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Research Article

Combining ability and inheritance studies for morphological and yield contributing attributes through line × tester mating design in wheat (*Triticum aestivum* L.)

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Abstract

In wheat improvement programs development of new high yielding varieties requires information about, inheritance mechanism, identification of superior germplasm and combining ability of parents to transmit desirable attributes to offspring. In the current study, three genetically diverse elite advanced lines i.e. PR-105, PR-108 and PR-109 and three commercial wheat cultivars Faisalabad -2008, Lasani-2008 and Pirsabak-2013 were sown in crossing block during 2013-14. They were crossed in line × tester mating design to develop F_1 hybrids. F_1 hybrids along with their parents were evaluated in randomized complete block design with three replications at Cereal Crops Research Institute Pirsabak, Nowshera Khyber Pakhtunkhwa-Pakistan during 2014-15 for seven important traits. Analysis of variance revealed highly significant ($P \leq 0.01$) differences among the genotypes for the studied traits. Based on desirable General Combining Ability (GCA) effects, among the lines and testers, line (PR-105) and tester (Faisalabad-2008) were found best for earlier heading, maturity and high grain yield. Based on desirable Specific Combining Ability (SCA) effects, crosses, PR-109 × Lasani-2008 (for days to heading and maturity), PR-108 × Pirsabak-2013 (for flag leaf area), (PR-108 × Faisalabad-2008 (for biological yield) and PR-105 × Lasani-2008 (for grain yield) were best specific hybrids involving high × low and high × high GCA effects of parents and could be advanced to later segregating generation to extract potential transgressive segregants lines. Contribution of lines × tester interaction to the total variation was greater than lines and testers individually, indicating greater potential/variation of hybrids appearing for most of the traits. Ratio of GCA variance to SCA variance showed predominance of non additive gene action for all the studied traits. The identified superior crosses could be advanced through mass selection and therefore, single plant selection should be delayed to late segregating generations (F_6) to derived potential lines for economically important traits.

Keywords: Combining Ability; Gene Action; Line × Tester; Mating Design; Variance Components; Yield

Introduction

Wheat (*Triticum aestivum* L.) is one of the leading cereal crops grown worldwide in a diversified geographical locations and environments ranging from high to low inputs. It is the most important food grains crop especially in many developing countries of the world and plays a vital role in food security. Globally wheat is the leading source of vegetable protein and has higher protein content then other major cereal like maize and rice. It has been reported that globally wheat provides approximately 55% carbohydrates and 20% of the food calories consumed [1]. Global demand for cereal grains consumption is consistently increasing due to ever increasing population of the world. However demand for wheat cannot meet because wheat production in many countries of the world, facing several challenges and are threatened by climatic change. Therefore, introducing new cultivars/ advanced lines with superior features like high yield, disease resistance and its adaptation to arid and semi-arid environments to diversified cultivars basis are prerequisites to feed the ever increasing population [2].

Grain yield is a polygenic trait; hence selection of genotypes based on grain yield alone is not very efficient therefore, to increase breeding efficiency identification of traits by wheat breeder contributing to final yield is of grater important [2, 3]. Modern wheat breeding emphasis on development of new high yielding varieties suited best diversified agro-climatic conditions. This requires information about genetic diversity existed in the available germplasm, inheritance mechanisms operative for the yield and its contributing traits. It can be achieved by breeders through identification/selection of superior germplasm and crossed them with each other using different crossing pattern to generate new variability and wheat plants with elevated levels of genetic diversity and/or recombination.

Selection of desirable/suitable parents and choice of the mating design is the key to success of plant breeding programs. In crop breeding or cultivar development several mating designs like bi-parental mating, ploycross, diallel mating, line × tester etc are used by plant breeders and geneticists to generate new populations and provide a base for further selection and develop new potential genotypes of desirable attributes [4, 5]. Line × tester is one of the mating designs proposed by [6] used by breeder to identify potential parents in term of their performance in different cross combinations. It provides information about general combining ability (GCA) of lines/parents and specific combining ability (SCA) of crosses. Furthermore it elucidates the nature of gene action and the inheritance mechanisms for various traits. Line × tester analysis determine combining ability of parents and exploring gene action for economically important traits has been reported by many researchers [7-9].

Current research was undertaken in wheat through line × tester analysis with the objectives to (i) Explore spring × spring, gene pool for economically important traits (ii) Identify potential lines, testers based on general combining ability (GCA) and their F_1 hybrids via specific combining ability (SCA) effects to be utilized in future wheat improvement programs (iii) Determine the mode of gene action and inheritance pattern operative for morphological, yield and it associated traits.

Materials and Methods

Breeding material and experimental site:

The research was conducted at Cereal Crops Research Institute (CCRI), Pirsabak Nowshera, Khyber Pakhtunkhwa-Pakistan. The experimental site elevation is 288 meters (945 Ft) and located on the intersection of longitude 740 E and latitude 320N. Breeding

material comprised of three diverse advanced lines i.e. PR-105, PR-108 and PR-109 designated as females and three wheat cultivars Faisalabad -2008, Lasani-2008 and Pirsabak-2013 of diverse origin which were used as males. The detail of the lines (females) and testers (males) used in the study are presented in (Table 1). Three lines and three testers were sown in crossing block during 2013-14 and were crossed in line × tester fashion to develop nine F_1 hybrids. All the genotypes (3 lines, 3 testers and their 9 F_1 hybrids) were evaluated in randomized complete block design with three replications during 2014-15. F_1 hybrids along with their parents were sown in the field in 2 rows of 2 meter long with row spacing of 30 cm and plant to plant distance 15cm. Standard cultural practices like irrigation; weeding management and fertilization of were carried out during the cropping seasons.

Table 1. Detail of the lines and testers (cultivars) crossed in line × tester mating design

Parents	Parentage	Selection History	Breeding Institute
Lines			
PR-105	MILAN/S87230//BABAX	CMSS97M03689T-040Y-030M-020Y-030M-015Y-30M-3Y-1M-0Y	Cereal Crops Research Institute(CCRI) Pirsabak Nowshera, Pakistan
PR-108	WHEAR/KRONSTADF2004	CGSS04Y00106S-099Y-099M-099Y-099M-13WGY-0B	-do-
PR-109	PBW343*2/KUKUNA/5/CNO79//PF70354/MUS/3/PASTOR/4/BA V92	CGSS03B00180S-099M-099Y-099M-17WGY-0B	-do-
Testers			
Faisalabad -2008	PBW65/2*PASTOR	CGSS97Y000367-099T0PB-067Y-099M-099Y-099B-16Y-0B	Ayub Agriculture Research Institute (AARI), Faisalabad Pakistan
Lasani-2008	LUAN/KOH97	PBP.29645-14A-18A-8A-4A-2A-0A	-do-
Pirsabak-2013	CS/TH.SC//3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI	CMSS97M04005T-040Y-020Y-030M-020Y-040M-28Y-3M-0Y	Cereal Crops Research Institute(CCRI) Pirsabak Nowshera, Pakistan

Data recording and statistical analysis

Data were recorded on days to heading, heading to maturity, flag leaf area (cm^2), spike length (cm), spikelets $spike^{-1}$, biological yield (g $plant^{-1}$) and grain yield (g $plant^{-1}$). Recorded data were analyzed according to **[10]** to determine significant differences among the genotypes and for means comparison least significant difference (LSD) test was used. Traits showing significant genotypic differences were further analyzed for combining ability studies. Line × tester analysis following **[11]** was used to estimates of combining ability i.e. general combining ability (GCA) of lines and testers and specific combining ability (SCA) of the hybrids. Proportional (%) contribution of lines, testers, line × testers to the total variation was also determined for each trait. Variance due to General combining ability (σ^2GCA), specific combining ability (σ^2SCA), ratio of σ^2GCA/σ^2SCA, for various traits were computed as per **[12]**.

Results and discussion

Analysis of variation and mean performance of parents (lines, testers) and hybrids

Statistical analysis of data revealed highly significant differences ($P \leq 0.01$) among the

genotypes, parents, lines, crosses and line × testers for flowering and yield associated traits. However lines effect for days to heading and testers were found non-significant for days to maturity, flag leaf area, spike length, biological yield and grain yield (Table 2). Results of the mean performance of lines, testers and their F_1 hybrids for the studied traits are provided in (Table 3). Based on mean performance for days to heading among the lines, PR-109 and among the testers, Pirsabak-2013 were best as it starts heading and matured earlier. Among the hybrids PR-105 × Faisalabad-2008 (123.0 days) and PR-108 × Faisalabad-2008 & PR-108 × Pirsabak-2013 (123.7 days) were found best for days to heading. For days to maturity crosses i.e. PR-105 × Faisalabad-2008 and PR-108 × Pirsabak-2013 (163.0 days) were best. Among the lines based on mean values PR-105 was best for flag leaf area, spike length, spikelets per spike, biological yield and grain yield. Among the testers, Faisalabad -2008 for flag leaf area, biological yield and grain yield and Pirsabak-2013 for spike length and spikelets per spike were best. Among the crosses, PR-109 × Lasani-2008 (for flag leaf area), PR-108 × Faisalabad-2008 (spike length and spikelets per spike), PR-105 × Lasani-2008 (for biological yield) and PR-109 × Faisalabad-2008 (for grain yield) were found best (Table 3). Mean values showed that hybrids performance was better than their lines and testers for most of the studied traits. Results regarding studied traits indicated the lines and testers used in the current research were diverse and varied significantly. Significant variation for flowering and yield traits have been reported by [13-16].

Table 2. Analysis of variance (ANOVA) for morphological and yield associated traits using line × tester mating design in bread wheat

Source of variation	D. F	Days to heading	Days to maturity	Flag leaf area	Spike length	Spikelets per spike	Biological yield	Grain yield
Replications	2	14.16	8.96	97.75	6.94	11.25	51.46	73.63
Genotypes	14	14.57**	8.31**	63.35**	2.35**	5.84**	518.83**	70.53**
Parents	5	12.89**	18.32**	48.40*	2.11**	3.28*	443.02*	66.70**
Parents vs Crosses	1	56.95**	6.85**	250.12**	1.24^{NS}	1.15^{NS}	623.01**	88.95**
Crosses	8	10.31**	2.23**	49.34**	2.63**	8.02**	553.19**	70.62**
Lines	2	1.81^{NS}	3.37**	46.28*	1.61*	4.22*	1280.73**	144.24**
Testers	2	23.59**	1.59^{NS}	27.18^{NS}	0.82^{NS}	6.92**	44.74^{NS}	8.29^{NS}
Lines × Testers	4	7.93**	1.98*	61.95**	4.05**	10.46**	443.64**	64.96**
Error	28	2.49	1.15	24.71	0.73	1.64	199.92**	26.63

* & **= Significant at 5% and 1% level of probability, respectively NS = Non significant

Table 3. Mean performance of lines, testers and their F_1 hybrids for morphological and yield traits in bread wheat

Genotypes	Days to heading	Days to maturity	Flag leaf area (cm^2)	Spike length (cm)	Spikelets per spike	Biological yield ($g\ plant^{-1}$)	Grain yield ($g\ plant^{-1}$)
Lines							
PR-105	123.3	165.0	49.96	14.42	22.9	102.15	39.37
PR-108	124.0	164.7	38.39	13.42	21.8	76.42	27.65
PR-109	121.3	164.0	43.28	12.33	21.3	93.72	32.35
Testers							
Faisalabad -2008	123.7	163.7	44.09	13.09	20.1	110.50	38.37
Lasani-2008	125.0	164.0	40.83	14.22	22.7	84.69	29.47
Pirsabak-2013	119.3	158.3	40.75	12.64	21.0	95.92	34.61
F_1 hybrids							

PR-105 × Faisalabad-2008	123.0	163.0	45.65	12.80	21.9	88.83	34.95
PR-105 × Lasani-2008	126.0	163.7	51.81	13.70	18.2	120.11	41.92
PR-105 × Pirsabak-2013	125.0	163.7	46.28	13.43	23.4	103.22	37.91
PR-108 × Faisalabad-2008	123.7	164.7	49.11	16.00	23.5	96.56	32.48
PR-108 × Lasani-2008	129.3	164.7	41.81	13.50	21.8	80.78	31.33
PR-108 × Pirsabak-2013	123.7	163.0	45.05	12.94	21.2	88.15	31.96
PR-109 × Faisalabad-2008	124.7	163.7	45.70	13.29	21.6	112.18	44.58
PR-109 × Lasani-2008	125.3	165.3	55.47	13.62	22.8	110.03	33.12
PR-109 × Pirsabak-2013	125.0	165.0	48.37	13.96	23.1	113.60	40.30
Lines mean	122.9	164.6	43.88	13.39	22.0	90.76	33.12
Testers mean	122.7	162.0	41.89	13.32	21.3	97.04	34.15
F_1 mean	125.1	164.1	47.69	13.69	22.0	101.50	36.51
$LSD_{(0.05)}$	2.6	1.8	8.31	1.43	2.1	23.65	8.63
$LSD_{(0.01)}$	3.6	2.4	11.22	1.93	2.9	31.90	11.64

LSD = Least significant difference

General combining ability effects

General combining ability is of significant importance and widely used by plant breeders to identify potential lines and testers to be used in future crossing programs and selecting superior lines in segregating population from resultant hybrids of these lines [17-18]. General combining ability effects of lines and testers for the studied traits are presented in (Table 4). Wheat breeders are interested in development of new genotypes starts heading and mature earlier. Therefore for days to heading and maturity negative combining ability effects are desirable. Among the lines, best general combiner were PR-105 for days to heading (-0.41) and maturity (-0.63), PR-109 for flag leaf area (2.15). Spiketets per spike (0.54), biological yield (10.44) and grain yield (2.83). However among the testers, Faisalabad-2008 was best general combiner for earlier heading (-1.30) and maturity (-0.30), spike length (0.34) and grain yield (0.83). Similar findings were also reported by [19] for days to heading, plant height, spike length and spikelets per spike. [20] also proposed that lines with positive GCA effects for important parameters should be used in future breeding programs to improve wheat yield.

Table 4. Estimates of general combining ability (GCA) of 6 Parents (3 lines and 3 testers) for the studied traits in bread wheat

Parents	Days to heading	Days to maturity	Flag leaf area	Spike length	Spikelets per spike	Biological yield	Grain yield
Lines							
PR-105	-0.41	-0.63	0.22	-0.38	-0.77	2.56	1.75
PR-108	0.48	0.04	-2.37	0.45	0.23	-13.00	-4.58
PR-109	-0.07	0.59	2.15	-0.07	0.54	10.44	2.83
SE (lines)	0.53	0.36	1.66	0.28	0.43	4.71	1.72

Testers							
Faisalabad -2008	-1.30	-0.30	-0.87	0.34	0.36	-2.31	0.83
Lasani-2008	1.81	0.48	2.00	-0.09	-1.00	2.14	-1.05
Pirsabak-2013	-0.52	-0.19	-1.13	-0.25	0.64	0.16	0.22
SE (Testers)	0.53	0.36	1.66	0.28	0.43	4.71	1.72

SE= Standard error

Specific combining ability effects

Results of specific combining ability effects for the studied traits are presented in Table 5. Development of new wheat genotypes with earlier heading and maturity are the keys to cope with different abiotic stress during crop life cycle. Therefore for these traits hybrids with negative SCA effects are preferred. For days to heading, negative SCA were shown by PR-109 × Lasani-2008 (-1.48), followed by PR-108 × Pirsabak-2013 (-1.37) and PR-108 × Faisalabad-2008 (-0.59). Regarding days to maturity, PR-108 × Pirsabak-2013 (-0.93), PR-109 × Faisalabad-2008 (-0.70) and PR-105 × Lasani-2008 (-0.26) were best specific hybrids. More flag leaf area is desirable and cross combinations i.e. PR-108 × Faisalabad-2008(4.66), PR-109 × Lasani-2008 (3.62) and PR-105 × Lasani-2008 (1.89) were found best. These results confirm the findings of [21, 22] who found positive SCA effect for flag leaf area. Long spike with more spikelets per spike are desirable and are important yield contributing parameters. Based on positive SCA values best cross combinations for spike length were PR-108 × Faisalabad-2008 (1.52), PR-109 × Pirsabak-2013 (0.58) and PR-105 × Pirsabak-2013 (1.62) and PR-109 × Lasani-2008 (1.33) for more spiketets per spike. F_1 hybrids: PR-105 × Lasani-2008 (13.91), PR-108 × Faisalabad-2008 (10.37) and PR-109 × Faisalabad-2008 (2.55) were promising one for biological yield. Pertaining to grain yield per plant best specific hybrids were PR-105 × Lasani-2008 (4.71), PR-109 × Faisalabad-2008 (4.41), PR-109 × Pirsabak-2013 (0.75). Based on SCA effects the superior performance of high × low, medium × low and high × high combinations could be due to the presence of genetic diversity among the lines and tester used in the study. The similar results were also reported earlier by [23, 24] for yield and yield associated traits.

Table 5. Estimates of specific combining ability (SCA) effects of 9 F_1 hybrids derived from lines × testers mating design for studied traits in bread wheat

Crosses	Days to heading	Days to maturity	Flag leaf area	Spike length	Spikelets per spike	Biological yield	Grain yield
PR-105 × Faisalabad-2008	-0.37	-0.15	-1.39	-0.85	0.34	-12.91	-4.14
PR-105 × Lasani-2008	-0.48	-0.26	1.89	0.48	-1.96	13.91	4.71
PR-105 × Pirsabak-2013	0.85	0.41	-0.51	0.37	1.62	-1.00	-0.57
PR-108 × Faisalabad-2008	-0.59	0.85	4.66	1.52	0.96	10.37	-0.28
PR-108 × Lasani-2008	1.96	0.07	-5.51	-0.56	0.64	-9.86	0.45
PR-108 × Pirsabak-2013	-1.37	-0.93	0.85	-0.95	-1.60	-0.50	-0.18
PR-109 × Faisalabad-2008	0.96	-0.70	-3.28	-0.67	-1.30	2.55	4.41
PR-109 × Lasani-2008	-1.48	0.19	3.62	0.09	1.33	-4.05	-5.16
PR-109 × Pirsabak-2013	0.52	0.52	-0.34	0.58	-0.02	1.50	0.75
SE (SCA)	0.91	0.62	2.87	0.49	0.74	8.16	2.98

SE= Standard error

Proportional contribution of lines, testers and line × tester interaction to the total variance and gene action for the studied traits

For each trait proportional contribution of lines, testers and line × tester interaction to the total variation are presented in (Figure 1). For days to heading and spikelets per spike of the total variance, the contribution of lines was smaller than the testers and line × tester interaction effect. Testers contributions for flag leaf area, spike length, biological yield and grain yield was lesser as testers and line × testers interaction effect. Line × testers interaction effect to the total variation for days to maturity, flag leaf area, spike length and spikelets per spike was much more then lines and testers individually. It clearly indicated that line × tester interaction provide greater variability for appearing of the studied traits. Our results are supported by [3-5] who reported that line × tester interaction contributed much for for spike length, spikelets per spike, biological yield and yield per plant. It is also worth mentioning that the F_1 hybrids had a higher values for days to heading, days to maturity, flag leaf area, spike length, biological yield and grain yield as compared to parents (lines and testers).Variance due to general combining ability (σ^2GCA) value was smaller than specific combining ability (σ^2SCA) for all the studied traits indicating predominance of non additive gene action. This was further supported by low ratio of σ^2GCA/ σ^2SCA being less than unity for all the traits studied (Table 6). Our results are supported by [19-27] who reported non additive gene action for yield and yield associated traits bread wheat

Table 6. Estimates of variances of general combining ability (σ^2gca), specific combining ability (σ^2sca) ratio of σ^2gca/ σ^2sca, for the studied traits in bread wheat

Genetic component	Days to heading	Day to maturity	Flag leaf area	Spike length	Spikelets per spike	Biological yield	Grain yield
σ^2gca	0.486	0.083	0.320	-0.045	0.019	24.495	2.432
σ^2sca	1.812	0.278	12.411	1.107	2.943	81.240	12.778
σ^2gca/ σ^2sca	0.268	0.297	0.026	-0.041	0.006	0.302	0.190

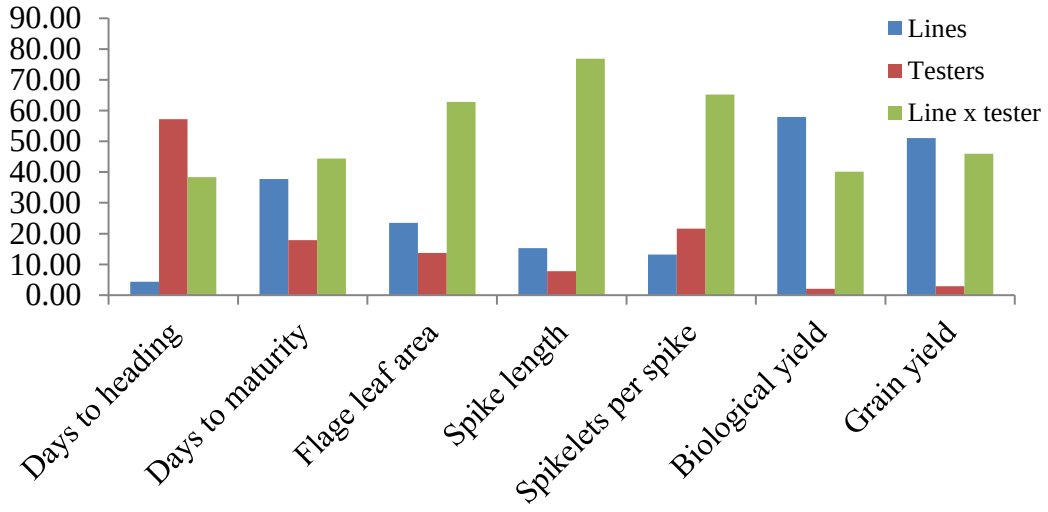

Figure 1. Proportional contribution (%) of lines, testers and line × testers' interaction effects to the total variation for the studied traits

Conclusions

Analyzed data revealed highly significant differences among the genotypes for all the characters studied. Analysis of line × testers revealed that lines, testers and line × tester effects were found highly significant for most of the traits. Based on general combining ability among the parents PR-105 and Faisalabad-2008 were found best for earlier heading, maturity and high grain yield per plant. Crosses for days to heading, PR-109 × Lasani-2008, maturity (PR-108 × Pirsabak-2013) flag leaf area (PR-108 × Faisalabad-2008 (4.66) for biological yield and grain yield (PR-105 × Lasani-2008) was best specific hybrid involving high × low and high × high GCA effects of parents. Contribution of lines × tester interaction to the total variation was greater than lines and tester individually, indicating greater potential/variation of hybrids appearing for most of the traits. Non additive gene action for all the studied traits was observed as ratio of GCA variance to SCA variance was less then unity. Due to greater contribution of line × tester interaction effect, predominance of non-additive gene action, these selected best crosses could be advanced through mass selection and selection should be carried out at later segregating generations (F_6 and onward) to derive /extracts potential lines for important traits.

Authors' contributions

Conceived and designed the experiments: M Ishaq, Performed the experiments: G Ahmad, K Afridi & M Ali, Analyzed the data: M Ishaq, TU Khan & B Ahmad, Contributed materials/ analysis/ tools: N Ahmad, I Ahmad, IA Shah, A Saleem & M Miraj, Wrote the paper: M Ishaq & K Afridi.

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