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Estimates of Combining Ability and Heterosis for Quality Traits in Durum Wheat (*Triticum durum* Desf.) Over Normal and Late Sown Conditions in Jammu

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ABSTRACT

The objective of this study was to investigate the magnitude of heterosis of durum wheat genotypes and their thirty-six F1 hybrids crossed in half diallel design by using quality traits under two different sowing times viz. normal and late sown conditions. Mean sum of squares due to GCA and SCA were found to be significant for all the traits under both conditions but mean sum of squares of GCA were higher than those of SCA under both conditions indicating the importance of additive gene effects for these traits. Genotypes viz., HI 8638, EC 18 and WH 896 were found to be good combiners under both normal and late sown conditions. Crosses viz., HI 8638 x PDW 300, HI 8638 x NIDW 225, HI 8638 x WH 896, NIDW 225 x WH 896 and EC 18 x HI 8591(one parent as good general combiner); PDW 291 x PDW 300, NIDW 295 x HI 8645 and HI 8645 x PDW 300 (both parents as poor combiners) and HI 8638 x WH 896 and EC 18 x WH 896 (both parents as good general combiners), were found to be desirable crosses under both conditions. Significant and positive heterosis for mid and better parents were observed in PDW 291 x PDW 300, NIDW 295 x WH 896, HI 8638 x PDW 300, HI 8638 x NIDW 225, HI 8638 x WH 896, HI 8645 x PDW 300, NIDW 225 x WH 896, EC 18 x WH 896 and HI 8591 x WH 896 for quality traits under both conditions. Hence, HI 8638 x WH 896 and EC 18 x WH 896 can be further utilized in breeding programmes as these cross combinations showed high heterosis over mid as well as better parents and also high GCA and SCA under both conditions.

Key words: *Durum wheat, Heterosis, Heterobeltiosis, Half diallel, Quality, General combining ability, Specific combining ability*

INTRODUCTION

Durum wheat (*Triticum durum* Desf.) is an important crop for human diet (e.g. macroni, pasta, couscous, semolina, etc.), particularly a traditional Mediterranean crop, with the Mediterranean Basin (Italy, Spain, Turkey, Syria, Tunisia, Algeria, Morocco, France and Greece) being the largest production area worldwide[3]. Global durum production increased 3 percent year over year to 40.2 million metric tons, 9 percent above the 5-year average and the largest since 2009-10[7].

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India produces about 1.0 MMT of durum, mostly in Madhya Pradesh, Rajasthan and Maharashtra[14], although ecology offers an opportunity for the production of high quality wheat, durum wheat has received less attention than bread wheat. Although durum wheat is very similar to bread wheat with respect to morphological attributes of plants and grains, there exists great difference for grain quality aspects. In general, the grains of durum wheat are golden, bold, vitreous, mottle free and possesses higher contents of β-carotene, protein and micronutrients viz., iron, copper,zinc and manganese essential for human health in women and children. In durum wheat, presence of more than 5ppm of β-carotene gives yellow colour to products[2], whereas availability of storage proteins i.e. gliadins that confer extensibility and glutenins that bestow elasticity[4] in the unique combination of gluten content that determines the functional properties of dough, ultimately determining the end-use quality[11].Looking into the nutritional importance of durum wheat, breeding work is in progress for evolving durum varieties having high protein with strong gluten to yield good semolina and good chapatti as well. Durum is also considered as a special class of wheat for obtaining semolina (suzi) for the preparation of various pasta products like macaroni, spaghetti, vermicelli, noodles, instant dalia, couscous, burger etc. in the alimentation of world population. Hybrid wheat is an alternative approach to increase the productivity and most important step in the hybrid breeding program in the detection of suitable parents with high general specific ability (GCA) and specific combining ability (SCA) for quality traits and then the exploitation of heterosis. The future scope of hybrid technology in wheat depends on the male sterility systems, floral biology, level of combining ability, heterosis and its exploitation of commercial level that may be useful in breaking yield barriers and enhancing the productivity in the major wheat belt of the country[13]. In this study, because the parent wheat varieties are highly adapted varieties, heterosis over the mid-parent and over the better-parent has played a highly significant role for improvement in quality.

MATERIAL AND METHODS

Nine genotypes of durum wheat (*Triticum durum* Desf.) varieties, namely, **PDW 291**, **NIDW 295**, **HI 8638**, **HI 8645**, **PDW 300**, **NIDW 225**, **EC 18** , **HI 8591** and **WH 896** were crossed in a half diallel design at Research Farm of the Division of Plant Breeding and Genetics, Sher-e-Kashmir University of Agricultural Sciences and Technology Jammu. Seeds of 36 F1 along with their parents were sown in randomized block design with three replications under normal and late sown conditions. Each entry was planted in two rows of 2 m each, with a plant-to-plant and row- to-row distance of 15 and 30 cm, respectively. Five guarded plants from each parental and hybrid lines randomly selected and data pertaining to kernel size, kernel shape, kernel density, vitreousness of kernel, total protein, gluten content, β-carotene, iron, copper, zinc and manganese under normal and late sown conditions were recorded. The means of five observations in each plot were used for statistical analysis for each character data. Combining ability analysis was run using Method 2 Model 1[5] in which one set of F1's including parents are included in the matrix.

Estimation of heterosis

Analysis of variance (ANOVA) was performed to determine the significance in differences among the experimental material[12], and significant differences for various traits were observed (Table 1). The percent increase (+) or decrease (-) of F1 cross over mid-parent as well as better parent was calculated to observe heterotic effects for all the parameters under both normal and late sown conditions. The estimate of heterosis over the mid-parent and better (heterobeltiosis) was calculated using the procedure of Matzingar *et al*.[9].

$$\text{Heterosis (\%)} = \frac{(F1 - MP)}{MP} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{(F1 - BP)}{BP} \times 100$$

where, MP = mid parental value of the particular F1 cross (P1+P2)/2

BP = better parent value in the particular F1 cross

The difference of F1 mean from the respective mid-parent and better parent value was evaluated by using a t-test according to Wynne *et al*[15],

$$t = \frac{(\overline{F1}ij - MPij)}{(3/8\ \sigma^2 e)^{1/2}} \times 100$$

where,

F1ij = the mean of ijth F1 cross

MPij = mid parent value of the ijth cross

$\sigma^2 e$ = estimate of error variance

Table 1. Name of the varieties, their source and distinguishing characters used for crossing programme

S.No.	Genotypes	Source	Pedigree	Characteristics
1	PDW 291	PAU-Ludhiana	BOOMER 21/MOJO 2	Superior genetic stock identified from National Genetic Stock Nursery (NGSN)- 2004-05 (resistant to all rusts and other diseases; superior quality characteristics)
2	NIDW 295	NGSN 2005-06, DWR Karnal	BOOMER 33/PLATA 8	Resistant to all rusts and other diseases
3	HI 8638	NGSN 2005-06, DWR Karnal	SEL. BUTTAH	Best sedimentation of durum wheat
4.	HI 8645	NGSN 2005-06, DWR Karnal	HI-8185/MESSAPIO HI-8381/MESSAPIO	Best sedimentation of durum wheat
5.	PDW 300	PAU, Ludhiana	PDW-242/PDW-233//PDW-232	High β-carotene
6.	NIDW 225	NGSN 2005-06, DWR Karnal	SWANE 1/DUKEM 14	High β-carotene
7.	EC 18	NGSN 2005-06, DWR Karnal	_______________	High protein and β-carotene
8.	HI 8591	NGSN 2005-06, DWR Karnal	HI-8144/NI 8625	Superior genetic stock identified from NGSN- 2004-05 (resistant to all rusts and other diseases ; superior grain characteristics)
9.	WH 896	Choudhary Charan Singh, HAU, Hisar	SIN'S'/WH852	Resistant to all rusts and other diseases like Powdery Mildew, Leaf Blight, Karnal Bunt; high agronomical characters like plant height, days to maturity, thousand grain weight; grain colour and structure

RESULTS AND DISCUSSION

Analysis of variance for combining ability for the nine quality traits studied under normal and late sown conditions is presented in Table 2. The estimates of general combining ability variance and specific combining ability variance were highly significant for all the traits for both normal and late sown conditions (Table 3 and Table 4). For quality traits, parents HI 8638, HI 8645, EC 18 and HI 8591 for kernel size, HI 8638 for kernel density, HI 8645, NIDW 225 and EC 18 for total protein, EC 18 for gluten content, PDW 300, NIDW 225 and EC 18 for β-carotene, NIDW 295, HI 8638 and WH 896 for iron, PDW 291 and PDW 300 for copper, PDW 291, NIDW 295 and EC 18 for zinc and WH 896 for manganese were found to good combiners under both normal and late sown conditions. Therefore, the parent EC 18 showed significant GCA effects for kernel size, total proteins, β-carotene and zinc; second parent HI 8638 for kernel size, kernel density and iron and WH 896 for iron and manganese in the present study. The crosses *viz.*, PDW 291 x PDW 300, NIDW 295 x HI 8645, HI 8638 x PDW 300, HI 8638 x NIDW 225, HI 8638 x WH 896, HI 8645 x PDW 300, NIDW 225 x WH 896, EC 18 x HI 8591, EC 18 x WH 896 and HI 8591 x WH 896 for quality traits (Table 4) were found desirable under normal and late sown conditions.

Therefore crosses *viz.*, HI 8638 x PDW 300, HI 8638 x NIDW 225, HI 8638 x WH 896, NIDW 225 x WH 896 and EC 18 x HI 8591 involved at least one parent as good general combiner indicated the superiority due to additive gene action. Three cross combinations *viz.*, PDW 291 x PDW 300, NIDW 295 x HI 8645 and HI 8645 x PDW 300 in which both parents are poor combiners indicated superiority due to non-additive type of gene action. Rest two crosses *viz*., HI 8638 x WH 896 and EC 18 x WH 896 have both parents as good general combiners in the present study. Similar results observed by Mehmood and Chowdhary[8], Singh *et al.*[13],

The results of the heterotic studies over mid-parent and better parent for various quality traits under normal and late sown conditions, in F1 hybrids are presented in Table 5. In the present study, estimates of mid and better parent heterosis were computed to identify the superior cross combinations for their potential use in hybrid breeding programme. High yield in cross combination EC 18 x WH 896 over both mid and better parents might be due to increased iron. Also parents involved in the cross were good general combiners indicating fixable type of gene action. These results are in agreement with Yagdi and Karan[16], and Iqbal[6],

High heterosis for quality traits in cross combination NIDW 295 x WH 896 over mid and better parents could be due to more β-carotene but non-fixable type of gene action as indicated by one of the parents being poor general combiner. Similarly, cross combination HI 8638 x PDW 300 over both mid and better parents might be due to increased β-carotene, iron, copper and zinc; high cross combination HI 8638 x NIDW 225 over both mid and better parents could be due to increased total protein, gluten content and manganese. The high yield cross NIDW 225 x WH 896 over both mid and better parents might be due to increased β-carotene but non-fixable type of gene action as indicated by one of the parents being good general combiner. Abdullah *et al.*[1], Mehla *et al.*[10], suggested that heterosis in general was more pronounced over mid parent than better parent which matches with the findings of the present investigation. Two high yield cross combinations viz., PDW 291 x PDW 300 over mid and better parents could be due to more total protein, gluten content, copper, zinc and manganese and another HI 8645 x PDW 300 over mid and better parents might be due to increased total protein, copper and zinc but non-fixable type of gene action as indicated by none of the parent being good general combiner.

The present study has revealed that the best crosses HI 8638 x WH 896 and EC 18 x WH 896 can be further utilized in breeding programmes due to fixable type of gene action as these cross combinations showed high heterosis over mid as well as better parents and also high GCA and SCA under both conditions. Since both parents in these crosses involved were good general combiner, there is a possibility of considerable residual heterosis so that even F2 seeds in this case can be used for commercial cultivations.

The best cross combinations (F1's) involving out of the present study, having significant positive SCA and heterotic effects for quality traits can be further used for selection of stable elite lines in advanced segregating generations.

Table 2. Analysis of variance for combining ability for quality traits in 9 x 9 half diallel sets under normal (E1) and late sown (E2) conditions

			Mean squares								
Source of variation	**df**	**Time of sowing**	**Kernel size (mm²)**	**Kernel density (g/cm³)**	**Total protein (%)**	**Gluten content (%)**	**β-carotene (ppm)**	**Iron (ppm)**	**Copper (ppm)**	**Zinc (ppm)**	**Manganese (ppm)**
GCA	8	**E1**	13.98**	1.14**	0.70 **	1.59**	0.96**	17.79**	0.50**	14.46**	4.11**
		E2	13.99**	3.34**	0.59**	0.47**	1.08**	26.92**	0.59**	18.61**	5.73**
SCA	3	**E1**	0.66**	0.23**	0.17 **	0.65**	0.23**	5.46 **	0.14**	4.54**	4.43**
	6	**E2**	0.78**	1.11**	0.20**	0.67**	0.25**	5.16**	0.19**	7.93**	7.83**
Error	8	**E1**	0.02	0.02	0.00	0.00	0.00	0.13	0.01	0.30	0.36
	8	**E2**	0.12	0.10	0.00	0.00	0.00	0.10	0.00	0.01	0.00

*, **: Significant at 5% and 1% level

Table 3. Estimates of general combining ability effects for quality traits in a 9 x 9 half diallel set based on Griffing's Method 2 Model 1 under normal (E1) and late sown (E2) condition

Genotype	**Time of sowing**	**Kernel size (mm²)**	**Kernel density (g/cm³)**	**Total protein (%)**	**Gluten content (%)**	**β carotene (ppm)**	**Iron (ppm)**	**Copper (ppm)**	**Zinc (ppm)**	**Manganese (ppm)**
PDW-291	**E1**	-1.87**	-0.35**	0.04*	0.90**	-0.27**	-0.38**	0.34**	1.84**	0.29
	E2	-1.89**	-0.60**	-0.02	0.11**	-0.31**	-0.42**	0.25**	2.53*	1.10**
NIDW-295	**E1**	-0.85**	0.07*	-0.06**	-0.03	-0.14**	1.59**	0.01	0.60**	0.11
	E2	-0.72**	0.10	0.02	0.32**	-0.14**	1.89**	0.17**	0.91**	0.80**
HI-8638	**E1**	1.85**	0.67**	-0.23**	-0.17**	-0.25**	1.27**	-0.14**	0.06	-0.77** -
	E2	1.79**	1.19**	-0.18**	-0.28**	-0.24**	1.80**	0.05**	-0.36**	0.44**
HI-8645	**E1**	0.37**	-0.09*	0.30**	-0.18**	-0.14**	-0.90**	-0.10**	0.23	0.37* -
	E2	0.44**	-0.14	0.21**	-0.19**	-0.10**	-1.13**	-0.03*	0.10**	0.15**
PDW-300	**E1**	-0.82**	-0.38**	0.01	0.10**	0.47**	-0.02	0.38**	-1.75**	-0.25 -
	E2	-0.96**	-0.64**	-0.07**	0.00	0.47**	0.06	0.21**	-1.77**	0.59**
NIDW-225	**E1**	-0.09*	0.18**	0.13**	-0.07**	0.46**	0.04	-0.16**	-0.52*	-0.68** -
	E2	-0.13	0.17	0.13**	-0.13**	0.50**	-0.38**	-0.43**	-0.71**	0.50**
EC-18	**E1**	0.52**	-0.22**	0.40**	0.16**	0.14**	-0.26*	-0.03	1.25**	-0.06 -
	E2	0.47**	-0.35**	0.33**	0.29**	0.10**	0.22*	-0.22**	0.82**	0.86**
HI-8591	**E1**	1.16**	0.15**	-0.38**	-0.31**	-0.25**	-2.53**	-0.18**	-1.28**	-0.27 -
	E2	1.22**	0.01	-0.47**	-0.01	-0.34**	-3.02**	-0.16**	-1.36**	0.20**
WH-896	**E1**	-0.28**	-0.04	-0.20**	-0.38**	-0.02	1.17**	-0.12**	-0.42*	1.25**
	E2	-0.23*	0.25**	0.05**	-0.11**	0.07**	1.41**	0.15**	-0.17**	0.85**
S.E. (gi)	**E1**	0.04	0.03	0.02	0.02	0.01	0.10	0.02	0.15	0.17
	E2	0.10	0.09	0.01	0.01	0.01	0.09	0.01	0.02	0.01
S.E. (gi-gj)	**E1**	0.06	0.05	0.02	0.03	0.02	0.15	0.03	0.23	0.25
	E2	0.15	0.14	0.02	0.02	0.01	0.14	0.02	0.03	0.02

*, **:Significant at 5% and 1% level

Table 4: Estimates of specific combining ability effects for quality traits in a 9 x 9 half diallel set based on Griffing's Method 2 Model 1under normal (E1) and late sown (E2) conditions

Crosses	Time of sowing	Kernel size (mm²)	Kernel density (g/cm³	Total protein (%)	Gluten content (%)	β-carotene (ppm)	Iron (ppm)	Copper (ppm)	Zinc (ppm)	Manganese (ppm)
PDW-291 x NIDW-295	E1 E2	-0.06 - 0.47	0.49** 0.83*	-0.38** - 0.77**	0.56** 0.18**	-0.79** -0.84**	-2.06** -1.02*	0.20* 0.30**	-1.95** -4.08*	-2.98** 0.20**
PDW-291 x HI-8638	E1 E2	-0.46* - 0.24	-0.67** -1.57**	0.12* 0.33**	0.41** 0.42**	0.45** 0.53**	-3.43** -2.76**	-0.05 -0.42**	0.20 0.32**	3.53** 4.18**
PDW-291 x HI-8645	E1 E2	1.32** 1.34**	-0.02 -0.30	0.22** 0.27**	0.05 0.02	0.41** 0.28**	4.14** 4.91**	0.64** 0.67**	1.66* 1.86**	-2.07** -3.32**
PDW-291 x PDW-300	E1 E2	-0.10 - 0.16	0.38* 0.16	0.44** 0.78**	-0.07 0.10*	0.73** 0.72**	0.92* 0.61*	0.03 -0.07*	2.54** 2.59**	0.51 1.12**
PDW-291 x NIDW-225	E1 E2	0.72** 0.67*	-0.59** -0.85*	0.63** 0.98**	-0.13* -0.24**	0.14* 0.49**	-0.44 -1.02*	0.37** 0.94**	3.35** 3.24**	3.38** 3.16**
PDW-291 x EC-18	E1 E2	1.20** 1.18**	-0.05 -0.06	0.49** 0.31**	0.01 -0.23**	0.23** 0.29**	2.93** 2.16**	-0.03 0.56**	-1.39* -1.90**	-0.48 -0.37**
PDW-291 x HI-8591	E1 E2	1.59** 1.66**	-0.62** -0.68*	-0.06 - 0.32**	0.78** 0.50**	-0.48** -0.50**	1.03* 0.62*	-0.38** -0.27**	-0.72 -0.88**	1.70* 2.90**
PDW-291 x WH-896	E1 E2	0.27 0.21	0.07 -0.05	-0.17* - 0.57**	0.78** 0.01	0.12* -0.12**	-0.47 -1.61**	0.16* -0.28**	-0.39 4.06**	2.31** 2.85**
NIDW-295 x HI-8638	E1 E2	0.74** 0.69*	-0.62** -1.47**	0.12* 0.26**	0.83** 0.77**	0.03 -0.11**	-4.81** -5.60**	-0.25** -0.54**	-0.26 -1.03**	4.45** 4.35**
NIDW-295 x HI-8645	E1 E2	-0.77** - 1.07*	-0.27* -0.56	0.09 - 0.17**	0.04 0.34**	-0.98** -1.19**	4.50** 3.57**	-0.46** - 0.72**	2.10** 2.41**	-0.63 -1.81**
NIDW-295 x PDW-300	E1 E2	-1.09** - 2.60**	0.46** 0.70*	0.54** 0.57**	0.36** - 0.18**	0.20** -0.02	2.18** 1.54**	-0.04 -0.33**	1.84** 1.65**	0.82 3.06**
NIDW-295 x NIDW-225	E1 E2	0.39* 0.50	-0.64** -1.25**	0.26** 0.11*	-0.50** -0.12*	0.52** 0.22**	1.55** 0.84*	0.37** 0.58**	1.45* 3.13**	2.95** 3.60**
NIDW-295 x EC-18	E1 E2	0.71** 0.71*	0.43** 0.47	0.36** 0.21**	0.73** 0.53**	0.30** 0.28**	1.02* 0.89*	0.60** 0.61**	-1.68* -0.44**	-0.33 -1.20**
NIDW-295 x HI-8591	E1 E2	0.67** 0.49	-0.31* - 0.48	-0.23** -0.26**	-1.06** 0.36**	0.23** 0.36**	0.96* 0.55	-0.02 -0.29**	2.02** 2.41**	-1.32* 0.04
NIDW-295 x WH-896	E1 E2	0.92** 0.74*	-0.62** -1.35**	-0.24** 0.29**	-0.49** 0.10*	0.57** 0.44**	0.12 1.25**	0.62** 0.43**	0.35 0.82**	0.36 -0.47**
HI-8638 x HI-8645	E1 E2	-0.04 - 0.24	0.20 1.34**	0.26** 0.17**	0.46** 0.61**	0.53** 0.61**	3.09** 2.72**	-0.27** 0.70**	-1.82** -2.46**	0.15 1.43**
HI-8638 x PDW-300	E1 E2	1.11** 1.29**	-0.53** -0.66*	-0.02 -0.23**	-0.79** - 0.68**	0.58** 0.55**	3.00** 3.76**	0.31** 0.26**	3.85** 4.41**	-2.23** -3.06**
HI-8638 x NIDW-225	E1 E2	0.09 0.03	-0.20 -1.04*	0.33** 0.24**	1.48** 1.45**	0.16** -0.08*	1.14* 1.00*	-0.18* -0.27**	-1.33* -1.71**	2.93** 4.44**
HI-8638 x EC-18	E1 E2	-0.39* - 0.30	0.14 0.45	0.33** 0.38**	0.65** 0.90**	-0.02 0.12**	3.58** 2.77**	0.45** 0.19**	1.33* 1.02**	-0.45 -0.92**
HI-8638 x HI-8591	E1 E2	-0.33* - 0.38	0.43** 0.26	-0.33** - 0.06	-0.91** -0.97**	0.50** 0.73**	0.18 0.11	0.24* -0.07*	-0.04 1.04**	2.05** 3.42**
HI-8638 x WH-896	E1 E2	0.05 - 0.10	-0.04 -0.18	-0.07 - 0.34**	-0.21* -0.64**	-0.96** -0.89**	-3.45** 0.24	-0.46** 0.18**	1.16* 1.95**	-4.67** -4.73**
HI-8645 x PDW-300	E1 E2	0.20 0.27	0.48** 1.10**	0.18** 0.38**	-0.22* -0.18**	-0.20** -0.07*	-1.59** -1.60**	0.37** 0.21**	2.35** 3.42**	0.63 0.45**
HI-8645 x NIDW-225	E1 E2	-0.22 - 0.33	-0.55** -0.70*	0.14* 0.08*	0.72** 0.35**	0.18** 0.14**	-0.29 -0.10	-0.29** -0.72**	3.03** 3.90**	-0.88 -1.52**

HI-8645 x EC-18	**E1** **E2**	-0.47* -0.12	-0.25* -0.65*	0.23** 0.22**	-1.91** -2.20**	0.20** 0.07*	-2.78** -3.06**	0.38** 0.04	-2.37** -2.47**	-0.59 -1.25**
HI-8645 x HI-8591	**E1** **E2**	0.15 0.46	-0.12 -0.34	0.74** 0.55**	0.46** 0.06	0.13* 0.01	0.02 0.58	0.16* 0.31**	1.19* 1.41**	1.55* 3.09**
HI-8645 x WH-896	**E1** **E2**	0.67** 0.21	-0.26* -0.91*	-0.40** -0.17**	-0.20* 0.43**	-0.06 0.00	0.15 -0.59	-0.23* 0.13**	-0.84 -1.55**	2.09** 2.71**
PDW-300 x NIDW-225	**E1** **E2**	0.43* 0.64*	-0.48** -0.78*	-0.28** -0.31**	0.64** 0.93**	-0.83** -0.72**	-0.57 -0.39	0.10 0.21**	-2.53** -2.70**	-1.16* -1.74**
PDW-300 x EC-18	**E1** **E2**	-0.02 0.28	-0.18 -0.42	0.22** 0.16**	1.11** 0.88**	0.12* 0.11**	-1.17* -1.32**	0.26** -0.10*	0.30 -0.54**	1.16* 1.22**
PDW-300 x HI-8591	**E1** **E2**	0.90** 0.72*	-0.29* -0.38	-0.34** -0.24**	-0.59** -1.09**	-0.26** -0.29**	-1.33** -2.55**	0.35** 0.40**	-1.54* -1.42**	-0.67 -1.44**
PDW-300 x WH-896	**E1** **E2**	0.25 0.35	-0.33* -0.85*	-0.21** -0.49**	0.35** 0.15**	0.28** 0.33**	0.30 -0.82*	-0.42** 0.22**	-2.20** -3.24**	0.91 0.35**
NIDW-225 x EC-18	**E1** **E2**	-0.31* - 0.15	0.45** 0.97*	0.21** 0.23**	-1.75** -2.16**	-0.13* 0.05	-1.46** -2.05**	-0.19** -0.26**	-0.89 -1.73**	-0.31 0.16*
NIDW-225 x HI-8591	**E1** **E2**	0.28* 0.26	-0.12 -0.72*	-0.25** -0.21**	0.92** 0.04	-0.48** -0.61**	0.01 0.95*	0.03 -0.09*	2.58** 3.29**	-1.27* -2.56**
NIDW-225 x WH-896	**E1** **E2**	-0.07 -0.12	0.34* 0.54	-0.26** -0.06	-0.48** 0.11*	0.76** 0.61**	0.24 0.42	-0.17* -0.23**	-0.22 -0.89**	-1.72* -0.48**
EC-18 x HI-8591	**E1** **E2**	-0.50** -0.70*	-0.45** -0.77*	-0.29** -0.34**	0.39** 0.72**	0.34** 0.42**	-1.19** -1.24**	-0.18* -0.13**	3.44** 4.92**	-0.89 -1.20**
EC-18 x WH-896	**E1** **E2**	-0.38* -0.48	-0.46** -1.17**	-0.43** -0.09*	-0.24** 1.05**	-0.22 -0.36**	3.71** 4.19**	-0.51** -0.07*	0.91 2.20**	0.69 0.89**
HI-8591 x WH-896	**E1** **E2**	-0.63** -0.73	0.30* 0.17	0.38** 0.37**	-0.30** 0.35**	-0.06 -0.19**	-0.09 -0.07	-0.29** 0.06	-1.53* -2.98**	-0.27 -0.81**
S. E. (Sij)	**E1** **E2**	0.14 0.31	0.11 0.29	0.05 0.04	0.06 0.04	0.04 0.03	0.33 0.29	0.07 0.03	0.50 0.07	0.54 0.05
S. E. (Sij – Sik)	**E1** **E2**	0.20 0.46	0.17 0.43	0.07 0.06	0.09 0.06	0.06 0.04	0.49 0.43	0.10 0.05	0.73 0.10	0.80 0.07
S. E. (Sij – Skl)	**E1** **E2**	0.19 0.44	0.16 0.41	0.07 0.06	0.09 0.06	0.06 0.04	0.46 0.41	0.10 0.05	0.70 0.10	0.76 0.07

*, **-significant at 5% and 1%

Table. 5: Heterosis of hybrids (F1 generation) in a 9 parent half diallel set for quality traits under normal (E1) and late sown (E2) conditions

Crosses	Time of sowing	Kernel size (mm^2) Over Over better mid parent parent	Kernel density (g/cm^3) Over Over better mid parent parent	Total protein (%) Over Over better mid parent parent	Gluten content (%) Over Over better mid parent parent	β-carotene (ppm) Over Over better mid parent parent	Iron (ppm) Over Over better mid parent parent	Copper (ppm) Over Over better mid parent parent	Zinc (ppm) Over Over better mid parent parent	Manganese (ppm) Over Over better mid parent parent
PDW-291 x NIDW-295	**E1** **E2**	-1.62 7.62** -9.85** 1.74	-11.38** -0.91 -25.00** -11.95	-0.27 0.54 -5.26** -3.57**	8.56** 13.82** 7.59** 8.67**	-13.61** - 9.34** -19.46** - 12.32**	-6.09** -1.48 -5.64** -0.09	5.56** 12.09** 5.71** 9.90**	-3.96 -0.40 -7.49** -3.93**	-3.30 -1.97 12.45** 13.85**
PDW-291 x HI-8638	**E1** **E2**	-14.43** 3.92** -13.70** 4.70*	-43.21** -28.96** -61.54** -49.30**	4.05** 5.19** 5.19** 6.02**	5.48** 16.89** 3.96** 11.31**	15.03** 17.06** 16.76** 18.36**	-13.86** - 8.03** -9.55** - 4.52**	-1.11 2.30 -2.96** -0.76	0.17 4.87** 0.08 6.42**	16.28** 19.94** 23.21** 27.40**

PDW-291 x HI-8645	**E1 E2**	-2.14* 13.13** -3.16 12.59**	-18.35** -13.59** -30.16** -28.74**	5.48** 7.30** 5.33** 6.55**	1.71 5.32** 0.66 0.99	6.35** 11.05** 0.00 7.04**	14.41** 20.27** 14.17** 20.13**	11.11** 16.62** 17.01** 18.54**	4.39* 10.43** 4.91** 12.38**	-5.59* -1.53 -5.79** -1.90
PDW-291 x PDW-300	**E1 E2**	-1.46 7.72** -3.45 5.85*	-5.15 0.00 -28.10* -20.55	5.79** 7.20** 8.76** 9.18**	3.42** 7.86** 2.61** 3.63**	4.09** 16.54** 2.97** 15.44**	4.05** 5.79** -0.61 2.41*	7.69** 8.29** 5.47** 7.34**	1.55 12.99** 2.17** 13.20**	2.93 5.78** 7.68** 10.71**
PDW-291 x NIDW-225	**E1 E2**	-1.80 11.05** -1.54 10.96**	-42.86** -32.49** -56.68** -47.40**	7.31** 9.16** 10.43** 11.57**	1.03 7.66** 0.33 1.69**	-5.80** 6.30** -3.27** 10.23**	-2.11 0.76 -3.29** - 1.72	5.56** 10.79** 14.95** 21.86**	6.80** 15.46** 6.28** 16.35**	16.08 ** 17.73** 20.12** 20.76**
PDW-291 x EC-18	**E1 E2**	-5.25** 11.09** -4.14 11.65**	-13.40* -12.50** -26.45* -24.89*	5.33** 8.64** 3.70** 6.33**	2.34* 3.55** -1.57** 3.30**	3.55** 10.27** 5.29** 11.45**	12.76** 14.03** 8.61** 8.86**	1.11 7.06** 12.37** 18.48**	-2.46 -1.67 -2.42** -0.82**	-2.02 2.01 0.72** 4.60**
PDW-291 x HI-8591	**E1 E2**	-1.51 15.74** -2.34 15.40**	-39.53** -30.97** -50.61** -43.16**	1.35* 1.35* -2.08*** - 1.57**	7.88** 14.13** 6.71** 7.59**	-8.56** - 5.00** -7.61** - 4.71**	0.58 4.82** -2.85* 2.42*	-7.22** - 2.91 0.52 1.04	-5.68** 4.14* -5.23** 6.42**	7.77** 9.98** 16.71** 18.44**
PDW-91 x WH-896	**E1 E2**	-3.50** 8.56** -6.33** 6.61**	-19.13** -12.26** -43.98** -31.41**	-4.80** - 1.57** -8.33** - 4.35**	7.19** 12.79** 6.02** 10.79**	1.55 7.10** -8.04** 0.73	-4.60** 0.87 -4.92** - 1.01	-0.54 1.09 0.49 2.77**	-2.58 -0.66 9.58** 13.70**	3.12 10.36** 8.34** 15.26**
NIDW-295 x HI-8638	**E1 E2**	-5.95** 5.61** -5.56** 2.67	-34.57** -25.61** -51.28** -43.84**	1.60* 3.52** 1.25** 3.86**	10.57** 17.20** 18.57** 26.24**	-0.52 6.15** -8.60** 0.75	-12.33* - 10.70** -11.45** - 11.16**	-3.57 - 0.92 -9.05** - 7.51**	3.15 4.17* 0.35 2.85**	15.26** 20.47** 19.81** 25.37**
NIDW-295 x HI-8645	**E1 E2**	-6.71** - 0.84 -8.46** - 5.27**	-23.58** -18.97** -41.28** -32.21**	3.66** 4.61** 1.00* 1.64**	-1.10 0.19 6.98** 8.42**	-14.66** - 14.21** -21.27** - 19.82**	9.89** 20.87** 3.84** 15.51**	-3.68 - 2.48 -12.86** - 8.27**	10.20** 12.50** 10.52** 14.14**	-2.11 0.75 -2.58** 0.23
NIDW-295 x PDW-300	**E1 E2**	-1.46 - 1.38 -15.38** - 12.63**	-13.01** 1.90 -27.91** -8.15	5.79** 6.35** 4.51** 5.97**	7.09** 7.69** 2.97** 5.05**	-1.36 5.60** -4.24** - 1.09*	6.09** 9.52** 1.80 4.71**	1.10 7.92** -3.81** - 1.70*	3.99 11.88** 3.65** 10.88**	3.31 4.74* 12.16** 13.93**
NIDW-295 x NIDW-225	**E1 E2**	1.35 5.15** 2.77 2.93	-35.00** -30.80** -51.87** -49.86**	3.66** 4.61** 2.51** 3.28**	-3.40** - 1.73 4.73** 5.08**	0.89 8.92** -4.49** 0.43	4.59** 6.66** -0.98 3.24**	10.43** 11.80** 0.00 9.95**	6.31** 10.99** 10.26** 16.49**	11.18** 14.29** 17.55** 19.64**
NIDW-295 x EC-18	**E1 E2**	-3.04** 4.70** -1.14 2.52	-9.76* 1.83 -26.74** -12.50	3.55** 5.97** 3.21** 3.98**	0.33 6.38** 8.57** 15.15**	6.60** 8.25** 1.36* 4.43**	2.38 8.56** -0.49 5.14**	19.38** 19.75** 3.33** 13.02**	-6.36** -2.13 0.42 2.64**	-2.12 0.57 -2.33** 0.23
NIDW-295 x HI-8591	**E1 E2**	-1.10 7.06** -2.34 2.98	-22.48** -20.63** -37.21** -35.71**	-2.39** - 1.61** -4.76** - 2.56**	-12.45**- 11.62** 8.43** 10.44**	2.62** 3.70** -3.62** 1.91**	-3.80** 4.96** -8.18** 2.18*	2.44 4.02* -8.57** - 4.48**	5.75** 12.87** 6.70** 15.75**	-1.44 -0.77 7.79** 8.05**
NIDW-295 x WH-896	**E1 E2**	4.11** 7.38** 1.36 2.36	-30.89** -28.57** -53.40** -50.96**	-6.06** -3.63** -1.90** 0.61	-6.79** - 6.44** 10.26** 14.03**	10.36** 10.94** 1.79** 2.47**	2.08 2.93 4.42** 6.28**	1.61 9.57** 6.19** 7.99**	0.00 1.73 5.47** 5.56**	-2.43 3.07 -0.94** 4.16**
HI-8638 x HI-8645	**E1 E2**	-4.30** 1.48 -4.65* 0.34	-22.22** -7.01* -18.38** 6.11	3.66** 6.58** 3.30** 5.30**	1.84 9.27** 9.86** 18.63**	8.47** 15.17** 5.63** 14.50**	1.45 13.46** 2.22 13.37**	-5.95** - 4.53** 9.36** 13.27**	-0.28 0.81 -0.64* 0.14	-2.38 4.87* 2.76** 10.48**
HI-8638 x PDW-300	**E1 E2**	-4.43** 7.40** -4.13* 7.30**	-41.36** -23.69** -50.43** -30.12**	0.00 2.43** -0.26 0.91*	-7.46** - 1.39 -2.45** 6.08**	2.27** 16.28** 1.69** 15.38**	3.49** 8.76** 7.74** 10.46**	4.40* 8.57** 6.40** 6.93**	10.22** 17.50** 13.07** 18.51**	-7.84** -2.40 -8.04** -2.33**
HI-8638 x NIDW-225	**E1 E2**	-5.57** 2.54** -5.81** 2.53	-24.69** -19.21** -44.87** -38.72**	2.87** 5.77** 3.56** 5.44**	21.48** 26.68** 21.51** 28.90**	-5.36** 8.44** -9.39** 4.47**	-1.11 2.69* -0.16 3.76**	-5.36** - 3.93* -10.84** - 3.47**	-1.04 2.35 -0.82** 2.31**	14.80** 16.78** 20.63** 24.08**

HI-8638 x EC-18	**E1** **E2**	-5.06** -0.92** -4.78* 0.00	-25.93** -6.61 -32.48** -9.71	2.03** 6.35** 2.96** 6.38**	-2.01* 9.74** 12.42** 27.38**	0.00 8.24** 3.85** 11.34**	4.34** 12.57** 4.61** 10.19**	8.33** 10.98** -0.99 6.63**	-0.08 5.41** 0.92** 5.66**	-4.88* 2.02 -4.92** 1.97**
HI-8638 x HI-8591	**E1** **E2**	-2.41** 1.58* -2.20 1.00	-13.58** -3.78 -30.34** -18.09**	-2.97** - 1.91** -0.26 0.00	-10.77** - 6.26** -5.43** 2.66**	7.49** 13.56** 12.18** 17.24**	-10.12** - 0.28 -8.89** 1.10	1.79 3.01 -3.94** - 1.27	0.47 6.25** 4.94** 11.24**	5.75* 11.25** 13.80** 19.35**
HI-8638 x WH-896	**E1** **E2**	-6.46** 2.14** -6.72** 0.49	-25.93** -13.36** -32.91** -26.12**	-6.06** -1.85** -7.86** -3.13**	-4.56** 0.80 2.40** 5.32**	-15.03** - 8.89** -17.41** - 8.42**	-9.95** - 9.02** 2.39* 3.88**	-18.28** - 14.12** 4.43** 4.43**	0.72 3.45 5.12** 7.84**	-17.80** -9.46** -14.98** -6.68**
HI-8645 x PDW-300	**E1** **E2**	-2.43** 3.80** -3.73 2.76	-5.50 5.10 2.38 15.18	4.96** 5.37** 5.84** 6.65**	-2.57* - 1.85* -3.26** - 2.62**	-6.82** 0.24 -4.24** 0.67	-4.52** 1.96 -8.23** - 0.52	6.04** 11.88** 5.47** 8.72**	8.80** 14.80** 13.37** 17.57**	0.37 1.91 -0.27 1.04**
HI-8645 x NIDW-225	**E1** **E2**	-1.14 1.39 -2.73 0.82	-36.43** -28.51** -47.06** -36.74**	5.48** 5.48** 5.08** 5.21**	5.88** 9.09** 3.00** 4.75**	-3.57** 4.60 -4.90** 1.75**	-3.12* 4.66** -2.76* 4.05**	-3.68 - 3.68* -12.70** - 8.59**	14.31** 16.97** 17.64** 20.44**	-4.95* 0.48 -5.25** -0.84**
HI-8645 x EC-18	**E1** **E2**	-2.90** -1.26 0.29 0.50	-21.10** -15.69** -32.54** -29.75**	5.33** 6.82** 4.69** 6.13**	-27.76** - 24.34** -23.20** - 19.67**	5.08** 7.25** 2.82** 4.04**	-3.29* 0.57 -7.69** - 2.51*	11.04** 12.07** 2.65** 6.89**	-9.07** -3.07 -6.66** -1.54**	-2.47 -2.30 -5.52** -5.27**
HI-8645 x HI-8591	**E1** **E2**	1.79* 3.78** 2.34 4.36*	-21.71** -15.13** -35.98** -27.59**	6.27** 8.10** 4.06** 5.81**	0.37 2.63** -0.82 - 0.33	2.12* 2.66** -4.23** -0.49	4.56** 5.51** 5.84** 5.89**	3.66 3.98* 6.25** 7.09**	6.77** 11.74** 8.91** 14.61**	2.84 5.15* 7.84** 10.69**
HI-8645 x WH-896	**E1** **E2**	1.86* 5.08** -0.86 1.62	-20.87** -18.75** -50.26** -40.06**	-4.55** - 2.95** -3.81** - 0.74	-7.72** - 6.17** 7.03** 12.23**	0.52 1.57 -3.57** - 1.14**	-4.34** 6.01** -4.15** 4.92	-13.98** - 8.31** 2.46** 6.12**	-4.21* -0.56 -2.78** 0.49	2.78 5.57** 4.77** 7.14**
PDW-300 x NIDW-225	**E1** **E2**	1.65 5.54** 2.62 5.81**	-41.43** -27.75** -56.15** -42.46**	0.00 0.39 0.25 0.90*	9.70** 12.21** 9.93** 12.54**	-8.93** - 8.11** -8.57** - 6.86**	-1.47 - 0.23 -3.12** - 1.76	0.55 6.09** -0.50 7.24**	-3.14 -0.05 -1.36** -0.05	-4.54 -0.54 -4.57** -1.37**
PDW-300 x EC-18	**E1** **E2**	-5.94** 1.64 -4.00 2.67	-16.84** -13.19** -33.62** -28.04*	3.05** 4.91** 2.22** 4.41**	5.35** 11.11** 6.85** 11.00**	1.36 6.95** 0.42 6.76**	-1.51 1.26 -5.11** - 2.45*	5.49** 12.28** -1.99* 5.07**	-7.29** 3.89* -6.49** 2.09**	1.01 2.38 0.45* 1.49**
PDW-300 x HI-8591	**E1** **E2**	0.00 8.33**-2.34 6.15**	-32.56** -19.44** -45.73** -32.06**	-3.68** -2.40** -2.58** -1.69**	-6.72** - 5.30** -10.86** - 10.71**	-9.09** - 1.72* -10.17** - 2.08**	-8.38** - 2.99* -15.58** - 8.45**	4.40* 9.83** 6.47** 8.91**	2.23 3.10 3.20** 4.77**	-1.98 -1.29 -2.93** -1.62**
PDW-300 x WH-896	**E1** **E2**	1.22 4.48** -1.51 2.67	-30.43** -20.79** -57.07** -43.25**	-5.30** -3.35** -8.10** -4.46**	2.99** 3.95** 5.28** 11.15**	1.36 7.99** 2.97** 5.65**	-1.65 2.35 -1.69 - 0.64	-9.14** - 8.15** 7.39** 7.92**	-13.17** -5.09* -12.07** -5.86**	-1.91 2.26 -2.38** 1.10**
NIDW-225 x EC-18	**E1** **E2**	-4.14** -0.07 -2.29 1.48	-17.86** -2.13 -23.53** -5.61	3.81** 5.28** 4.20** 5.76**	-25.08** - 19.28 -21.02** - 15.93**	-4.02** 2.14** -3.67** 4.19**	4.59** - 0.72 -5.52** - 4.20**	-0.61 0.31 -0.57 0.00	-7.20** 1.06 -6.82** 0.49	-4.23 1.07 -2.15** 2.15**
NIDW-225 x HI-8591	**E1** **E2**	0.41 4.95** -0.83 4.73*	-22.14** -18.96** -44.92** -41.31**	-2.87** -1.20* -2.04** -0.52	11.54** 12.40** 1.16* 3.39**	-13.84** - 6.08** -17.14** - 8.14**	-6.80** - 0.15 -4.99** 1.72	0.00 0.31 -6.25** -1.10	13.78** 16.43** 17.33** 20.68**	-3.55 -0.20 -3.19** -1.25**
NIDW-225 x WH-896	**E1** **E2**	1.80 2.42** 0.15 1.30	-16.43** -8.24* -22.51** -21.69**	-4.80** -3.21** -3.57** -0.37	-6.46** - 5.20** 6.11** 9.35**	5.80** 13.67** 2.86** 7.46**	-1.65 1.12 0.34 2.82**	-13.98** - 8.31** -8.87** -1.33	-4.57* 1.28 -3.04** 2.52**	-9.90** -2.31 -4.26** 2.37**
EC-18 x HI-8591	**E1** **E2**	-0.27 0.00 -2.34 -0.63	-32.56** -22.32** -47.56** -38.57**	-3.81** -0.79 -4.44** -1.53**	-6.02** 0.54 5.46** 9.74**	5.58** 8.33** 6.73** 9.63**	-3.39* - 0.41 -7.88** - 2.66*	-1.22 0.00 -3.65** 1.09	1.86 13.29** 8.15** 19.71**	-4.69 -2.72 -5.01** -2.75**

EC-18 x WH-896	**E1** **E2**	-5.25** -0.65 -4.14 -1.54	-29.57** -22.86** -57.59** -47.23**	-4.04** -3.80** -2.38** -0.61	-13.04** - 7.47** 12.93** 24.10**	0.51 1.54 -5.80** - 2.31**	6.60** 13.91** 10.34** 14.61**	-17.20** - 10.98** -3.45** 3.98**	-2.37 0.35 4.33** 6.54**	-2.00 0.85 -1.70** 0.79**
HI-8591 x WH-896	**E1** **E2**	-4.12** 0.79 -5.38** -1.15	-10.85** -5.74 -30.89** -25.63**	-3.79** -0.52 -4.76** -0.12	-7.22** - 6.69** 7.51** 13.31**	-1.04 0.53 -9.37** - 3.56**	-9.20** -0.19 -7.63** 1.16	-16.13** - 10.86** -0.49 2.28**	-10.13** -2.53 -10.33** -2.64**	-5.03* -0.32 -4.34** 0.36*
S. E.	**E1** **E2**	0.21 0.18 0.48 0.42	0.17 0.15 0.45 0.39.	0.08 0.07 0.06 0.05	0.09 0.08 0.06 0.05	0.06 0.05 0.04 0.03	0.51 0.44 0.45 0.39	0.11 0.09 0.05 0.04	0.77 0.67 0.11 0.09	0.84 0.73 0.07 0.06

*, **-significant at 5% and 1%

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