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Combining ability analysis in bread wheat (*Triticum aestivum* L.) for grain yield with heat tolerance traits under different environmental conditions

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Abstract
The present study was carried out in 9 diverse parents, their 36 hybrids and 2 checks evaluated during *Rabi* 2020-21 at RCA, Udaipur in RBD in three replications in three different environments. Analysis of variance revealed differences between parents and crosses for GCA and SCA, respectively due to GCA and SCA effects were significant for all the characters on pooled basis. Similarly, mean squares due to GCA x E and SCA x E were significant for all characters except total protein content in grains revealed influence of environment on GCA and SCA, respectively. The variance due to GCA was higher than their respective SCA for chlorophyll stability index indicated that additive type of gene action played role in the expression of the trait. Among parents, RAJ 3777, RAJ 4120, HD 2967, DBW 173 and GW 451 were exhibited significant GCA effects for grain yield and heat tolerance traits. Parent GJW 463 was exhibited maximum GCA effects for proline content (2.64) and DBW 173 for grain yield (1.80) over the environments. Among crosses, ten crosses were exhibited significant SCA effects for grain yield and heat tolerance traits. Over the environments cross HD 2967 x DBW 173 exhibited maximum SCA effects (4.00) for grain yield. Whereas, cross DBW 173 x RAJ 4120 were exhibited maximum SCA effects for proline content (3.25) and total chlorophyll content (0.29). Attempting cross combinations involving different parents with high GCA for desirable grain yield along with heat tolerance parameters could be useful.

Keywords: Bread wheat, combining ability analysis, general combining ability (GCA), heat tolerance and specific combining ability (SCA)

Introduction

Wheat (*Triticum aestivum* L.) is a hexaploid and self-pollinated plant with 2n = 6x = 42 chromosome number, belongs to order cyperales, genus *Triticum* and family Poaceae. It is cultivated as winter sown crop and most important staple food crop globally. According to Vavilov (1992) [26], the centre of origin for diploid wheat (*T. monococcum*, 2n=14) is Asia Minor, for tetraploid wheat (*T. durum*, 2n=28) is Mediterranean bassin and Abyssinia and for hexaploid wheat (*T. aestivum*, 2n=42) is Afghanistan. The genomic constitution of hexaploid wheat is AABBDD in which A genome comes from *T. urartu*, B from an unknown source and D from *Aegilopes squarrosa*. It is grown to cool climatic conditions in different agro-ecological habitats. In India, wheat is grown on an area of 30.55 million ha (13.43% of global area) with the production of 107.18 million tonnes and productivity of 3508 kg/ha. It is mostly grown in Northern, North Western and Central India. Major wheat growing states in India are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar and Gujarat.

In Rajasthan wheat is cultivated on 3.02 million ha area, 10.57 million tonnes production and productivity of 3501 kg/ha (Annual Report of IIW&BR, Karnal, 2019). Rajasthan ranks 4th in area, 3rd in productivity and 5th in the Largest Wheat Producing States of the Country. In India the total production is about 10% of this state.

Heat is a big threat to the world affecting nearly 40% of total area (Hede *et al*., 2001). Wheat yield improvement is possible by knowing the gene action and combining ability (CA) analysis of the parents with wider adaptability. In the past decades, the production of wheat is decreased due to abiotic stresses like increased high temperature and heat injury at flowering and grain filling time (Kumar *et al.*, 2016) [11]. CA helps to overcome this problem with specific gene pool and high yielding cultivars against increasing temperature. Many yield contributing traits like chlorophyll content, total biomass, starch and yield is affected by heat stress along with heat tolerance traits. Around about 10% decrease in yield of wheat with every 1 °C increase in temperature above a mean of 23 °C (Gibson and Paulsen, 1999) [5].

The climate change negatively affects the growth of wheat which results in severe hampered productivity (Janjua *et al*., 2010) [8]. High temperature affects the growth of plant and development which results in reduction of economic yield of crop.

Therefore, the present study was conducted to evaluate the performances of 9 diverse genotypes with 36 hybrid combinations which were developed through diallel (without reciprocals) analysis for general and specific combining ability effects for grain yield along with heat tolerance traits under three different environments.

Material and Methods

The present study was conducted to evaluate GCA and SCA effects in 9 diverse parents (H1 1620, RAJ 3777, GW 451, RAJ 4120, HD 2967, GJW 463, LOK 1, DBW 173 and JW 3336), their 36 hybrids (developed through half diallel design during *Rabi* 2019-20) and 2 checks (RAJ 4079 and HI 1544). The experimental material was evaluated during *Rabi* 2020-21 in randomized block design in three replications and three different environments. Plant to plant and row to row distance was maintained 10 cm and 23 cm, respectively and row length was 3 meter. Three different environments were created by sowing the experimental material in three different dates as early sown (15-20 October), normal sown (10-15 November) and late sown (10-15 December). Observations were recorded on five competitive plants from each genotype were randomly selected in all the environments for 7 different various characters like, grain yield plant^{-1}, total protein content in grains, heat injury, leaf canopy temperature, total chlorophyll content, proline content and chlorophyll stability index. Proposed plant protection measures were followed to raise the good crop over the environments.

Statistical Analysis

The analysis of variance (ANOVA) used according the standard procedures of Panse and Sukhatme (1985). Combining ability analysis was done by using Griffing's (1956) [6] Model II (parents and one set of F1s without reciprocals), Model I (fixed effect), and pooled analysis over environments was done according to method suggested by Singh (1973) [20].

Results and Discussion

Analysis of variance

A pooled analysis was estimated to obtain less biased estimates of different types of variances and their interactions with the environments is presented (Table 1). The analysis of variance for combining ability revealed that mean squares due to general combining ability (GCA) in parents were significant in all environments for all characters. Due to specific combining ability (SCA) mean squares were also significant for all characters except total protein content in grains in all environments. Similarly, Joshi *et al.* (2004), Yadav *et al.* (2008) [27], Desale and Mehta (2013) [4] and Kumar *et al.* (2015) [10] also reported the same findings.

Pooled analysis for 7 characters *viz.,* grain yield plant^{-1}, total protein content in grains, heat injury, leaf canopy temperature, proline content, total chlorophyll content and chlorophyll stability index (Table 2) was resulted significant mean squares of GCA parents and SCA crosses over environments for all characters which indicated differences between parents and crosses. Mean squares due to GCA x E and SCA x E were significant for all the characters except total protein content in grains which indicated additive and non additive type of gene action in the expression of characters. Similar findi were also reported by Singh *et al.* (2007) [22], Padhar *et al.* (2013) [16], Kumar and Kerkhi (2015) [12] and Mandal and Madhuri (2016) [14].

General combining ability effects

Among 9 parents, parent RAJ 4120, DBW 173 and GW 451 were exhibited maximum GCA effects for total protein content in grains, heat injury, proline content, total chlorophyll content, chlorophyll stability index and grain yield plant^{-1}. Over the environments parent DBW 173 was exhibited maximum significant positive GCA effect for grain yield (1.80) and parent GW 451 for total protein content (0.81). Parent GW 451 showed maximum negative GCA effect (-2.47) for heat injury and parent JW 3336 for leaf canopy temperature (-0.44). Parent GJW 463 was observed for maximum GCA effect (2.64) for proline content. Maximum GCA effects were observed for chlorophyll content by parent HI 1620 (0.23) and for chlorophyll stability index parent DBW 173 (0.97). Fixable component of variances like additive and additive x additive epistasis interaction were exhibited by good general combiners. Therefore, these parents offer the best possibilities of exploitation of GCA effects in bread wheat for development of improved high yielding parents with heat tolerance parameters. Kumar *et al.* (2011) [13], Singh *et al.* (2011) [23], Pancholi *et al.* (2012) [17], Singh *et al.* (2014) [24], Arya *et al.* (2018) [3], Nagar *et al.* (2018) [15] and Ali *et al.* (2019) [2] also reported the similar findings with good general combiners.

Specific combining ability effects

For deciding and selecting superior cross combinations specific combining ability is an important parameter (Sprague and Tatum, 1942) [25]. Among thirty six crosses, cross HD 2967 x DBW 173 was exhibited maximum SCA effects in E_1 (3.45), E_2 (3.83) and E_3 (4.71) for grain yield. Over the environments cross HD 2967 x DBW 173 depicted maximum SCA effects (4.00) followed by RAJ 3777 x RAJ 4120 (2.92) for grain yield. For total protein content in grains maximum SCA effects were observed by cross GW451 x RAJ 4120 in E_1 (0.98) and E_3 (1.06), while DBW 173 x GW 451 in E_2 (1.12) environment. DBW 173 x RAJ 4120 was exhibited maximum SCA effects (-1.52) over the environments for leaf canopy temperature. Maximum significant negative SCA effects were exhibited by cross HD 2967 x GW 451 in E_1 (-4.49), E_2 (-4.54) whereas, DBW 173 x GW 451 in E_3 (-6.72) environment for heat injury. Among crosses, sixteen crosses were exhibited significant and positive SCA effects for proline content. For proline content maximum SCA effects were exhibited by cross DBW 173 x RAJ 3777 (3.00) in E_1, DBW 173 x RAJ 4120 (3.47) in E_2 and (4.9) in E_3 environment. The maximum SCA effects were recorded for cross GW 451 x RAJ 3777 in E_1 (0.68), GJW 463 x RAJ 4120 in E_2 (0.27) and DBW 173 x RAJ 4120 in E_3 (0.32) environment for chlorophyll content. Over the environments, HD 2967 x DBW 173, DBW 173 x GW 451, DBW 173 x RAJ 3777 and DBW 173 x RAJ 4120 were exhibited significant values for many heat tolerant parameters with grain yield. Similar results were also reported by Singh *et al.* (2014) [24], Ahmad *et al.* (2016) [1], Patel *et al.* (2018) [19] and Singh *et al.* (2020) for grain yield and heat tolerance traits.

Over the environments maximum negative significant SCA effects for heat injury was observed in cross DBW 173 x GW 451 (-4.79) and proline content also (3.25) which indicated that the response of high temperature and proline accumulation increased correspondingly. Singh *et al.* (2020) and Singh *et al.* (2011) [23] also confirmed the similar findings with relation of temperature and proline content.

It may be concluded that among nine diverse parents, RAJ 3777, RAJ 4120, HD 2967, DBW 173 and GW 451 were observed good general combiners for heat tolerance parameters along with grain yield. Among crosses, HD 2967 x DBW 173, DBW 173 x RAJ 3777, DBW 173 x RAJ 4120 and DBW 173 x GW 451 were observed best specific combiners on pooled basis in all environments for grain yield and heat tolerance parameters. These cross combinations involving different parents with high GCA for desirable grain yield along with heat tolerance parameters could be useful.

Table 1: Combining ability mean square and EMS over the environments for different characters

SN	Characters	Source						Bartlet	Variance Model I			
		Env	GCA	SCA	GCA x E	SCA x E	Pool Error		GCA	SCA	GCA x E	SCA x E
		[2]	[8]	[36]	[16]	[72]	[264]	[2]				
1	Grain yield plant^{-1} (g)	46.50**	2.75**	6.10**	0.39**	0.30**	0.05	5.37	2.06	0.66	72.65	0.50
2	Total protein content in grains (%)	0.47**	0.51**	0.56**	0.01	0.01	0.01	2.15	0.02	0.12	6.63	0.00
3	Heat injury (%)	83.97**	12.97**	20.75**	0.31**	0.41**	0.05	2.84	3.73	3.13	248.31	0.37
4	Leaf canopy temperature (°C)	51.67**	0.78**	1.47**	0.24**	0.19**	0.02	5.05	2.30	0.18	17.36	0.33
5	Proline content (µg/100mg)	102.58**	7.95**	9.98**	0.54**	0.53**	0.01	1.77	4.56	1.93	119.68	0.77
6	Total chlorophyll content (mg/g)	1.93**	0.12**	0.10**	0.02**	0.01*	0.01	11.60**	0.09	0.03	1.06	0.02
7	Chlorophyll stability index	30.76**	11.10**	9.80**	0.24**	0.23**	0.01	1.78	1.37	2.69	117.43	0.33

*,** Significant at 5 and 1 per cent, respectively

Table 2: GCA and SCA effects for different characters on pooled basis

SN	Genotype	Grain yield plant $^{-1}$ (g)	Total protein content in grains (%)	Heat injury (%)	Leaf canopy temperature (°C)	Proline content (µg/100mg)	Total chlorophyll content (mg/g)	Chlorophyll stability index
1	HI 1620	-0.29	-0.18*	0.11	-0.08*	0.17**	0.23**	-0.22*
2	RAJ 3777	0.09	-0.01	-0.53*	-0.20*	-0.26*	0.00	-0.93*
3	RAJ 4120	0.73**	0.18**	-0.73*	0.11**	0.47**	0.17**	0.14**
4	HD 2967	0.85**	-0.17*	0.81**	0.12**	-0.67*	-0.01	0.40**
5	DBW 173	1.80**	-0.05*	-0.15	0.04	0.45**	-0.04*	0.97**
6	GJW 463	-0.2	-0.01	-0.54*	0.22**	2.64**	0.03*	0.50**
7	JW 3336	-0.08	0.02	0.80**	-0.44*	0.12**	-0.05*	0.05**
8	GW 451	-0.69*	0.81**	-2.47*	-0.11*	-0.03	-0.07*	-0.40*
9	LOK 1	-0.14	0.41**	0.70**	0.10**	-0.80*	-0.04*	-0.50*
10	HI 1620 x LOK 1	-0.91*	-0.01	1.27**	-0.08	0.22**	-0.07	0.65**
11	RAJ 3777 x LOK 1	-0.45	-0.08	1.48**	-0.15*	0.43**	-0.14**	0.28**
12	RAJ 3777 x HI 1620	-0.05	0.25	-1.33**	-0.43**	1.15**	-0.03	0.90**
13	RAJ 3777 x JW 3336	-0.60	-0.15	2.66**	-0.37**	-2.13**	-0.06	-0.99**
14	RAJ 3777 x RAJ 4120	2.92**	0.40*	-1.29**	-0.03	2.74**	0.19**	0.84**
15	RAJ 4120 x LOK 1	-0.23	0.06	0.23	0.26**	-1.06**	-0.05	-0.81**
16	RAJ 4120 x HI 1620	0.24	-0.21	0.07	0.23**	0.90**	0.19**	1.26**
17	RAJ 4120 x JW 3336	-0.40	-0.14	0.57**	-0.36**	-0.72**	0.00	-0.40**
18	HD 2967 x LOK 1	-0.73	-0.25	4.39**	0.35**	-2.03**	-0.21**	-4.37**
19	HD 2967 x HI 1620	0.05	0.22	-0.94**	-0.20**	0.10	-0.06	-0.83**
20	HD 2967 x RAJ 4120	1.14**	0.11	-1.19**	-0.35**	0.22**	0.15**	0.83**
21	HD 2967 x RAJ 3777	-0.21	-0.25	1.71**	0.17*	1.11**	-0.03	-0.03
22	HD 2967 x GW 451	-1.83**	0.84**	-4.33**	-0.79**	-1.20**	-0.23**	0.09
23	HD 2967 x JW 3336	0.02	-0.29	3.76**	-0.82**	-0.64**	-0.06	-1.07**
24	HD 2967 x DBW 173	4.00**	0.21	-1.97**	-1.16**	1.43**	0.04	3.01**
25	DBW 173 x LOK 1	-0.63	-0.26	1.87**	0.49**	-0.58**	-0.07	0.05
26	DBW 173 x HI 1620	-0.49	-0.29	2.26**	-1.07**	-0.37**	0.02	0.38**
27	DBW 173 x JW 3336	-0.62	-0.47*	2.38**	-0.69**	-1.46**	-0.24**	0.16**
28	DBW 173 x RAJ 4120	2.56**	0.85**	-2.85**	-1.52**	3.25**	0.29**	2.41**
29	DBW 173 x RAJ 3777	2.72**	0.36*	-0.28	0.39**	2.80**	0.14**	2.82**
30	DBW 173 x GW 451	-0.09	0.96**	-4.79**	-0.44**	-0.31**	-0.22**	1.21**
31	GJW 463 x LOK 1	-1.15**	-0.14	2.39**	0.21**	-1.56**	0.07	-0.70**
32	GJW 463 x HI 1620	0.27	0.04	0.99**	-0.27**	-0.27**	-0.12**	2.39**
33	GJW 463 x JW 3336	-0.79	-0.21	1.77**	-0.08	-1.00**	-0.08	0.80**
34	GJW 463 x RAJ 4120	0.96	0.03	0.21	-1.20**	1.83**	0.27**	0.63**
35	GJW 463 x RAJ 3777	-0.51	-0.21	-0.21	0.46**	3.09**	0.29**	1.76**
36	GJW 463 x GW 451	-1.47**	0.37*	-0.26*	0.77**	-0.05	-0.18**	1.18**
37	GJW 463 x DBW 173	1.48**	-0.15	-0.57**	0.42**	2.55**	-0.01	2.49**
38	GJW 463 x HD 2967	0.67	-0.02	-0.57**	-0.51**	-2.53**	-0.11*	0.74**

39	GW 451 x LOK 1	-2.30**	-0.16	-0.20	-0.21**	-0.38**	-0.02	-1.27**
40	GW 451 x HI 1620	-0.39	-0.04	2.98**	-0.41**	0.50**	-0.08	0.14*
41	GW 451 x JW 3336	-1.01**	-0.32*	1.10**	0.20**	-0.36**	-0.19**	-4.00**
42	GW 451 x RAJ 4120	1.54**	1.06**	-2.69**	0.35**	2.18**	0.07	0.55**
43	GW 451 x RAJ 3777	1.16**	0.40**	-1.81**	0.40**	2.40**	0.24**	1.87**
44	JW 3336 x HI 1620	0.60	-0.37*	4.34**	0.35**	-0.22**	-0.18**	-0.81**
45	JW 3336 x LOK 1	-0.86	-0.50**	6.08**	-0.18*	-1.48**	-0.29**	-1.31**

*,** Significant at 5 and 1 per cent, respectively

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