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Combining ability analysis for grain yield and its contributing characters in bread wheat (*Triticum aestivum* L. Em. Thell) under normal and high temperature stress condition

Guman Singh, Dhirendra Singh, Naresh Parashar, DK Gothwal and RK Solanki

Abstract
Ten genetically diverse genotypes of wheat were evaluated for the combining ability. The significant differences were observed among the parents for all the characters except days to heading and peduncle length in both E_1 and E_2, grain filling duration and 1000 grain weight in E_2, biological yield per plant and harvest index in E_1. Likewise, generations (F_1's and F_2's) also showed significant differences for all the characters in both E_1 and E_2, advocated the presence of sufficient genetic variability. GCA and SCA variances were significant for all the characters in both the environments GCA for flag leaf area and peduncle length in E_2 in F_1; while SCA for days to heading and days to maturity in both F_1 and F_2 in E_2, grain filling duration in F_1 of E_1, plant height and peduncle length for both F_1 and F_2 of E_1 and 1000-grain weight in F_1 of E_1 environment, indicated the importance of both additive and non-additive gene effects in the genetic control of the characters under study. The GCA / SCA variance ratio indicated the preponderance of non-additive gene action. An overall evaluation of GCA effects and *per se* performance over the environments showed that Raj 4120 and Raj 3777 in E_1; Raj 3765, Raj 1482 and Raj 4120 in E_2 appeared as good general combiners for grain yield and some associated characters, while the cross Raj 1482xRaj 4120, Raj 3777xRaj 4120 and Raj 1482xRaj 4120 in E_1 and Raj 3765xRaj 3777, Raj 1482xRaj 3777 and Raj 3765xRaj 4079 in E_2 appeared as good specific cross combinations for grain yield and some associated traits.

Keywords: Wheat, combining ability, GCA, SCA, half diallel

Introduction
Bread wheat (*Triticum aestivum* L. Em. Thell) is the most important food grain crop among the cereals and stands next to rice in India. It is one of the ancient grain crop consumed as primary food by human beings since the dawn of civilization and is known as the protector of man from hunger. It is a self pollinated crop belonging to the family *Poaceae*. It is a hexaploid species (2n=6x=42: AABBDD genomes) with 21 pairs of chromosome. It significantly contributed towards the success of the "Green Revolution" and has greatly helped to transform our country from a situation of ship to mouth to become a self –sufficient. Wheat crop grown in Northern India under late sown condition get exposed to very low temperature upto booting stage and at later stages it has to face warm temperature that leads to forced maturity under high temperature conditions leading to poor grain yield. As a result the reproductive (spike initiation to anthesis) and ripening (anthesis to maturity) growth phases of late sown wheat crop is generally exposed to high temperature stress during the month of March to April where temperature remains around 35-40 ºC. Each genotype within a plant species needs an optimum temperature range for growth at different stages such as 20-25°C for germination, 16-20 °C for tillering and 20-23 °C for grain formation in case of wheat. Wheat is especially sensitive to temperature that exceeds 32-33 °C for any significant period, plants can be injured at seedling emergence, reproductive development, and stem elongation, heading and flowering by high temperature.

During last decade an increasing attention has been given to the development of short duration varieties with heat tolerance during grain formation stage. Breeding for heat tolerance is an integral component of wheat breeding programme at both national and international levels (Acevedo *et al.*, 1990) [1]. These programmes will help in spreading wheat cultivation to non-traditional warm areas besides optimizing wheat yield in tropical environments under the present situation of multiple cropping systems.

Both of these goals require significant breeding efforts to improve high temperature tolerance of cereals for yield and quality.

Though several new varieties have been released for commercial cultivation in recent years, most of the cultivars currently recommended were never intended for late sowing. A time has come when breeders can no longer ignore this reality. The available scientific information on breeding aspects for high temperature tolerance is scanty.

The assessment of combining ability and determining gene action are elementary tools for selection of ideal genotypes. Advancement in the yield of this important crop species requires adequate information regarding the nature of combining ability of the parents available in a wide array of genetic material to be used in the hybridization programme and also the nature of gene actions involved in the expression of quantitative and qualitative traits of economic importance. Diallel mating design has been extensively used to analyze the combining ability effects of wheat genotypes and also to provide information regarding genetic mechanism controlling grain yield and other traits. Therefore, the present research investigation was carried out to understand the effect of yield contributing attributes under high temperature conditions and identification of tolerant genotypes suitable for such environments.

Materials and Methods

The experimental material for the present study comprised of ten genetically diverse wheat genotypes collected from All India Coordinated Wheat and Barley Improvement Project (AICW&BIP), Rajasthan Agricultural Research Institute, Durgapura, Jaipur and their 45 F1's. Crosses were made among the ten barley genotypes namely; Raj 1482, Raj 3765, Raj 3077, Raj 3777, Raj MR-1, Raj 4238, Raj 4079, Raj 4120, DPW 621-50 and WH 1105 in half diallel fashion during *rabi* 2015-16 at Agronomy Farm, S.K.N. College of Agriculture, Jobner. Ten parents and their resulting 45 F1's were grown in a randomized block design with three replications under high temperature condition during *rabi* 2016-17 at Agronomy farm, S.K.N. College of Agriculture, Jobner. Sowing was done about 30 days later than normal date of sowing which created high temperature stress environment at post anthesis. The parents and F1's were grown in a plot of two rows of 2 meter length with row to row distance of 30 cm and plant to plant distance of 10 cm. 10 randomly selected plants in each of the F_1's progenies along with each parent while 30 plants were selected in F_2's population from each replication for recording observations on thirteen characters namely, days to heading, grain filling duration, days to maturity, plant height (cm), number of tillers per plant, flag leaf area (cm2), number of grains per spike, peduncle length (cm), spike length (cm), 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g) and harvest index.

The mean of each plot was used for statistical analysis. The data were first subjected to the usual analysis followed for a randomized block design (PANSE and SUKHATME 1967). In this experiment we have confined ourselves with the fixed effect model (model I) and parents and F1's generations were analyzed in estimating the genetic components. Hence, the combining ability analysis was done following method 2, model I of Griffings (1956) [7].

Flag Leaf area (cm2) = Length x breadth (maximum) x 0.79

Result and Discussion

The character-wise pooled analysis of variance indicated significant differences among the environments, showing their varied effect on the expression of different characters under study. Further parents' vs generations (F_1's and F_2's) exhibited significant differences for all the characters studied except grain filling duration, days to maturity, plant height, 1000 grain weight and biological yield per plant. The mean squares due to parents were also significant for all the characters studied except for days to heading, peduncle length and 1000 grain weight, similarly, mean squares due to F_1 vs F_2 were also significant for all the characters studied except for days to heading. The genotype x environment interaction was also significant for all the studied characters. Taking into consideration, significant G × E interaction for all the characters, the analysis of variance was done for the individual environment separately.

The analysis of variance in individual environment revealed significant differences among the genotypes (parents, F_1s and F_2s) for all the characters under study. Further, analysis revealed significant difference among parents for all the characters except days to heading in both E_1 and E_2, grain filling duration in E_2, peduncle length in both E_1 and E_2, 1000 seed weight in E_2, biological yield per plant in E_1 and harvest index in E_1, Likewise, generations (F_1's and F_2's) also showed significant differences for all the characters in both E_1 and E_2. The parent's *vs* generations were significant for most of the traits except grain filling duration in both E_1 and E_2, days to maturity in E_1, plant height in both E_1 and E_2, number of tillers per plant in E_2, 1000 grain weight in both E_1 and E_2 and biological yield per plant in both E_1 and E_2.

The mean and range in E_1 environment for most of the characters was higher than E_2. In general, the mean of the F_1s exceeded that of parental mean for all the characters except day to heading and days to maturity indicating existence of heterosis. Based on all the characters parent Raj 1482, Raj 3777, Raj 3765 and Raj 4120 were found to be superior with high mean values. Further, the crosses Raj 3777xRaj 4120, Raj 3765xRaj 3077, Raj MR-1xRaj 4120 and Raj 3765xRaj 4079 were found to be superior with high mean values.

The combining ability analysis in the individual environment revealed that the GCA and SCA variances were significant for all the characters in both the environments except GCA for flag leaf area and peduncle length in F_1 in E_2, while SCA for days to heading and days to maturity in E_2 for both F_1 and F_2, grain filling duration and 1000 grain weight in E_1 for both F_1 and F_2 and plant height and peduncle length in E_1 for both F_1 and F_2, indicated the importance of both additive and non-additive gene effects in the genetic control of the characters under study. These findings were in close agreement with those reported by Sharma and Singh (1990) [15], Joshi *et al.* (2002) [9], Ajmal *et al.* (2004) [3], Gothwal (2006) [6], Singh *et al.* (2007) [16], Akinci (2009) [4], Yao *et al.* (2011) [17], Houshmand and Vanda (2011), Pancholi *et al.* (2012) [11], Adel *et al.* (2013) [2] and Kalhoro *et al.* (2015).

The GCA: SCA ratio (predictability ratio) was less than unity in both the environments for all the characters under study except days to heading in E_1 for both F_1 and F_2, grain filling duration and plant height in E_1 for both F_1 and F_2 and number of tillers per plant in E_1 of F_1, where predictability ratio was more than unity, which showed preponderance of additive gene action. The results were in conformity with findings obtained by Joshi *et al.* (2002) [9], Pancholi *et al.* (2012) [11]

and Adel *et al.* (2013) [2], Mandal and Madhuri (2016) [10], Rajput, (2017) [13] Ali *et al.* (2018) [5] and Rajput and Khandalkar (2018) [14].

On the basis of GCA effects and *per se* performance over the environments, the parents Raj 4120 and Raj 3777 in E_1; Raj 3765, Raj 1482 and Raj 4120 in E_2 appeared as good general combiners for grain yield and some associated characters. An overall evaluation showed that the parent Raj 4120 in both the environments emerged as good general combiners for grain yield with simultaneous consideration of other characters. Hence, these parents could be intensively used in the hybridization programme to develop lines with several desirable characters for further tangible advancement of yield in wheat crop.

On the basis of SCA effects and *per se* performance, some crosses *viz.*, Raj 1482xRaj 4120, Raj 3777xRaj 4120 and Raj 1482xRaj 4120 in E_1 and Raj 3765xRaj 3777, Raj 1482xRaj 3777 and Raj 3765xRaj 4079 in E_2 appeared as good specific cross combinations for grain yield and some associated characters. These crosses have great potential for improvement of wheat and may be utilized in multiple crossing programmes.

An overall result based on the study of combining ability effects, revealed that the crosses Raj 1482xRaj 4120 and Raj 3765xRaj 3777 emerged as good specific cross combinations for grain yield in E_1 and E_2 environments, respectively. SCA effects of the 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. These crosses hold great promise in improving the grain yield in future breeding programme of wheat. The crosses involving good × good and good x poor general combiners may be utilized to develop purelines.

Table 1: Pooled analysis of variance showing mean sum of squares of parents, F_1's and F_2's for yield and its attributes

Source of variation	df	Days to heading	Grain filling duration (days)	Days to maturity	Plant height (cm)	No. of tillers per plant	Flag leaf area (cm²)	Peduncle length (cm)	Spike length (cm)	No. of grains per spike	1000-grain weight (g)	Biological yield per plant (g)	Grain yield per plant (g)	Harvest index (%)
Env.	1	12973.45**	8340.28**	42117.88**	25695.67**	512.45**	3282.86**	5569.61**	323.11**	4270.40**	10723.65**	4606.62**	1844.89**	2208.06**
Replication	4	1.73**	1.58	1.23	1.19	0.6**	0.37	0.44	0.04	3.02	1.77	1.55	0.29	1.10
Genotypes	99	6.58**	30.39**	23.15**	35.56**	1.02**	4.39**	7.16**	1.31**	27.70**	12.74**	79.10**	8.04**	32.56**
Parents	9	2.96	21.08**	26.82**	36.24**	0.68**	2.84*	2.82	0.67**	12.62**	2.86	25.19**	3.33**	9.10**
Generations	89	6.5**	31.51**	22.94**	35.85**	1.06**	4.13**	7.29**	1.33**	27.27**	13.75**	85.33**	8.34**	33.60**
F_1's	44	5.88**	26.87**	18.66**	34.28**	0.77**	3.87**	5.68*	1.34**	28.56**	8.03**	79.63**	5.59**	33.10**
F_2's	44	7.16**	35.21**	25.11**	36.91**	1.13**	2.69**	8.69**	1.24**	21.71**	17.11**	85.70**	6.61**	25.21**
F_1 vs F_2	1	4.82	73.34**	115.74**	58.48**	13.29***	78.92**	16.56*	5.03**	215.21**	117.70**	319.84**	205.73**	425.26**
Par. vs Geno.	1	45.92**	14.21	9.04	3.75	0.66**	41.36**	4.90**	4.77**	201.26**	11.55	10.01	24.05***	150.65**
F_1 Vs Parent	1	50.74**	1.02	37.35**	17.24	3.52**	77.63*	47.06**	7.61**	322.19**	42.10**	70.71**	81.00**	321.14**
F_2 Vs Parent	1	33.64**	38.14**	0.14	0.21	0.10	11.93**	19.42*	1.98**	82.87**	0.01	5.64	0.12	30.09**
Geno. x Env.	99	5.67**	18.00**	13.63**	42.85**	0.96**	5.36**	8.23**	1.17**	21.41**	11.49**	45.63**	5.44**	15.65**
Error	396	0.86	2.28	1.75	1.49	0.03	0.46	1.18	0.03	1.15	1.04	2.92	0.24	1.22

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

Table 2: Analysis of variance showing mean sum of squares in normal (E_1) and High temperature stress (E_2) for parents, F_1's and F_2's for yield and its attributes

Characters	Env.	Source of variation										
		Replications (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)	F_1 Vs Parent (1)	F_2 Vs Parent (1)	Error (198)
Days to heading	E_1	2.17	6.35**	3.57	6.41**	6.40**	6.45**	4.80	26.80**	31.32**	18.28**	2.02
	E_2	8.22	5.89**	4.58	5.87**	5.57**	6.29**	0.83	19.42*	20.05*	15.42*	3.17
Grain filling duration (days)	E_1	2.44	21.06**	23.94**	20.66**	20.92**	20.84**	1.79	30.51	23.64	32.15*	8.12
	E_2	7.02	27.33**	6.77	29.71**	22.75**	34.71**	116.03**	0.04	11.77	9.39	5.56
Days to maturity	E_1	3.37	17.30**	37.56**	15.44**	16.08**	14.86**	12.46	0.12	0.54	1.94	7.07
	E_2	0.01	19.42**	7.26*	20.71**	14.90**	23.88**	136.53**	21.16*	62.55**	0.74	3.40
Plant height (cm)	E_1	6.10	51.31**	87.29**	48.19**	47.76**	49.18**	23.70*	5.46	13.66	0.58	5.58
	E_2	0.83	27.10**	25.43**	27.57**	31.45**	23.52**	35.35**	0.16	4.74	1.99	3.39
Number of tillers per plant	E_1	0.12	1.20**	0.66**	1.26**	0.69**	1.34**	22.77**	0.38*	4.12**	0.72**	11.52
	E_2	0.22	0.79**	0.32**	0.84**	0.76**	0.94**	0.15	0.28	0.39*	0.15	0.07
Flag leaf area (cm²)	E_1	0.56	5.18**	4.04**	5.05**	3.64**	5.41**	51.29**	27.39**	51.11**	8.01*	1.24
	E_2	1.68	4.57**	3.12*	4.60**	4.10**	4.54**	29.18**	14.92**	28.21**	4.22	1.50
Peduncle length (cm)	E_1	2.28	6.50**	3.75	6.62**	4.93	8.26**	8.93	20.30*	27.00**	11.52	3.99
	E_2	0.37	8.89**	1.81	9.54**	7.54**	11.58**	7.65	14.82*	20.29	8.05	3.09
Spike length (cm)	E_1	0.01	1.15**	0.50**	1.17**	0.64**	1.59**	5.99**	4.76**	9.94**	1.80**	0.09
	E_2	0.25	1.33**	0.80**	1.39**	1.68**	1.11**	0.52*	0.82**	1.17**	0.42*	0.08
No. of grains per spike	E_1	0.08	19.98**	8.78**	20.36**	11.29**	28.01**	83.11**	86.26**	134.66**	37.29**	1.57
	E_2	17.89*	29.13**	17.78**	29.30**	37.11**	19.09**	135.26**	116.11**	189.90**	5.80**	5.32

1000-grain weight (g)	E_1	5.27	9.41**	5.72*	9.86**	7.65**	11.73**	24.11**	3.00	9.80	0.03	2.58
	E_2	5.38	14.82**	4.81	15.89**	8.70**	20.96**	108.85**	9.46	36.94**	0.05	3.68
Biological yield per plant (g)	E_1	5.01	58.73**	18.52	63.23**	38.38**	73.91**	686.89**	19.40	146.45**	13.71	9.87
	E_2	4.33	66.01**	21.74**	71.23**	73.64**	70.42**	0.84	0.01	0.04	0.12	7.68
Grain yield per plant (g)	E_1	1.53	8.34**	3.41**	8.71**	4.42**	8.11**	224.44**	19.12**	75.46**	0.12	0.91
	E_2	0.18	5.14**	1.81**	5.47**	5.40**	5.02**	28.12**	6.56**	16.33**	0.71	0.55
Harvest index (%)	E_1	6.62	14.82**	4.76	15.31**	15.12**	12.96**	126.95**	62.12**	119.07**	16.96*	4.27
	E_2	0.01	33.39**	6.89*	35.43**	30.49**	33.91**	320.29**	89.80**	208.26**	13.24*	3.06

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

Table 3: Means and ranges for different characters in parents, F_1s and F_2s in normal (E_1) and high temperature stress (E_2) environment

Characters	Env.	Parents		F1's		F2 's	
		Mean	Range	Mean	Range	Mean	Range
Days to heading	E_1	80.83	78.67-82.67	79.70	76.67-82.00	79.97	77.00-82.00
	E_2	71.40	69.67-73.67	70.50	66.67-73.33	70.61	66.00-73.00
Grain filling duration (days)	E_1	42.83	39.00-47.00	43.81	37.67-47.67	43.98	39.33-48.33
	E_2	36.37	34.33-38.33	35.67	30.33-41.33	36.99	32.00-45.67
Days to maturity	E_1	123.67	119.33-129.33	123.52	119.33-127.67	123.95	120.33-128.67
	E_2	107.77	104.67-109.33	106.17	101.33-110.67	107.59	103.00-114.67
Plant height (cm)	E_1	87.86	78.00-94.93	88.61	80.27-96.53	88.01	78.97-96.47
	E_2	75.11	70.73-80.20	75.55	69.67-81.87	74.82	68.10-79.00
Flag leaf area (cm^2)	E_1	22.42	20.15-24.04	23.86	21.86-25.98	22.99	20.62-26.21
	E_2	17.98	16.82-19.64	19.05	14.91-20.93	18.39	15.79-21.29
Number of tillers per plant	E_1	7.11	6.47-8.07	7.52	6.53-8.67	6.94	5.50-8.77
	E_2	5.28	4.80-5.80	5.41	4.67-7.07	5.36	4.43-6.70
Peduncle length (cm)	E_1	27.37	25.87-29.13	28.42	25.53-31.07	28.06	24.70-31.77
	E_2	21.39	19.80-22.47	22.30	17.27-25.07	21.97	17.83-26.00
Spike length (cm)	E_1	12.21	11.60-12.73	12.78	11.53-13.73	12.48	11.03-14.20
	E_2	10.97	10.27-11.80	11.19	9.87-13.00	11.10	9.90-12.50
Number of grains per spike	E_1	51.19	48.60-53.40	53.53	48.33-57.67	52.42	46.33-59.63
	E_2	45.59	41.60-49.33	48.37	42.33-55.07	46.96	41.23-53.53
1000- grain weight (g)	E_1	38.87	36.76-41.07	39.50	36.36-43.01	38.91	35.28-42.88
	E_2	30.18	28.30-31.57	31.41	27.91-35.71	30.14	24.89-34.91
Biological yield / plant (g)	E_1	36.59	32.77-41.34	39.03	33.49-49.47	35.84	27.01-49.68
	E_2	31.80	27.52-35.12	31.76	23.90-42.70	31.87	24.04-42.20
Grain yield / plant (g)	E_1	14.21	12.60-15.95	15.96	13.43-18.78	14.14	11.72-20.49
	E_2	11.02	9.66-11.82	11.83	9.77-15.61	11.19	9.19-13.83
Harvest Index (%)	E_1	38.87	37.25-40.93	41.07	37.64-45.51	39.70	35.90-43.73
	E_2	34.76	32.87-38.40	37.67	31.31-43.98	35.49	29.48-43.45

Table 4: Analysis of variance for general and specific combining ability in normal (E_1) and high temperature stress (E_2) environment for yield and its attributes

Characters	Env.	Source of variation							
		GCA (df = 9)		SCA (df = 45)		Error (df = 108)		GCA/SCA	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	E_1	2.69**	2.76**	2.02**	1.92**	0.76	0.61	0.13	0.14
	E_2	5.61**	6.52**	1.15	1.17	1.02	1.09	3.02	5.92
Grain filling duration(days)	E_1	27.04**	24.06**	3.18	3.81*	2.84	2.51	5.88	1.38
	E_2	12.97**	24.39**	5.36**	6.96**	1.49	2.20	0.25	0.39
Days to maturity	E_1	34.38**	30.32**	0.87	1.30	2.05	2.57	-2.28	-1.81
	E_2	8.26**	15.54**	4.15**	5.16**	0.99	1.23	0.19	0.30
Plant height (cm)	E_1	93.77**	97.03**	2.73	2.45	2.02	1.69	10.69	10.53
	E_2	26.02**	18.68**	6.78**	5.64**	1.24	0.97	0.37	0.32
Number of tillers per plant	E_1	1.07**	0.91**	0.09**	0.31**	0.03	0.02	1.65	0.26
	E_2	0.52**	0.56**	0.17**	0.22**	0.03	0.02	0.29	0.23
Flag leaf area (cm^2)	E_1	3.56**	4.61**	1.12**	1.17**	0.44	0.43	0.38	0.47
	E_2	0.69	1.26**	1.62**	1.47**	0.42	0.55	0.02	0.06
Peduncle length (cm)	E_1	6.82**	8.50**	0.69	1.33	0.85	1.71	-3.08	-1.47
	E_2	1.49	3.92**	2.43**	3.17**	0.97	1.05	0.03	0.11
Spike length (cm)	E_1	0.76**	0.78**	0.15**	0.41**	0.03	.03	0.52	0.16
	E_2	0.67**	0.54**	0.48**	0.31**	0.04	.02	0.12	0.15
Number of grains per spike	E_1	13.35**	13.54**	2.59**	7.28**	0.56	0.53	0.53	0.16
	E_2	26.79**	4.21*	9.33**	6.90**	1.93	1.66	0.28	0.04
1000-grain weight (g)	E_1	11.38**	13.78**	0.67	1.45*	0.87	0.88	-4.45	1.88
	E_2	6.97**	5.36**	2.03**	6.08**	1.11	1.32	0.53	0.07
Biological yield	E_1	35.56**	31.44**	7.72**	19.14**	3.34	3.25	0.61	0.15

per plant (g)	E_2	52.13**	39.77**	15.02**	16.45**	2.35	2.70	0.33	0.22
Grain yield per plant (g)	E_1	5.99**	3.12**	1.03**	2.25**	0.33	0.29	0.68	0.12
	E_2	4.86**	2.44**	1.03**	1.27**	0.17	0.19	0.46	0.17
Harvest index (%)	E_1	8.24**	5.82**	4.48**	3.50**	1.27	1.48	0.18	0.18
	E_2	4.52**	9.48**	11.04**	9.71**	1.07	0.95	0.03	0.08

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

Table 5: Top three of the parents, F_1's and F_2's for their mean values, GCA and SCA estimates in individual environment for yield and its attributes

Characters	Env.	High mean Parents	High mean		GCA		SCA	
			F_1	F_2	F_1	F_2	F_1	F_2
Days to heading	E_1	Raj 4120	Raj 3765xRaj 4120	Raj 3765xRaj 4079	Raj 3765	Raj 3765	Raj 4120xDPW 621-50	Raj 3077xRaj MR-1
		Raj 3765	Raj 1482xRaj 4120	Raj 3077xRaj MR-1	Raj 4120	Raj 4120	RajMR-1xDPW 621-50	Raj 3077xRaj 4238
		Raj MR-1, Raj 3077	Raj 3765xRaj 3777, Raj 3765xRaj 4079, Raj 3077xRaj 4079,Raj 4120xDPW 621-50, Raj 3765xRaj 3077	Raj 3077xRaj 4238	Raj 3077	Raj 3077	Raj 1482xRaj 4120	Raj 1482xRaj 4079
	E_2	Raj 3765	Raj 3765xWH 1105	Raj 3765xWH 1105	Raj 3765	Raj 3765	Raj MR-1xRaj 4120	Raj 3765xWH 1105
		Raj 3777	Raj 3077xRaj 4238	Raj 3077xRaj 4238	Raj 4238	WH 1105	Raj 3765xWH 1105	Raj 1482xDPW 621-50
		Raj 3077	Raj 4238xRaj 4079	Raj 3777xRaj 4238	WH 1105	Raj 4238	Raj 4238xRaj 4079	Raj MR-1xRj 4120
Grain filling duration (duration)	E_1	WH 1105	Raj 4120xDPW 621-50	Raj 3765xWH 1105	DPW 621-50	DPW 621-50	Raj 1482xRaj 4120	Raj 3077xRaj MR-1
		DPW 621-50	Raj MR-1xDPW 621-50	Raj 4120xDPW 621-50	WH 1105	WH 1105	Raj MR-1xDPW 621-50	Raj 3077xRaj 4238
		Raj 1482	Raj 4238xDPW 621-50, Raj 3777xDPW 621-50	Raj 1428xRaj 4120	Raj 3765	Raj 3765	Raj 4120xDPW 621-50	Raj 1482xRaj 4238
	E_2	Raj 3077	Raj MR-1xWH 1105	Raj 3765xWH 1105	WH 1105	WH 1105	Raj 4238xRaj 4079	Raj 3765xDPW 621-50
		WH 1105	Raj 4238xRaj 4079	Raj 3765xDPW 621-50	Raj 4238	Raj 4238	Raj 1482xRaj 4120	Raj MR-1xRaj 4079
		Raj 4238	Raj 3777xWH 1105	Raj MR-1xRaj 4079	Raj MR-1	Raj 3765	Raj MR-1xWH 1105	Raj 3765xWH 1105
Days to maturity	E_1	Raj MR-1	Raj MR-1xRaj 4120	Raj 3777xRaj MR-1	Raj 4120	Raj MR-1	DPW 621-50xWH 1105	DPW 621-50xWH 1105
		Raj 4120	Raj 3777xRaj 4120	Raj 4079xRaj 4120	Raj MR-1	Raj 3777	Raj MR-1xRaj 4238	Raj MR-1xRaj 4238
		Raj 1482	Raj 3077xRaj 4120	Raj 3077xRaj 3777	Raj 3777	Raj 4120	Raj 1482xRaj 4238	Raj 4079xRaj 4120
	E_2	Raj 3777	Raj 3077xDPW 621-50	Raj 3765xRaj 3077	Raj 3735	Raj 3777	Raj 3077xDPW 621-50	Raj 3765xRaj 3077
		Raj 4079	Raj 3777xRaj MR-1	Raj 3765xRaj 3777	Raj 4079	Raj 3077	Raj 3777xRaj MR-1	Raj 4238xRaj 4079
		Raj 3765	Raj 3765xRaj 4079	Raj 1482xRaj 3077	Raj 3777	Raj 4120	Raj 3077xRaj 4238	Raj 1482xRaj 3077
Plant height (cm)	E_1	Raj 3777	Raj 3777xRaj MR-1	Raj 3777xRaj MR-1	DPW 621-50	Raj 3777	Raj 3777xWH 1105	Raj 3777xWH 1105
		Raj MR-1	Raj 3777xRaj 4120	Raj 3777xRaj 4079	WH 1105	Raj MR-1	Raj 1482xDPW 621-50	Raj MR-1xDPW 621-50
		Raj 4079	Raj MR-1xRaj 4120	Raj MR-1xRaj 4238	Raj 4238	Raj 4120	Raj MR-1xRaj 4238	Raj 1482xRaj 4120
	E_2	DPW 621-50	DPW 621-50xWH 1105	Raj 4238xWH 1105	DPW 621-50	DPW 621-50	Raj 3765xRaj 4079	Raj 3077xRaj 3777
		Raj 3777	Raj 4079xDPW 621-50	Raj MR-1xWH 1105	Raj MR-1	WH 1105	Raj 3077xRaj 4238	Raj 4238xWH 1105
		Raj MR-1	Raj 3077xRaj MR-1	Raj 4079xDPW 621-50	WH 1105	Raj 4238	Raj 4238xWH 1105	Raj 3765xRaj 4238
No. of tillers per plant	E_1	Raj 3777	Raj 3777xRaj 4120	Raj 1482xRaj 4120	Raj 3777	Raj 3777	Raj 3077xWH 1105	Raj 1482xRaj 4120
		DPW 621-50	Raj 1482xRaj 3777	Raj 3077xRaj 3777	Raj 4120	Raj 4120	Raj 3765xDPW 621-50	Raj 4079xDPW 621-50
		Raj 4120	Raj 3777xDPW 621-50, Raj 3777xRaj 4238	Raj 3777xRaj MR-1	DPW 621-50	Raj 3077, DPW 621-50	Raj 3077xRaj 4238, Raj 3777xRaj 4120	Raj 4079xWH 1105
	E_2	Raj 3777	Raj 3765xRaj 3777	Raj 3765xRaj 3777	Raj 3777	Raj 3777	Raj 3765xRaj 3777	Raj 3765xRaj 3777
		Raj 4120	Raj 1482xRaj 3777	Raj 1482xRaj 3777	Raj 4079	Raj 3765	Raj 4079xDPW 621-50	Raj 4238xWH1105

		Raj 1482	Raj 4079xDPW 621-50	Raj 3777xRaj MR-1	Raj 4120	Raj 4120	Raj 1482xRaj 3777	Raj 1482xRaj 3777
Flag leaf area (cm^2)	E_1	Raj 1482	Raj 4079xRaj 4120	Raj 3765xRaj MR-1	Raj 1482	Raj 4238	Raj 4079xRaj 4120	Raj 1482xRaj 4120
		Raj 4238	Raj 4120xWH 1105	Raj 1482xRaj 4120	Raj 3765	Raj 1482	Raj 3765xRaj MR-1	Raj 3765xRaj MR-1
		DPW 621-50	Raj 3765xMR-1	Raj 3765xRaj 4238	Raj 4120	Raj 3765	Raj 4120xWH 1105	Raj 4238xWH 1105
	E_2	Raj 3077	Raj 3777xRaj 4238	Raj 4079xRaj 4120	Raj 4079	Raj 3077	Raj 3077xRaj 4238	Raj 409xRaj 4120
		Raj 4079	Raj 1482xRaj 3765	Raj 3777xRaj MR-1	Raj 3777	Raj 3777	Raj 3765xWH 1105	Raj 3777xRaj MR-1
		Raj 1482	Raj 3777xRaj 4120	Raj MR-1xRaj 4079	Raj 4120	Raj 3765	Raj1482xRaj 3765	Raj 1482xWH 1105
Peduncle length (cm)	E_1	Raj 1482	Raj 1482xRaj 4238	Raj 3765xRaj 4238	Raj 4238	Raj 4238	Raj 4079xRaj 4120	Raj 3765xRaj 4238
		Raj 4238	Raj 3765xRaj 4238	Raj 1482xDPW 621-50	Raj 1482	Raj 1482	Raj 3765xRaj 4238	Raj 4079xRaj 4120
		DPW 621-50	Raj 1482xDPW 621-50	Raj 1482xWH 1105	DPW 621-50	DPW 621-50	Raj 3777xRaj 4238	Raj 1482xWH 1105
	E_2	Raj 3765	Raj 3765xRaj 4120	Raj 1482xRaj MR-1	Raj 1482	Raj 4079	Raj MR-1xRaj 4079	Raj 1482xRaj MR-1
		Raj 1482	Raj MR-1xRaj 4079	Raj 4079xDPW 621-50	DPW 621-50	Raj 3777	Raj 3765xRaj 4120	Raj 3077xRaj 3777
		Raj 3077	Raj 1482xRaj 3765	Raj 3077xRaj 3777	Raj 4120	Raj 1482	Raj 4238xWH 1105	Raj 4079xDPW 621-50
Spike length (cm)	E_1	Raj 4238	Raj 4238xRaj 4120	Raj 1482xRaj 4120	Raj 3777	Raj 4079	Raj 4238xRaj 4120	Raj 3077xRaj 3777
		Raj 3777	Raj 1482xRaj 4120	Raj 3777xRaj 4079	Raj 4238	Raj 4120	DPW 621-50xRaj 4120	Raj 1482xRaj 4120
		Raj 1482	Raj 3777xRaj 4120	Raj 3077xRaj 3777	Raj 4120, Raj 1482	Raj 4238	Raj 3777xRaj 4079	Raj 4079xDPW 621-50
	E_2	Raj 4079	Raj MR-1xRaj 4120	Raj MR-1xRaj 4120	Raj 4079	Raj 3765	Raj MR-1xRaj 4120	Raj MR-1xRaj 4120
		Raj 3765	Raj 4079xRaj 4120	Raj 4079xRaj 4120	Raj 3765	Raj 4120	Raj 3765xRaj 3777	Raj MR-1xDPW 621-50
		Raj 1482	Raj 3765xRaj 3777	Raj 3077xRaj 4120	Raj 4120	Raj 4079	Raj 1482xRaj 4238	Raj 1482xRaj 4238
Number of grains per spike	E_1	Raj 4238	Raj 4238xRaj 4120	Raj 1482xRaj 4120	Raj 4238	Raj 4079	Raj 4238xRaj 4120	Raj 3077xRaj 3777
		Raj 3777	Raj 1482xRaj 4120	Raj 3777xRaj 4079	Raj 3777	Raj 4120	Raj 3777xRaj 4079	Raj 1482xRaj 4120
		Raj 4120	Raj 3777xRaj 4120	Raj 3077xRaj 3777	Raj 4120	Raj 4238	DPW 621-50xWH 1105	Raj 4079xDPW 621-50
	E_2	Raj 4079	Raj 3765xRaj 3777	Raj MR-1xRaj 4120	Raj 3765	Raj 4120	Raj MR-1xRaj 4120	RajMR-1xRaj 4120
		Raj 3765	Raj 1482xRaj 3765	Raj 4079xRaj 4120	Raj 1482	Raj 4079	Raj 3765xRaj 3777	Raj MR-1xDPW 621-50
		Raj 1482	Raj MR-1xRaj 4120	Raj 1482xRaj 3777	Raj 4079	Raj 3765	Raj MR-1xDPW 621-50	Raj 1482xRaj 4238
1000-grain weight (g)	E_1	Raj MR-1	Raj MR-1xRaj 4079	Raj MR-1xRaj 4120	Raj MR-1	Raj MR-1	Raj 3765xRaj 4079	Raj 3765xRaj 4238
		Raj 4079	Raj 3765xRaj 4079	Raj MR-1xRaj 4079	Raj 4079	Raj 4079	Raj 4238xWH 1105	Raj 1482xRaj 4079
		WH 1105	Raj MR-1xRaj 4120	Raj 4079xRaj 4120	Raj 4120	Raj 4120	Raj 3765xRaj 4238	Raj 4120xRaj 4079
	E_2	Raj 3765	Raj 3765xRaj 4079	Raj 4079xRaj 4120	Raj 3765	Raj 4238	Raj 3077xRaj 4079	Raj 3777xRaj MR-1
		Raj 3777	Raj 3765xRaj 4120	Raj 3777xRaj MR-1	Raj 3077	Raj 4120	Raj 3765xRaj 4079	Raj 4079xWH 1105
		Raj 1482	Raj 3077xRaj 4079	Raj 3077xRaj 4120	Raj 1482	Raj 3765	Raj 3765xRaj 4120	Raj 4079xRaj 4120
Biological yield per plant (g)	E_1	Raj 3777	Raj 3777xRaj 4120	Raj 1482xRaj 4120	Raj 3777	Raj 3777	Raj 3777xRaj 4120	Raj 1482xRaj 4120
		Raj 1482	Raj MR-1xRaj 4120	Raj 4079xDPW 621-50	Raj 4120	Raj 4120	Raj 3765xRaj 4238	Raj 4079xDPW 621-50
		Raj 4120	Raj 1482xRaj 3777	Raj 3777xRaj 4120	Raj 3765	Raj 4079	Raj MR-1xRaj 4120	Raj 3765xRaj 3077
	E_2	Raj 3777	Raj 3077xRaj 4079	Raj 3765xRaj 4120	Raj 3765	Raj 4120	Raj 3077xRaj 4079	Raj MR-1xWH 1105
		Raj 3077	Raj 3777xWH 1105	Raj 3077xRaj 4120	Raj 4079	Raj 3765	Raj 3777xWH 1105	Raj 4238xWH 1105
		Raj 4120	Raj 3765xRaj 4238	Raj 4238xWH 1105	Raj 1482	Raj 3777	Raj 3765xRaj 4238	Raj 3765xRaj 4120
Grain yield per plant (g)	E_1	Raj 3777	Raj 3777xRaj 4120	Raj 1482xRaj 4120	Raj 4120	DPW 621-50	Raj 3765xRaj 4238	Raj 1482xRaj 4120
		Raj 4120	Raj 1482xRaj 4120	Raj 3077xRaj 3777	Raj 3777	WH 1105	Raj 3777xRaj 4079	Raj 4079xDPW 621-50
		Raj 4238	Raj 4238xRaj 4120	Raj 4079xDPW 621-50	Raj 4238	Raj MR-1	Raj MR-1xRaj 4120	Raj 3077xRaj 3777
	E_2	Raj 1482	Raj 3765xRaj 3777	Raj 4079xRaj 4120	Raj 3765	Raj 4120	Raj 3765xRaj 3777	Raj 3777xRaj MR-1
		Raj 3765	Raj 1482xRaj 3777	Raj 3777xRaj MR-1	Raj 1482	Raj 3777	Raj 3077xRaj 4079	Raj 4079xRaj 4120
		Raj 3077	Raj 3765xRaj 4079	Raj 3765xRaj 3777	Raj 4079	Raj 3765	Raj MR-1xRaj 4120	Raj 3077xRaj 4079
Harvest index (%)	E_1	Raj 4238	Raj 3077xRaj 4238	Raj 1482xDPW 621-50	Raj 4238	Raj 4238	Raj 3077xRaj 3777	Raj 3077xRaj 4120
		Raj 3765	Raj 1482xDPW 621-50	Raj 3765xDPW 621-50	DPW 621-	DPW 621-	Raj 1482xDPW	Raj 3765xDPW 621-

					50	50	621-50	50
		Raj 4120	Raj 3077xRaj 3777	Raj 4238xDPW 621-50	Raj 3077	Raj 1482	Raj 3077xRaj 4120	Raj 1482xDPW 621-50
	E_2	Raj 4238	Raj 1482xRaj 4238	Raj 4238xDPW 621-50	Raj 4238	Raj 1482	Raj 1482xRaj 4238	Raj 4238xDPW 621-50
		Raj 1482	Raj 3077xRaj 4120	Raj 1482xRaj 4238	Raj 3077	DPW 621-50	Raj 3077xRaj 4120	Raj 3077xRaj MR-1
		Raj 3765	Raj 4238xRaj 4079	Raj 3077xRaj MR-1	DPW 621-50	Raj 4079	Raj 4238xRaj 4120	Raj 4120xWH 1105

Conclusion

It may be concluded that for improving wheat, both additive and dominant gene action have to be exploited by adopting adequate breeding strategies *viz.*, biparental mating, diallel selective mating and reciprocal recurrent selection.

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