variances clearly suggested that additive and dominance genetic expression were equally important for various parameters under study (Table 2). σ^2gca / σ^2sca ratio was observed less than one for all of the traits studied, indicated a predominant significant role of non-additive genetic expression in inheritance, except for maturity. Singh et al. (2012) have also reported non additive gene action for yield and some quality parameters while studying 15 bread wheat genotypes and concluded that parent K-9107 from among testers and UP2338*2 from among lines while ATILA*2/STAAR was good specific F_1 cross for grain yield. Our results are also in general agreement with those of Muhammad (2009) and Esmail (2007), who also reported the non-additive genetic actions for yield traits and affirmed that magnitude and direction of combining ability effects provide a guide line about efficient utilization of wheat parents in hybridization scheme.

Combining ability estimates provide the authentic information of about parents and resultant hybrid combinations in F_1 generations and so far efficient utilization of potential wheat genotypes in Wheat Breeding Programme. GCA effects was significant for most of traits under consideration (Table 3). It was noticed that among 10 parents no parent was proved as good general combiner simultaneously for all parameters.

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Table 1: *ANOVA for various parameters in bread wheat evaluated under rainfed condition*

Characters	Means Squares		
	Replication df=2	Genotypes df=33	Error df=66
Days to heading	1.26	13.51**	0.73
Days to maturity	2.13	9.06**	1.84
Flag leaf area (cm^2)	5.83	58.83**	1.43
Grain filling duration	7.69	17.48**	3.35
Plant height (cm)	1.49	101.17**	3.13
Tillers plant^{-1}	1.27	16.77**	2.35
Spike length (cm)	0.48	1.36**	0.16
Spikelets spike^{-1}	1.39	3.90**	0.49
Grains spike^{-1}	1.75	113.68**	6.58
Spikes plant^{-1}	3.76	13.14**	2.30
1000-Grain weight (g)	3.47	48.12**	2.02
Grain yield plant^{-1} (g)	0.89	65.35**	1.16
Biological yield plant^{-1} (g)	6.89	615.50**	3.97
Harvest index (%)	2.95	122.8**	2.01

*,**: *Significant at 5 and 1% probability level, respectively*

Table 2: *Estimation of variances and narrow sense heritability in wheat under rainfed environment*

Characters	σ^2gca (Lines)	σ^2gca (Testers)	σ^2gca (Average)	σ^2sca (Crosses)	σ^2A	σ^2D	σ^2gca/σ^2sca (ratio)	$(\sigma^2sca/\sigma^2gca)^{1/2}$ Mean degree of dominance	Heritability (h^2_{ns})
Days to heading	0.90	1.38	1.19	3.14	2.38	3.14	0.38	0.62	0.42
Days to maturity	0.92	2.39	1.80	1.13	3.60	1.13	1.59	1.26	0.62
Flag leaf area (cm^2)	0.94	2.20	1.70	9.04	3.40	9.04	0.19	0.43	0.18
Grain filling duration	1.68	0.21	0.80	4.14	1.60	4.14	0.19	0.44	0.17
Plant height (cm)	3.09	7.99	6.03	6.10	12.06	6.10	0.98	0.99	0.54
Tillers plant^{-1}	0.82	0.03	0.35	2.04	0.69	2.04	0.17	0.41	0.19
Spike length (cm)	0.14	0.01	0.06	0.39	0.12	0.39	0.15	0.39	0.16
Spikelets spike^{-1}	0.06	0.02	0.04	0.06	0.08	0.06	0.63	0.79	0.10
Grains spike^{-1}	0.38	3.17	0.25	12.37	0.49	12.37	0.02	0.14	0.03
Spikes plant^{-1}	0.70	0.07	0.33	1.39	0.65	1.39	0.23	0.48	0.21
1000-Grain weight (g)	0.81	0.38	0.55	4.44	1.11	4.44	0.12	0.35	0.14
Grain yield plant^{-1} (g)	6.72	0.29	2.86	8.40	5.72	8.40	0.34	0.58	0.35
Biological yield plant^{-1} (g)	16.19	2.71	8.10	55.26	16.21	55.26	0.15	0.38	0.17
Harvest index (%)	1.39	0.17	0.66	12.28	1.32	12.28	0.05	0.23	0.07

DTH: *Days to heading;* **PHT:** *Plant height (cm);* **GPS***: Grains spike^{-1};* **BYP:** *Biological yield plant^{-1} (g);* **DTM:** *Days to maturity;* **TPP:** *Tillers plant^{-1};* **SP:** *Spikes plant^{-1};* **HI:** *Harvest index (%);* **FLA:** *Flag leaf area (cm^2);* **SPL:** *Spike length (cm);* **TGW:** *1000-grain weight (g);* **GFD:** *Grain filling duration;* **SSP:** *Spikelets spike^{-1};* **GYP:** *Grain yield plant^{-1} (g)*

Table 3: *Estimation of general combining ability of 10 parents (6 lines and 4 testers) for various parameters in wheat under rainfed environment*

Parents		DTH	DTM	FLA	GFD	PHT	TPP	SPL	SSP	GPS	SP	TGW	GYP	BYP	HI
Lines	Pedegree/Parentage														
B4N11	KAUZ//ALTAR84/AOS3/P..	-2.18**	-0.51	1.57**	-0.69	-1.94**	0.16	-0.51**	-0.29	3.24**	-0.28	0.62*	-0.89*	-0.53	0.44
B6N5	KAUZ//ALTAR84/AOS/3MI.	0.82**	-1.85**	-0.70	-3.11**	-0.59	1.07**	0.39*	0.16	-1.01**	1.21**	-0.09	0.44	-1.94**	3.27**
B6N12	REH/HARE//2*BCN/3/CRO..	0.99**	-0.01	0.96*	0.22	-1.76**	-0.41	0.54**	-0.27	-1.17**	-0.31	2.41**	-2.39**	-1.44	1.29*
BRF1	KAGHAN.93/4/TARST//KA.	0.57**	1.24**	-1.03*	1.39**	-0.62	-0.71**	-0.62**	0.33	1.08**	-0.49*	-0.95**	1.03**	0.39	-0.68
BRF3	PS85/SALEEM.2000	-1.10**	-0.10	2.02**	1.31**	3.91**	1.54**	-0.24	0.43*	-0.26	1.26**	-0.31	5.11**	10.14**	-1.31*
BRF17	KATILA-11	0.90**	1.24**	-2.82**	0.89	0.99*	-1.64**	0.43*	-0.36	-1.89**	-1.40**	-1.69**	-3.31**	-6.61**	-3.01**
SE(gi)±		0.24	0.39	0.53	0.46	0.39	0.23	0.16	0.20	0.27	0.20	0.30	0.38	0.74	0.55
SE(gi-gj)±		0.09	0.16	0.18	0.19	0.16	0.09	0.07	0.09	0.11	0.08	0.12	0.15	0.30	0.22
CD (5%)		0.20	0.31	0.36	0.37	0.32	0.19	0.13	0.17	0.22	0.16	0.24	0.30	0.60	0.44
Testers															
ZM04	KAUZ*2/OPATA//KAUZ...	-0.43*	1.13**	0.68	1.25**	2.94**	0.51**	-0.08	-0.04	1.08**	0.35**	-1.19**	1.53**	0.89	0.59
KT10	ALTAR84/AESQ//AROSA2.	2.07**	0.74*	0.03	-0.75*	1.83**	-0.28	-0.20	0.32	0.04	-0.32	0.47	-0.47	3.44**	0.27
PS08	KAUZ/PASTORCNSS93B0..	-0.71**	0.57	1.97**	-0.92*	-3.79**	-0.77	-0.16	-0.30	1.02**	-0.64	-0.55*	0.53	0.56	1.37**
JZ	SERI*3//RL6010/4*YR/3/...	-0.93**	-2.43**	-2.68**	0.42	-0.97**	0.53**	0.45**	0.02	-2.14	0.60**	1.27**	-1.58**	-4.89**	-2.23**
SE(gi)±		0.18	0.31	0.43	0.38	0.32	0.19	0.14	0.17	0.22	0.16	0.24	0.31	0.61	0.42
SE(gi-gi)±		0.07	0.11	0.12	0.13	0.11	0.06	0.04	0.06	0.07	0.05	0.08	0.10	0.20	0.15
CD (5%)		0.79	0.21	0.24	0.25	0.22	0.12	0.09	0.11	0.15	0.11	0.16	0.20	0.40	0.30

*,**: *Significant at 5 and 1%, respectively;* **Note:** *For abbreviations see Table 2*

These results are in general agreement with those of Jatav et al. (2014) who also reported change in trend of lines for general combining ability effects for various traits and emphasized that lines with high GCA values for important trait like grain yield should be used in future breeding programs to improve wheat yield. Among lines, BRF3 perform best for the maximum parameters like days to heading, tillers per plant, spikelets per spike, spikes per plant, grain yield per plant and biological yield per plant. The line B6N5 was emerged as good general combiner for days to maturity, grain filling duration, tillers plant^{-1}, spike length, spikes plant^{-1} and harvest index. Similarly, the genotype B4N11 was found a better combiner for heading, plant height, grains per spike and 1000-grains weight. Likewise, line B6N12 was observed as good combiner for traits plant height, spike length, 1000-grain weight and harvest index. In addition, genotype BRF1 was found as good general combiner for three parameters like, flag leaf area, grains per spike and grain yield per plant. The genotypes, BRF17 was good general combiners only for two traits like leaf area and spike length. These variations were expected because of diversity in genetic makeup of the wheat parents for various traits under consideration. Positive GCA effects for 1000-grain weight and spike length have been reported by Akbar et al. (2009) in bread wheat, furthermore, he elaborated the fact that 1000-grain weight is an important character significantly contributing towards grain yield. Among testers, JZ observed as best general combiner as it had significant GCA effect for maximum 8 traits like heading, maturity, leaf area, plant height, tillers per plant, spike length, spikes per plant and 1000-grains weight. Similarly, ZM04 emerged as promising general combiner for days to heading, tillers per plant, grains per spike, spikes per plant and grain yield per plant. However, tester PS08 was appeared as best general combiner for heading, plant height, grain filling duration, grains spike^{-1} and harvest index.

Table 4: *Estimation of specific combining ability effects of 24 F_1 hybrids for various characters in wheat under rainfed environment*

F_1 Hybrids	DTH	DTM	FLA	GFD	PHT	TPP	SPL	SSP	GPS	SP	TGW	GYP	BYP	HI
B4N11×ZM04	2.35**	-1.49	0.26	1.58	-3.01**	-2.81**	-0.58	-0.52	-1.08*	-2.39**	1.87	-3.94**	2.19	-0.60
B4N11×KT10	0.18	0.01	-0.62	-3.42**	-2.56**	-0.96*	-0.82*	0.84*	0.62	-0.39	-0.53	-1.61*	-6.03**	-0.46
B4N11×PS08	0.63	-0.21	-3.10**	-1.92*	0.66	0.93*	0.83*	-0.27	0.31	0.59	-3.12**	3.72**	6.19**	0.28
B4N11×JZ	-3.15**	1.68*	3.46**	3.75**	4.91**	2.83**	0.56	-0.06	0.14	2.19**	1.78	1.83*	-2.36	0.78
B6N5×ZM04	0.68	1.46	-3.41**	0.00	0.64	1.61**	0.76*	-0.04	6.17**	1.45**	1.94	1.06	7.61**	-1.37
B6N5×KT10	-2.49**	1.18	2.81**	3.33**	-0.91	-0.94**	-0.72*	0.26	-2.79**	-0.88*	3.63**	-2.61**	-9.61**	0.28
B6N5×PS08	0.96	-2.65**	2.44**	-0.83	2.18**	-0.32	-0.33	-0.12	-4.11**	-0.43	-6.41**	0.72	-0.06	0.45
B6N5×JZ	0.85	0.01	-1.84*	-2.50**	-1.91*	-0.35	0.30	-0.11	0.73	-0.14	0.84	0.83	2.06	0.64
B6N12×ZM04	-0.82	-0.71	-0.85	0.01	-1.19	-1.24**	0.27	-0.21	-0.33	-0.99*	-0.58	-0.11	-4.89**	0.24
B6N12×KT10	1.68**	-0.32	-4.98**	-1.33	1.26	1.88**	0.16	-0.24	-0.96	0.98*	-3.70**	0.22	7.89**	-0.89
B6N12×PS08	-0.21	0.51	0.85	0.17	0.88	-0.83	-0.02	-0.02	1.06	-0.71	-0.53	-0.44	-3.89**	-0.03
B6N12×JZ	-0.65	0.51	4.98**	1.17	-0.94	0.20	-0.42	0.46	0.23	0.72	4.82**	0.33	0.89	0.68
BRF1×ZM04	-2.40**	-0.96	2.41**	0.17	1.01	0.72	0.43	-0.21	-2.24**	0.81*	-2.16*	2.47*	3.94**	7.44**
BRF1×KT10	-0.90	0.76	-0.18	0.17	0.12	0.31	0.89**	-0.24	2.79**	0.15	0.03	5.47**	4.39**	1.07
BRF1×PS08	1.54**	-0.07	-1.64	-0.67	-1.72*	0.07	-0.16	0.05	-0.52	0.10	6.73**	-6.53**	-6.06**	-4.18**
BRF1×JZ	1.76**	0.26	-0.59	0.33	0.59	-1.10**	-1.16**	0.39	-0.02	-1.07*	-4.61**	-1.42	-2.28	-4.34**
BRF3×ZM04	1.26*	0.04	3.33**	-1.08	3.48**	0.07	-0.84*	0.49	-7.24**	-0.27	-1.05	1.06	-16.14**	-4.23**
BRF3×KT10	0.43	-0.24	1.04	-1.08	-1.08	-0.07	0.65	0.13	3.46**	0.40	0.97	-0.28	4.97**	0.73
BRF3×PS08	-1.46**	0.60	-0.40	2.75**	-2.79**	0.55	-0.33	-0.38	2.81**	0.72	2.91**	0.72	8.53**	6.37**
BRF3×JZ	-0.24	-0.40	-3.97**	-0.58	0.39	-0.55	0.53	-0.24	0.98	-0.85*	-2.83**	-1.50*	2.64	-2.87**
BRF17×ZM04	-1.07*	0.38	1.62	-0.67	-0.94	1.66**	-0.04	0.48	4.72**	1.40**	-0.02	-0.53	7.28**	-1.49
BRF17×KT10	1.10*	0.10	1.05	2.33*	3.17**	-0.22	-0.15	-0.76	-3.11**	-0.26	-0.40	-1.19	-1.61	-0.73
BRF17×PS08	-1.46**	1.60*	-0.63	0.50	0.79	-0.40	0.01	0.73	0.44	-0.28	0.42	1.81	-4.72**	-2.89**
BRF17×JZ	1.43**	-2.07**	-2.05*	-2.17*	-3.03**	-1.03**	0.20	-0.46	-2.06**	-0.85*	0.01	-0.08	-0.94	5.11**
SE(Sij)±	0.49	0.77	0.89	0.92	0.78	0.46	0.33	0.41	0.54	0.39	0.60	0.75	1.48	1.10
SE(Sij-Skl)	0.39	0.63	0.72	0.75	0.64	0.37	0.27	0.33	0.44	0.32	0.49	0.61	1.21	0.90
CD (5%)	0.79	1.25	1.43	1.49	1.26	0.74	0.53	0.66	0.88	0.63	0.96	1.22	2.40	1.78

*,**: *Significant at 5 and 1%, respectively;* **Note:** *For abbreviations see Table 2*

The estimation of specific combining ability given in Table 4 revealed that F_1 hybrid BRF3 × PS08 had significant SCA effects for most of the traits like, heading, plant height, grains per spike, 1000-grains weight, biological yield per plant and harvest index, and at least one parents of this cross involved were the good general combiners for such traits. Similarly, F_1 hybrids B4N11 × PS08 and BRF1 × ZM04 were best specific combiners for second highest traits including grain yield plant^{-1} For plant height and spikes plant^{-1} cross combination B4N11 × JZ had desirable SCA effects and parents of cross involved were also best general combiners for these traits. Significantly positive SCA effects for plant height and spikes per plant have been also reported by Meena and Sastry (2003) and Jag et al. (2003). For lodging resistant and short statured plants F_1 hybrids B6N5 × JZ and BRF1 × PS08 were desirable specific combiners. Similarly, for grains spike^{-1}, spikes plant^{-1} and biological yield plant^{-1}, the F_1 crosses B6N5 × ZM04 and BRF17 × ZM04 had significantly positive SCA effects and one of the parent of these crosses involved were best general combiner for such traits. Under rainfed environment leaf area is greatly inclined by transpirational loss because of its exposure to high intensity solar radiation and subsequently effect the grain yield (Riaz, 2003). Keeping this point much emphasis is placed on selection of plants with narrow leaf for rainfed environment. F_1 crosses B4N11 × PS08, B6N5 × ZM04, B6N5 × JZ, B6N12 × KT10, BRF3 × JZ and BRF17 × JZ had negative SCA value under rainfed condition was potential specific combiners for producing progeny with desirable flag leaf area under rainfed environment. As the main aim is the development of pure line wheat cultivars and thus there are great chances of recovering transgressive segregants in later generations (F_5 and F_6) with more yield compared to parents. Based on SCA effects the top specific combiners for various characters are given in Table 5. Similar findings were observed by Rehman et al. (2002) who observed negative SCA effects for flag leaf area with non-additive gene action in F_1 wheat populations.

Table 5: *Lines and testers with significant GCA and F_1 hybrids with significant SCA effects for different traits in wheat*

Traits	Best general combiners	Best specific combiners
Days to heading	Lines: B4N11, BRF3 Testers: ZM04, PSO8, JZ	B4N11 × JZ, B6N5 × KT10, BRF1 × ZM04, BRF3 × PS08, BRF17 × ZM04, BRF17 × JZ
Days to maturity	Lines: B6N5, Testers: JZ	B6N5 × PS08, BRF17 × JZ
Flag leaf area (cm^2)	Lines: BRF17,BRF1 Testers: JZ	B4N11 × PS08, B6N5 × ZM04, B6N5 × JZ B6N12 × KT10, BRF3 × JZ, BRF17 × JZ
Grain filling duration	Lines: B6N5, Testers: KT10, PS08	B4N11×KT10, B4N11 × PS08 B6N5 × JZ, BRF17 × JZ
Plant height (cm)	Lines: B4N11, B6N12 Testers: PS08, JZ	B4N11 × ZM04, B4N11 × KT10, B6N5 × JZ BRF1 × PS08, BRF3 × PS08, BRF17 × JZ
Tillers plant^{-1}	Lines: B6N5, BRF3 Testers: ZM04, JZ	B4N11 × JZ, B6N5 × ZM04, B6N12 × KT10, BRF17 × ZM04, BRF17 × JZ
Spike length (cm)	Lines: B6N5, B6N12 BRF17 Testers: JZ	B4N11 × PS08, B6N5 × ZM04, BRF1 × KT10
Spikelets spike^{-1}	Lines: BRF3	B4N11 × KT10
Grains spike^{-1}	Lines: B4N11, BRF1 Testers: ZM04, PS08	B6N5 × ZM04, BRF1 × KT10, BRF3 × KT10 BRF17 × ZM04
Spikes plant^{-1}	Lines: B6N5, BRF3 Testers: ZM04, JZ	B4N11 × JZ, B6N5 × ZM04, B6N12 × KT10, BRF1 × ZM04, BRF17 × ZM04
1000-Grain weight (g)	Lines: B4N11, B6N12, Testers: JZ	B6N5 × KT10, B6N12 × JZ, BRF1 × PS08, BRF3 × PS08
Grain yield plant^{-1} (g)	Lines: BRF1, BRF3 Testers: ZM04	B4N11 × PS08, B4N11 × JZ, BRF1 × ZM04, BRF1 × KT10
Biological yield plant^{-1} (g)	Lines: BRF3 Testers: KT10	B4N11 × PS08, B6N5 × ZM04, B6N12×KT10, BRF1× ZM04, BRF1 × KT10, BRF3 × KT10, BRF17 × ZM04
Harvest index (%)	Lines: B6N5, B6N12 Tester: PS08	BRF1 × ZM04, BRF3 × PS08, BRF17 × JZ

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Dominance variances were quite more than additive variances for almost all parameters studied, except for maturity, spikelets per spike and plant height. Narrow sense heritability was greater (> 0.60) for maturity only while moderate for plant height and grain yield per plant ($0.30 < h^2_{ns} < 0.60$). However, important yield contributing parameters like tillers per plant, spikes per plant, spike length, spikelets per spike, 1000-grain weight, biological yield and harvest index had low narrow-sense heritability ($h^2_{ns} < 0.30$). Moderate to low heritability for tillers plant^{-1}, 1000-grain weight and spikelets spike^{-1} are also reported by Noorka and Silva (2014) who also reported that environmental variances accounted for a major portion of total phenotypic variation. Furthermore, low heritability suggests that non fixable genetic variation governs this trait and selection for that trait among segregating populations will be better in later generations. The mean degree of dominance and ratio of σ^2gca and σ^2sca clearly indicated that non-additive genetic effects were predominant for maximum traits under study. Best general combiners for grain yield per plant were lines BRF1, BRF3 and tester ZM04. Estimates of GCA effect as a whole recommended wheat parents and F_1 hybrids with desirable significant general and specific combining ability for important maturity and yield contributing traits need to be utilized for developing new cultivars. Best general combiners for grain yield per plant were lines BRF1, BRF3 and tester ZM04. While B4N11 × PS08, B4N11 × JZ, BRF1 × ZM04, BRF1 × KT10 were best specific cross combinations for grain yield per plant which can be efficiently use in hybrid wheat Breeding.

Conclusion

Low narrow-sense heritability coupled with low GCA effects as compared with SCA effects were observed for all traits except days to maturity. Both GCA and SCA effect were found significant along with moderate narrow sense heritability for heading, days to maturity, plant height and grain yield. Line BRF1, B4N11 and B6N5 while tester JZ and ZM-04 were best general combiners for yield and associated traits, while F_1 hybrid BRF17 × JZ and B4N11 × JZ were best specific combiners for various traits including grain yield.

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Conflict of Interest

No conflict of interest

Authors' Contribution

MS did research and IHK supervised the research work as well as assist in data analysis.

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