Pak. J. Bot., 47(5): 1831-1837, 2015.

HETEROSIS AND HETEROBELTIOTIC STUDIES OF F_1 HYBRIDS IN *BRASSICA CARINATA*

NAUSHEEN[1], FARHATULLAH[1]*, IFTIKHAR HUSSAIN KHALIL[1]AND AMANULLAH[2]

[1]Department of Plant Breeding and Genetics and [2]Department of Agronomy
The University of Agriculture, Peshawar-25120, Pakistan.
**Correspondence author e-mail: drfarhat@aup.edu.pk*

Abstract

An experiment was carried out at the University of Agriculture, Peshawar during 2012-13 using a set of F_1 hybrids of *B. carinata* for estimating heterosis and heterobeltiosis for important yield and quality parameters. The experimental material comprised of six *B. carinata* parental genotypes viz. C-88, C-89, C-90, C-93, C-95, C-97 and their 30 F_1 hybrids as direct crosses. A randomized complete block design with two replicates was used for field evaluation of 36 *B. carinata* genotypes (6 parental lines and 30 F1 hybrids). Significant genetic variation was observed for primary branches plant^{-1}, main raceme length, seed yield plant^{-1}, oil and protein content among parents as well as F1 hybrids. The highest heterosis and heterobeltiosis for primary branches (24.25 vs. 12.30%) and main raceme length (37.31 vs. 22.93%) was recorded for F1 hybrids C-88 × C-93 and C-89 × C-97, respectively. Hybrid C-93 × C-90 had the highest positive heterosis for seed yield plant $^{-1}$ (23.33%). For protein content, the maximum heterosis was recorded for hybrid C-88 × C-89 (11.34%). Similarly, F1 hybrid C-88 × C-97 showed maximum heterosis for oil content (14.41%). The highest heterobeltiosis was exhibited by hybrids C-90 × C-97 for seed yield (9.53%) , C-89 × C-90 for oil content (7.61%) and C-93 × C-97 for protein content (4.11%). Based on high mean performance and heterotic values, aforemntioned hybrids and their corresponding parental lines will be exploited further for commercial hybrid production.

key words: Heterosis, Heterobeltiosis, *Brassica carinata* L., Yield, Protein and oil content

Introduction

Oil crops are important source of energy for human, livestock and industry. The fatty acid composition is the major factor of oil seed crop, which is important for both industrial and nutritional purpose. Keeping in view the importance and growing demand of the country, new strategies for boosting production of edible oilseed are needed.

Pakistan is deficient in edible oil since long. One of the major reason for this is the rapid increase in population. In Pakistan brassica is the 2nd important source of vegetable oil, after cottonseed (Khan *et al*., 2008). It contributes about 21% to edible oil production (Abbas *et al*., 2008). Its seed residue is used as fertilizers and also as cattle feed (French, 1977). Brassica is one of the major sources of vegetable oil of the world. Globally, oilseed Brassica species (*Brassica napus, B. campestris and B. juncea*) are the 3rd most important source of edible vegetable oil after palm and soybean (Zhang & Zhou, 2006).

The family Brassicaceae consists of 375 genera and 3200 species, out of which 52 genera and 160 species are found in Australia (Jessop & Tolken, 1986). Majority parts like stem, buds, flowers, leaves, and roots of these oilseed species are edible. Seed is also used as condiment. Some of these species are also used as forage (Doddabhimappa *et al*., 2009).

In human civilization (5000 BC) rapeseed (*Brassica napus, L.*) and mustard (*B. juncea* L.) (4000 BC) are the oldest cultivated plant species of the world (Yan, 1990). Abyssinian mustard (*Brassica carinata* L., 2n=34) is native to highlands (Sheikh *et al*., 2014) was collected from wild for human consumption (Schippers, 2002). In the Ethiopian highlands it is cultivated as an oil and leafy vegetable crop (Mnzava, 1986; Schippers, 2002). *Brassica carinata* was cultivated as an option to the traditional mustard especially for low rainfall areas of the world. It possesses acceptable yield levels as well as resistance to physical and environmental stresses (Getinet *et al*., 1996). Instead of all these positive aspects the oil of *B. carinata* has generally high levels of undesirable glucosinolate (Getinet *et al*., 1997) and erucic acid (Velasco *et al*., 1998), making it a undesirable oilseed crop in comparison to *Brassica napus* (canola). Its oil has industrial applications like erucic acid is one of the additives of biodiesel and can be used as biofuel in jet aircraft (http://www.asdnews.com/news-46032/ 2012). Glucosinolate has useful role in plant defense against insects/pests and other biotic stresses (Getinet *et al*., 1996). However, quality traits like oil, protein and glucosinolate contents as well as fatty-acid can be modified by classical breeding (Nasim and Farhatullah, 2013; Sidra *et al*., 2014) and genetic approaches (Mahwish *et al*., 2014).

Heterosis is known as the superiority of a hybrid over its parents (Pourdad & Sachen, 2003). In increasing crop production, heterosis is quick, cheap and easy method (Pal & Sikka, 1956) for hybrid seed production. Heterobeltiosis (best parent heterosis) is the percent increase or decrease of the F_1 over its better parent. One of the most important objectives in oilseed breeding programs around the world is breeding for high seed oil content (Zhong *et al*., 2009). Hybrids between genetically diverse groups had better heterotic expression than within group cross combination (Akbar *et al*., 2007). The partitioning of total effect of F_1 progeny into general and specific combining ability effects deciphers the causes of heterosis. In F_1, the higher yields may be due to fixed (additive) and/or non-fixed (non-additive) gene action (Mahto & Haider, 2004). Selection of parental lines with good general combining ability helps in the creation of considerable genetic development in crop plants having different breeding behaviors (Anand & Murty, 1968; Marani & Avieli, 1973).

Keeping in view the above aspects, this research work on *B. carinata* was conducted to work out mid and best parent heterosis for morphological and biochemical traits under field conditions.

Materials and Methods

Experiment on heterotic studies of F_1 hybrids of *Brassica carinata* L. was conducted at The University of Agriculture, Peshawar during 2012-13.

Breeding materials: A set of six exotic parental genotypes viz. C-88, C-89, C-90, C-93, C-95 and C-97 were procured from the University of California, Davis, USA and their 30 F_1 crosses were provided by the Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar. The crosses were made in the season of 2010-11. The experiment was sown in two replications using a randomized complete block (RCB) design on 13th of October, 2012. Each replication consisted of six parental lines and their all 30 direct F1 hybrids. Row to row distance was 60 cm and plant to plant distance was 30 cm. The experimental material was sown under natural field conditions (fertilizer and pesticides were not applied) in order to measure full potential of exotic parental lines and their F1 hybrids under natural conditions.

Data were recorded on major yield contributing parameters viz. primary branches plant^{-1}, main raceme length and seed yield plant^{-1}.

Biochemical analysis: Biochemical analysis is an important feature of oil seed crops. In oil seed crops, quality seed production is the major objective. The quality of oil seed in brassica depends on high percentage of oleic acid, protein, oil, and low percentage of linolinic acid, glucosinolate and erucic acid.

To determine the afformentioned chemical constituents, well cleaned dried seed samples were scanned through near Infra-Red Reflectance (NIRS) spectroscopy system at the Biochemical Laboratory, Crop Breeding Section of Nuclear Institute for Food and Agriculture (NIFA), Tarnab Peshawar for oil and protein content.

Table 1. Mean squares for yield and oil quality traits of 36 *Brassica carinata* L. genotypes evaluated during 2012-13.

Parameters	Genotypes (df = 35)	Error (df = 35)	CV (%)
Primary branches plant^{-1}	32.6**	12.9	16.0
Main raceme length	356.5**	117.7	16.3
Seed yield plant^{-1}	133.9**	14.3	14.8
Oil content	5.6**	0.84	1.9
Protein content	5.2**	2.1	7.1

** = Significant at 1% probability level

Statistical analysis: Data were subjected to the analysis of variance for randomized complete block design (Table 1) with two replications (Steel & Torrie, 1960). The significant differences among genotypes (parental lines and F1 hybrids) were further compared through least significant difference (LSD) test at 5% level of probability.

Results

Primary branches plant^{-1}: The analysis of variance for brassica genotypes showed highly significant differences ($p<0.01$) for primary branches plant^{-1}. The coefficient of variation for primary branches plant^{-1} was 16.00% (Table 1). Means for primary branches plant^{-1} of six parental lines of *Brassica carinata* genotypes ranged from 21.00 to 29.00 indicating a net difference of 8.00 with the mean value of 25.28. Parental lines C-93 and C-90 showed the minimum (21.00) and the maximum (29.00) primary branches plant^{-1}, respectively. Similarly, means of F_1 hybrids ranged from 11.00 to 32.50 indicating a net difference of 21.50 with a mean value of 21.90. Hybrids C-93 × C-89 (11.00) and C-88 × C-90 (32.50) showed the minimum and maximum primary branches plant^{-1}, respectively (Table 2).

Heterotic data regarding primary branches plant^{-1} demonstrated that 23 out of 30 crosses showed negative heterosis, in which 19 values were significant, while remaining seven hybrids showed positive heterosis. Mid-parent hetrosis of F_1 hybrids ranged from -54.16 to 24.25%, where the maximum negative (-54.16%) heterosis was recorded for intraspecific cross C-93C × -89, while the maximum positive (24.25%) heterosis was for C-88 × C-93. On overall basis, 23 out of 30 mid parent heterotic values were significant, while values of the rest of the crosses were non-significant (Table 3).

Data regarding heterobeltiosis showed that 27 out of 30 F1 hybrids showed negative heterobeltiosis, in which 25 heterobeltiosis were significant, while remaining three hybrids displayed heterobeltiosis in positive direction. The negative values varied from -1.53 to -59.25%, where the minimum and the maximum negative values were noted for hybrids C-88 × C-95 and C-93 × C-89, respectively. The positive values varied from 4.05 to 12.30%, where the minimum (4.05%) and maximum (12.30%) positive values were noted for hybrids C-93 × C-95 and C-88 × C-93, respectively (Table 3).

Main raceme length (cm): The analysis of variance for *B. carinata* genotypes showed highly significant differences ($p<0.01$) for main raceme length. The coefficient of variation for main raceme length was 11.80% (Table 1). Means for main raceme length of six parental lines of *B. carinata* genotypes ranged from 55.50 to 87.00 cm, representing a net difference of 31.50 cm with a mean of 63.83 cm. Parental lines C-90 (55.50 cm) and C-88 (87.00 cm) showed minimum and maximum values for main raceme length. Similarly mean raceme length for 30 F_1 hybrids ranged from 43.65 to 96.00 cm, representing a net difference of 52.35 cm with a mean of 66.96 cm. Hybrids C-97 × C-93 (43.65 cm) and C-89 × C-88 (96.00 cm) showed minimum and maximum values for main raceme length, respectively (Table 2).

Table 2. Mean performance of parents and their 30 F_1 hybrids for yield and oil quality traits of *Brassica carinata* L.

Genotypes	No. of primary branches plant^{-1}	Main raceme length (cm)	Seed yield (g plant^{-1})	Oil content (%)	Protein content (%)
I. Parental lines					
C-88	26.00	87.00	41.05	48.55	20.90
C-89	27.00	58.00	17.30	45.80	17.90
C-90	29.00	55.50	32.00	46.60	19.30
C-93	21.00	56.00	28.00	47.30	22.30
C-95	22.20	65.50	22.20	53.10	23.95
C-97	26.50	61.00	29.00	50.50	23.10
Parents mean	25.28	63.83	28.25	48.64	21.24
II. F_1 hybrids					
C-88 × C-89	19.90	70.10	29.00	45.60	21.60
C-88 × C-90	32.50	89.20	41.00	50.30	21.05
C-88 × C-93	29.20	75.50	38.50	47.75	20.50
C-88 × C-95	25.60	76.00	23.50	48.35	18.40
C-88 × C-97	24.50	93.00	41.50	49.50	21.00
C-89 × C-90	20.10	73.30	30.00	50.15	19.90
C-89 × C-93	25.60	75.50	27.70	50.35	20.75
C-89 × C-95	22.65	68.65	19.60	48.40	19.65
C-89 × C-97	23.00	81.70	22.60	49.20	18.45
C-90 × C-93	22.00	71.70	23.00	47.80	22.35
C-90 × C-95	22.80	74.00	27.65	48.50	21.15
C-90 × C-97	19.00	56.00	35.05	48.60	19.85
C-93 × C-95	23.10	57.60	26.50	46.35	21.15
C-93 × C-97	22.70	53.10	20.50	47.70	24.05
C-95 × C-97	24.65	61.00	21.00	49.75	19.60
C-89 × C-88	20.60	96.00	24.20	48.70	20.95
C-90 × C-88	18.00	73.20	35.00	49.05	20.95
C-93 × C-88	23.00	48.75	25.15	49.70	22.75
C-95 × C-88	19.00	70.00	31.60	51.20	19.15
C-97 × C-88	24.60	58.50	19.10	48.15	21.15
C-90 × C-89	15.50	70.50	18.85	48.05	19.80
C-93 × C-89	11.00	46.50	13.65	49.00	21.55
C-95 × C-89	19.20	58.50	20.70	50.75	19.35
C-97 × C-89	23.00	78.50	14.50	46.20	19.15
C-93 × C-90	26.10	63.75	37.00	50.50	18.95
C-95 × C-90	20.00	64.50	15.10	48.70	19.35
C-97 × C-90	19.60	66.00	17.50	51.80	19.00
C-95 × C-93	20.60	50.20	22.50	50.35	18.10
C-97 × C-93	20.50	43.65	11.05	48.20	17.95
C-97 × C-95	19.20	44.00	18.90	49.30	19.30
F1s mean	21.90	66.96	25.06	48.93	20.23
LSD (0.05)	7.29	22.02	7.68	1.86	2.95

Table 3. Estimates of mid-parent heterosis (MPH) and best-parent heterosis (BPH) for yield and oil quality traits of 30 *Brassica carinata* L. F_1 hybrids.

F_1 hybrids	No. of primary branches plant^{-1}		Main raceme length		Seed yield plant^{-1}		Oil content		Protein content	
	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)
C-88×C-89	-24.90**	-26.29**	-3.31	-19.42*	-0.59	-29.35**	-3.33**	-6.07**	11.34**	-3.34*
C-88×C-90	18.18**	12.06**	25.19**	2.52	12.25**	-0.12	5.72**	-3.60**	4.72**	0.71
C-88×C-93	24.25**	12.30**	5.594	-13.21*	11.51**	-6.21	-0.36**	-1.64*	-5.09**	-8.07**
C-88×C-95	-6.22**	-1.53	-0.32	-12.64	-25.69**	-42.75**	-4.86**	-8.94**	-17.94**	-23.17**
C-88×C-97	-6.66*	-7.54*	25.67**	6.89	18.48**	1.09	14.41**	1.95*	-4.54**	-9.09**
C-89×C-90	-28.21**	-30.68**	29.16**	26.37**	21.70**	-6.25	8.54**	7.61**	6.98**	3.10*
C-89×C-93	6.66**	-5.18	32.45**	30.17**	22.29**	-1.07	8.16**	6.44**	3.23*	-6.95**
C-89×C-95	-7.92**	-16.11	11.17	4.80	-0.75	-11.71**	-2.12*	-8.85**	-6.09**	-17.95**
C-89×C-97	-14.01**	-14.81**	37.31**	33.93**	-2.37	-22.06**	2.18	7.42**	-10.00**	-20.12**
C-90×C-93	-12.00**	-24.13**	28.60**	28.03**	-23.33**	-28.12**	1.81*	1.05	7.45**	0.22
C-90×C-95	-10.93**	-21.37**	22.314*	12.97	2.02	-13.59**	-2.70**	-8.66**	-2.19	-11.69**
C-90×C-97	-31.53**	-34.48**	-3.86	-8.19	14.91**	9.53**	0.10	4.29**	-6.36**	-14.06**
C-93×C-95	6.94**	4.05	-5.18	-12.06	5.57	-5.35	-7.66**	-2.00*	-8.54**	-11.69**
C-93×C-97	-4.42	-14.33**	-9.23	-12.95	-28.07**	-29.31**	-2.45**	0.84	5.94**	4.11**
C-95×C-97	1.23	-6.98**	-3.55	-6.87	-17.96**	-27.58**	-3.95**	-6.30**	-16.68**	-15.15**
C-89×C-88	-22.26**	-23.70**	32.41**	10.34	-17.05**	-41.04**	3.23**	0.30	7.98**	0.23
C-90×C-88	-34.54**	-37.93**	2.73	-15.86*	-4.17	-14.73**	3.10**	1.02	4.22**	0.23
C-93×C-88	-2.12	-11.53**	-31.81**	-43.96**	-27.15**	-38.73**	3.70**	2.36**	5.32**	2.01
C-95×C-88	-21.16**	-26.92**	-8.19	-19.54*	-0.07	-47.38**	0.73**	-3.57**	-14.60**	-20.04**
C-97×C-88	-6.28	-7.16*	-20.94*	-32.75**	-45.46**	-53.47**	-2.77**	-0.82	-3.86**	-8.44**
C-90×C-89	-44.64**	-46.55**	24.22*	21.55**	-23.52	-41.09**	4.00**	3.11**	6.45**	2.59*
C-93×C-89	-54.16**	-59.25**	-18.42	-19.82*	-39.73**	-94.10**	5.26**	3.59**	7.21**	-3.36*
C-95×C-89	-21.95*	-28.88**	-5.26	0.86	4.81	-6.75**	2.62**	-4.42**	-7.52**	-19.20**
C-97×C-89	-14.01**	-14.81**	31.93	28.68**	-37.36**	-50.00**	-4.04**	0.87	-6.58**	-17.09**
C-93×C-90	4.40	-10.00**	14.34	13.83	23.33**	-15.62**	7.56**	6.76**	-8.89**	-15.02**
C-95×C-90	-21.87**	-31.03**	6.61	-1.52	-44.28**	-52.81**	-2.30**	-8.28**	-10.52**	-19.20**
C-97×C-90	-29.36**	-32.41**	13.30	8.19	-42.62*	-45.31**	11.15**	6.69**	-10.37**	-95.67**
C-95×C-93	-4.62	-7.20*	-17.36	-23.35	-10.35**	-19.64**	6.44**	0.29**	-21.72**	-24.42**
C-97×C-93	-13.68**	-22.64**	-25.38**	-28.44**	-61.22**	-61.89**	1.90*	-1.43**	-20.92**	-22.29**
C-97×C-95	-21.14**	-27.54**	-30.43**	-32.82**	-26.17**	-34.82**	-4.82**	-7.15**	-17.95**	-16.45**
S.E.	**3.11**		**9.39**		**3.27**		**0.79**		**1.25**	
CD at P= 1%	**8.48**		**25.6**		**8.91**		**2.15**		**3.4**	
CD at P= 5%	**6.31**		**19.07**		**6.64**		**1.6**		**2.53**	

*, ** = Significant at 5 and 1% probability level, respectively. S.E. = Standard error, CD = Critical difference

Heterotic values regarding main raceme length demonstrated that 14 out of 30 crosses showed negative mid-parent heterosis, in which four values were significant, while remaining 16 hybrids showed positive heterosis. Mid-parent heterosis for 30 F_1 hybrids ranged from -31.81 to 37.31%, where the maximum negative heterosis was recorded for intraspecific cross C-93 × C-88, while the maximum positive heterosis (37.31%) was for C-89 × C-97. On overall basis, 29 out of 30 mid-parent heterotic values were significant, while one value was non-significant (Table 3).

Data regarding heterobeltiosis showed that 16 out of 30 F1 hybrids showed negative heterobeltiosis, in which eight values for heterobeltiosis were significant, while remaining 14 hybrids displayed positive heterobeltiosis. The negative values ranged from -1.52 to -43.96%, where the minimum and the maximum negative values (-1.52 and -43.96%) were noted for hybrids C-95 × C-90 and C-93 × C-88. The positive values of heterobeltiosis varied from 0.86 to 33.93%, where the minimum (0.86%) and maximum (33.93%) positive values were noted for hybrids C-95 × C-89 and C-89 × C-97, respectively. On

overall basis, 14 out of 30 best parent heterotic values were significant, while heterotic values for remaining crosses were non-significant (Table 3).

Seed yield plant^{-1}(g): Theanaly sis of variance revealed highly significant genetic differences (P<0.01) among *B. carinata* genotypes for seed yield plant^{-1}. The coefficient of variation for number of seed yield plant^{-1} was 14.79% (Table 1). Means for seed yield plant^{-1} of six parental lines of *B. carinata* genotypes ranged from 17.30 to 41.05 g, indicating a net difference of 23.75 g with the mean of 28.25 g. Parental lines C-89 (17.30 g) and C-88 (41.05 g) had minimum and maximum seed yield plant^{-1}. Similarly seed yield of 30 F_1 hybrids ranged from 11.05 to 41.50 g plant^{-1} indicating a net difference of 30.45 g with a mean of 25.06 g. Hybrids C-97 × C-93 (11.05 g) and C-88 × C-97 (41.50 g) showed minimum and maximum values for seed yield plant^{-1}, respectively (Table 2).

Mid-parent heterotic for number of seed yield plant^{-1} demonstrated that 20 out of 30 F_1 crosses showed negative heterosis, in which 14 values were significant, while remaining 10 hybrids showed positive heterosis. Mid-parent heterosis for F_1 hybrids ranged from -61.22 to 23.33%, where the maximum negative heterosis was recorded for intraspecific cross C-97 × C-93, while the maximum positive heterosis (23.33%) was for C-93 × C-90. On overall basis, 21 out of 30 mid parent heterotic values were significant, while the values for the rest of the crosses were non-significant (Table 3).

Data regarding heterobeltiosis showed that 27 out of 30 F_1 hybrids showed negative heterobeltiosis, in which 22 values of heterobeltiosis were significant, while remaining three hybrids displayed heterobeltiosis in positive direction. The negative values varied from -0.12 to -61.89%, where the minimum (-0.12%) and maximum (-61.89%) negative values were noted for hybrids C-88 × C-90 and C-97 × C-93, respectively. The positive values varied from 1.091 to 15.62%, where the minimum and maximum positive values (1.09 vs. 15.62%) were noted for hybrids C-88 × C-97 and C-93 × C-90, respectively. On overall basis, 24 out of 30 best parent heterotic values were significant, while the values for the rest of the crosses were non-significant (Table 3).

Oil content (%): The analysis of variance showed highly significant genetics differences (p<0.01) among Brassica genotypes for oil content. The coefficient of variation for oil content was 1.88% (Table 1). Mean oil content of six parental lines of *Brassica carinata* genotypes ranged from 45.80 to 53.10%, showing a net difference of 7.30% with the mean of 48.64%. Parental lines C-89 (45.80%) and C-95 (53.10%) had minimum and maximum oil content. Similarly mean oil content of 30 F_1 hybrids ranged from 45.60 to 51.80% showing a net difference of 6.205 units with a mean of 48.93%. F1 hybrids C-88 × C-89 (45.60%) and C-97 × C-90 (51.80%) showed minimum and maximum values for oil content, respectively (Table 2).

Mid-parent heterotic values regarding oil content showed that 14 out of 30 F1 crosses showed negative heterosis, in which 12 heterosis were significant, while remaining F1 hybrids showed positive heterosis. Mid-parent heterosis for F_1 hybrids ranged from -7.66 to 8.54%, where maximum negative heterosis was recorded for intraspecific cross C-93 × C-95, while maximum positive mid-parent heterosis (8.54%) was observed for C-89 × C-90. On overall basis, 25 out of 30 mid parent heterotic values were significant, while the values were non-significant (Table 3).

Data regarding heterobeltiosis showed that 12 out of 30 F1 hybrids showed negative heterobeltiosis, in which 10 heterobeltiosis were significant, while remaining hybrids displayed positive heterobeltiosis. The negative values varied from -0.82%to -8.94%, where the minimum (-0.82%) and the maximum (-8.94%) negative values were noted for hybrids C-97 × C-88 and C-88 × C-95, respectively. The positive heterobeltiosis values varied from 0.30 to 11.15%, where the minimum and maximum positive values (0.30 vs. 11.15%) were noted for hybrids C-89 × C-88 and C-97 × C-90, respectively. On overall basis, 23 out of 30 best parent heterotic values were significant, while the values for the rest of the crosses were non- significant (Table 3).

Protein content (%): The analysis of variance exhibited highly significant genetics differences (p<0.01) among brassica genotypes for protein content. The coefficient of variation for protein content was 7.13% (Table 1). Means protein content of six parental lines of *Brassica carinata* ranged from 17.90 to 23.95% showing a net difference of 6.05% with the mean of 21.24%. Parental lines C-89 (17.90%) and C-95 (23.95%) showed minimum and maximum values for protein content. Similarly protein content of 30 F_1 hybrids ranged from 18.10 to 24.05% showing a net difference of 5.95% with a mean of 20.23%. Hybrids C-95 × C-93 (18.10%) and C-93 × C-97 (24.05%) showed minimum and maximum protein content, respectively (Table 2).

Mid-parent heterotic values regarding protein content demonstrated that 19 out of 30 F1 crosses showed negative heterosis, in which 19 values were significant, while remaining hybrids showed positive heterosis. Mid-parent heterosis for protein content of 30 F_1 hybrids ranged from -21.72 to 11.34%, where the maximum negative heterosis was recorded for intraspecific cross C-95 × C-93, while the maximum (11.34%) for C-88 × C-89 (Table 3).

Data regarding heterobeltiosis for protein content showed that 20 out of 30 F1 hybrids showed negative heterobeltiosis, in which 19 values for heterobeltiosis were significant, while remaining hybrids had positive heterobeltiosis. The negative heterobeltiosis values for protein content of F1 hybrids varied from -3.36 to -95.67%, where the minimum and the maximum negative values (-3.36 and -95.67%) were noted for hybrids C-93 × C-89 and C-97 × C-90. The positive values for protein content of F1 hybrids varied from 0.22 to 8.07%, where the minimum and the maximum positive values (0.22 and 8.07%) were noted for hybrids C-90 × C-93 and C-88 × C-93, respectively (Table 3).

We conclude that significant genetics differences were observed among parental *B. carinata* genotypes (obtained from University of California, Davis-USA) and their 30 F_1 hybrids for primary branches plant^{-1}, main raceme length**,** seed yield plant^{-1}, oil and protein content. The highest heterosis and heterobeltiosis for primary

branches (24.25 vs. 12.30%) and main raceme length (37.31 vs. 22.93%) was recorded for F1 hybrids C-88 × C-93 and C-89 × C-97, respectively. F1 hybrid C-93 × C-90 had the highest positive heterosis for seed yield plant $^{-1}$ (23.33%). For protein content, the maximum heterosis was recorded for hybrid C-88 × C-89 (11.34%). Similarly, F1 hybrid C-88 × C-97 showed maximum heterosis for oil content (14.41%). The highest heterobeltiosis was exhibited by hybrids C-90 × C-97 for seed yield (9.53%), C-89 × C-90 for oil content (7.61%) and C-93 × C-97 for protein content (4.11%). Based on high mean performance and heterotic values, aforementioned hybrids and their corresponding parental lines should be exploited further for commercial hybrid production.

Discussion

Estimation of genetic parameters in context of trait characterization is an essential component of future targeted crop improvement. Collection of basic knowledge about heterosis of the germplasm is the basic step for initiation of any breeding program. Heterosis is considered as a quick, cheap and easy method for increasing crop production (Pal & Sikka, 1956). Heterosis is known as the superiority of a hybrid over its parents (Pourdad & Sachen, 2003). Heterobeltiosis is the percent increase or decrease of the F_1 over its better parent. It is reported that hybrids between genetically diverse parents showed better heterosis than within group cross combination (Akbar *et al*., 2007). The selection of different parental lines with good general combining ability helps in considerable genetic development in crop plants with desirable breeding values (Anand & Murty, 1968; Marani & Avieli, 1973). The present study was therefore planned to investigate heterosis for different yield and oil quality characters viz., number of primary branches plant^{-1}, main raceme length, seed yield plant^{-1}, oil and protein content.

In the present study highly significant differences were observed for primary branches plant^{-1}, main raceme length and seed yield plant^{-1}. Similar observations have been reported by Sadat *et al*. (2010) and Akbar *et al*. (2007) for primary branches in mustard (*B. juncea*). Significant genetic differences in primary branches are also reported by Pathak *et al*. (2000). Results of the present work are in agreement with findings of Shah *et al*. (2000) and Verma & Sachin (2000) who found highly significant genetic variability for seed yield plant^{-1} in Brassica speciae. Further, such results about significant differences among Brassica genotypes for main raceme length are also reported by Choudhary *et al*. (2002).

Highly significant differences among carinata genotypes were observed for oil and protein content. Similar results have been reported by Khulbe *et al*. (2000) and Bilgili *et al*. (2001) who found significant differences for protein content in Brassica. Pathak *et al*. (2000) also found significant differences for oil content in *Brassica juncea*. Similarly, Alemayehu *et al*. (2005) also strengthened our findings by reporting significant variation for oil and protein in diallel crosses of six inbred lines of *B. carinata*.

Reduced main raceme length is preferred in *Brassica* species, which are helpful for lodging resistance. Therefore, negative heterotic value is useful regarding this trait. Our results are similar with the results of Changming *et al*. (2001), who reported significant mid-parent heterosis for length of main inflorescence. Our findings of main raceme length are similar with the results of Gupta *et al*. (2011), who also find negative heterosis for main raceme length.

In *Brassica*, short stature plants with primary branches plant^{-1} and high seed yield plant^{-1} may provide opportunity for increased yields and these above parameters are directly linked with seed yield in *Brassica*. Therefore, positive heterosis and heterobeltiosis values are desirable for these traits for the improvement of Brassica lines/hybrids. In present study, positive heterosis and heterobeltiosis were recorded in different F_1 hybrids for the above mentioned traits. Our results are similar to the earlier findings of Satwinder *et al*. (2000), who reported that F_1 generations expressed significantly positive heterosis for primary branches plant^{-1}. Rameeh (2011) also found high positive heterosis for seed yield plant^{-1}. Our results are further strengthened by Dar *et al*. (2010), who reported highly significant positive heterosis for primary branches plant^{-1}and seed yield plant^{-1}in different populations of Brassica Our results are similar to the earlier findings of Mahto & Haider (2004), who reported positive heterosis and heterobeltiosis for primary branches plant^{-1} and seed yield plant^{-1}. Further, results of this study are similar to earlier findings of Nassimi *et al*. (2006), who reported significant positive heterosis for number of primary branches plant^{-1} in *B. napus* genotypes. Akbar *et al*. (2007) and Wang *et al*. (2006) have also reported positive heterosis for number primary branches plant^{-1}.

Based on the findings of this study, F1 cross combinations C-90 × C-93 and C-97 × C-93 have the potential for improvement of yield and oil quality traits and are recommended to be used in future breeding programs for developing high yielding *Brassica carinata* cultivars.

References

Abbas, S.J., I.A. Khan, Farhatullah, K.B. Marwat and I. Munir. 2008. Molecular and biochemical assessment of *Brassica napus* and indigenous *B. campestris* species. *Pak. J. Bot.* 40(60): 2461-2469.

Ahmad, R., R.S. Khan and Farhatullah. 2014. Transcript analyses of the gene associated with CMS in *Brassica napus*. *Euph*., 200:455–463.

Akbar, M., Tahira and M. Hussain. 2007. Heterosis for seed yield and its components in rapeseed. *J. Agri. Res*., 45(2): 95-104.

Alemayehu, N. and H. Becher. 2005. Quantitative genetic analysis of total glucosinolate, oil and protein contents in Ethiopian mustard (*Brassica carinata* A. Braun). *Ethiopian J. Sci*., 28(2): 141-150.

Anand, J. and B.R. Murty. 1968. Genetic divergence and hybrid performance in linseed. *Indian J. Genet*., 28: 178-185.

Bilgili, M.S., A. Uzun and E. Acikgoz. 2001. The influence of row spacing and seeding rate on seed yield and yield components of forage turnip (*Brassica rapa* L.). *J. Agron. Crop Sci*., 189: 250-260.

Changming, L., S. Fushen, and H. Kai. 2001. Heterosis in interspecific hybrids between *Brassica napus* and *Brassica rapa*. *SABRAO J. Breed. Genet*., 33(2): 73-85.

Choudhary, B.R., P. Joshi and S.R. Rao. 2002. Cytogenetics of *Brassica juncea x Brassicarapa*hybrids and patterns of variation in the hybrid derivatives. *Plant Breed*., 121: 292-296.

Dar, Z.A., S.A. Wani, G. Zaffar, M. Habib, M.A. Wani, A. Ishfaq, M.H. Khan and S.M. Razvi. 2010. Variability studied in Brown sarson (*Brassica rapa L.*) *Res. J. Agr. Sci*., 1(3): 273-274.

Doddabhimappa. R., Gangapur, B.G. Parkash, P.M. Salimath, R.L. Ravikumar and M.S.L. Rao. 2009. Correlation and path analysis in Indian mustard (*Brassica juncea L.*Czen and Cross). *Karnataka J. Agric. Sci*., 22(5): 971-977.

French, R.T. 1977. Oriental and Brown mustard seed production techniques. *Bulletin*, 2:1-2.

Getinet, A., G. Rakow and R.K. Downey. 1996. Agronomic performance and seed quality of Ethiopian mustard in Saskatchewan. *Can. J. Pl. Sci*., 76: 387-92.

Getinet, A., G. Rakow, J.P. Raney and R.K. Downey. 1997. Glucosinolate content in interspecific crosses of *Brassica carinata* with *B. juncia* and *B. napus*. *Plant Breed*., 116: 39-46.

Gupta, P., H.B. Chaudhary and S.K. Lal. 2011. Heterosis and combining ability analysis for yield and its components in Indian mustard (*Brassica juncia* L, Czern and Coss). *Acad. J. Pl. Sc*., 4(2): 45-52.

Jessop, J.P. and H.R. Tolken. 1986. Flora of South Australia. Adelaide, SA Government Printing Division.

Khan, S., Farhartullah, I.H. Khalil, M.Y. Khan and N. Ali 2008. Genetic variability, heritability and correlation for some quality traits in $F_{3:4}$ *Brassica* populations. *Sarhad J. Agric*., 24 (2): 223-231.

Khulbe, R. K., D. P. Pant and N. Saxena. 2000. Variability, heritability and genetic advance in Indian mustard (*Brassica junceaL*.) Czern and Coss. *Crop Res. Hisar*., 20(3): 551-552.

Mahto, J.L. and Z.A. Haider. 2004. Heterosis in Indian mustard (*Brassica juncea* L. and cosson). *J. Trop. Agric*., 42(1-2): 39-41.

Marani, A. and E. Avieli. 1973. Heterosis during the early phases of growth intraspecific and interspecific crosses of cotton. *Crop Sci*., 13: 15-18.

Mehwish, K., Farhatullah, M.A. Rabbani, S. Iqbal, L. Fayyaz and I. Nawaz. 2014. The assessment of genetic diversity between and within brassica species and their wild relative (*Eruca sativa*) using SSR markers. *Pak. J. Bot*., 46(4): 1515-1520.

Mnzava, N.A. 1986. Compensatory leaf and seed yield of increases in vegetable mustard (*Brassica carinata* A. Braun) in response to defoliation intensity. *Hort. Sci*., 21(3): 723.

Nasim, A. and Farhatullah. 2013. Combining ability studies for biochemical traits in *Brassica rapa* (L.) ssp. Dichotoma (Roxb.) Hanelt. *Pak. J. Bot*., 45(6): 2125-2130

Nassimi, A.W., Raziuddin, S. Ali, G. Hassan and N.A. Turi. 2006. Combining ability analysis for maturity and other traits in Rapeseed (*Brassica napus* L.). *J. Agron*., 5(3): 523-526.

Pal, B.P. and S.M. Sikka. 1956. Exploitation of hybrid vigor in the improvement of crop plant, fruits and vegetables. *Indian J. Genet. Plant Breed*., 16(2): 95- 193.

Pathak, A.D., R.M. Tripathi, M.K. Sharma, T. Rupam and R. Tripathi. 2000. Evaluation of genetic components in Indian mustard (*Brassica juncea* L.) Czern and Coss) through partial diallel crosses in incomplete block design. *Annals Agric. Res*., 21(2): 282-287.

Pourdad, S.S. and J.N. Sachen. 2003. Study on heterosis and inbreeding depression in agronomic and oil quality characters of rapeseed (*Brassica napus* L.). *Seed Plant*., 19(3): 29-33.

Rameeh, V. 2011. Line × tester analysis for seed yield and yield components in spring and winter type varieties of oilseed rape. *J. Cereals Oilseeds*, 2(5): 66-70.

Sadat, H.A., G.A. Nematzadeh, N.B. Jelodar and O.G. Chapi. 2010. Genetic evaluation of yield and yield components at advanced generations in rapeseed (*Brassica napus* L.). *African J. Agric. Res*., 5(15): 1958-1964.

Satwinder, K., S. Paramjit, V.P. Gupta, S. Kaur and P. Singh. 2000. Combining ability analysis for oil yield and its components in *Brassica napus* L. *Crucif. Newsl*., 22: 67-68.

Schippers, R.R. 2002. African Indigenous vegetables, an overview of the cultivated species 2002. Revised version in CD–ROM. Natural Resources International Limited, Aylesford, UK.

Shah, A.H., M.M. Gillani and F.A. Khan. 2000. Comprehensive selection of yield and yield influencing character in *Brassica* species. *Int. J. Agri. Biol*., 2: 245-7.

Sheikh, F.A., S. Bangha and S.S. Banga. 2014. Broadening the genetic base of Abbysinian mustard (*Brassica carinata* A. Braun) through introgression of genes from related allotetraploid species. *Span. J. Agric. Res*., 12 (3): 742-752.

Sidra, I., Farhatullah, A. Nasim, M. Kanwal and L. Fayyaz. 2014. Heritability studies for seed quality traits in introgressed segregating populations of *Brassica*. *Pak. J. Bot*., 46(1): 239-243.

Steel, R.G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw Hill Inc., NY. pp: 599.

Velasco, L., J.M.F. Martinez and A.D. Haro. 1998. Increasing erucic acid content in Ethopian mustard throug mutation breeding. *Plant Breed*., 117: 85-87.

Verma, S.K. and J.N. Sachan. 2000. Genetic divergence in Indian mustard (*B. juncea* L. Czern and Coss). *Crop Res. Hisar*., 19: 271-6.

Wang, J.S., W.X. Zhang, J.H. Tian and D.R. Li. 2006. Study on inheritance and heterosis of plant type traits in compact rapeseed lines. *Acta Agriculture Boreali-Occidentalis Sinica*. 03.

Yan, Z. 1990. Overview of rapeseed production and research in china. Proc. Int. Canola cont. potash and phosphate Institute, Atlanta. P. 29-35.

Zhang, G. and W. Zhou. 2006. Genetic analysis of agronomic and seed quality traits of synthesis oilseed *Brassica napus* produced from inter specific hybridization of *Brassica campestris* and *Brassica oleracea*. *J. Genet*., 85(1): 45-51.

Zhong, W.H., L.G. Hua, W. Xin-fa, L. Jing, Y. Qing and H. Wie. 2009. Heterosis and breeding of high oil content in rapeseed (*Brassica napus* L.). 16thAustralian Research Assembly on *Brassica*. Ballarat Victoria.

(Received for publication 7 October 2014)