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Estimation of Economic Heterosis for Grain Yield and it's Attributing Traits in Macaroni Wheat (*Triticum durum* Desf.)

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***Abstract*— *The present investigation was undertaken in order to estimate the heterosis for grain yield and its attributing traits in Macaroni wheat (Triticum durum Desf.). The crosses were attempted by using line × tester mating design among eight lines and four testers during rabi 2023-24. The resultant 32 hybrids together with 12 parents and 1 standard check (GW 1339) were tested using randomized block design with three replications at Wheat Research Station, Junagadh Agricultural University, Junagadh during Rabi 2024-25. A total of six and five hybrids exhibited significant desirable heterobeltiosis and standard heterosis, respectively for grain yield per plant. The heterobeltiosis for grain yield per plant ranged from -43.43 % to 83.99 %, while standard heterosis ranged from -58.69 % to 42.36 %. The highest heterosis over better parent in desirable direction was recorded by cross MACS 3949 × GDW 1255 (83.99%), UAS 475 × GDW 1255 (69.02%) and HD 4758 × HI 8737 (61.26%). The highest significant heterosis towards positive direction over standard check were recorded by five crosses viz., MACS 3949 × GDW 1255 (42.36%), HD 4758 × WHD 965 (28.66%), HD 4758 × HI 8737 (27.40%), UAS 475 × GDW 1255 (19.36%) and MACS 3949 × WHD 965 (9.45%). Hybrids with desirable traits for yield components showed increased grain yield, which is likely due to the combined effect of those improved traits.*

***Keywords*— Heterosis, Triticum durum Desf.**

I. INTRODUCTION

Wheat is a most extensively grown food crop in the world. Wheat is prized for its high nutritious content. Approximately 32% of all cereal growing land worldwide is planted with wheat, which is cultivated throughout a variety of latitudes. India's major wheat-growing states include Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Rajasthan, Maharashtra and Gujarat.

In India, farmers cultivated 31.83 million hectares of land, yielding a total of 113.29 million tonnes, which breaks down to an average productivity of 3559 kilograms per hectare. While Gujarat accounted for 1.24 million hectares of land, 3.77 million tonnes of production and 3027 kg of productivity per hectare [2]. In India there are six mega wheat-growing environments *i.e.* North-Western Plains Zone (NWPZ), North-Eastern Plains Zone (NEPZ), Central Zone (CZ), Peninsular Zone (PZ), Northern Hills Zone (NHZ) and Southern Hills Zone (SHZ) [1].

The durum wheat is higher in protein, β-carotene and vital micronutrients like iron and zinc, so it offers greater nutrition [14]. Durum wheat contains high level of folate. which is much important during pregnancy time. A single cup of uncooked enriched durum wheat semolina is a great source of folate, providing you with 306 micrograms of this important nutrient. Durum wheat pasta, unlike regular wheat pasta, doesn't spike your blood sugar as much. Durum wheat pasta has a lower glycemic index (47), which means it's digested more slowly and won't cause your blood sugar to spike as quickly as common wheat pasta (68). Additionally, durum wheat contains about twice as much lutein, a beneficial antioxidant that's great for eye health. These are great for your health, particularly for your eyes.

The choice of parents to be incorporated in hybridization programme is a crucial step for breeders, particularly if the aim is improvement of complex quantitative characters, such as grain yield and its components. The use of parents of known superior genetic worth ensures much better success. We need to thoroughly analyze the genes of both current plant varieties and new promising ones so that we can use them to develop better crops or release them directly as new cultivars. Nature and magnitude of heterosis is one of the important aspects for selection of right parents for crosses and also help in identification of superior cross combinations that produce desirable transgressive segregants in advanced generations.

II. MATERIALS AND METHODS

The field experiment was conducted at Wheat Research Station, Junagadh Agricultural University, Junagadh during *Rabi,* 2023-24 and 2024-25. This region has a typical sub-tropical climate. The soil of the experimental site was medium black, alluvial in origin and poor in organic matter. The experimental material of present study was comprised of 32 elite hybrids developed by crossing eight lines and four testers in line × teste mating design along with one standard check (GW 1339). DDW 48, GW 1348, HD 4758, HI 8841, MACS 3949, MPO 1357, RAJ 3307 and UAS 475 used as lines and GDW 1255, HI 8737, WHD 965 and NIDW 1158 used as testers. The genotypes were obtained from the Junagadh Agricultural University's Wheat Research Station in Junagadh.

The crossing programme was carried out during *Rabi,* 2023-24 at Wheat Research Station, Junagadh Agricultural University, Junagadh. At the same time, the male and female parents were selfed to get pure seeds of parents for the experiment. The experimental material consisting of 45 entries, including 12 parents, 32 crosses and one standard check (GW 1339) were tested in randomized block design with three replications during *Rabi,* 2024-25. A single row plot of 2.5 m was allotted randomly to each entry. The space between plants was maintained at 10 cm and 22.5 cm from row to row.

Five competitive plants per genotype in each replication in each environment were selected randomly for recording observations on plant height, number of effective tillers per plant, length of main spike, number of spikelets per main spike, number of grains per main spike, 100-grain weight, grain yield per plant, biological yield per plant and harvest index (except days to anthesis, grain filling period and days to maturity) and their average values were used in the statistical analysis.

III. RESULTS AND DISCUSSION

Analysis of variance

The genotypes in our experiment showed significant differences across all traits, confirming that we have enough genetic variation to study. The genotype variance was further subdivided into parent, hybrid, and parent *vs.* hybrid variance. For every character under study, it was also determined that the differences between the hybrids and parents were highly significant. Mean squares due to parents *vs* hybrids were found highly significant for all the characters except for plant height and number of spikelets per main spike were found significant and 100-grain weight was found non-significant. These differences in parents and hybrids were found significant due to recombination of genes derived from diverse parents leading to generation of an array of variability for different traits. This suggested the existence of overall heterosis and the chance of significant differences between the parents and crosses with respect to these characters. By seeing possibility of heterosis among these selected genotypes further analysis was needed. Similar observations were also reported Dedaniya *et al.* (2018) [3], Joshi and Kumar (2020) [8], Kumar *et al.* (2021) [9] and Dudhat *et al.* (2022) [4] in wheat.

Heterosis

The percentage increase or reduction in F1 over the better parent (heterobeltiosis) and over the standard check (standard heterosis) for twelve characters was used to measure heterosis. Standard heterosis is more useful than the measure of heterosis over superior parents. character-wise results on heterosis over better parent (heterobeltiosis) and over standard check, GW 1339 (standard heterosis) were presented in Table 2 to Table 5 and described as under.

Table 1 Analysis of variance (mean squares) for grain yield and its attributing traits in durum wheat

Source of variation	**d. f.**	**Days to anthesis**	**Grain filling period**	**Days to maturity**	**Plant height**	**Number of effective tillers per plant**	**Length of main spike**	**Number of spikelets per main spike**	**Number of grains per main spike**	**100-grain weight**	**Grain yield per plant**	**Biological yield per plant**	**Harvest index**
Replications	2	5.14**	0.29	6.19**	1.49	0.06	0.14	1.43	5.91	0.45*	0.03	0.68	2.11
Genotypes	43	36.21**	41.39**	17.06**	51.89**	7.05**	1.26**	6.94**	36.42**	0.55**	42.99**	670.89**	306.74**
Parents (P)	11	55.12**	60.64**	36.03**	95.78**	1.23**	1.01**	3.13**	13.75**	0.80**	14.86**	219.48**	333.06**
Hybrids (H)	31	26.20**	33.31**	10.62**	35.92**	8.49**	1.28**	8.33**	42.19**	0.48**	53.03**	781.87**	301.50**
P *vs.* H	1	138.33**	80.18**	7.88**	64.57*	26.14**	3.16**	5.89*	106.92**	0.01	41.09**	2195.73**	179.72**
Error	86	0.61	0.36	0.55	15.18	0.18	0.23	0.91	4.72	0.14	1.25	7.92	9.65

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

Table 2 Per cent heterobeltiosis (HB) and standard heterosis (SH) for days to anthesis, grain filling period and days to maturity in durum wheat

Sr. No.	Crosses	Days to anthesis		Grain filling period		Days to maturity	
		HB (%)	SH (%)	HB (%)	SH (%)	HB (%)	SH (%)
1	DDW 48 × GDW 1255	0.49	10.81**	-18.63**	-15.31**	-2.70**	1.77**
2	DDW 48 × HI 8737	-4.52**	14.05**	-10.78**	-7.14**	1.68**	6.71**
3	DDW 48 × WHD 965	4.64**	9.73**	-13.73**	-10.20**	-1.69**	2.83**
4	DDW 48 × NIDW 1158	9.79**	15.14**	-27.93**	-18.37**	-1.01	3.53**
5	GW 1348 × GDW 1255	-11.76**	-2.70**	28.57**	19.39**	4.95**	4.95**
6	GW 1348 × HI 8737	-5.43**	12.97**	-9.89**	-16.33**	-2.02**	2.83**
7	GW 1348 × WHD 965	-1.60	-0.54	11.34**	10.20**	2.82**	3.18**
8	GW 1348 × NIDW 1158	7.57**	7.57**	-14.41**	-3.06*	0.00	3.89**
9	HD 4758 × GDW 1255	3.92**	14.59**	-23.97**	-6.12**	-1.62**	7.42**
10	HD 4758 × HI 8737	-0.90	18.38**	-34.71**	-19.39**	-3.56**	5.30**
11	HD 4758 × WHD 965	4.26**	5.95**	-16.53**	3.06*	-3.88**	4.95**
12	HD 4758 × NIDW 1158	12.23**	14.05**	-33.88**	-18.37**	-5.83**	2.83**
13	HI 8841 × GDW 1255	4.88**	16.22**	-7.50**	-24.49**	1.40*	2.12**
14	HI 8841 × HI 8737	-4.07**	14.59**	-2.50	-20.41**	-2.36**	2.47**
15	HI 8841 × WHD 965	0.98	11.89**	-9.28**	-10.20**	3.51**	4.24**
16	HI 8841 × NIDW 1158	0.49	11.35**	-23.42**	-13.27**	-1.02	2.83**
17	MACS 3949 × GDW 1255	-0.48	12.97**	-8.79**	-15.31**	-2.99**	3.18**

18	MACS 3949 × HI 8737	-4.98**	13.51**	-13.19**	-19.39**	-3.99**	2.12**
19	MACS 3949 × WHD 965	-5.24**	7.57**	-6.19**	-7.14**	-3.65**	2.47**
20	MACS 3949 × NIDW 1158	-10.00**	2.16**	-16.22**	-5.10**	-6.31**	-0.35
21	MPO 1357 × GDW 1255	-3.70**	12.43**	2.25	-7.14**	-1.97**	5.65**
22	MPO 1357 × HI 8737	-6.33**	11.89**	10.11**	0.00	0.00	7.77**
23	MPO 1357 × WHD 965	0.46	17.30**	-27.84**	-28.57**	-5.90**	1.41*
24	MPO 1357 × NIDW 1158	-3.24**	12.97**	-26.13**	-16.33**	-4.59**	2.83**
25	RAJ 3307 × GDW 1255	-3.92**	5.95**	-1.09	-7.14**	1.41*	1.41*
26	RAJ 3307 × HI 8737	-8.14**	9.73**	0.00	-6.12**	-0.67	4.24**
27	RAJ 3307 × WHD 965	11.11**	13.51**	-15.46**	-16.33**	2.82**	3.18**
28	RAJ 3307 × NIDW 1158	5.82**	8.11**	-16.22**	-5.10**	-0.34	3.53**
29	UAS 475 × GDW 1255	0.00	10.27**	-9.52**	-3.06*	0.34	5.65**
30	UAS 475 × HI 8737	-5.88**	12.43**	-9.52**	-3.06*	1.68**	7.07**
31	UAS 475 × WHD 965	6.22**	10.81**	-6.67**	0.00	1.68**	7.07**
32	UAS 475 × NIDW 1158	2.59**	7.03**	-8.11**	4.08**	0.67	6.01**
S.Em ±		0.64	0.64	0.48	0.48	0.60	0.60
Range of heterosis		-11.76 to 12.23	-2.70 to 18.38	-34.71 to 28.57	-28.57 to 19.39	-6.31 to 4.95	-0.35 to 7.77
No. of crosses with significant and desirable heterosis (negative)		13	1	25	26	15	0

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

Table 3 Per cent heterobeltiosis (HB) and standard heterosis (SH) for plant height, number of effective tillers per plant and length of main spike in durum

Sr. No.	Crosses	Plant height		Number of effective tillers per plant		Length of main spike	
		HB (%)	SH (%)	HB (%)	SH (%)	HB (%)	SH (%)
1	DDW 48 × GDW 1255	4.79	-4.68	-8.26*	-5.66	5.30	-13.23**
2	DDW 48 × HI 8737	-7.47*	-3.00	34.38**	21.70**	-6.19	-9.12*
3	DDW 48 × WHD 965	-1.22	-4.47	-7.34	-4.72	-0.60	-14.60**
4	DDW 48 × NIDW 1158	4.70	-3.22	10.31*	0.94	1.49	-6.55
5	GW 1348 × GDW 1255	15.67**	5.21	-18.02**	-14.15**	12.49*	-12.03**
6	GW 1348 × HI 8737	-4.60	0.01	-24.32**	-20.75**	-7.25	-10.15*
7	GW 1348 × WHD 965	-0.23	-3.52	18.02**	23.58**	11.86*	-3.90
8	GW 1348 × NIDW 1158	7.80*	-0.36	-12.61**	-8.49*	-5.12	-12.63**
9	HD 4758 × GDW 1255	14.17**	3.85	-25.69**	-23.58**	0.51	-14.95**
10	HD 4758 × HI 8737	-9.31**	-4.93	72.22**	46.23**	-10.34*	-13.15**
11	HD 4758 × WHD 965	4.54	1.10	16.51**	19.81**	3.29	-11.26*
12	HD 4758 × NIDW 1158	6.12	-1.91	46.39**	33.96**	-12.65*	-19.57**

13	HI 8841 × GDW 1255	-10.01**	-2.85	-48.62**	-47.17**	-4.70	-6.21
14	HI 8841 × HI 8737	-0.33	7.59*	35.63**	11.32*	14.27**	12.46**
15	HI 8841 × WHD 965	-8.18*	-0.88	4.59	7.55	-8.31	-9.76*
16	HI 8841 × NIDW 1158	-13.28**	-6.39	-2.06	-10.38*	1.22	-0.39
17	MACS 3949 × GDW 1255	6.32	3.16	44.95**	49.06**	26.05**	12.72**
18	MACS 3949 × HI 8737	-11.85**	-7.59*	28.41**	6.60	-9.02*	-11.86*
19	MACS 3949 × WHD 965	-0.36	-3.32	22.94**	26.42**	12.45*	0.56
20	MACS 3949 × NIDW 1158	-0.57	-3.53	12.37*	2.83	3.35	-4.84
21	MPO 1357 × GDW 1255	-2.53	5.39	-26.61**	-24.53**	10.30	-12.89**
22	MPO 1357 × HI 8737	-12.90**	-5.83	2.11	-8.49*	-9.55*	-12.38**
23	MPO 1357 × WHD 965	-6.57*	1.01	12.84**	16.04**	7.88	-7.32
24	MPO 1357 × NIDW 1158	-8.61*	-1.19	-14.43**	-21.70**	-12.47*	-19.40**
25	RAJ 3307 × GDW 1255	5.99	3.03	21.10**	24.53**	-6.09	-15.46**
26	RAJ 3307 × HI 8737	-16.46**	-12.43**	22.47**	2.83	0.71	-2.44
27	RAJ 3307 × WHD 965	2.83	-0.05	3.67	6.60	2.95	-7.32
28	RAJ 3307 × NIDW 1158	-5.13	-7.79*	-36.08**	-41.51**	-6.88	-14.26**
29	UAS 475 × GDW 1255	6.86	-2.80	44.95**	49.06**	8.26	-13.58**
30	UAS 475 × HI 8737	-5.51	-0.95	11.46*	0.94	-12.38**	-15.12**
31	UAS 475 × WHD 965	-5.42	-8.54*	13.76**	16.98**	9.77*	-5.70
32	UAS 475 × NIDW 1158	9.12*	0.87	14.43**	4.72	-24.84**	-30.79**
SE ±		**3.14**	**3.14**	**0.34**	**0.34**	**0.39**	**0.39**
Range of heterosis		**-16.46 to 15.67**	**-12.43 To 7.59**	**48.62 to 72.22**	**-47.17 to 49.06**	**-28.84 to 26.05**	**-30.79 to 12.72**
No. of crosses with significant and desirable heterosis (positive)		**10**	**4**	**18**	**12**	**5**	**2**

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

Table 4 Per cent heterobeltiosis (HB) and standard heterosis (SH) for number of spikelets per main spike, number of grains per main spike and 100-grain weight in durum wheat

Sr. No.	**Crosses**	**Number of spikelets per main spike**		**Number of grains per main spike**		**100-grain weight**	
		HB (%)	**SH (%)**	**HB (%)**	**SH (%)**	**HB (%)**	**SH (%)**
1	DDW 48 × GDW 1255	-9.29*	-10.87*	-4.11	-10.78*	3.49	-17.42**
2	DDW 48 × HI 8737	3.10	1.30	13.33**	0.52	-2.20	-19.48**
3	DDW 48 × WHD 965	-14.16**	-15.65**	-1.32	-9.04*	-7.47	-11.62*
4	DDW 48 × NIDW 1158	-10.18*	-11.74*	-8.83*	-12.00**	-12.53**	-7.92
5	GW 1348 × GDW 1255	-8.80	-14.35**	-7.48	-13.91**	-13.07*	-21.54**
6	GW 1348 × HI 8737	-1.46	-11.74*	-0.78	-12.00**	-14.48*	-22.81**
7	GW 1348 × WHD 965	9.35*	1.74	1.51	-6.43	9.44	4.54

8	GW 1348 × NIDW 1158	-16.89**	-18.70**	-15.32**	-18.26**	-22.13**	-18.03**
9	HD 4758 × GDW 1255	0.93	-5.22	1.31	-5.74	10.39	-11.92*
10	HD 4758 × HI 8737	15.53**	3.48	15.88**	2.78	15.14*	-5.20
11	HD 4758 × WHD 965	4.67	-2.61	5.47	-2.78	-7.73	-11.86*
12	HD 4758 × NIDW 1158	-15.56**	-17.39**	-14.05**	-17.04**	-22.24**	-18.15**
13	HI 8841 × GDW 1255	-12.50*	-17.83**	-4.67	-11.30**	4.40	-16.70**
14	HI 8841 × HI 8737	49.03**	33.48**	50.00**	33.04**	10.21	-9.26*
15	HI 8841 × WHD 965	8.88	1.30	9.81*	1.22	-3.42	-7.74
16	HI 8841 × NIDW 1158	2.67	0.43	3.60	0.00	-23.10**	-19.06**
17	MACS 3949 × GDW 1255	12.96**	6.09	11.21*	3.48	10.28	-1.39
18	MACS 3949 × HI 8737	-3.40	-13.48**	0.39	-10.96**	-2.37	-12.70*
19	MACS 3949 × WHD 965	-1.40	-8.26	-0.57	-8.35*	-3.04	-7.38
20	MACS 3949 × NIDW 1158	0.44	-1.74	1.44	-2.09	-22.93**	-18.87**
21	MPO 1357 × GDW 1255	-15.74**	-20.87**	-11.96**	-18.09**	-11.55*	-12.89*
22	MPO 1357 × HI 8737	-7.51	-14.35**	-5.58	-14.61**	-11.43*	-12.76*
23	MPO 1357 × WHD 965	0.47	-6.52	1.32	-6.61	-8.85	-10.22*
24	MPO 1357 × NIDW 1158	-23.56**	-25.22**	-17.30**	-20.17**	-35.40**	-32.00**
25	RAJ 3307 × GDW 1255	-6.02	-11.74*	-3.74	-10.43*	-2.11	-18.57**
26	RAJ 3307 × HI 8737	-3.88	-13.91**	-2.55	-13.57**	-4.80	-20.81**
27	RAJ 3307 × WHD 965	-3.27	-10.00*	-2.64	-10.26*	-8.23	-12.34*
28	RAJ 3307 × NIDW 1158	-12.44**	-14.35**	-10.63*	-13.74**	-24.31**	-20.33**
29	UAS 475 × GDW 1255	-1.85	-7.83	-0.93	-7.83*	20.77**	-3.63
30	UAS 475 × HI 8737	-2.91	-13.04**	0.00	-11.30**	-7.27	-23.65**
31	UAS 475 × WHD 965	3.74	-3.48	2.26	-5.74	-7.16	-11.31*
32	UAS 475 × NIDW 1158	-15.56**	-17.39**	-13.69**	-16.70**	-19.43**	-15.18**
SE ±		**0.77**	**0.77**	**1.76**	**1.76**	**0.30**	**0.30**
Range of heterosis		**-23.56 to 49.03**	**-25.22 To 33.48**	**-17.30 to 50.00**	**-20.17 to 33.04**	**-35.40 to 20.77**	**-32.00 to 4.54**
No. of crosses with significant and desirable heterosis (positive)		**4**	**1**	**5**	**1**	**2**	**0**

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

Table 5 Per cent heterobeltiosis (HB) and standard heterosis (SH) for biological yield per plant and harvest index in durum wheat

Sr. No.	Crosses	Grain yield per plant		Biological yield per plant		Harvest index	
		HB (%)	SH (%)	HB (%)	SH (%)	HB (%)	SH (%)
1	DDW 48 × GDW 1255	-25.36**	-36.50**	-36.12**	-40.21**	-23.34**	6.56

2	DDW 48 × HI 8737	8.01	-8.11	41.79**	32.73**	-43.15**	-30.65**
3	DDW 48 × WHD 965	-14.23**	-9.09*	3.04	-3.55	-49.29**	-5.34
4	DDW 48 × NIDW 1158	-28.23**	-34.52**	3.17	-3.43	-51.47**	-32.34**
5	GW 1348 × GDW 1255	0.91	-23.92**	29.40**	-37.93**	-28.11**	22.47**
6	GW 1348 × HI 8737	-25.59**	-41.22**	105.68**	33.19**	-51.40**	-17.21*
7	GW 1348 × WHD 965	-3.78	1.99	66.64**	-5.49	-42.12**	8.04
8	GW 1348 × NIDW 1158	-19.00**	-26.10**	-34.71**	-57.34**	1.53	72.96**
9	HD 4758 × GDW 1255	-12.23	-41.52**	-34.03**	-50.33**	-15.19**	17.89*
10	HD 4758 × HI 8737	61.26**	27.40**	76.57**	32.94**	-20.92**	-3.53
11	HD 4758 × WHD 965	21.38**	28.66**	41.49**	6.53	-35.21**	20.93**
12	HD 4758 × NIDW 1158	-0.90	-9.58*	-16.69**	-37.27**	3.34	44.09**
13	HI 8841 × GDW 1255	-42.31**	-58.69**	-33.57**	-52.93**	-36.72**	-12.04
14	HI 8841 × HI 8737	29.58**	2.37	34.13**	-4.97	-11.16	8.37
15	HI 8841 × WHD 965	1.98	8.09	0.12	-29.06**	-18.04**	52.97**
16	HI 8841 × NIDW 1158	2.78	-6.22	-10.05*	-36.27**	5.41	46.97**
17	MACS 3949 × GDW 1255	83.99**	42.36**	128.33**	9.52**	-24.16**	30.46**
18	MACS 3949 × HI 8737	-18.05**	-35.26**	75.93**	13.92**	-51.40**	-16.41*
19	MACS 3949 × WHD 965	3.26	9.45*	70.99**	-3.03	-39.58**	12.77
20	MACS 3949 × NIDW 1158	2.72	-6.28	-5.49	-38.24**	-11.84**	51.64**
21	MPO 1357 × GDW 1255	-36.32**	-41.83**	19.66**	-4.30	-47.60**	-27.15**
22	MPO 1357 × HI 8737	-9.99*	-17.77**	-37.50**	-50.01**	34.89**	64.54**
23	MPO 1357 × WHD 965	-12.48**	-7.24	-16.17**	-32.95**	-25.97**	38.18**
24	MPO 1357 × NIDW 1158	-43.43**	-48.32**	-31.10**	-44.89**	-32.76**	-6.25
25	RAJ 3307 × GDW 1255	24.64**	-16.95**	16.53**	-16.66**	-28.04**	0.03
26	RAJ 3307 × HI 8737	-9.62	-28.60**	-32.63**	-51.82**	21.57**	48.30**
27	RAJ 3307 × WHD 965	-19.63**	-14.81**	-11.55*	-36.74**	-27.86**	34.65**
28	RAJ 3307 × NIDW 1158	-36.18**	-41.77**	-49.59**	-63.95**	15.85**	61.54**
29	UAS 475 × GDW 1255	69.02**	19.36**	80.46**	15.37**	-25.59**	3.44
30	UAS 475 × HI 8737	-2.90	-23.29**	28.80**	-16.60**	-24.31**	-7.67
31	UAS 475 × WHD 965	-6.34	-0.73	4.26	-33.35**	8.12*	101.80**
32	UAS 475 × NIDW 1158	-9.12	-17.09**	41.99**	-7.22*	-35.94**	-10.68
SE ±		**0.90**	**0.90**	**0.90**	**2.29**	**2.50**	**2.50**
Range of heterosis		**-43.43 to 83.99**	**-58.69 to 42.36**	**-49.59 to 128.33**	**-63.95 to 33.19**	**-51.47 to 34.89**	**-32.34 to 101.80**
No. of crosses with significant and desirable heterosis (positive)		**6**	**5**	**15**	**6**	**4**	**15**

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

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For wheat days to anthesis, the heterotic effect in a negative direction was preferable. Heterobeltiosis ranged from -11.76 per cent (GW 1348 × GDW 1255) to 12.23 per cent (HD 4758 × NIDW 1158) for days to anthesis. Thus, the earliest hybrids were GW 1348 × GDW 1255 (-11.76 %) followed by MACS 3949 × NIDW 1158 (-10.00 %) and RAJ 3307 × HI 8737 (-8.14 %). Out of 32 hybrids, 13 hybrids manifested significant and desirable (negative) estimate of heterobeltiosis. The range of standard heterosis was varied from -2.70 per cent (GW 1348 × GDW 1255) to 18.38 per cent (HD 4758 × HI 8737). The results were in accordance with the finding of Singh *et al.* (2012) [13] and Singh *et al.* (2013) [11].

For grain filling period ranged from -34.71 per cent (HD 4758 × HI 8737) to 28.57 per cent (GW 1348 × GDW 1255) and top cross combinations *viz.,* HD 4758 × HI 8737 (-34.71%), HD 4758 × NIDW 1158 (-33.88%) and DDW 48 × NIDW 1158 (-26.13%), which showed significant and negative heterotic effect for grain filling period. Out of 32 hybrids, 25 hybrids manifested significant and desirable (negative) estimate of heterobeltiosis. Heterosis over standard check ranged from -28.57 per cent (MPO 1357 × WHD 965) to 19.39 per cent (GW 1348 × GDW 1255). The most preferable standard heterosis over standard check was shown by the cross MPO 1357 × WHD 965 (-28.57%), which was followed by HI 8841 × GDW 1255 (-24.49%) and HI 8841 × HI 8737 (-20.41%). Out of 32 hybrids, 26 hybrids showed significant and desirable (negative) heterosis over standard check. The results were in accordance with the finding of Dedaniya *et al.* (2018) [3] and Dudhat *et al.* (2022) [4].

Negative heterosis for days to maturity is believed to be beneficial for wheat crop earliness. The range of heterobeltiosis varied from -6.31 per cent (MACS 3949 × NIDW 1158) to 4.95 per cent (GW 1348 × GDW 1255). The earliest hybrid was MACS 3949 × NIDW 1158 (-6.31%) followed by MPO 1357 × WHD 965 (-5.90%) and HD 4758 × NIDW 1158 (-5.83%). Fifteen of the thirty-two hybrids had negative heterosis over the superior parent. The range of standard heterosis varied from -0.35 per cent (MACS 3949 × NIDW 1158) to 7.77 per cent (MPO 1357 × HI 8737). Out of 32 hybrids, none of the hybrid exhibited significant and negative heterosis over standard check (Table 4). The similar findings were observed Reddy *et al*. (2023) [11] and Puri *et al*. (2025) [10].

The heterotic effect in negative direction is desirable for plant height in wheat. Heterobeltiosis ranged from -16.46 per cent (RAJ 3307 × HI 8737) to 15.67 per cent (GW 1348 × GDW 1255) for plant height. Highest desirable heterobeltiosis was recorded by the cross RAJ 3307 × HI 8737 (-16.46%) followed by HI 8841 × NIDW 1158 (-13.28%) and MPO 1357 × HI 8737 (-12.90%). Out of 32 hybrids, 10 hybrids shown significant and desirable (negative) heterosis over better parent for this trait. Heterosis over standard check ranged from -12.43 per cent (RAJ 3307 × HI 8737) to 7.59 per cent (HI 8841 × HI 8737). The cross RAJ 3307 × HI 8737 (-12.43%) exhibited the highest desirable standard heterosis over standard check followed by UAS 475 × WHD 965 (-8.54%), RAJ 3307 × NIDW 1158 (-7.79%) and MACS 3949 × HI 8737 (7.59%). Out of 32 hybrids, four hybrids showed significant and desirable (negative) heterosis over standard check. The results were in confirmation with the findings of Fouad *et al*. (2023) [6] and Reddy *et al*. (2023) [11].

The minimum and maximum values for heterobeltiosis recorded were -48.62 per cent (HI 8841 × GDW 1255) and 72.22 per cent (HD 4758 × HI 8737) for number of effective tillers per plant. The highest significant positive heterosis over better parent was recorded by the hybrid HD 4758 × HI 8737 (72.22 %) followed by HD 4758 × NIDW 1158 (46.39 %) and UAS 475 × GDW 1255 (44.95%). Out of 32 hybrids, 18 hybrids showed significant and positive heterosis over better parent. The magnitude of standard heterosis ranged from -47.17 per cent (HI 8841 × GDW 1255) to 49.06 per cent (MACS 3949 × GDW 1255 and UAS 475 × GDW 1255) for number of tillers per plant and total 12 crosses were showing positive and significant effect. Top three crosses were MACS 3949 × GDW 1255 (49.06%), UAS 475 × GDW 1255 (49.06%) and HD 4758 × HI 8737 (46.23%). The results were in similarity with the findings of Dudhat *et al*. (2022) [4] and Puri *et al*. (2025) [10].

The range of heterosis over better parent was recorded from -24.84 per cent (UAS 475 × NIDW 1158) to 26.05 per cent (MACS 3949 × GDW 1255) for length of main spike. The highest desirable heterosis was recorded by the hybrid MACS 3949 × GDW 1255 (26.05%) followed by HI 8841 × HI 8737 (14.27%) and MACS 3949 × WHD 965 (12.45%). Out of 32 hybrids, 5 hybrids showed significant and positive heterosis over better parent for length of main spike. Heterosis over standard check ranged from -30.79 per cent (UAS 475 × NIDW 1158) to 12.72 per cent (MACS 3949 × GDW 1255). The highest desirable heterosis were recorded in two hybrids MACS 3949 × GDW 1255 (12.72%) and HI 8841 × HI 8737 (12.46%). The results were in accordance with the findings of Kumar *et al*. (202) [9], Dudhat *et al*. (2022) [3] and Fouad *et al*. (2023) [6].

For Number of spikelets per main spike heterobeltiosis ranged from -23.56 per cent (MPO 1357 × NIDW 1158) to 49.03 per cent (HI 8841 × HI 8737) for number of spikelets per main spike. Four hybrids *viz*., HI 8841 × HI 8737 (49.03%), HD 4758 × HI 8737 (15.53%), MACS 3949 × GDW 1255 (12.96%) and GW 1348 × WHD 965 (9.35) exhibited significant and positive heterotic effect over better parent. The range of standard heterosis was -25.22 per cent (MPO 1357 × NIDW 1158) to 33.48 per cent (HI 8841 × HI 8737). Out of 32 hybrids, only HI 8841 × HI 8737 (33.48%) exhibited significant and positive heterosis over standard check. The results were in accordance with the findings of Joshi and Kumar (2020) [8], Dudhat *et al*. (2022) [4] and Fouad *et al*. (2023) [6].

Number of grains per main spike was one of the most important traits contributing to the grain yield and hence, their positive values are beneficial in wheat. The range of heterosis over better parent varied from -17.30 per cent (MPO 1357 × NIDW 1158) to 50.00 per cent (HI 8841 × HI 8737). The highest heterosis over better parent in desirable direction was recorded by crosses HI 8841 × HI 8737 (50.00%) followed by HD 4758 × HI 8737 (15.88%) and DDW 48 × HI 8737 (13.33%). The range of standard heterosis for number of grains per main spike varied from -20.17 per cent (MPO 1357 × NIDW 1158) to 33.04 per cent (HI 8841 × HI 8737). Out of 32 hybrids, only HI 8841 × HI 8737 (33.04%) exhibited significant and positive heterosis over standard check. These results were in agreement with the earlier studies carried out by Reddy *et al*. (2023) [11] and Puri *et al*. (2025) [10].

The heterobeltiosis for 100-grain weight ranged from -35.40 per cent (MPO 1357 × NIDW 1158) to 20.77 per cent (UAS 475 × GDW 1255). The highest heterosis over better parent in desirable direction was recorded by two crosses viz., UAS 475 × GDW 1255 (20.77%) and HD 4758 × HI 8737 (15.14) for 100-grain weight. The range of standard heterosis for 100-grain weight varied from -32.00 per cent (MPO 1357 × NIDW 1158) to 4.54 per cent (GW 1348 × WHD 965). Out of 32 hybrids, none of the hybrid exhibited significant and positive heterosis over standard check for 100-grain weight. The results were in accordance with the findings of Kumar *et al*. (2021) [9] and Dudhat *et al*. (2022) [4].

The estimates of heterosis over better parent varied from -43.43 per cent (DDW 48 × NIDW 1158) to 83.99 per cent (MACS 3949 × GDW 1255) for grain yield per plant. The significantly highest heterosis over better parent in desirable direction was recorded by cross MACS 3949 × GDW 1255 (83.99%) followed by UAS 475 × GDW 1255 (69.02%) and HD 4758 × HI 8737 (61.26%). Out of 32 hybrids, 6 hybrids expressed significant positive heterosis over better parent for grain yield per plant. The economic heterosis for grain yield per plant ranged from -58.69 per cent (MPO 1357 × NIDW 1158) to 42.36 per cent (MACS 3949 × GDW 1255). The highest significant heterosis towards positive direction over standard check were recorded by five crosses *viz*., MACS 3949 × GDW 1255 (42.36%) followed by HD 4758 × WHD 965 (28.66%), HD 4758 × HI 8737 (27.40%), UAS 475 × GDW 1255 (19.36%) and MACS 3949 × WHD 965 (9.45%). The results were in accordance with the findings of Joshi and Kumar (2020) [8], Kumar *et al*. (2021) [9], Dudhat *et al*. (2022) [4], Fouad *et al*. (2023) [6], Reddy *et al*. (2023) [11], Fareed *et al*. (2024) [5] and Puri *et al*. (2025) [10].

For biological yield per plant heterosis over better parent ranged from -49.59 per cent (RAJ 3307 × NIDW 1158) to 128.33 per cent (MACS 3949 × GDW 1255). The highest significant heterobeltiosis was recorded by the cross MACS 3949 × GDW 1255 (128.33%) followed by GW 1348 × HI 8737 (105.68%) and UAS 475 × GDW 1255 (80.46%). Out of 32 hybrids, 15 hybrids expressed significant and positive heterosis over better parent for biological yield per plant. The range of heterosis over standard check observed from -63.95 per cent (RAJ 3307 × NIDW 1158) to 33.19 per cent (GW 1348 × HI 8737). The cross GW 1348 × HI 8737 (33.19%) exhibited the highest significant heterosis over standard check followed by HD 4758 × HI 8737 (32.94%) and DDW 48 × HI 8737 (32.73%). For biological yield per plant six of the 32 hybrids showed significant and favourable heterosis over the standard check. The results were in accordance with the findings of Reddy *et al*. (2023) [11] and Puri *et al*. (2025) [10].

The estimates of heterobeltiosis for harvest index varied from -51.47 per cent (DDW 48 × NIDW 1158) to 34.89 per cent (MPO 1357 × HI 8737). The highest significant and desirable heterosis over better parent was recorded by the cross MPO 1357 × HI 8737 (34.89%) followed by RAJ 3307 × HI 8737 (21.57%), RAJ 3307 × NIDW 1158 (15.85%) and UAS 475 × WHD 965 (8.12%). Out of 32 hybrids, four hybrids demonstrated significant and positive heterosis over better parent for harvest index. The range of heterosis over standard check observed from -32.34 per cent (DDW 48 × NIDW 1158) to 101.80 per cent (UAS 475 × WHD 965). The cross UAS 475 × WHD 965 (101.80%) exhibited the highest significant heterosis over standard check followed by GW 1348 × NIDW 1158 (72.96%) and MPO 1357 × HI 8737 (64.54%). 15 of the hybrid plants showed a better performance than the standard check. The results were in accordance with the findings of Kumar *et al*. (2021) [9] and Dudhat *et al*. (2022) [4].

Comparative studies of standard heterotic crosses along with *per se* performance for grain yield corresponding to other attributes are presented in Table 4. It was revealed that high, significant and positive heterosis for grain yield per plant in these crosses were not accompanied by single unique trait. These crosses also exhibited significant and desirable heterosis for component traits.

For grain yield, the five best-performing crosses were MACS 3949 × GDW 1255, HD 4758 × WHD 965, HD 4758 × HI 8737, UAS 475 × GDW 1255, and MACS 3949 × WHD 965, all of which significantly outperformed both their parent lines and the standard varieties. These crosses also showed significant and desirable heterobeltiosis and standard heterosis for grain yield and attributing traits *viz.,* days to anthesis, grain filling period, days to maturity, plant height, number of effective tillers per plant length of main spike, number of spikelets per main spike, number of grains per main spike, 100-grain weight, grain yield per plant, biological yield per plant and harvest index.

IV. CONCLUSION

High heterotic hybrids had also shown high mean performance, so it revealed that the selection of hybrids either on the basis of *per se* performance or on the basis of magnitude of heterotic effects would be equally reliable. On the basis of *per se* performance, heterotic response involved in the inheritance of grain yield and its attributing traits, the three crosses *viz.,* MACS 3949 × GDW 1255, HD 4758 × WHD 965 and HD 4758 × HI 8737 appeared to be the most superior cross combinations. These hybrids recorded 42.36, 28.66 and 27.40 per cent higher yield over standard check (GW 1339), respectively. Therefore, these crosses could be exploited for heterosis breeding programme to boost the grain yield in durum wheat.

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