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Genetic Analysis of Grain Yield, Its Components and Quality Parameters in Durum Wheat (*Triticum durum* desf.) Over Environments

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ABSTRACT

Forty five hybrids developed by diallel mating design excluding reciprocals along with ten parents were studied for the estimation of combining ability variances and its effects. The analysis of variance for combining ability revealed that mean square values due to parents were significant for all the characters except for kernel length. Likewise, mean square values due to hybrids were significant for all the characters except for spike density and kernel length which revealed that existence of differences among the parents and hybrids. Significance of both σ^2_{GCA} and σ^2_{SCA} for the characters days to 50% heading, days to maturity, length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, spike density, protein content and sedimentation value suggested that importance of both additive and non-additive gene effects for the inheritance of these characters. The estimates of potence and predictability ratio revealed preponderance of additive genetic variance for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main and spike, density. The value of average degree of dominance was less than one for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main spike and spike density which revealed partial dominance behaviour of interacting alleles for these characters. The parent GW 2002-51 was good general combiner for the characters length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, protein content and sedimentation value. Whereas, the crosses GW 2007-77 x GW 1276 and HI 8725 x GW 1 were good specific combiners for days to 50% heading, days to maturity, plant height, number of effective tillers per plant, peduncle length, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, grain yield per plant, test weight, biological yield per plant, and spike density.

Key words: *Combining ability, Diallel, GCA, SCA and Wheat*

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INTRODUCTION

Wheat is one of the ancient staple food grain crop consumed by human beings. It is believed that cultivated form of wheat have been evolved from wild diploid species of *Triticum boeoticum sub sp. aegilopoides* to produce *T. monococcum* (einkorn wheat 2n = 2x = 14) and wild tetraploid *T. dicoccoides* to produce *T. dicoccum* (emmer wheat 2n = 4x = 28). The hexaploid wheats (*Triticum aestivum* L. 2n = 6x = 42) were the last to evolve and are grouped as bread/ common/ modern wheat. Wheat belongs to family: *poaceae* (syn. *gramineae*), tribe: *triticeae,* sub tribe: *triticinea* and genus: *triticum.*

Wheat is highly self-pollinated crop with cross pollination ranges from 0.5 to 1.0 per cent. Wheat inflorescence is known as ear or head spike. Ear consist of many lateral spikelets and a single terminal spikelet. The most widely cultivated species is *Triticum aestivum* L. (Bread wheat), which accounts for more than 90 per cent of area in the country. *Triticum durum* Desf. (Macaroni wheat) is commonly grown in central and peninsular India; while, *Triticum dicoccum* L. (Emmer wheat) is grown in limited scale in Karnataka, Maharashtra, Gujarat and Tamil Nadu. In the world, durum wheat varieties are mainly cultivated in Central India, Southern USSR, Mediterranean countries, East Africa, Argentina, Chille, United States of America and Canada. Presently, India is the second largest wheat producing country in the world next to China. Globally durum or macaroni wheat is grown in about 30 million hectares and accounts for almost 8 per cent of total world wheat production. In India, the major wheat growing states are Uttar Pradesh, Punjab, Haryana, Gujarat, Rajasthan, West-Bengal and Uttarakhand. In Gujarat, the irrigated wheat is mostly grown in the districts of Ahmedabad, Junagadh, Rajkot, Sabarkatha and Kheda; whereas, unirrigated wheat is mostly grown in the districts of Ahmedabad, Anand, Bhavnagar, Surendranagar, Bharuch, Patan and Dahod. The uniqueness of wheat in contrast to other cereals is that wheat contains gluten protein which enables leavened dough to rise by forming minute gas cells and this property enables bakers to produce light breads. In addition to these, wheat is sown to a limited extent as a forage crop, and the straws can be used as fodder. Bread wheat is mostly preferred for making chapaties/breads because of its binding properties of gluten; whereas, durum wheat is highly valued for preparation of macaroni, spaghetti, vermicelli and noodles. Macaroni wheats till recently were confined to only rainfed areas of Central and Penisular India. However, being responsive to higher fertilizer application and development of rust resistant high yielding varieties encouraged cultivation of durum wheat under irrigated conditions. Combining ability study in self-pollinated crops is regarded useful to select parents with better nicking ability, which on crossing would produce more desirable recombinants. Such studies also elucidate the nature and magnitude of gene effects for an inheritance of grain yield and its component characters.

MATERIAL AND METHODS

The experimental materials consisted of ten genetically diverse parental lines including GW 2002-51, GDW 1255, GW 2007-77, GW 2007-112, GW 1276, GW 1277, GW 2007-54, HI 8725, GW 1 and Arnej 206 were crossed in a diallel mating design excluding reciprocals. The resulting 55 genotypes (45 hybrids and 10 parents) were grown in Randomized Complete Block Design with three replications. The investigation was carried out at Regional Research Station, AAU, Anand during *Rabi* 2012-13. Each genotype was grown in a single row of 5.0 cm length with 22.50 x 10 cm^2 spacing. Observation for different quantitative characters under study excluding phonological trait like days to 50% heading and days to maturity were recorded on five randomly selected competitive plants in each experimental unit; however, phonological traits were recorded on population of an experimental unit. Whereas, quality parameters were estimated as a random sample of seeds were taken from bulk seeds harvested from five selected plants of each replication of the experiment and analysed using Fourier Transform-Near Infrared Reflectance Spectroscopy (FT-NIRS). The mean values of analysis of variance and the estimation of combining ability variances and its effects for all the characters of parents and their hybrids were analysed as per Model-1, Method-2 of Griffing[4,5] while, the magnitude of GCA and SCA variances were estimated as

(a) Potence ratio: $\frac{1}{\text{d.f.}}\ \hat{\sigma}^2 gca \,/\, \frac{1}{\text{d.f.}}\ \hat{\sigma}^2_{sca}$ [11]

(b) Predictability ratio: $2\ \hat{\sigma}^2 gca \,/\, (2\hat{\sigma}^2 gca + \hat{\sigma}^2_{sca})^2$

RESULTS AND DISCUSSION

The analysis of variance for combining ability pooled over the environments (Table 1) revealed that mean square values due to parents were significant for all the characters except for kernel length. Likewise, mean square values due to hybrids were significant for all the characters except for spike density and kernel length which revealed that existence of differences among the parents and hybrids.

The interaction variance resulted from GCA x environments and SCA x environments were significant for all the characters except GCA x environments and SCA x environments for number of spikelets per main spike, number of grains per main spike and kernel length, and SCA x environments for spike density as well as hectolitre weight, which revealed that estimates of both σ^2gca and σ^2sca were influenced by environments.

The perusal estimates of σ^2gca and σ^2sca revealed that both additive and non-additive gene effects were involved for inheritance of days to 50% heading, days to maturity, length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, spike density, protein content and sedimentation value. The result was in conformity with reports of Perenzin *et al.*[10], Budak[3], Singh and Singh[15], Joshi *et al.*[6], Saeed *et al.*[12], Kumar[7] and Singh *et al*[16]. The estimates of only σ^2sca were significant for the characters plant height, number of effective tillers per plant, peduncle length, grain yield per plant, biological yield per plant, harvest index, hectolitre weight, specific sedimentation volume and β carotene revealing importance of only non additive gene effect and the finding confirmed the reports of Singh *et al.*[17], Sanjeev *et al.*[13], Singh *et al.*[14], Mahpara *et al.*[8], Allah *et al.*[1], Nazeer *et al.*[9] and Kumar[7]. While, for the character kernel length none of the components of genetic variance had significant estimate, which could be because of absence of sufficient genic variability among the parental genotypes and/or possibility for more complicated bahaviour of genes for inheritance of this character.

However, the magnitude of either of component of genetic variance could be judged from their potence ratio and predictability ratio; when, both the components σ^2gca and σ^2sca had significant estimates, the said parameters/ratio were worked out. The above one estimate of potence ratio and above 0.5 value of predictability ratio for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main spike and spike density revealed preponderance of additive genetic variance. Whereas, below one value of potence ratio and less than one half value of predictability ratio for the characters grain yield per main spike, test weight, protein content and sedimentation value suggested preponderance of non-additive genetic variance. The result was in conformity with report of Kumar[7].

The characters plant height, length of main spike, grain yield per main spike, test weight, harvest index, hectolitre weight, specific sedimentation volume, protein content, sedimentation value and β carotene had above one value of average degree of dominance, which revealed over dominance behaviour of interacting alleles was evidenced. The value of average degree of dominance was less than one for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main spike and spike density which revealed partial dominance behaviour of interacting alleles for these characters. Whereas, for the character kernel length the value of average degree of dominance was close to zero, it revealed absence of dominance for the character and the finding confirmed the report of Kumar[7].

The general combining ability effect of the parents and specific combining ability effect of the crosses were estimated for those characters, which had significant value of respective variance of the combining ability analysis. The parents having significant GCA effect in desired direction, non-significant GCA effect and significant GCA effect in undesired direction were classified as good, average and poor general combiner, respectively. Accordingly, crosses were also classified as good, average and poor specific combiner. The GCA effect of the parents varied from -3.30 (GW 1276) to 2.40 (GDW 1255) for days to 50% heading, -4.50 (GW 2007-54) to 3.49 (GDW 1255) for days to maturity, -0.31 (GW 2007-77) to 0.23 (GW 2002-51) for length of main spike, -0.49 (GW 2007-54) to 0.59 (GW 2007-112) for number of spikelets per main spike, -1.92 (GW 2007-54) to 1.93 (GDW 1255) for number of grains per main spike, -0.15 (Arnej 206) to 0.22 (GW 2002-51) for grain yield per main spike, -2.70 (HI 8725) to 4.47 (GW 2007-77) for test weight, -0.08 (GW 1276) to 0.09 (GW 1277) for spike density, -0.43 (GW 1276) to 0.39 (GW 2002-51) for protein content and -3.06 (GDW 1255) to 2.14 (GW 1) for sedimentation value. Among the parents, parent GW 2002-51 was good general combiner for the characters length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, protein content and sedimentation value, parent GW 2007-112 for number of spikelets per main spike, number of grains per main spike, grain yield per main spike, spike density and protein content, parent GW 1277 for number of spikelets per main spike, number of grains per main spike, grain yield per main spike and spike density, parent GW 1 for days to 50% heading, days to maturity, length of main spike and sedimentation value, parent GDW 1255 for length of main spike, number of spikelets per main spike and number of grains per main spike, parent GW 2007-77 for grain yield per main spike, test weight and spike density, parent GW 1276 for days to 50% heading, days to maturity and test weight, parent GW 2007-54 for days to 50% heading, days to maturity and sedimentation value, parent HI 8725 for spike density and sedimentation value and parent Arnej 206 for days to maturity and protein content (Table 2). Most of the parents had relatively high degree of correspondence between *per se* performance and their GCA effects for majority of the characters, which could be because of existence of genes showing additivity and *pseudo* additive gene effects. Therefore, in selection of parents for hybridization work, equal importance should be given to their *per se* performance along with GCA effects.

The information pertaining to different aspects of SCA effect pooled over the environments was presented in Table 3. The SCA effect of the crosses varied from -3.26 (GDW 1255 x GW 2007-54) to 3.13 (GW 2002-51 x GW 2007-112) for days to 50% heading, -7.97 (GDW 1255 x GW 2007-54) to 5.99 (GW 1277 x HI 8725) for days to maturity, -5.06 (GW 1 x Arnej 206) to 6.39 (GW 2007-112 x Arnej 206) for plant height, -1.25 (GDW 1255 x GW 2007-54) to 2.50 (GW 2002-51 x GW 1) for number of effective tillers per plant, -0.47 (GW 2002-51 x GDW 1255) to 0.72 (GW 2002-51 x GW 1) for length of main spike, -2.51 (GW 2007-77 x HI 8725) to 3.11 (GW 1 x Arnej 206) for peduncle length, -1.01 (GW 2007-77 x GW 2007-54) to 1.31 (GDW 1255 x GW 1) for number of spikelets per main spike, -3.59 (GW 2007-77 x GW 2007-54) to 4.76 (GDW 1255 x GW 1) for number of grains per main spike, -0.46 (GW 2007-77 x GW 2007-54) to 0.51 (GW 2007-77 x Arnej 206) for grain yield per main spike, -1.33 (GW 2007-77 x GW 2007-54) to 2.78 (GW 2002-51 x GW 1) for grain yield per plant, -9.27 (GW 2002-51 x GW 1276) to 11.56 (GW 2002-51 x GW 1) for test weight, -1.88 (GW 2007-77 x GW 2007-54) to 4.55 (GW 2002-51 x GW 1) for biological yield per plant, -2.63 (GW 2007-112 x GW 1) to 3.06 (GW 1277 x HI 8725) for harvest index, -0.19 (GW 2007-77 x GW 2007-54) to 0.17 (GW 2002-51 x GW 2007-54) for spike density, -1.85 (GW 2002-51 x GW 2007-112) to 1.76 (GW 1277 x GW 2007-54) for hectolitre weight, -0.79 (GW 2007-77 x GW 1277) to 0.35 (GW 2002-51 x GW 2007-54) for specific sedimentation volume, -1.63 (GW 2002-51 x GW 2007-54) to 1.19 (GW 2007-77 x GW 2007-54) for protein content, -8.77 (GW 2007-77 x GW 1277) to 4.71 (GDW 1255 x HI 8725) for sedimentation value and -0.38 (GW 2002-51 x GW 1276) to 0.39 (GW 2007-112 x HI 8725) for β carotene.

Among the crosses, crosses GW 2007-77 x GW 1276 and HI 8725 x GW 1 were good specific combiners for days to 50% heading, days to maturity, plant height, number of effective tillers per plant, peduncle length, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, grain yield per plant, test weight, biological yield per plant and spike density. For grain yield per plant, crosses GW 2002-51 x GW 1 (2.78**), GW 2007-77 x GW 1277 (2.57**) and GW 1276 x HI 8725 (2.39**) had higher SCA estimates, and all these crosses were good/average specific combiners for rest of the characters. Therefore, these crosses may be given due weightage in crop improvement work. In most of the crosses, the involvement of either one or both the parents with significant GCA effect, contributed to significant SCA effect for the crosses, indicating the occurrence of additive gene action in such crosses. The crosses which involved at least one good general combiner parent would produce transgressive segregants. However, for full exploitation of existing genetic variance in these crosses, intermating of elite plants in the early segregating generations would be profitable to built up elite population for early and dwarf plants with high grain yield.

Table 1: Analysis of variance for combining ability pooled over the environments for the different characters

Source of variation	Days to 50% heading	Days to maturity	Plant height	Number of effective tillers per plant	Length of main spike
Environments	107.97**	4882.53**	208.10**	213.61**	10.06**
Parents	142.03**	215.24**	60.36**	1.41*	1.19**
Hybrids	8.70**	27.22**	44.74**	2.79**	0.33**
Pooled error	1.32	2.36	4.60	0.60	0.09
σ^2_{GCA} ($\sum g_i^2$)	11.11*	15.67*	1.30	-0.12	0.07*
σ^2_{SCA} ($\sum\sum s_{ij}^2$)	7.38*	24.86*	40.14*	2.19*	0.24*
GCA x Environments	6.76**	25.43**	13.45**	2.46**	0.35**
SCA x Environments	4.45**	15.15**	7.87**	2.40**	0.13**
Potence ratio	7.53	3.15	-	-	1.52
Predictability ratio	0.75	0.56	-	-	0.38
σ^2A	22.22	31.34	2.60	-0.23	0.14
σ^2D	7.38	24.86	40.14	2.19	0.24
$(\sigma^2D/\sigma^2A)^{0.5}$	0.58	0.89	3.93	-1.40	1.28

Cont……

Source of variation	Peduncle length	Number of spikelets per main spike	Number of grains per main spike	Grain yield per main spike	Grain yield per plant
Environments	16.05**	4.86**	41.20**	0.39**	189.62**
Parents	12.82**	7.16**	82.33**	0.50**	2.88**
Hybrids	14.82**	1.11**	14.57**	0.21**	4.11**
Pooled error	2.08	0.36	6.09	0.007	1.07
σ^2_{GCA} ($\sum g_i^2$)	-0.17	0.50*	5.65*	0.02*	-0.10
σ^2_{SCA} ($\sum\sum s_{ij}^2$)	12.74*	0.75*	8.48*	0.20*	3.04*
GCA x Environments	5.84**	0.49	8.28	0.39**	2.62**
SCA x Environments	2.86*	0.41	6.76	0.27**	3.57**
Potence ratio	-	3.36	3.33	0.59	-
Predictability ratio	-	0.57	0.57	0.19	-
σ^2A	-0.33	1.01	11.29	0.05	-0.21
σ^2D	12.74	0.75	8.47	0.20	3.04
$(\sigma^2D/\sigma^2A)^{0.5}$	-3.52	0.86	1.22	2.05	-1.68

Cont……

Source of variation	Test weight	Biological yield per plant	Harvest index	Spike density	Kernel length
Environments	375.94**	693.97**	213.08**	0.50**	0.76**
Parents	195.03**	4.73**	6.05*	0.15**	0.07
Hybrids	80.65**	9.06**	5.30**	0.02	0.07
Pooled error	3.86	2.10	2.88	0.01	0.50
σ^2_{GCA} ($\sum g_i^2$)	9.53*	-0.36	0.06	0.01*	0.00
σ^2_{SCA} ($\sum\sum s_{ij}^2$)	76.80*	6.95*	2.42*	0.01*	0.02
GCA x Environments	48.76**	5.93**	12.12**	0.03*	0.05
SCA x Environments	46.30**	6.95**	7.69**	0.02	0.06
Potence ratio	0.62	-	-	11.43	-
Predictability ratio	0.20	-	-	0.82	-
σ^2A	19.06	-0.72	0.12	0.02	0.00
σ^2D	76.80	6.95	2.42	0.01	0.02
$(\sigma^2D/\sigma^2A)^{0.5}$	2.01	-2.50	4.42	0.23	0.00

Cont……

Source of variation	Hectolitre weight	Specific sedimentation volume	Protein content	Sedimentation value	β carotene
Environments	0.83	8.83**	2.98**	2628.18**	0.76**
Parents	3.12*	0.28**	3.30**	77.15**	0.23**
Hybrids	2.58**	0.14**	1.31**	26.25**	0.12**
Pooled error	1.31	0.03	0.30	1.33	0.01
σ^2_{GCA} ($\sum g_i^2$)	0.05	0.01	0.17*	4.24*	0.01
σ^2_{SCA} ($\sum\sum s_{ij}^2$)	1.27*	0.11*	1.01*	24.92*	0.12*
GCA x Environments	2.58*	0.19**	0.99**	31.70**	0.21**
SCA x Environments	1.55	0.12**	0.98**	21.37**	0.14**
Potence ratio	-	-	0.82	0.85	-
Predictability ratio	-	-	0.25	0.25	-
σ^2A	0.09	0.02	0.33	8.48	0.02
σ^2D	1.27	0.11	1.01	24.92	0.12
$(\sigma^2D/\sigma^2A)^{0.5}$	3.76	2.17	1.74	1.71	2.73

Peduncle length = Measure from base (collar) of the spike to the first node on spike
Biological yield per plant = Sum of fodder yield and grain yield
Harvest index (%) = Grain yield per plant / Total Biological yield per plant **X** 100
Spike density = Number of spikelets per main spike **/** Length of main spike
Test weight = Weight of 1000 grains
Hectolitre weight = It was measured by physical instrument and obtained value was multiplied by 1.05.
Specific sedimentation volume = Sedimentation value / Protein content

Table 2: Estimates of general combining ability effect of parents pooled over the environments for the different characters

Sr. No.	Parents	Days to 50% heading	Days to maturity	Length of main spike	Number of spikelets per main spike	Number of grains per main spike	Grain yield per main spike
1	GW 2002-51	1.91** **P** (67.33)	0.96** **P** (110.78)	0.23** **G** (7.23)	0.28** **G** (15.13)	1.09** **G** (44.49)	0.22** **G** (2.07)
2	GDW 1255	2.40** **P** (70.33)	3.49** **P** (119.56)	0.16** **G** (7.64)	0.55** **G** (16.22)	1.93** **G** (46.64)	0.02 **A** (2.33)
3	GW 2007-77	0.28 **A** (67.89)	0.44 **A** (113.67)	-0.31** **P** (6.55)	-0.25* **P** (15.62)	-0.69 **A** (46.60)	0.12** **G** (2.44)
4	GW 2007-112	1.35** **P** (66.67)	2.42** **P** (114.22)	0.06 **A** (6.93)	0.59** **G** (16.16)	1.77** **G** (47.39)	0.03* **G** (2.01)
5	GW 1276	-3.30** **G** (59.44)	-2.91** **G** (105.78)	0.04 **A** (7.31)	-0.47** **P** (14.69)	-1.66** **P** (42.07)	0.02 **A** (2.10)
6	GW 1277	1.25** **P** (68.11)	1.42** **P** (111.89)	-0.02 **A** (6.85)	0.55** **G** (16.29)	1.80** **G** (47.58)	0.04** **G** (2.10)
7	GW 2007-54	-3.20** **G** (58.11)	-4.50** **G** (102.33)	-0.13* **P** (6.86)	-0.49** **P** (14.58)	-1.92** **P** (43.02)	-0.11** **P** (2.12)
8	HI 8725	0.66** **P** (66.89)	1.06** **P** (110.89)	-0.27** **P** (6.76)	-0.25* **P** (15.00)	-1.02* **P** (43.36)	-0.13** **P** (1.94)
9	GW 1	-1.03** **G** (61.67)	-1.15** **G** (103.56)	0.15** **G** (6.65)	-0.13 **A** (14.16)	-0.15 **A** (41.49)	-0.06** **P** (1.54)

10	Arnej 206	-0.31 **A** (66.00)	-1.23** **G** (108.33)	0.07 **A** (6.57)	-0.38** **P** (14.36)	-1.15** **P** (40.87)	-0.15** **P** (1.57)
Range	**Min.**	-3.30	-4.50	-0.31	-0.49	-1.92	-0.15
Max.		2.40	3.49	0.23	0.59	1.93	0.22
SE (g_i)±		0.19	0.25	0.05	0.10	0.41	0.01
C. D. 5%		0.37	0.49	0.10	0.19	0.79	0.03
SE (g_i-g_j)±		0.28	0.38	0.08	0.15	0.61	0.02
C.D. 5 % (g_i-g_j)		0.56	0.74	0.15	0.29	1.20	0.04
Positive		06	06	06	04	04	06
Positive significant		05	05	03	04	04	04
Negative		04	04	04	06	06	04
Negative significant		03	04	03	05	04	04

Cont….

Sr. No.	Parents	Test weight	Spike density	Protein content	Sedimentation value
1	GW 2002-51	3.22** **G** (51.73)	-0.03 **A** (2.12)	0.39** **G** (17.24)	1.15** **G** (59.97)
2	GDW 1255	-1.01** **P** (38.47)	0.02 **A** (2.15)	-0.31** **P** (15.24)	-3.06** **P** (53.52)
3	GW 2007-77	4.47****G** (51.27)	0.06** **G** (2.40)	0.10 **A** (15.45)	-0.56** **P** (56.59)
4	GW 2007-112	-1.44** **P** (38.92)	0.06** **G** (2.34)	0.33** **G** (17.42)	0.06 **A** (59.16)
5	GW 1276	1.05** **G** (45.87)	-0.08** **P** (2.02)	-0.43** **P** (13.92)	-1.31** **P** (51.23)
6	GW 1277	-0.53 **A** (34.95)	0.09** **G** (2.40)	-0.05 **A** (16.41)	-0.17 **A** (58.83)
7	GW 2007-54	0.49 **A** (47.86)	-0.03 **A** (2.15)	-0.20* **P** (15.59)	1.34** **G** (58.92)
8	HI 8725	-2.70** **P** (43.14)	0.05* **G** (2.23)	-0.32** **P** (15.14)	0.39* **G** (57.11)
9	GW 1	-1.97** **P** (35.97)	-0.06** **P** (2.14)	0.16 **A** (15.39)	2.14** **G** (57.59)
10	Arnej 206	-1.59** **P** (37.46)	-0.08** **P** (2.20)	0.32** **G** (16.12)	0.02 **A** (56.50)
Range	**Min.**	-2.70	-0.08	-0.43	-3.06
Max.		4.47	0.09	0.39	2.14
SE (g_i)±		0.32	0.02	0.09	0.19
C. D. 5%		0.63	0.04	0.18	0.37
SE (g_i-g_j)±		0.48	0.03	0.13	0.28
C.D. 5 % (g_i-g_j)		0.95	0.06	0.27	0.59
Positive		04	05	05	06
Positive significant		03	04	03	04
Negative		06	05	05	04
Negative significant		05	03	03	03

A = Average combiner G = Good combiner P = Poor combiner

Value in bracket indicted the *per se* performance of the parent for their respective character

Table 3: Estimation of specific combining ability effect of hybrids pooled over the environments for the different characters

Characters	Top ranking three crosses in desire direction	SCA effect of the crosses	Number of crosses with significant +ve and –ve SCA effect	
			+ve	-ve
Days to 50% heading	GDW 1255 x GW 2007-54	-3.26**	16	21
	GDW 1255 x GW 1276	-2.61**		
	GW 1277 x Arnej 206	-2.45**		
Days to maturity	GDW 1255 x GW 2007-54	-7.97**	21	19
	GW 2007-77 x GW 1277	-4.95**		
	HI 8725 x Arnej 206	-4.69**		
Plant height	GW 1 x Arnej 206	-5.06**	23	12
	GDW 1255 x GW 2007-77	-2.30**		
	HI 8725 x GW 1	-1.50**		

Number of effective tillers per plant	GW 2002-51 x GW 1	2.50**	18	16
	GW 2007-77 x GW 1277	2.04**		
	GW 1276 x HI 8725	1.57**		
Length of main spike	GW 2002-51 x GW 1	0.72**	22	12
	GW 1276 x GW 1277	0.52**		
	HI 8725 x Arnej 206	0.47**		
Peduncle length	GW 2007-77 x HI 8725	-2.51**	27	13
	GDW 1255 x GW 2007-54	-2.44**		
	GW 1277 x Arnej 206	-1.57**		
Number of spikelets per main spike	GDW 1255 x GW 1	1.31**	21	13
	GW 2002-51 x GW 2007-54	1.00**		
	GW 2007-54 x GW 1	0.82**		
Number of grains per main spike	GDW 1255 x GW 1	4.76**	19	11
	GW 1276 x GW 2007-54	2.87**		
	GDW 1255 x HI 8725	2.62**		
Grain yield per main spike	GW 2007-77 x Arnej 206	0.51**	23	18
	GW 2002-51 x GW 2007-112	0.43**		
	GW 2002-51 x GW 1	0.39**		
Grain yield per plant	GW 2002-51 x GW 1	2.78**	16	12
	GW 2007-77 x GW 1277	2.57**		
	GW 1276 x HI 8725	2.39**		
Test weight	GW 2002-51 x GW 1	11.56**	30	13
	GDW 1255 x GW 1277	7.44**		
	GDW 1255 x GW 2007-77	6.64**		
Biological yield per plant	GW 2002-51 x GW 1	4.55**	17	16
	GW 1276 x HI 8725	4.19**		
	GW 2007-77 x GW 1277	3.61**		
Harvest index	GW 1277 x HI 8725	3.06**	16	15
	GW 2007-54 x Arnej 206	2.68**		
	GW 1276 x Arnej 206	1.99**		
Spike density	GW 2002-51 x GW 2007-54	0.17**	11	15
	GDW 1255 x GW 1	0.14**		
	GW 2007-77 x GW 1276	0.12**		
Hectolitre weight	GW 1277 x GW 2007-54	1.76**	17	15
	GW 2007-112 x GW 1	1.26**		
	GW 1 x Arnej 206	1.18**		
Specific sedimentation volume	GW 2002-51 x GW 2007-54	0.35**	20	15
	GW 1277 x HI 8725	0.35**		
	GW 2002-51 x GW 1277	0.34**		
Protein content	GW 2007-77 x GW 1277	1.19**	15	18
	GW 2002-51 x GW 1276	1.15**		
	GW 1 x Arnej 206	0.83**		
Sedimentation value	GDW 1255 x HI 8725	4.71**	20	20
	GW 2002-51 x GW 1276	3.81**		
	GW 2007-112 x GW 1	3.37**		
β carotene	GW 2002-51 x GW 1277	0.39**	23	18
	GW 2007-112 x HI 9825	0.39**		
	GW 2007-77 x Arnej 206	0.38**		

CONCLUSION

The analysis of variance for combining ability revealed that mean square values due to parents were significant for all the characters except for kernel length. Likewise, mean square values due to hybrids were significant for all the characters except for spike density and kernel length which revealed that existence of differences among the parents and hybrids. Significance of both σ^2_{GCA} and σ^2_{SCA} for the characters days to 50% heading, days to maturity, length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, spike density, protein content and sedimentation value suggested that importance of both additive and non-additive gene effects for the inheritance of these characters. The estimates of potence and predictability ratio revealed preponderance of additive genetic variance for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main and spike, density. The value of average degree of dominance was less than one for the characters days to 50% heading, days to maturity, number of spikelets per main spike, number of grains per main spike and spike density which revealed partial dominance behaviour of interacting alleles for these characters. The parent GW 2002-51 was good general combiner for the characters length of main spike, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, test weight, protein content and sedimentation value. Whereas, the crosses GW 2007-77 x GW 1276 and HI 8725 x GW 1 were good specific combiners for days to 50% heading, days to maturity, plant height, number of effective tillers per plant, peduncle length, number of spikelets per main spike, number of grains per main spike, grain yield per main spike, grain yield per plant, test weight, biological yield per plant, and spike density.

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