International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; 8(5): 774-778

Received: 23-06-2020
Accepted: 03-08-2020

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Combining ability studies on terminal heat tolerance in wheat (*Triticum aestivum* L.) under late sown irrigated condition using Line X Tester analysis

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DOI: https://doi.org/10.22271/chemi.2020.v8.i5k.10393

Abstract
The present investigation entitled "Combining ability studies on terminal heat tolerance in wheat (*Triticum aestivum* L.) under late sown irrigated condition using Line X Tester design" was carried out during *rabi* 2017-18 and 2018-19 at the All India Co-ordinated Wheat and Barley Improvement Project, B.T.C. College of Agriculture and Research Station (IGKV), Bilaspur (C.G.). The experiment was conducted in RBD involving six lines, three testers and 18 F_1s hybrids of wheat with two replications for study of character associated with yield and yield contributing traits. The analysis indicated that variance due to treatments was highly significant for all the characters under studied. All the characters except spike weight were highly significant. GCA, SCA and additive effect was found highest for character of harvest index. Among the lines, CG 1015 (Chhattisgarh Gehu)-04 was found good general combining ability (GCA) effect for the character of peduncle length, spike length, number of seed per plant and biological yield per plant. MP 3336 was found good GCA effect for chlorophyll reflection index, harvest index and number of tillers per plant. HD 2285 was found good GCA effect for days to maturity, 1000 seed weight and canopy temperature depreciation. Among the testers, Halna was good GCA effect for the character of days to 50% flowering, days to maturity and spike length. PHSL 10 was good GCA effect for number of tillers per plant, spike weight, seed yield per plant and harvest index. Among the crosses, CG 1015 (Chhattisgarh Gehu-04) X HUW 661 was good specific combining ability (SCA) effect for seed yield per plant. MP 3336 X PHSL 10 was good SCA effect for number of spikelet per spike and number of seed per plant. HD 2932 X Halna was good SCA effect for spike weight and 1000 seed weight and crosses HD 2864 X Halna was good SCA effect for the character of canopy temperature depreciation and biological yield per plant.

Keywords: combining ability studies, wheat, line X tester, terminal heat tolerance, GCA and SCA effect, late sown irrigated condition

Introduction
Wheat is grown in Chhattisgarh mainly after the harvest of soybean kharif crops. Wheat seeding is usually delayed after November-December, due to late paddy harvesting. In these cases the growth and yields of wheat are adversely affected during growth and reproduction phases due to high temperatures. The line X tester analysis was used to estimate yield and components of both General Combining Capacity Effects (G.C.A.) and Unique Combining Capacity Effects (S.C.A.) and other essential agronomic characteristics of wheat. It was confirmed that both additive and non-additive inheritance influenced many of the traits. At the other hand, Barot *et al.*, (2014) [1] observed that the magnitude of the general combining ability variances was higher than that of the individual combining ability variances for all characters indicating the inheritance preponderance of the additive gene action.

Materials and methods
The present research was conducted in two seasons of *rabi* in 2017-18 and 2018-19 at All India Co-ordinated Wheat and Barley Improvement Project at B.T.C. College of Agriculture

and Research Station (Indira Gandhi Krishi Vishwavidyalaya), Bilaspur, Chhattisgarh, India. Nine wheat genotypes including six lines and three testers were crossed in a Line x Tester matting design and developed 18 F_1 hybrids during *rabi* 2017-18, Kempthorne (1957) [7] (Table 1). The experiment was laid out with 18 hybrids and 9 parents in a randomized block design with two replication during *rabi* 2018-19. Five competitive plants were randomly selected to record the observation on 15 characters *viz.* days to 50% flowering, days to maturity, plant height, peduncle length, spike length, number of tillers, number of spikelet per spike, number of seeds per spike, spike weight, seed yield per plant, 1000 seed weight, canopy temperature depreciation, chlorophyll reflection index, biological yield per plant and harvest index.

Result and discussion

Analysis of variance for combining ability

Analysis of variance for combining ability was estimated for all the traits as per procedure described by Kempthorne (1957) [7]. The analysis indicated that variance due to treatments was highly significant for all the characters under studied (Table 4). All the characters except spike weight were highly significant. None of replication variance was significant indicating the validity of the experiment. The variance due to parents found highly significant for more of character except spike length and spike weight. The variance due to parents vs. crosses showed significant result for all character except characters spike length, and spike weight. Similar results observed by Singh *et al*., (2013)

GCA, SCA and additive effect

The highest general combining ability, specific combining ability and additive effect was found for the character of harvest index (Table-2). Similar results observed by Raj and khandalkar (2003)

GCA effect of female (line) parents

Among the lines, CG 1015 (Chhattisgarh Gehu)-04 was found good general combining ability (GCA) effect for the character of peduncle length, spike length, number of seed per plant and biological yield per plant. Similar results observed by Manmohan *et al*., (2003) [8] MP 3336 was found good GCA effect for chlorophyll reflection index, harvest index and number of tillers per plant. HD 2285 was found good GCA effect for days to maturity, 1000 seed weight and canopy temperature depreciation (Table-3).

GCA effect of male (tester) parents

Among the testers, Halna was good GCA effect for the character of days to 50% flowering, days to maturity and spike length. (Table-3) PHSL 10 was good GCA effect for number of tillers per plant, spike weight, seed yield per plant and harvest index. Similar results observed by Jatav *et al*., (2003)

SCA effect of hybrids (crosses)

Among the crosses, CG 1015 (Chhattisgarh Gehu-04) X HUW 661 was good specific combining ability (SCA) effect for seed yield per plant. Hussan *et al*., (2007) [4] MP 3336 X PHSL 10 was good SCA effect for number of spikelet per spike and number of seed per plant. HD 2932 X Halna was good SCA effect for spike weight and 1000 seed weight. Gupta *et al*., (2017) [2] and crosses HD 2864 X Halna was good SCA effect for the character of canopy temperature depreciation and biological yield per plant. (Table-3)

Conclusion

The analysis indicated that variance due to treatments was highly significant for all the characters under studied. All the characters except spike weight were highly significant. None of replication variance was significant indicating the validity of the experiment. The highest general combining ability, specific combining ability and additive effect was found for the character of harvest index. Among the line (female) CG 1015 Chhattisgarh Gehu-04, MP 3336 and HD 2285 was found good general combining ability (GCA) effects for more number of characters. Among the tester (male) Halna and PHSL 10 was found good GCA effects for more number of characters. Among the hybrids (crosses) CG 1015 (Chhattisgarh Gehu-04) X HUW 661, MP 3336 X PHSL 10, HD 2932 X Halna and HD 2864 X Halna were good specific combining ability (SCA) effects for more number of traits. The findings of the experiment could be helpful in wheat breeding programmes under late sown irrigated and terminal heat stress condition.

Table 1: Details of parents used in study

S. N.	Genotypes	Notificat-ion year	Parentage	Released by	Farming condition
	Male/tester				
1	Halna	2002	HD 1982/K816	SVRC	Late sown
2	HUW 661	2016-17	NASN 2016-17(32)	-	-
3	PHSL 10	2016-17(83)	NASN 2016-17(83)	-	-
	Female/ Line				
1	Chhattisgarh Genhu 4 (CG-1015)	2017	NI 908/BL 1986	SVRC	Late sown
2	HD-2932	2008	KAUZ/STAR//HD2643	CVRC	Late sown
3	HD-2864	2004	DL 509-2/DL 377-8	CVRC	Late sown
4	Raj-4238	2013	HW 2021/RAJ 3765	CVRC	Late sown
5	MP-3336	2013	HD 2402/GW 173	CVRC	Late sown
6	HD 2285	1984	HD 1918/HD 1592/HD 1962/E 4870/K-65/4/HD 2160/5/HD 2180	CVRC	Late sown

Table 2: GCA and SCA effects

S. No.	Character	GCA effect	SCA effect	Aditive effect
1	Days to 50% flowering (days)	0.28	3.92	0.57
2	Days to maturity (days)	0.98	0.38	1.97
3	Plant height (cm)	6.52	-5.35	11.09
4	Peduncle length (cm)	2.15	4.53	2.22

5	Spike length (cm)	-0.08	0.48	-0.16
6	Number of tillers (per plant)	0.18	0.28	0.36
7	Number of spikelets per spike	3.04	7.21	4.04
8	Number of seed per spike	4.33	9.07	6.79
9	Spike weight (g)	-0.003	0.03	-0.00
10	Yield per plant (g)	0.98	0.45	1.96
11	1000 seed weight (g)	0.62	3.10	1.25
12	Canopy temperature depreciation (°C)	0.06	0.16	0.12
13	Chlorophyll reflection index	-0.46	7.06	-0.92
14	Biological yield per plant (g)	0.67	0.16	1.35
15	Harvest index (%)	12.31	11.58	22.65

Table 3: GCA and SCA effect of parents and crosses

S. No.	Lines/ Testers/ Crosses	Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Peduncle length (cm)	Spike length (cm)
1	CG 1015	2.60**	0.88**	0.84	-3.81**	0.58*
2	HD 2864	-1.16**	-0.88**	-6.17**	2.77**	0.32
3	HD 2932	1.20**	0.76**	-0.63	0.26	-0.22
4	RAJ 4238	-2.42*	0.51	-2.11**	-2.62**	0.02
5	MP 3336	-2.41**	0.63**	2.61**	3.40**	0.08
6	HD2285	0.45	-1.38**	5.01**	1.13	-0.50*
	SE(m)+	0.62	0.45	2.6	1.08	0.42
1	Halna	-0.68**	-1.12**	0.21	-0.86	-0.02
2	HUW 661	0.63**	1.02**	-1.77	-0.11	0.20**
3	PHSL 10	0.02	0.68**	-1.88	1.04	-0.45
	SE(m)+	0.37	0.27	1.59	0.65	0.26
1	CG1015 X Halna	0.19	1.89**	-2.86	-0.63	0.37
2	CG1015 X HUW661	1.87**	-0.27	-3.79	-1.48	-0.8
3	CG1015 X PHSL 10	-0.52	-0.46	2.06	-2.93**	-1.47*
4	HD 2864 X Halna	-0.05	0.13	2.67	-2.22**	0.17
5	HD 2864 X HUW661	-0.38	-1.53**	5.53*	4.89**	1.08*
6	HD 2864 X PHSL10	-1.77**	-0.19	-2.59	-0.65	-1.28*
7	HD 2932 X Halna	-1.43**	-0.98	4.92	-1.08	-0.88
8	HD 2932 X HUW661	6.24**	0.84	3.36	-2.35**	1.00*
9	HD 2932 X PHSL 10	-0.65	-1.31*	-7.59**	2.11**	-0.23
10	RAJ 4238 X Halna	0.19	-0.73	8.41**	0.37	1.12*
11	RAJ 4238 X HUW661	-2.13**	0.59	-6.17**	-1.6	-0.67
12	RAJ 4238 X PHSL10	1.48**	0.43	-1.12	1.23	-0.26
13	MP 3336 X Halna	-1.30*	-0.86*	-6.71**	-0.89	-1.18*
14	MP 3336 X HUW661	-2.13**	0.47	3.68	0.96	0.64
15	MP 3336 X PHSL10	2.47**	0.80*	2.77	-1	1.56*
16	HD 2285 X Halna	2.81**	-0.86*	-3.47	-1.94	0.12
17	HD 2285 X HUW661	-2.51**	0.47	1.85	0.97	-0.46
18	HD 2285 X PHSL10	-0.4	-0.19	2.63	0.89	-0.28
	SE(m)±	1.07	0.77	4.5	1.87	0.73

*Significant at p=0.05% level, **Significant at p=0.01% level

Continue……

Table 3: Continue...

S. No.	Lines/ Testers/ Crosses	Number of tillers (per plant)	Number of spikelets per spike	Number of seed per spike	Spike weight (g)	Yield per plant (g)
1	CG 1015	-0.95**	1.85*	2.94**	-0.02	-0.39
2	HD 2864	0.19	-3.77**	-2.56**	-0.13	-0.23
3	HD 2932	-0.02	0.34	0.62	0.18*	0.46
4	RAJ 4238	0.07	1.85**	-0.55	0.13	0.13
5	MP 3336	0.49**	-2.16**	-1.02	-0.03	0.47
6	HD2285	0.36	-1.91**	-0.3	-0.1	0.31
	SE(m)+	0.35	1.68	1.28	0.14	0.63
1	Halna	0.06	-0.31	1.19**	-0.10**	-1.16**
2	HUW 661	-0.50**	0.12	-0.89	-0.06**	0.89**
3	PHSL 10	0.72**	-2.49**	-3.03**	0.19**	1.41**
	SE(m)+	0.21	1.01	0.79	0.09	0.38
1	CG1015 X Halna	-0.61	3.81*	2.12	0.03	-0.09
2	CG1015 X HUW661	0.34	-4.63**	-2.8	0.47	1.82*
3	CG1015 X PHSL 10	-0.84*	-5.01**	-1.87	0.01	-2.1
4	HD 2864 X Halna	0.39	-2.56	0.61	0.11	1.18
5	HD 2864 X HUW661	0.18	-1.5	2.95	-0.36	-0.06
6	HD 2864 X PHSL10	-0.81*	2.62	-1.39	-0.14	0.26

7	HD 2932 X Halna	1.17	-3.19*	-4.57**	0.49**	0.56
8	HD 2932 X HUW661	-0.62	4.86**	2.01	0.04	-2.89**
9	HD 2932 X PHSL 10	-0.31	-1.01	1.67	-0.32	-0.2
10	RAJ 4238 X Halna	-0.59	2.31	2.36	0.03	-1.30
11	RAJ 4238 X HUW661	0.09	-0.12	1.18	0.1	0.82
12	RAJ 4238 X PHSL10	2.08**	-1.02	0.85	-0.13	2.19
13	MP 3336 X Halna	-0.5	-2.68**	-4.17**	0.11	-1.48
14	MP 3336 X HUW661	0.01	1.88	1.16	0.16	0.6
15	MP 3336 X PHSL10	0.49	7.48**	7.95**	0.16	1.73*
16	HD 2285 X Halna	0.28	5.06**	3.62	0.23	0.47
17	HD 2285 X HUW661	-0.14	-1.87	-1.54	-0.19	-0.25
18	HD 2285 X PHSL10	0.53	-5.76**	-6.63**	-0.003	0.38
	SE(m)±	0.62	2.91	2.24	0.25	1.09

*Significant at p=0.05% level, **Significant at p=0.01% level

Continue…

Table 4: Continue...

S. No.	Lines/ Testers/ Crosses	1000 seed weight (g)	Canopy temperature depreciation (°C)	Chlorophyll reflection index	Biological yield per plant (g)	Harvest index (%)
1	CG 1015	-2.78**	0	-1.04	1.21**	-3.81**
2	HD 2864	-1.35	0.25**	-2.65**	-1.19**	0.44
3	HD 2932	2.42**	-0.97**	0.28	0.22	-0.61
4	RAJ 4238	-0.92	0.03	3.18**	-1.46**	3.84**
5	MP 3336	0.97	-0.63**	2.50**	-1.57**	7.70**
6	HD2285	3.44**	0.47**	0.008	0.49	1.22
	SE(m)+	1.52	0.19	1.15	0.98	2.27
1	Halna	-0.77	-0.02	-0.09	-1.14	-1.52*
2	HUW 661	-0.01	0.28**	-0.23	1.14	1.4
3	PHSL 10	-0.90*	-0.1	-0.35	0.61	4.75**
	SE(m)+	0.91	0.11	0.7	0.6	1.5
1	CG1015 X Halna	-7.43**	-0.41	1.19	-0.61	-0.2
2	CG1015 X HUW661	4.35**	0.19	-1.94	0.23	7.27**
3	CG1015 X PHSL 10	1.1	-0.33	-0.74	-2.10*	-5.46*
4	HD 2864 X Halna	-0.45	0.72**	0.55	3.27**	-3.26
5	HD 2864 X HUW661	2.58	0.16	-0.25	-0.37	1.65
6	HD 2864 X PHSL10	-1.42	-0.40*	2.26	-0.26	3.23
7	HD 2932 X Halna	9.87**	0.02	0.46	1.22	2.17
8	HD 2932 X HUW661	-7.81**	0.46*	5.85**	-0.81	-12.92**
9	HD 2932 X PHSL 10	-1.18	-0.04	-1.72	-2.34*	7.50**
10	RAJ 4238 X Halna	-4.31**	0.40*	-4.38**	-0.37	-7.11**
11	RAJ 4238 X HUW661	1.08	-0.84**	-1.85	-0.65	6.06
12	RAJ 4238 X PHSL10	1.9	-0.72**	-3.56**	1.24	6.64
13	MP 3336 X Halna	2.38	-0.41	4.28**	-1.85	0.7
14	MP 3336 X HUW661	1.05	0.26	0.03	1.23	-0.3
15	MP 3336 X PHSL10	-2.91	0.46*	-1.74	2.66*	-0.66
16	HD 2285 X Halna	-1.04	-0.62**	-0.45	-2.25*	7.39**
17	HD 2285 X HUW661	-0.68	0.17	0.23	2.15*	-6.39**
18	HD 2285 X PHSL10	2.34	0.29	-0.19	1.48	-3.51
	SE(m)±	2.61	0.32	2	1.67	3.96

*Significant at p=0.05% level, **Significant at p=0.01% level

Table 4: Analysis of variance for combining ability

Source	Df	Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Peduncle length (cm)	Spike length (cm)	Number of tillers (per plant)	Number of spikelets per spike	Number of seeds per spike
Replication	1	0.03	0.08	0.19	0.48	0.05	0.77	0.08	0.03
Treatment	26	13.63**	5.55**	75.52**	22.35**	2.03**	3.69**	36.32**	31.87**
Parents	8	15.12**	5.65**	48.17**	10.21**	1.58	2.74**	19.21**	14.57**
Testers	2	1.83	3.00*	1.16	3.18*	0.84	0.96	23.34**	12.88**
Lines	5	17.52**	7.67**	67.02**	10.47**	1.73	2.73**	15.47**	16.84**
Testers vs Lines	1	23.03**	1.70**	38.42**	32.17**	2.51	0.34	37.74**	3.43**
Crosses	17	12.74**	5.10**	86.93**	26.38**	2.23**	3.74**	42.73**	38.72**
Parents vs. Crosses	1	26.63**	19.01**	5.64**	27.68**	0.24	7.22**	16.61**	1.06**
Error	26	6.16	2.94	67.01	11.45	1.43	1.27	30	20.56
SE(m)±		1.76	1.21	5.79	2.39	0.85	0.80	3.84	3.21
CD (5%)		4.99	3.45	16.46	6.80	2.41	2.26	11.01	9.11
CV (%)		4.1	1.84	11.1	11.55	11.86	14.6	10.26	8.57

*Significant at p=0.05% level, **Significant at p=0.01% level

Table 4: Continued…

Source	Df	Spike weight (g)	Yield per plant (g)	1000 seed weight (g)	Canopy temperature depreciation (°C)	Chlorophyll reflection index	Biological yield per plant (g)	Harvest index (%)
Replication	1	0.06	0.004	0.622	0.007	0.221	0.16	0.32
Treatment	26	0.21*	4.81**	25.38**	3.08**	22.45**	19.64**	102.66**
Parents	8	0.12	4.37**	13.91**	3.00**	22.33**	6.34**	108.61**
Testers	2	0.21	5.84**	6.42**	1.03	1.40	7.19**	93.20**
Lines	5	0.07	4.47**	18.37**	1.10	28.47**	6.25**	110.67**
Testers vs Lines	1	0.10	0.02	1.73	0.009	1.79	8.58**	114.73**
Crosses	17	0.25	5.24**	29.81**	0.98	23.31**	10.44**	101.43**
Parents vs. Crosses	1	0.16	1.04**	7.49**	5.98**	65.63**	20.79**	311.87**
Error	26	0.10	2.37	29.65	0.17	18.52	8.93	53.89
SE(m)+		0.24	1.09	3.86	0.29	3.05	2.11	5.19
CD (5%)		0.65	3.10	10.95	0.85	8.65	6.02	14.74
CV (%)		14.84	13.64	14.51	14.93	8.12	13.57	14.27

*Significant at p=0.05% level, **Significant at p=0.01% level

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