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Dissection of genetic parameters for wheat (*Triticum aestivum* L.) breeding under thermal stress conditions

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ABSTRACT

The present experiment was conducted using wheat crop during Rabi 2015-16. Study consisted ten wheat varieties, their 45 F_1's (Excluding reciprocals) and F_2's. These generations were evaluated during Rabi 2015-16 in two thermal stress environments along with their parental genotypes following randomized block design at Agricultural Research Farm of RARI, Durgapura (Rajasthan). These Environments were created through late and very late sowing as temperature increases at the time of maturity creates stress. Significance of genetic parameters revealed the influence of both types of gene action while the predictability ratio depicted prevalence of non-additive gene action. Comprehensive evaluation of all genetic parameters viz. per se performance, GCA, SCA, heterosis and heterobeltiosis exhibited that parental genotype Raj 3777, Raj 4037 and Raj 4083 and F_1's WH 1021 × Raj 3777, WH 1021 × Raj 4120, Raj 4083 × PBW 550 and Raj 4037 × Raj 4238 were advantageous. These crosses could be able to throw potential transgressive segregants in later generations. It is advocated that these crosses might be incorporate in multiple crossing programme following diallel selective mating or bi-parental mating followed by selection. To utilize non-additive variance, systematic breeding programme for the targeted environment are required for further tangible advancement in wheat yield. Conclusively, it has been advocated that reciprocal recurrent selection, diallel selective mating, bi-parental mating and multiple cross could be productive breeding approaches for developing thermal stress tolerant genotypes from this potent breeding material.

Keywords: Diallel mating, heat stress, combining ability, gene action, heterosis

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important agricultural product of the globe and among the major three cereal crops (rice, wheat and maize) that provides 20 per cent of the total energy requirement in human food. But, the present scenario of climate change and global warming is creating higher thermal stress in wheat which is becoming a major constraint in increasing its productivity. In that event, breeding for thermal stress tolerance forms an essential constituent of wheat breeding programmes at global level. In any crop, an understanding of the genetic factors that govern the yield components is necessary because breeding for yield largely depends upon genetic manipulation of the components along with yield. The combining ability is a preferable statistical tool in understanding the gene action involved in the inheritance of different quantitative traits including yield and may also suggest the suitable breeding strategy. Besides this, heterosis in other words hybrid vigor may play a crucial role in selecting advantageous parents, as genetic information regarding yield and various yield components contribute significantly in the selection. The understanding of genetic parameters and inheritance pattern of different traits helps breeder to select advantageous breeding strategy for the development of thermal stress tolerant genotypes. Therefore, the present experiment was conducted to understand the effect of yield contributing traits under thermal stress conditions, identification of tolerant genotypes and development of advantageous breeding strategy for such environment.

MATERIALS AND METHODS

The present experiment consisted ten wheat varieties (selected on the basis of genetic diversity and their stability for different yield traits), their all possible F_1's (Excluding reciprocals) and F_2's. Diallel matting design excluding reciprocals was followed for generation of F_1 hybrids. These hybrids were advanced in the subsequent season. Finally, these 45 F_1's and F_2's were evaluated during *Rabi* 2015-16 in two thermal stress

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environments along with their parental genotypes following randomized block design at Agricultural Research Farm of RARI, Durgapura (Rajasthan). Each replication was divided in to two parts; first part comprised of 10 parents and 45 F_1's while the plots of second part consisted of 45 F_2's sown in two rows and four rows plots and two environments (late and very late sowing) respectively. Standard plant geometry of 30 × 10 cm was followed in a 3 m row. Non-experimental rows were also planted all around the experiment to eliminate the effects, if any. Observations on various morpho-physiological traits *viz.* days to heading, days to maturity, grain filling period, plant height, flag leaf area, peduncle area and spike and grain related traits *viz.* spike area, number of grains per spike, grain yield per spike, 1000-grain weight and grain yield per plant were recorded by randomly selecting 10 plants in each of parent and F_1's and 30 plants in F_2's. Statistical analysis was performed using mean values over selected plants. Combining ability analysis was carried out following Griffing (1956) method 2 Model I and percent heterosis and heterobeltiosis of a cross was calculated (Fonseca and Patterson, 1968).

RESULTS AND DISCUSSION

Analysis of Variance

Variance analysis of both the environments (Table 1) manifested the existence of abundant genetic diversity among the parental genotypes for all the studied traits. Additionally, analysis also revealed significant mean squares due to parents and generations for all the traits except for spike area of parents in E_1. Similarly, F_1's and F_2's progenies exhibited notable difference for all the traits excluding F_2's progeny of spike area. Yao *et al.* (2011); Pancholi *et al.* (2012); Singh *et al.* (2012); Ahmed *et al.* 2017; Kumar *et al.* (2017) and Sharma *et al.* (2019) also reported similar findings. Significance of mean squares due to F_1 *vs* F_2 supported the existence of inbreeding depression for all the traits except of days to heading in both environments, peduncle area in

Table 1: ANOVA sowing mean squares in two environments for morpho-physiologcal and spike and grain related attributes

Characters	Env.	Source of variation								
		Replication (2)	Genotypes (99)	Parents (9)	Generation (89)	F_1's (44)	F_2's (44)	F_1 *vs* F_2 (1)	Parents vs Generation (1)	Error (198)
Days to	E_1	1.69	23.03**	11.13**	24.13**	24.80**	23.76**	11.61	32.01**	4.24
heading	E_2	6.04	22.48**	23.29**	22.53**	21.37**	24.17**	1.34	11.21*	2.42
Days to	E_1	13.92	67.04**	77.80**	64.81**	73.62**	40.12**	763.39**	168.75**	4.82
maturity	E_2	2.91	31.63**	22.37**	32.40**	34.67**	29.95**	40.83**	45.63**	3.50
Grain filling	E_1	13.42	93.52**	66.26**	96.72**	98.18**	75.56**	963.33**	53.76*	9.41
period	E_2	0.32	43.53**	22.63**	46.02**	38.92**	53.37**	34.85*	10.23	6.29
Plant height	E_1	8.71	54.86**	80.21**	52.67**	53.75**	50.08**	117.06**	23.53	6.71
	E_2	3.92	45.60**	50.43**	39.14**	44.23**	34.90**	1.62	577.08**	8.09
Flag leaf	E_1	10.30	21.21**	26.45**	18.62**	14.24*	21.09**	102.50**	204.86**	9.17
area	E_2	2.64	10.39**	16.19**	9.67**	11.41**	8.13**	0.95	22.54**	2.82
Peduncle	E_1	10.03	17.57**	18.37**	17.36**	17.15**	17.69**	11.96	29.56*	5.87
area	E_2	0.71	37.37**	88.70**	31.76**	30.66**	33.10**	21.12*	75.19**	3.74
Spike area	E_1	18.93	29.61**	19.70	29.77**	26.05**	22.04*	533.60**	104.36**	15.11
	E_2	0.09	37.26**	47.82**	35.72**	42.25**	29.87	5.74	79.11	2.90
No. of grain	E_1	8.77	119.42**	69.78**	124.86**	126.65**	116.26**	424.70**	81.79**	10.43
per spike	E_2	8.56	66.05**	42.50**	66.23**	73.98**	59.43**	24.07*	262.63**	4.54
Grain yield	E_1	0.005	0.31**	0.23**	0.31**	0.28**	0.33**	0.97**	1.04**	0.002
per spike	E_2	0.003	0.16**	0.06**	0.17**	0.18**	0.15**	0.25**	0.22**	0.003
1000- grain	E_1	7.04	43.45**	57.45**	38.52**	38.97**	37.27**	73.42**	356.02**	7.17
weight	E_2	1.95	39.93**	15.13**	42.68**	39.57**	46.30**	19.70*	18.56*	3.47
Harvest	E_1	1.89	60.67**	46.78**	61.82**	53.71**	65.81**	243.33**	83.16**	4.34
Index	E_2	14.33	67.46**	29.31**	70.92**	65.77**	75.27**	105.76**	103.05**	10.86
Grain yield	E_1	5.93	17.25**	18.49**	16.53**	16.50**	14.15**	122.17**	70.51**	3.87
per plant	E_2	0.52	22.18**	19.07**	22.49**	21.56**	21.49**	107.10**	22.40**	1.73

**, **Significant at 5 percent and 1 percent levels, respectively*

E_1 only and plant height, flag leaf area and spike area in E_2. Non-significant F_1*vs* F_2 for days to heading was also observed by Singh *et al.* (2012). The differences among parent *vs* generations were significant for all the traits suggested the presence of heterosis except for plant height in E_1, and grain filling period and spike area in E_2.

Combining ability

The analysis of combining ability showed the significance of GCA and SCA for all the traits in both generations except SCA for spike area in E_1 only (Table 2). Significance of these parameters depicted the importance of both additive and non-additive gene action in the genetic control of all the traits. These results were corroborative with the findings of Singh *et al.* (2012); Adel *et al.* (2013); Kalhoro *et al.* (2015); Kumar *et al.* (2017) and Sharma *et al.* (2019). The low value of predictability ratio (<1) exhibited the preponderance of non-additive gene action for all the traits. The results were in close agreement with the earlier findings of Pancholi *et al.* (2012); Singh *et al.* (2012); Adel *et al.* (2013) and Kumar *et al.* (2017). The pre-eminence of non-additive gene action for most of the traits suggested that further advancement in wheat might be achieved through selecting the best cross combinations on the basis of SCA. This finding assists in catching out the desirable parents and crosses for hybridization and exploitation of heterosis. If GCA effects or additive gene action is dominant, a significant amount of improvement could be attained through conventional breeding methods such as pedigree and bulk method while in the case of non-additive gene effects, recurrent selection e.g. diallel selective mating or bi-parental mating in early generations might prove to be effectual breeding strategy.

Table 2: ANOVA for GCA and SCA in two environments for morpho-physiologcal and spike and grain related attributes

Character	Env.	Source of variation							
		GCA (df = 9)		SCA (df = 45)		Error (df =110)		GCA/SCA	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	E1	15.34**	16.04**	6.06**	5.42**	1.3	1.34	0.25	0.3
	E2	6.25**	9.49**	7.33**	7.62**	0.74	0.83	0.07	0.11
Days to maturity	E1	85.42**	58.81**	12.22**	9.68**	1.55	1.55	0.66	0.59
	E2	37.5**	28.57**	5.44**	6.06**	1.01	1.33	0.69	0.48
Grain filling period	E1	85.96**	75.56**	19.27**	15.91**	3.2	2.81	0.43	0.46
	E2	23.88**	33.05**	9.43**	12.47**	2.03	2.07	0.25	0.25
Plant height	E1	57.84**	11.76**	4.03**	46.77**	2.28	2.19	0.49	0.37
	E2	33.46**	30.14**	14.84**	12.73**	2.73	2.22	0.21	0.22
Flag leaf area	E1	4.74*	11.67**	6.29**	8.37**	2.21	3.45	0.05	0.14
	E2	5.15**	4.23**	3.9**	3.05**	0.92	0.9	0.12	0.13
Peduncle area	E1	11.09**	11.8**	4.88**	4.76**	2.09	1.93	0.27	0.29
	E2	39.45**	39.82**	8.71**	9.09**	1.21	1.21	0.43	0.41
Spike area	E1	17.94**	18.3**	8.28**	4.89	4.53	5.37	0.3	-2.27
	E2	49.8**	37.71**	7.63**	5.83**	0.6	1.1	0.58	0.65
No. of grain per spike	E1	90.13**	82.12**	29.53**	27.01**	0.59	5.65	0.26	0.3
	E2	61.43**	62.17**	16.21**	10.85**	2.38	2.1	0.36	0.57
Grain yield per spike	E1	0.09**	0.21**	0.10**	0.08**	0.001	0.001	0.08	0.21
	E2	0.15**	0.10**	0.03**	0.04**	0.001	0.001	0.38	0.23
1000- Grain weight	E1	13.32**	28.2**	15.63**	12.49**	0.91	3.55	0.07	0.23
	E2	9.84**	16.72**	11.99**	12.98**	0.96	1.48	0.07	0.11
Harvest Index	E1	38.57**	43.8**	13.03**	17.14**	1.22	1.56	0.26	0.23
	E2	69.18**	71.42**	10.76**	10.24**	1.16	5.36	0.59	1.13
Grain yield per plant	E1	11.24**	13.4**	5.31**	3.33**	1.09	1.39	0.2	0.52
	E2	25.9**	24.05**	3.55**	3.48**	0.45	0.59	0.68	0.68

General Combining Ability

GCA is a productive tool applied in selection of parents on the basis of progenies performance, normally in the F_1 but it has also been applied in F_2 and later generations. In the present study, most of the traits were inconsistence for the GCA estimates of the parents. Nevertheless, some parents were consistence for more than one specific trait as they showed desirable and undesirable GCA estimates with varied extent (Table 3 & 4). An interesting association was also denoted as the parents with desirable GCA effects for grain yield/plant also showed desirable GCA for one or more yield contributing traits in both the generations. The parents namely Raj 3777 revealed advantageous GCA effect for grain yield/plant, days to maturity, grain filling period, flag leaf area, peduncle area, number of grains/spike, grain yield/spike and harvest index and Raj 4037 for grain yield/plant, days to maturity, grain yield/spike and harvest index in both the environments while Raj 4083 depicted this parameter only in E_1, for grain yield/plant, days to maturity and harvest index. Since GCA effects are assigned to additive and additive × additive gene effects then the stated parents necessarily possess acceptable potential for the particular trait and may be utilize in a multiple crossing programme to synthesize a potent population with most of the beneficial genes accumulated. Notwithstanding of this, there is still further scope for ameliorating the combining ability for contributing traits, as none of the good combiners for grain yield was also a good combiner or at the minimum an average combiner for all the advantageous traits. In wheat, parents depicting good GCA were also by Pancholi *et al.* (2012); Singh *et al.* (2013); Kumar *et al.* (2017) and Sharma *et al.* (2019).

Specific Combining Ability

In the present investigation, not a single cross combination showed consistently high SCA effects for all the traits. However, a number of crosses revealed consistently desirable and undesirable SCA effects for more than one specific trait. For instance, the crosses having desirable SCA effects for grain yield/plant also showed desirable SCA effects for one or more yield contributing traits and were included in top three crosses for the respective trait. The crosses namely WH 1021 × Raj 3777 for days to heading, number of grains/spike and grain yield/spike; Raj 4083 × Raj 4238 for number of grains/spike, grain yield/spike, 1000 grain weight and harvest index; Raj 4083 × PBW 550 for peduncle area and harvest index in E_1 and Raj 4083 × PBW 550 for grain filling period, flag leaf area and spike area; Raj 4037 × Raj 4238 for grain filling period, grain yield per spike and 1000 grain weight and WH 1021 × Raj 3777 for days to maturity, gain filling period and grain yield per spike in E_2 depicted desirable SCA estimates consistently in addition to grain yield/plant. Best cross combinations having desirable SCA effects for different traits in thermal stress condition are listed in Table 3 & 4. It was really interesting to establish that SCA effects of the best cross combinations and GCA effects of their parents were the consequence of good × poor (Raj 4083 × PBW 550 and WH 1021 × Raj 3777) or poor × poor (WH 1021 × Raj 4120 and Raj 4037 × Raj 4238) combinations. High value of SCA effect from two good general combiners resemble additive × additive type of gene action and shows that favorable genes has been provided by the parents, while the presence of additive × dominance or dominance x dominance interaction is interpreted by the involvement of good × poor or poor × poor combiners, respectively. Therefore, cross combinations having only good general combiner parents are of greater applicability in crop like wheat, because genes which are heading these effects may be fixed permanently in the form of end product of a breeding programme. Biparental progeny selection may be a better tool to get good transgressive segregants from such type of crosses. These findings are in close agreement with those obtained by Pancholi *et al.* (2012); Singh *et al.* (2013); Kumar *et al.* (2017) and Sharma *et al.* (2019).

Heterosis and Heterobeltiosis

The supremacy of hybrids specifically over the better parent (heterobeltiosis) is of paramount importance in finding out the parental combinations which are efficient in producing good transgressive segregants. Among high

Table 3: Top three parents, F_1's and F_2's for their mean values, GCA and SCA estimates for morpho-physiological attributes

Characters	Env.	Parents	High mean		GCA		SCA		Heterosis & Heterobeltiosis
			F_1	F_2	F_1	F_2	F_1	F_2	
Days to heading		RAJ 3765	RAJ 3765 × PBW 550	RAJ 3765 × RAJ 4238	RAJ 3765	RAJ 3765	PBW 343 × PBW 550	PBW 343 × DBW 17	H
	E_1	WH 1021	RAJ 3765 × RAJ 4238	WH 1021 × DBW 17	WH 1021	WH 1021	RAJ 4037 × RAJ 4083	RAJ 4120 × PBW 343	HB
		RAJ 4083	RAJ 4037 × RAJ 4083	RAJ 3765 × PBW 550	PBW 550	PBW 550	RAJ 4083 × DBW 17	WH 1021 × RAJ 4037	-
		RAJ 4120	RAJ 4238 × PBW 550	RAJ 4238 × PBW 550	PBW 550	PBW 550	PBW 343 × DBW 17	PBW 343 × PBW 550	H, HB
	E_2	PBW 550	RAJ 3777 × RAJ 4083	PBW 343 × PBW 550	RAJ 4083	RAJ 3765	PBW 343 × PBW 550	RAJ 4238 × PBW 550	H
		RAJ 4238	PBW 343 × PBW 550	RAJ 3765 × PBW 550	RAJ 4238	RAJ 4037	RAJ 3777 × RAJ 4083	WH 1021 × RAJ 4037	HB
Days to maturity		RAJ 4083	RAJ 3777 × RAJ 4037	RAJ 4037 × RAJ 4120	RAJ 3777	RAJ 4083	DBW 17 × PBW 550	PBW 343 × RAJ 4238	H, HB
	E_1	RAJ 3777	RAJ 4037 × RAJ 4120	RAJ 3765 × RAJ 4083	RAJ 4037	RAJ 4037	RAJ 4120 × RAJ 4238	DBW 17 × PBW 550	H
		RAJ 4037	RAJ 3777 × RAJ 4120	WH 1021 × RAJ 4120	RAJ 4083	RAJ 3777	WH 1021 × DBW 17	WH 1021 × PBW 343	-
		RAJ 4083	RAJ 4120 × RAJ 4238	RAJ 4120 × RAJ 4238	RAJ 4083	RAJ 3777	DBW 17 × PBW 550	PBW 343 × DBW 17	H, HB
	E_2	RAJ 4120	RAJ 4083 × RAJ 4238	WH 1021 × RAJ 4120	RAJ 3777	RAJ 4120	RAJ 4120 × RAJ 4238	DBW 17 × PBW 550	H, HB
		RAJ 3777	RAJ 4037 × RAJ 4120	RAJ 3765 × RAJ 4120	RAJ 4037	RAJ 4037	RAJ 3765 × DBW 17	WH 1021 × RAJ 4120	HB
Grain filling period		RAJ 3777	RAJ 3777 × RAJ 4037	RAJ 3777 × RAJ 4037	RAJ 3777	RAJ 4037	DBW 17 × PBW 550	PBW 343 × RAJ 4238	H
	E_1	RAJ 4083	RAJ 3777 × RAJ 4120	RAJ 4037 × DBW 17	RAJ 4037	RAJ 4083	WH 1021 × RAJ 4238	PBW 343 × RAJ 4083	H, HB
		RAJ 4120	RAJ 4037 × RAJ 4120	PBW 343 × RAJ 4083	RAJ 4120	RAJ 4120	WH 1021 × RAJ 4083	RAJ 4037 × DBW 17	-
		DBW 17	RAJ 3777 × RAJ 4120	WH 1021 × RAJ 4120	RAJ 3777	RAJ 4120	RAJ 3777 × RAJ 4120	WH 1021 × PBW 343	H, HB
	E_2	RAJ 4238	RAJ 3765 × DBW 17	RAJ 3777 × RAJ 4037	RAJ 4083	RAJ 3777	RAJ 4083 × PBW 550	PBW 343 × RAJ 4238	H
		RAJ 3777	RAJ 4120 × RAJ 4238	RAJ 4120 × RAJ 4238	RAJ 4037	RAJ 4083	DBW 17 × PBW 550	DBW 17 × PBW 550	-
Plant height		DBW 17	DBW 17 × PBW 550	RAJ 4037 × RAJ 4238	DBW 17	RAJ 4238	RAJ 3777 × RAJ 4120	RAJ 3777 × RAJ 4120	H
	E_1	RAJ 4238	RAJ 4083 × PBW 550	RAJ 3777 × RAJ 4120	PBW 550	DBW 17	RAJ 3765 × RAJ 4238	RAJ 4037 × RAJ 4238	-
		PBW 550	RAJ 3765 × RAJ 4238	RAJ 4238 × DBW 17	RAJ 4238	PBW 550	WH 1021 × RAJ 4120	RAJ 3777 × RAJ 4238	-
		RAJ 4238	PBW 343 × RAJ 4238	RAJ 4037 × PBW 550	PBW 343	PBW 343	DBW 17 × PBW 550	RAJ 4037 × PBW 550	-
	E_2	PBW 343	RAJ 4083 × DBW 17	RAJ 3777 × PBW 343	RAJ 4238	RAJ 4238	RAJ 4037 × PBW 550	WH 1021 × PBW 550	H, HB
		RAJ 4083	RAJ 4037 × PBW 550	RAJ 4083 × DBW 17	DBW 17	DBW 17	RAJ 3777 × RAJ 4120	RAJ 3777 × PBW 343	-
Flag leaf area		RAJ 3777	RAJ 4120 × PBW 550	RAJ 4037 × PBW 343	RAJ 3777	RAJ 3777	RAJ 4037 × PBW 343	RAJ 4037 × PBW 343	-
	E_1	DBW 17	RAJ 4037 × PBW 343	RAJ 4037 × PBW 550	RAJ 4120	RAJ 4120	RAJ 4083 × PBW 550	RAJ 4037 × PBW 550	H, HB
		RAJ 4120	RAJ 4083 × PBW 550	RAJ 3777 × RAJ 4037	DBW 17	RAJ 4037	RAJ 4120 × PBW 550	WH 1021 × RAJ 3777	H
		RAJ 3777	RAJ 4037 × PBW 343	RAJ 4037 × DBW 17	RAJ 3777	RAJ 4120	RAJ 4037 × PBW 343	RAJ 4083 × PBW 550	H, HB
	E_2	RAJ 4120	RAJ 3765 × RAJ 4238	RAJ 3765 × PBW 550	RAJ 4120	RAJ 3777	RAJ 3765 × PBW 4238	RAJ 3765 × PBW 550	H, HB
		DBW 17	RAJ 4120 × PBW 550	RAJ 4083 × PBW 550	DBW 17	RAJ 4037	RAJ 4120 × PBW 550	RAJ 4037 × DBW 17	-
Peduncle area		RAJ 3777	RAJ 3777 × RAJ 4120	PBW 343 × RAJ 4083	RAJ 3777	RAJ 3777	PBW 343 × RAJ 4083	PBW 343 × RAJ 4083	H, HB
		RAJ 4037	RAJ 4037 × PBW 550	WH 1021 × RAJ 3777	RAJ 3765	RAJ 3765	RAJ 3777 × RAJ 4120	RAJ 4120 × DBW 17	-
	E_1	RAJ 3765	PBW 343 × RAJ 4083	RAJ 3777 × RAJ 4120	RAJ 4037	RAJ 4120	RAJ 4037 × PBW 550	WH 1021 × RAJ 3777	H
		RAJ 3765	RAJ 3765 × DBW 17	RAJ 3765 × DBW 17	RAJ 3777	RAJ 3777	RAJ 3765 × DBW 17	RAJ 4120 × PBW 550	-
	E_2	RAJ 3777	RAJ 3777 × RAJ 4120	RAJ 4037 × PBW 550	RAJ 3765	RAJ 3765	RAJ 3777 × RAJ 4120	RAJ 3765 × DBW 17	-
		RAJ 4083	WH 1021 × RAJ 4083	RAJ 3777 × RAJ 4083	RAJ 4037	RAJ 4083	RAJ 4120 × PBW 550	WH 1021 × RAJ 4238	-

Table 4: Top three of the parents, F_1's and F_2's for their mean values, GCA and SCA estimates for spike and grain attributes

Characters	Env.	Parents	High mean		GCA		SCA		Heterosis & Heterobeltiosis
			F_1	F_2	F_1	F_2	F_1	F_2	
Spike area	E_1	RAJ 3777	RAJ 4238 × DBW 17	RAJ 3777 × RAJ 4120	RAJ 3777	RAJ 3777	RAJ 4238 × DBW 17	RAJ 3765 × RAJ 4037	H,HB
		RAJ 4083	RAJ 3777 × RAJ 4083	RAJ 3765 × RAJ 4037	RAJ 4083	RAJ 4120	RAJ 4037 × PBW 343	RAJ 4120 × PBW 343	-
		PBW 550	RAJ 3777 × PBW 550	RAJ 4037 × PBW 550	RAJ 4238	RAJ 4037	RAJ 3765 × RAJ 4238	RAJ 4037 × PBW 550	H,HB
	E_2	RAJ 3777	RAJ 3777 × PBW 550	RAJ 4037 × PBW 550	RAJ 3777	RAJ 3777	DBW 17 × PBW 550	DBW 17 × PBW 550	H,HB
		RAJ 4083	DBW 17 × PBW 550	RAJ 3777 × DBW 17	PBW 550	PBW 550	RAJ 3777 × DBW 17	RAJ 3777 × DBW 17	-
		RAJ 4037	RAJ 3777 × DBW 17	RAJ 3777 × PBW 343	RAJ 4037	RAJ 4037	WH 1021 × PBW 550	WH 1021 × RAJ 4238	H,HB
Number of grains per spike	E_1	RAJ 3777	WH 1021 × RAJ 3777	WH 1021 × RAJ 3777	RAJ 3777	RAJ 3777	PBW 343 × RAJ 4238	PBW 343 × RAJ 4283	H,HB
		RAJ 4037	RAJ 3777 × DBW 17	RAJ 3777 × RAJ 4083	WH 1021	WH 1021	WH 1021 × RAJ 4120	WH 1021 × RAJ 4120	H
		WH 1021	RAJ 3777 × PBW 550	WH 1021 × RAJ 4120	PBW 550	DBW 17	RAJ 4120 × RAJ 4238	RAJ 3765 × DBW 17	-
	E_2	RAJ 4037	RAJ 3765 × RAJ 3777	RAJ 3765 × RAJ 3777	RAJ 3777	RAJ 3777	RAJ 3765 × PBW 343	WH 1021 × DBW 17	H
		RAJ 3777	RAJ 3777 × RAJ 4037	RAJ 3777 × RAJ 4037	RAJ 4238	WH 1021	WH 1021 × PBW 550	RAJ 4120 × RAJ 4238	HB
		RAJ 4083	RAJ 3777 × RAJ 4083	RAJ 4083 × RAJ 4238	RAJ 4083	RAJ 4238	RAJ 4120 × RAJ 4238	RAJ 4083 × RAJ 4238	-
Grain yield per spike	E_1	RAJ 3777	RAJ 4083 × RAJ 4238	RAJ 3765 × RAJ 3777	RAJ 3777	RAJ 3777	WH 1021 × RAJ 4120	RAJ 4083 × RAJ 4238	-
		RAJ 4037	RAJ 3777 × RAJ 4037	RAJ 3765 × RAJ 4037	RAJ 4037	RAJ 3765	RAJ 4083 × PBW 550	RAJ 3765 × RAJ 4037	H,HB
		WH 1021	RAJ 4037 × RAJ 4083	WH 1021 × RAJ 4120	RAJ 4083	RAJ 4037	WH 1021 × RAJ 4238	RAJ 3765 × PBW 550	-
	E_2	RAJ 4037	RAJ 3777 × RAJ 4037	RAJ 3777 × RAJ 4037	RAJ 3777	RAJ 3777	RAJ 4037 × RAJ 4083	RAJ 4037 × RAJ 4083	HB
		RAJ 4083	RAJ 4037 × RAJ 4083	RAJ 3777 × RAJ 4120	RAJ 4037	RAJ 4037	WH 1021 × PBW 550	RAJ 3765 × RAJ 4238	-
		RAJ 4037	RAJ 3765 × RAJ 3777	RAJ 4037 × RAJ 4083	RAJ 3765	RAJ 3765	RAJ 3765 × PBW 343	RAJ 3765 × DBW 17	-
1000-grain weight	E_1	WH 1021	RAJ 3765 × RAJ 4083	RAJ 3765 × RAJ 3777	WH 1021	WH 1021	RAJ 3765 × RAJ 4083	PBW 343 × DBW 17	H
		RAJ 4037	RAJ 4083 × RAJ 4238	RAJ 3777 × PBW 343	RAJ 4238	RAJ 3777	RAJ 4083 × RAJ 4238	RAJ 3765 × RAJ 4083	-
		RAJ 3777	RAJ 4238 × PBW 550	RAJ 3765 × RAJ 4083	PBW 550	PBW 550	RAJ 3777 × PBW 550	DBW 17 × PBW 550	-
	E_2	RAJ 4037	RAJ 3765 × RAJ 4083	RAJ 3777 × RAJ 4120	RAJ 4037	RAJ 3777	PBW 343 × DBW 17	RAJ 4083 × RAJ 4238	H,HB
		RAJ 3777	RAJ 4083 × RAJ 4238	RAJ 4083 × RAJ 4238	RAJ 4083	RAJ 4037	RAJ 3765 × RAJ 4083	DBW 17 × PBW 550	HB
		RAJ 3765	PBW 343 × DBW 17	RAJ 3777 × RAJ 4083	RAJ 4238	RAJ 4083	RAJ 4238 × DBW 17	RAJ 3777 × RAJ 4120	H,HB
Harvest index	E_1	RAJ 4037	WH 1021 × RAJ 4037	WH 1021 × RAJ 4037	RAJ 3777	RAJ 3777	WH 1021 × RAJ 4037	WH 1021 × RAJ 4037	-
		RAJ 3777	RAJ 4083 × RAJ 4238	RAJ 4037 × RAJ 4238	RAJ 4037	RAJ 4037	RAJ 3765 × PBW 343	RAJ 3765 × DBW 17	-
		RAJ 3765	RAJ 3777 × RAJ 4083	RAJ 3777 × RAJ 4238	RAJ 4238	RAJ 4238	RAJ 3765 × DBW 17	RAJ 4120 × PBW 343	-
	E_2	RAJ 4037	RAJ 3777 × RAJ 4083	RAJ 3777 × RAJ 4037	RAJ 4083	RAJ 4238	RAJ 3777 × RAJ 4037	RAJ 4120 × RAJ 4083	-
		RAJ 3777	RAJ 3777 × RAJ 4037	RAJ 4120 × RAJ 4043	RAJ 4238	RAJ 3777	RAJ 3777 × RAJ 4083	RAJ 3777 × RAJ 4037	HB
		RAJ 4083	RAJ 4083 × RAJ 4238	RAJ 4037 × RAJ 4238	RAJ 4037	RAJ 4083	PBW 343 × PBW 550	WH 1021 × RAJ 4083	-
Grain yield per plant	E_1	RAJ 4037	WH 1021 × RAJ 3777	RAJ 3777 × RAJ 4037	RAJ 3777	RAJ 4037	WH 1021 × RAJ 3777	RAJ 3765 × PBW 343	H
		RAJ 3777	RAJ 4083 × PBW 550	RAJ 3765 × RAJ 3777	RAJ 4037	RAJ 3777	WH 1021 × RAJ 4120	RAJ 4083 × PBW 550	H,HB
		RAJ 4083	RAJ 4083 × RAJ 4238	RAJ 4083 × PBW 550	RAJ 4083	RAJ 4083	RAJ 4083 × RAJ 4238	WH 1021 × DBW 17	-
	E_2	RAJ 4037	RAJ 4037 × RAJ 4238	RAJ 3777 × RAJ 4037	RAJ 4037	RAJ 3777	RAJ 4083 × PBW 550	RAJ 4083 × PBW 550	H,HB
		RAJ 3777	WH 1021 × RAJ 3777	RAJ 3765 × RAJ 4037	RAJ 3777	RAJ 4037	WH 1021 × RAJ 3777	WH 1021 × RAJ 3777	H,HB
		RAJ 4083	RAJ 4083 × PBW 550	WH 1021 × RAJ 3777	RAJ 3765	RAJ 3765	RAJ 4037 × RAJ 4238	RAJ 4083 × RAJ 4238	HB

yielding F_1s *viz.* WH 1021 ×Raj 3777, Raj 3765 × **P**BW 343, WH 1021 × Raj 4120, WH 1021 × Raj 4238, Raj 4083 × Raj 4238, Raj 4083 × PBW 550, Raj 4037 × Raj 4238 and WH 1021 × DBW 17 depicted advantageous heterosis and heterobeltiosis for one or more traits along with yield (Table 3 & 4). Consequently, these crosses may be taken into consideration for substantial advancement in the yield of bread wheat under thermal stress condition. An engrossing association in respect to heterosis and heterobeltiosis was observed as parents, which were desirable for grain yield per plant, were also desirable for at least one or more yield attributing traits. For instance, heterosis for grain yield per plant was mainly furnished by number of grains per spike, grain yield per spike and plant height. Thus, heterobeltiosis for grain yield might be the result of heterobeltiosis of other yield contributing traits. Nonetheless, the crosses depicting heterotic appearance for grain yield per plant were not heterotic for all the traits under study. The outcome of the study is in close agreement with those of Pancholi *et al.* (2011); Singh *et al.* (2012); Raj and Kandalkar (2013) and Ismail (2015).

On the basis of *per se* performance, GCA effects, SCA effects, heterosis and heterobeltiosis; the parent Raj 3777, Raj 4037 and Raj 4083 and crosses WH 1021 × Raj 3777, WH 1021 × Raj 4120, Raj 4083 × PBW 550 and Raj 4037 × Raj 4238 were advantageous. These crosses could be able to throw potential transgressive segregants in later generations. It is advocated that these crosses might be incorporate in multiple crossing programme following diallel selective mating or bi-parental mating followed by selection. To utilize non-additive variance, systematic breeding programme for the targeted environment are required for further tangible advancement in wheat yield. Conclusively, it may suggest that reciprocal recurrent selection diallel selective mating, use of multiple crosses and bi-parental mating may be constructive approaches for amelioration in bread wheat yield.

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