IJPS INTERNATIONAL JOURNAL OF PLANT SCIENCES
e ISSN-0976-593X Volume **12** | Issue 2 | July, 2017 | 95-101
DOI: 10.15740/HAS/IJPS/12.2/95-101
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RESEARCH ARTICLE

Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L. em. Thell.) over environments

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SUMMARY

Combining ability was analyzed using a half diallel of ten parents in bread wheat (*Triticum aestivum* L. em. Thell.). Combining ability analysis, revealed the importance of both additive as well as non-additive genetic variances for control of various traits. However, the ratio of σ2GCA/ σ2SCA revealed preponderance of non-additive gene actions in almost all the traits. Parents Raj 4120 were the good general combiners, whereas crosses Raj4120 x WH1021 and Raj4120 x DBW17 were found to be best specific combiners for grain yield per plant and some of the yield contributing traits. However, on the basis of per se performance and significant SCA effects for grain yield per plant and some of its important components, hybrids DBW621 x WH1021,DBW17 x DBW621 and Raj 4238 x PBW343 were considered to be most promising for further exploitation in breeding programmes.

Key Words : Wheat, General combining ability, Specific combining ability

How to cite this article : Yadav, Jyoti, Sharma, Satya Narayan, Jakhar, M.L. and Shweta (2017). Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L. em. Thell.) over environments. *Internat. J. Plant Sci.*, **12** (2): 95-101, **DOI: 10.15740/HAS/IJPS/12.2/95-101**.

Article chronicle : Received : 11.01.2017; **Revised :** 15.04.2017; **Accepted :** 01.05.2017

Wheat was one of the first domesticated food crops and for 8000 years has been the basic staple food of the major civilizations of Europe, West Asia and North Africa. Today, wheat is grown on more land area than any other commercial crop and continues to be the most important food grain source for humans. Its production leads all crops, including rice, maize and potatoes. Wheat is one of the ancient grain crops consumed as primary food by human beings since the dawn of civilization. Among different wheat species, *T. aestivum*, the bread wheat (hexaploid) has major share of cultivation and *T. durum* or durum wheat (tetraploid) is the second species in some parts of the world. However, *T. dicoccum* is also cultivated in some parts of the world. Globally wheat annual production is about 729.5 million tons (Anonymous, 2016). China is the largest

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producer of wheat with 17.6 per cent global wheat production from about 11 per cent area under wheat. The major wheat producing countries are India, the United State of America, Russia and Australia. These five countries together contribute more than half of the global wheat production. Less developed countries grow about 110 million hectares and produce about 307 million tons. During the last four decades of the 20th century the global wheat production is doubled from 3 to 6 billion mark and it is estimated that by the year 2012, it will reach the 8 billion mark (Prasad and Nagarajan, 2004). Globally, demand for wheat by the year 2020 is forecasted around 950 million tons to meet future demands imposed by population and prosperity growth. This target may be achieved only, if global wheat production is increased by 2.5 per cent per annum (Singh *et al.*, 2007). This must be achieved under reduced water availability, a scenario of global warming, stricter end-use quality characteristics, and evolving pathogen and pest populations. Most of the production growth must occur in developing countries where wheat will be consumed. Breeding wheat cultivars with increased grain yield potential, enhanced water–use efficiency, heat tolerance, end-use quality and durable resistance to important diseases and pests can contribute to meet at least half of the desired production increases. The remaining half must come through better agronomic and soil management practices and incentive policies.

Wheat is the second most important crop in India after rice, providing more than 50 per cent of the calories to the people who mainly depend on it. Large number of end – use products such as chapatti, bread, biscuit and pasta products are made from wheat. It contains about 8-15 per cent protein, and its unique gluten content makes it very essential for bakery industries. Besides staple food for human beings; its stover is used for large population of cattle in India. This golden grain winter cereal is a major contributor to the food security system and the economy of India. It occupying nearly 30.23 million hectares and producing around 93.53 million tons yield (Anonymous, 2016). Around 95 per cent of the wheat area is sown under *Triticum aestivum*, which is grown throughout the country, while durum and dicoccum wheat occupy nearly 5 per cent area. The major wheat growing states of India are U.P., M.P., Punjab, Haryana, Rajasthan, Bihar, Gujarat and Maharastra.

MATERIAL AND METHODS

The present investigation aimed to gather information on the genetic basis of yield and its contributing traits in ten diverse genotypes of bread wheat (*Triticum aestivum* L. em. Thell.) *viz.*, Raj 4083, Raj 4037, Raj 4079, Raj 4120, Raj 4238,PBW 343, DBW 17, DBW 621, HD 2967 and WH1021 selected from the germplasm maintained at Rajasthan Agriculture Research Institute, Durgapura, Jaipur, on the basis of a broad range of genetic diversity for major yield components. These selected genotypes were planted at Rajasthan Agriculture Research Institute, Durgapura, Jaipur, for hybridization in diallel fashion excluding reciprocals. The experiment was laid out in a Randomized Block Design with three replications. The experiment plot comprised two rows each of parent and F_1 and six row of F_2 of 3 meter length. Row to row and plant to plant spacing was maintained at 30 cm and 10 cm. Recommended uniform agronomical practices were followed for raising the crop in all the three environments. Observations were recorded on twenty randomly selected competitive plants of each parent and F_1's and sixty plants in F_2's in every replication for following traits *viz*., days to heading, days to maturity, plant height (cm), tillers per plant, flag leaf area, spike area (cm^2), spikelets per spike, grains per spike, grain yield per spike, 1000-grain weight (g), harvest index (%) and grain yield per plant (g). In case of maturity traits (days to heading and days to maturity), the data were recorded on the whole plot basis. The mean of each plot used for statistical analysis. The data were first subjected to the usual analysis followed for a Randomized Block Design for individual environment as suggested by Panse and Sukhatme (1985). The combining ability analysis was done following Griffing (1956).

RESULTS AND DISCUSSION

Significant differences were observed among the treatments (parents and their F1s) revealing existence of variability for all the traits. Analysis of variance for combining ability (Table 1) revealed that mean squares due to GCA as well as SCA were significant for all the traits, indicating the importance of both additive and non-additive gene effects in the inheritance of characters. However, the ratio of σ2GCA/ σ2SCA was recorded below unity showed preponderance of non-additive type of gene actions for all the characters. Similar results were earlier reported by Menon and Sharma (1994); Kathiria and Sharma (1996); Esmail (2002) and Gothwal (2006). The combining ability analysis in the individual environment (Table 1) also revealed significant mean squares due to GCA and SCA for all the characters in both the generations in all the environments. This suggested that characters were controlled by additive as well as non-additive gene effects. This was accordance Sharma *et al*. (2004); Singh *et al*. (2004); Desai *et al*.(2005); Jagshoran *et al*. (2005); Gothwal (2006); Golparvar (2013); Padhar *et al*. (2013); Kumar and Kerkhi (2015); Mari *et al*. (2015) and Samir and Ismail (2015).

Further, the GCA/ SCA variance ratio indicated preponderance of non-additive gene effects in both the generations for all the characters studied in all the environments except for flag leaf area in F_2 generation in E_3. Similar results were earlier reported by Nayeem and Veer (2000); Sheikh and Singh (2000); Arshad and Chowdhary (2002); Singh (2002); Punia (2003) and

Table 1 : ANOVA for combining ability for various characters in three environments in F_1 and F_2 generations in wheat

Characters	DF	GCA(9)				SCA (45)				Error (108)		GCA/ SCA	
	Gen.	F_1		F_2		F_1		F_2		F_1	F_2	F_1	F_2
	Env.												
Days to heading	E_1	19.71	**	13.77	**	0.84	**	1.26	**	0.33	0.47	3.21	1.47
	E_2	13.90	**	14.63	**	1.02	**	2.89	**	0.52	0.58	2.22	0.51
	E_3	7.67	**	9.25	**	6.52	**	8.29	**	0.76	1.37	0.11	0.10
Days to maturity	E_1	52.14	**	46.03	**	4.10	**	7.18	**	1.51	0.99	1.63	0.61
	E_2	38.58	**	25.39	**	2.04	**	3.69	**	0.79	0.67	2.52	0.62
	E_3	12.33	**	9.97	**	3.46	**	2.25	*	0.07	0.82	0.39	0.54
Plant height (cm)	E_1	13.25	**	14.52	**	4.93	**	9.25	**	0.36	1.83	0.24	0.14
	E_2	21.34	**	20.25	**	7.10	**	12.92	**	0.55	1.32	0.27	0.14
	E_3	14.01	**	17.07	**	8.25	**	21.35	**	0.55	0.70	0.15	0.07
Tillers per plant	E_1	4.34	**	3.29	**	0.35	**	0.30	**	0.02	0.11	1.08	0.95
	E_2	3.84	**	2.73	**	0.30	**	0.28	**	0.30	0.02	1.16	0.87
	E_3	0.86	**	0.67	**	0.18	**	0.24	**	0.02	0.01	0.43	0.24
Flag leaf area (cm^2)	E_1	15.80	**	15.62	**	6.48	**	4.71	**	0.68	0.62	0.22	0.31
	E_2	12.71	**	14.70	**	4.92	**	4.53	**	0.77	0.67	0.24	0.30
	E_3	10.16	**	3.67	**	3.25	**	2.11		0.88	1.71	0.33	0.41
Spike area (cm^2)	E_1	46.89	**	50.67	**	11.87	**	10.83	**	1.00	0.96	0.35	0.42
	E_2	50.50	**	47.27	**	9.27	**	8.09	**	0.70	0.74	0.49	0.53
	E_3	33.75	**	30.25	**	7.63	**	6.48	**	0.81	0.62	0.40	0.42
Spikeletsper spike	E_1	2.62	**	1.96	**	0.19	**	0.19	**	0.04	0.03	1.45	0.98
	E_2	1.97	**	1.99	**	0.27	**	0.32	**	0.07	0.07	0.79	0.64
	E_3	0.83	**	0.84	**	0.23	**	0.86	**	0.09	0.07	0.45	0.34
Grains per spike	E_1	20.45	**	17.50	**	2.76	**	1.55	**	0.14	0.18	0.65	1.05
	E_2	29.03	**	14.93	**	2.23	**	1.62	**	0.47	0.32	1.35	0.94
	E_3	33.52	**	17.86	**	1.96	**	1.80	**	0.38	0.39	1.75	1.03
Grain yield per spike	E_1	0.03	**	0.02	*	0.02	**	0.21	**	0.01	0.01	0.11	0.08
(g)	E_2	0.03	**	0.03	**	0.04	**	0.31	**	0.01	0.02	0.05	0.06
	E_3	0.04	**	0.03	**	0.04	**	0.32	**	0.02	0.03	0.14	0.07
1000- Grain weight	E_1	12.15	**	11.52	**	2.03	**	1.44	**	0.19	0.21	0.54	0.77
(g)	E_2	7.57	**	7.24	**	1.94	**	1.32	**	0.36	0.39	0.39	0.61
	E_3	3.83	**	3.33	**	1.85	**	1.48	**	0.59	0.48	0.22	0.24
Harvest index (%)	E_1	27.75	**	23.11	**	6.89	**	8.41	**	0.63	0.42	0.36	0.24
	E_2	17.41	**	16.08	**	5.86	**	6.93	**	0.62	0.52	0.27	0.20
	E_3	13.75	**	13.18	**	4.82	**	5.02	**	0.56	0.49	0.26	0.23
Grain yield per plant	E_1	17.71	**	10.92	**	4.40	**	1.31	**	0.26	0.14	0.35	0.77
(g)	E_2	14.30	**	11.12	**	7.12	**	3.00	**	0.34	0.34	0.17	0.34
	E_3	3.43	**	3.57	**	1.10	**	0.43	**	0.17	0.06	0.29	0.80

* and ** indicate significant of values at $P \leq 0.05$ and 0.01, respectively

Manmohan *et al.*(2003); Desai *et al.* (2005); Jagshoran *et al.* (2005); Gothwal (2006); Irshad *et al.* (2014); Kaukab *et al.* (2014); Mari *et al.* (2015) and Kumar *et al.* (2015). Some differences in the reports occur because of the differences in the experimental material and conditions under which evaluation is done. It is thus, evident that grain yield and other characters are controlled by both additive and non-additive gene effects. However, SCA variance was more pronounced than GCA variance for all the characters studied also been reported by Singh *et al.* (2012); Padhar *et al.* (2013) and Kaukab *et al.* (2014). The preponderance of non-additive genetic variance for all the characters indicated that the best cross combinations might be selected on the basis of SCA for further tangible advancement in wheat.

Nature and magnitude of combining ability effects provide an idea about the role of fixable and non-fixable gene effects in the inheritance of different characters. This helps in identification of suitable parents and crosses for hybridization/exploitation of heterosis. The mean squares due to GCA x E and SCA x E were found significant for most of the traits in present investigation. As a general consequence of these interactions, the estimates of GCA and SCA effects frequently changed from environment to environment, complicating the problem of identification of promising parents and crosses. For e.g. days to heading, days to maturity and plant height, Raj 4037 showed significant negative GCA effects in both generations under E_1 and E_2 but its effects changed to positive and non-significant under E_3 in both F_1 and F_2 in all three above characters; for tillers per plant, DBW 621 had significant positive GCA effect in E_1F_1, E_1F_2, E_2F_1 and E_2F_2 but showed non-significant negative effect in E_3F_1 and E_3F_2; for flag leaf area, Raj4079 had significant negative GCA effects in both F_1 and F_2 under E_1 and E_2 but had its effect changed to non-significant under E_3 condition; for spike area, Raj4037 had significant negative GCA effects in both F_1 and F_2 under E_1 and E_2 condition but had significant positive GCA effects in both F_1 and F_2 under E_3; for spikelets per spike, Raj4083 had significant negative GCA effects in E_1F_2, E_2F_2 and E_3F_2 but showed positive non-significant effects in E_1F_1, E_2F_1 and E_3F_1; for grains per spike, DBW621 had positive significant GCA effect in E_2F_1 and E_2F_2 but had negative effects in E_1F_1 and E_1F_2;

Table 2 : Beast wheat parent possessing high GCA along with their *per se* performance grain yield per plant and significant desirable GCA effects for other traits in both generations over the environments

Environments	Generations	Best parent	GCA effect	Grain yield per plant	Desirable GCA effect										
					Days to heading	Days to maturity	Plant height	Tillers plant	Flag leaf area	Spike area	Spiklets/ spike	Grains/ spike	Grain yield / spike	1000 grain weight	Harvest index
E_1		Raj4238	2.76	21.1	-	-	-	0.93**	2.17**	-	-	0.46**	-	1.14**	-
	F_1	HD2967	2.26	20.67	-	-	-	0.92**	1.97**	2.06**	0.93**	1.84**	0.16	1.21**	-
		Raj4083	0.44	20.3	-2.17**	-2.42**	-1.2**	0.26**	-	-	-	-	-	0.39**	-
		Raj4238	1.63	21.1	-	-	-	0.83**	2.24**	-	-	0.58**	-	1.05**	-
	F_2	HD2967	1.58	20.67	-	-	-	0.77**	1.78**	2.12**	0.53**	1.43**	0.18	1.26**	-
		Raj4083	0.44	20.3	-1.32**	-2.07**	-1.32**	0.23**	-	-	-	-	-	-	-
E_2		Raj4238	1.81	20.2	-	-	-	0.92**	1.89**	0.62**	-	0.79**	-	0.93**	-
	F_1	HD2967	1.35	19.7	-	-	-	0.81**	1.74**	1.80**	0.49**	2.25**	0.24	0.80**	-
		Raj4083	1.29	19.3	-1.65**	-2.3**	-1.65**	0.27**	-	-	-	-	-	0.36**	-
		Raj4238	1.65	20.2	-	-	-	0.73**	2.02**	0.46**	-	0.56**	-	0.87**	-
	F_2	HD2967	1.18	19.7	-	-	-	0.68**	1.72**	1.67**	0.52**	1.42**	0.11	0.72**	-
		Raj4083	0.73	19.3	-1.29**	-2.02**	-1.29**	0.21**	-	-	-	-	0.11	0.47**	-
E_3		Raj4238	0.91	14.9	-	-	-	0.41**	1.69*	-	-	1.21**	-	0.85**	
	F_1	HD2967	0.72	13.33	-	-	-	0.44**	1.55**	2.2**	0.26**	1.73**	0.14	0.79**	
		Raj4083	0.46	13.1	-	-1.77**	-	0.20**	-	-	-	-	-	-	-
		Raj4038	1.08	13.33	-	-	-	0.24**	-	-	-	0.84**	0.17	0.62**	-
	F_2	Raj4238	0.70	4.90	-	-	-	0.25**	0.99**	1.97**	0.39**	1.1**	0.11	1**	-
		HD2967	0.35	13.1	-	-1.71**	-	0.42**	-	-	-	-	0.11	-	-

* and ** indicates significance of values at P≤ 0.05 and 0.01, respectively

for 1000-grain weight, Raj4083 had significant positive GCA effects in E_1F_1, E_2F_1, E_2F_2 and E_3F_1 but had its effects changed to negative under E_3F_2; for harvest index, Raj4037 had significant negative GCA effects in both F_1 and F_2 under E_1 and E_2 condition but its effect changed to positive non-significant and E_3 and for grain yield per plant, DBW621 had positive significant effect in E_1F_1 but its effects changed to non-significant and negative in E_1F_2 and E_3F_1. Such change in the direction and magnitude of GCA effects of several parents in different environments in both F_1 and F_2 were also observed for other characters also.

Best parents having desirable GCA effects for grain yield per plant in different environments are presented in Table 2.

The parents Raj4083 for days to heading, days to maturity, plant height,tillers per plant and 1000-grain weight; Raj4238 for tillers per plant, flag leaf area, spike area, grains per spike and HD 2967 for tillers per plant, flag leaf area, spike area, spikelets per spike, grains per spike, grain yield per spike, 1000-grain weight and harvest index for in both the generations under different environments emerged as good general combiners along with the grain yield per plant. Similar observations on closer relationship between *per se* performance and GCA effects has been reported by Singh (1998); Rajora (1999); Punia (2003); Joshi *et al*. (2003); Desai *et al.* (2005); Singh and Chaudhry (2008); Kant *et al.* (2011); Kumar *et al.* (2011); Pancholi *et al*. (2012); Singh *et al.* (2012 and 2013) and Kumar *et al.* (2015) provided similar information on combining ability in wheat.

Perusal of Table 3 revealed that the crosses, which showed desirable SCA effects for grain yield per plant, also exhibited desirable SCA effects for one or more yield contributing traits. The crosses DBW621 x WH1021, DBW17 x WH1021 and DBW621 x HD2967 in E_1F_1; DBW17 x DBW621, DBW17 x WH1021 and DBW621 x WH1021 in E_1F_2; DBW17 x DBW621, PBW343 x WH1021 and PBW343 x DBW17 in E_2F_1; DBW 17 x DBW621, DBW621 x WH1021 and DBW17 x WH1021 in E_2F_2; Raj4238 x PBW343, DBW17 x DBW621 and DBW621 x WH1021 in E_3F_1 and Raj4238 x PBW343, DBW621 x WH1021 and PBW343 x DBW17 in E_3F_2 emerged as good specific cross

Table 3 : Beast crosses possessing high SCA effects with their *per se* performance of grain yield and significant desirable SCA effects for other traits in both F_1 and F_2 over the environments

Environments	Generations	Crosses	SCA effect	Grain yield per plant	Desirable SCA effect										
					Days to heading	Days to maturity	Plant height	Tillers plant	Flag leaf area	Spike area	Spiklets/ spike	Grains/ spike	Grain yield / spike	1000 grain weight	Harvest index
E_1	F_1	DBW621 x WH1021	3.54**	24.17	-1.54**	–	-2.14**	0.55**	3.39**	–	–	–	0.25**	1.38**	–
		DBW17 x DBW621	3.51**	24.17	–	–	-3.67**	0.71**	1.71*	4.57**	–	–	0.35**	–	–
		Raj4238 x PBW343	3.27**	25.07	–	–	-1.27*	0.85**	–	2.92**	–	–	0.29**	1.81**	–
	F_2	DBW17 x DBW621	2.97**	20.60	–	–	–	0.74**	–	0.18**	–	–	0.21**	–	–
		DBW17 x WH1021	1.55**	17.80	–	-2.24*	-4.20**	0.39**	3.11**	–	–	–	0.17**	–	–
		DBW621 x WH1021	1.20**	19.00	-2.14**	-2.68**	-2.14**	0.42**	2.85**	–	–	–	–	1.55**	–
E_2	F_1	DBW17 x WH1021	4.17**	24.10	–	–	–	0.56**	–	2.96**	–	–	0.25**	–	–
		PBW343 x WH1021	3.69**	23.67	–	–	–	–	3.85**	2.99**	–	1.62*	–	–	–
		PBW343 x DBW17	3.21**	22.87	–	–	–	–	2.65**	3.47**	–	–	0.29**	1.22*	3.49**
	F_2	Raj4120 x Raj4238	2.37**	22.93	–	–	–	0.59**	–	–	–	–	–	1.73*	–
		DBW17 x DBW621	2.22**	20.90	–	-1.89*	–	0.35**	2.34**	3.01**	–	–	0.17**	–	–
		DBW621 x WH1021	2.17**	20.47	-2.18**	–	-4.52**	0.29*	–	–	–	–	–	–	–
E_3	F_1	Raj4238 x PBW343	1.46**	13.40	–	–	-1.63*	–	–	–	–	–	–	–	–
		DBW17 x DBW621	1.36**	14.23	-3.12**	–	–	0.23*	–	2.09*	–	1.72**	0.16**	–	–
		DBW621 x WH1021	1.18**	14.73	-2.16**	–	-2.24**	0.23*	–	–	–	1.78**	–	–	–
	F_2	Raj4238 x PBW343	1.75**	11.77	-2.27**	–	-1.89*	–	–	–	–	–	–	–	–
		DBW621 x WH1021	1.40**	12.00	–	–	-3.38**	–	–	–	–	–	–	–	–
		PBW343 x DBW17	1.43**	11.63	–	-2.14*	-2.12**	–	–	2.28**	–	–	–	–	2.14**

* and ** indicate significance of values at P≤0.05 and 0.01, respectively

combination for three to six yield contributing traits along with grain yield per plant in both generations under different environments.

An overall appraisal revealed that the crosses DBW621 x WH1021 except E_2F_1, DBW17 x DBW621 except E_3F_2 and Raj4238 x PBW343 emerged as good specific cross combination in both the generations under all environments for most of characters studied. The parents DBW621, WH1021, DBW17, Raj4238, PBW343 and Raj4120 involved in these crosses were good general combiners for grain yield and one or two yield contributing traits while the other parents were emerged as poor combiners. It is interesting to note that SCA effects of best crosses and GCA effects of their parents indicated that the good specific cross combinations were the result of good x good, good x poor or poor x poor combinations. Thus, it was evident that a good cross combination is not necessarily the result of good x good general combiners; rather it might occur from good x poor or poor x poor combiners as well. A number of studies also refer to such a situation (Muralia and Sastry, 2001; Dubey *et al.*, 2001; Desai *et al.*, 2005; Gothwal, 2006; Kant *et al.*, 2011; Kumar *et al.*, 2011; Singh *et al.*, 2012; Singh *et al.*, 2013 and Kumar *et al.*, 2015).

It is desirable to search out parental lines with high GCA effects and low sensitivity to environmental variation in a crop improvement programme with respect to combining ability effects. From the present study following broad inferences could be drawn (i) In general, the crosses showing desirable SCA effect for seed yield per plant also had high SCA effects for some of it's yield contributing characters *viz*., number of tillers, number of spikelets, number of grains/ spike and biological yield/ plant, (ii) Best performing parents were mostly good general combiners for majority of the characters, (iii) The crosses exhibiting desirable SCA effects did not always involve parents with high GCA effects, thereby suggesting the importance of intrallelic interaction.

The parent Raj4120 and the cross Raj4120 x WH1021 and Raj4120 x DBW17 emerged as good general combiner and specific cross combinations, respectively in late sown condition. Therefore, these genotypes may be used in the future breeding programme for development of a heat tolerant wheat variety suitable for warmer areas to maximize production.

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