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Genetic Analysis of Various Traits in Oilseed Brassicas

Hafiz Basheer Ahmad[1], Salsabeel Rauf[2], Waqas Shafqat Chattha[3], Abdul Khaliq[3], Amir Amin[4], Rashad ul Sher[5], Sajid Ali[6]

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ABSTRACT

Background: The combining ability and manifestation of heterosis within and among the species of oilseed brassicas (*B. campestris, B. napus* and *B. juncea*) were studied for yield and yield related traits in 12F_1 combinations.

Methods: All crosses (12F_1) along with their parents (7 parents) were sown in randomized complete block design (RCBD) with three replications.

Result: The analysis of variance showed extensive variability among the genotypes. The physical appearance of interspecific crosses was intermediate. *B. campestris* showed significant GCA effects among lines and *B. juncea* among testers for seed yield per plant. General combining behaviour of *B. campestris* was better as compared to *B. napus* and *B. juncea*. The SCA effects were higher within species than among the species. This also revealed that within the species *B. juncea* had more SCA (17.45) than *B. napus* (9.82) and *B. campestris* (8.01) for seed yield. The SCA showed the improvement of *B. Juncea,* is the best than other two species. It is also concluded that to obtain better yield, crossing within the species is more appropriate than among the species. Moreover, to introduce novel traits in brassica species is possible through interspecific hybridization.

Key words: Brassica, Combining ability, Heterosis, Interspecific crosses.

INTRODUCTION

Rapeseed and mustard species are closely related to one another (Nagaharu, 1935). All three diploid species are self-incompatible and their amphidiploids are self-fertile (Kitashiba and Nasrallah, 2014).

Studies on introgressions and their crossability between and among the species are of great value for a plant breeder. The success of the crosses depends on genetics of the parent and direction of crosses (Downey and Rakow, 1987; Niemann *et al*., 2015). Moreover, there are some other factors which also touch the success of the interspecific hybridization such as growth, temperature, embryo rescue techniques, age of siliqua and culture media (Takeshita *et al*., 1980). The rate of success of crosses is high if amphidiploids are used as female parent; nevertheless it is difficult to obtain the hybrids among the mono genomic species (Downey *et al*., 1980). The cross compatibility of *B. rapa* is higher with *B. napus* than that of *B. juncea* (Tsuda *et al*., 2012). Natural crossing among these three species and hybridization in the field can be done, but no natural crossing between other cultivated species such as *B. nigra* and *Sinapsis arvensis* is possible (Bing *et al*., 1996). Crossing of *B. rapa* with *B. juncea* was successful if the *B. rapa* was used as male parent. Similar other successful crosses of *B. rapa* with *B. carinata* and *B. niga* were reported (Fitz John *et al*., 2007). The objectives of this study were (i) To study the probable introgressions of *B. campestris* from *B. napus* and *B. juncea* (ii) To estimate the heterosis and specific combining of intraspecific and interspecific crosses for seed yield and related traits and (iii) To compare the different cross combinations within the species for traits studied.

[1]Sugarcane Research Institute, AARI, Faisalabad, Pakistan.
[2]Oilseeds Research Institute, AARI, Faisalabad, Pakistan.
[3]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan.
[4]Pulses Research Institute, AARI, Faisalabad, Pakistan.
[5]Agronomic Research Institute, AARI, Faisalabad, Pakistan.
[6]Vegetable Research Institute, AARI, Faisalabad, Pakistan.

Corresponding Author: Hafiz Basheer Ahmad, Sugarcane Research Institute, AARI, Faisalabad, Pakistan. Email: easahafiz@yahoo.com

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MATERIALS AND METHODS

The experimental material comprised of (three different species) seven parents including three of *B. campestris* (Toria, UAF11, 1072), two of *B. napus*, (Napus1, Napus2) and two of *B. juncea* (Juncea1 and Shora). Three genotypes were used as female parent (Toria, Napus1 and Juncea1) each from each species and four as male parent *i.e.* two from *B. campestris* (UAF11 and 1072) one *B. napus* (Napus2) and one *B. juncea* (Shora). These were crossed in the field to obtain intra and interspecific hybrids/crosses in a line × tester fashion during 2015-2016. All crosses (12F_1) along with their parents (7 parents) were sown in randomized complete block design (RCBD) with three replications at the farm of Department of Plant Breeding and Genetics University of Agriculture Faisalabad during 2016-2017. Ten plants were tagged in each replication and data were recorded for thirteen traits. Data includes four phenological (days to flowering initiation, days to 50% flowering, days to 50% siliqua formation and days to maturity), five morphological (plant height, primary branches, secondary branches, green biomass yield, harvest index) and four yield and yield related (siliquae per plant, seed per siliqua, tested seed weight and yield per plant).

Statistical analysis

Data were statistically analysed for genetic variability (Steel *et al*., 1997). The estimates of combining ability were obtained using the formula given by Kempthorne (1957). Heterosis over the mid parent and better parent was estimated according to Falconer, (1960).

RESULTS AND DISCUSSION

Analysis of variance for different characters in oilseed brassicas

The analysis of variance showed highly significant mean squares values among the genotypes obtained through introgressions and extensive variability for all traits studied (Table 1). The sum of square values for indicated traits were partitioned into parents, crosses and parent vs. crosses, displayed considerable differences among themselves. The mean square values for crosses was further divided in line and tester fashion. Highly significant differences were present among lines and testers, for all the traits except for primary branches and secondary branches for testers. Evaluation of genetic variability for economic important traits in rapeseed and mustard is a fundamental purpose in breeding. Early studies on genetics of brassica species showed that morphological differences were created through breeding (Offerson, 1924). Oilseed brassicas have considerable differences at inter and intraspecific levels for morphological, phenological and yield related traits reported by earlier worker (Abideen *et al*., 2013 and Parveen *et al*., 2015).

General and specific combining ability effects for various traits of intra and interspecific hybrids

Variation for general combing ability effects for 4 intra and 8 interspecific combinations were studied (Table 2). Toria (*B. campestris*) was the best combiner (-9.72) while Napus1 (*B. napus* (6.44) and Juncea1 (*B. juncea*) (3.28) were the poor general combiner for the flowering initiation. UAF11 (*B. campestris*) was the best combining line (-12.78) while Shora (*B. juncea*) (7.00) was the poor combining tester for 50% flowering. Toria (-17.75) was the best combining line and UAF11 (*B. campestris*) was the best tester line (-7.78) for 50% siliquae formation. Toria (*B. campestris*) (-6.06) was the best general combiner among the lines and among the tester UAF11 (-5.42) for days to maturity. The parent UAF-11 (-21.86) and Toria (-10.86) indicated negative and significant GCA effects for plant height. Positive and considerable GCA effects for primary and secondary branches were observed in line Toria (1.78) and (8.81) respectively. For primary branches, the best general combiners were Shora (3.75) and Juncea1 (2.28) and the poorest was napus2 (-1.25). The Shora (18.75) was the best combiner line for secondary branches.

Regarding the green biomass the parental line Juncea1 (21.83) and Napus2 (28.64) showed significant GCA effects in positive direction. Parent line Toria (24.70) showed the highest positive gca for harvest index. For number of siliquae per plant the positive and highly significant GCA effects were shown by Napus1 among lines, the 1072. Whilst, the negative SCA effects were shown by Toria among lines and Shora among testers.

The average general combiner parents for number of seed per siliqua was Shora and Napus1. For tested seed weight the positive GCA effects were shown by Toria and Napus1 among lines and Shora among the testers. The positive and significant GCA effects for seed yield per plant were displayed by Toria among lines and Shora among testers. The parents Toria and Shora can be considered as the superior parents because they showed high positive and remarkable GCA effects for seed yield. The estimates of specific combining ability effects of 12 intra and interspecific combinations of *B. campestris* and its relative brassicas were also calculated (Table 3). Minimum number of days to flowering is a more favorable trait for *B.campestris*. The crosses Toria × UAF11 (*B. campestris* × *B. campestris*) and Napus1 × UAF11 (*B. Napus* × *B .campestris*) were the best, showing negative and significant specific combining ability effects (-11.53) and (-5.28) for days to flowering initiation respectively. Cross combinations Juncea1 × 1072 followed by Toria × UAF11 showed desirable significant negative specific combining ability effects for days to 50% flowering. Toria × Shora followed by Juncea1 × 1072 depicted the considerable and negative specific combining ability effects for days to 50% siliqua formation. Toria × UAF11 and Juncea1 × Shora showed significant and negative specific combining ability effects for days to maturity. These crosses combinations can be exploited to find early maturing genotypes in subsequent generations. Five cross combinations *i.e.* Toria × Shora (-29.58**), Napus1 × Napus2 (11.94**), Napus1 × Shora (-18.83*), Juncea1 × 1072 (-45.58**) and Juncea1 × UAF11 (-29.47**) showed the negative and significant specific combining ability for plant height.

Hybrids Toria × UAF11 and Napus1 × Napus2 exhibited significant and positive SCA effects for primary branches. The combination Juncea1 × Shora showed positive specific combining ability effects for secondary branches. Regarding the biomass and harvest index, hybrids Juncea1 × 1072 and Napus1 × UAF11 for biomass, Toria × 1072 and Juncea 1 × Shora for harvest index showed positive and significant specific combining ability effects. Only one cross combination Juncea1 × UAF11 showed positive and considerable SCA effects for number of seed per siliqua. The highest SCA effects were shown by the combination Juncea1 × Shora and followed by Napus1 × Napus2 for yield. Combining ability provides constructive information for the selection of parent, their crossesand the progenies (Dhillon, 1975). Anderson (1960) studied general and specific combining ability and noted significant differences between GCA and SCA. For the selection of basic material

Table 1: Analysis of variance (Mean squares) for various traits in oilseed brassicas.

SOV	DF	DFI	DF	DSF	DM	PH	PB	SB	GB	HI	SLP	SS	TW	YP
Rep	2	49.95**	75.23**	134.97**	171.02**	107.70	3.18	3.21	17.39	13.31	89479.00*	0.77	0.00	0.36
Gen	18	720.72**	777.11**	1176.97**	2286.20**	5013.08**	50.06**	452.40**	4273.14**	1999.35**	6397220.41**	215.97**	0.02**	724.12**
P	6	1327.98**	1506.38**	1633.08**	5048.30**	4703.60**	98.89**	893.27**	2729.65**	692.56**	806964.83**	70.05**	0.02**	1340.14**
T	3	1454.31**	1479.22**	1583.22**	5229.64**	7600.56**	77.00**	846.53**	2872.31**	985.17**	818824.33**	99.56**	0.03**	2083.42**
L	2	1590.33**	2010.78**	2164.33**	7212.11**	300.44	171.44**	1281.00**	3877.78**	358.80**	682560.44**	24.57**	0.01**	725.42**
L vs T	1	424.32**	579.06**	720.14**	176.67**	4819.06**	19.44	258.04**	5.43	482.28**	1020195.06**	72.48**	0.02**	339.74**
C	11	446.76**	433.33**	1034.49**	814.26**	4764.57**	24.84**	252.03**	5498.98**	2890.54**	7602869.79**	166.59**	0.02**	355.01**
P vs C	1	90.70**	182.98**	7.70**	1904.85**	9603.58**	34.43**	11.34**	49.94**	37.06**	26676610.71**	1634.71**	0.03**	1088.22**
Testers	3	784.25**	688.07**	451.63**	1421.04**	3713.44**	9.67	89.44	4070.18**	3430.81**	104137.58**	67.08**	0.01**	405.75**
Lines	2	880.78**	846.58**	2835.75**	538.36**	6847.69**	33.78**	713.03**	6215.58**	5866.01**	2398556.33**	54.73**	0.04**	175.34**
L × T	6	133.33**	168.21**	725.49**	602.84**	4595.77**	29.44**	179.66**	5974.51**	1628.58**	2478771.75**	253.63**	0.02**	389.54**
Error	36	6.69	6.27	13.78	13.81	126.57	5.27	25.21	41.46	18.55	22061.35	1.14	0.00	4.13

DFI for days to flowering initiation, DF for days to 50% flowering, DSF for days 50% siliqua formation, DM for days to maturity, PH for plant height, PB for primary branches, SB for secondary branches, GB for green biomass yield, HI for harvest index, SL/P for siliquae per plant, S/S for seed per siliqua, TW for tested seed weight, Y/P for yield per plant, Rep for replications, L for lines, T for testers, P for parents, C for crosses.

Table 2: Estimates of GCA effects of parents for various traits in brasicas.

Parents		Phenological traits				Morphological traits					Yield related traits			
		DFI	D50%F	D50%SF	DM	PH	PB	SB	GB	H.I	SL/P	S/S	TSW	Y/P
Lines	Toria	-9.72**	-9.58**	-17.75**	-6.06 *	-10.86**	1.78**	8.81*	-23.58**	24.70**	-475.00**	-0.76	0.04	4.30**
	Napu1	6.44**	6.08*	9.00*	7.19**	27.39**	-1.56	-5.53	1.75	-6.76**	430.75**	2.41	0.02	-1.29**
	Juncea1	3.28	3.50	8.75**	-1.14	-16.53	-0.22	-3.28	21.83**	-17.94**	44.25	-1.65	-0.06	-3.01**
	S.E	0.35	0.22	0.54	0.41	0.36	0.35	0.22	0.54	0.41	0.36	0.35	0.22	0.54
Testers	1072	3.64**	3.33	6.33*	-11.11**	0.25	1.06	-3.25**	0.31	23.99**	712.61**	-1.10	-0.03	3.37**
	Napus2	2.31	2.44	5.67**	-0.89	27.03 **	-0.83	-1.47	28.64**	-21.55**	-295.17**	-1.52	-0.02	-5.09**
	Shora	7.64*	7.00*	-4.22	17.78**	-5.42	0.72	4.08	-6.81	5.87**	-451.06**	4.09	0.05	7.81**
	UAF11	-13.58**	-12.78**	-7.78**	-5.78	-21.86 **	-0.94	0.64	-22.14**	-8.31**	33.61	-1.47**	0.00	-6.09**
	S.E	0.4	0.25	0.62	0.48	0.41	0.4	0.25	0.62	0.48	0.41	0.4	0.25	0.62

Table 3: Estimates of SCA effects of intra and inter specific crosses for various traits in brassicas.

Combinations	Phenological traits				Morphological traits					Yield related traits			
	DFI	DF	DSF	DM	PH	PB	SB	GB	HI	SLP	SS	TW	YP
Toria × 1072	4.28*	4.92**	13.42**	-9.39**	30.75	-1.56	-4.92**	-24.97**	26.02**	-1385.44**	10.75	0.02	4.19**
Toria × Napus2	2.28	2.81	10.75**	7.72**	-14.69	0.67	-6.36	17.03**	-24.27**	-142.67	-5.23	-0.05	-4.89**
Toria × Shora	-0.06	-0.08	-23.69*	18.06**	-29.58**	-2.56**	2.42	-5.86**	-6.86	1736.22**	-8.04	-0.03	-7.32**
Toria × UAF11	-6.50**	-7.64**	-0.47	-16.39**	13.53**	3.44*	8.86	13.81**	5.11	-208.11*	2.52	0.05	8.01**
Napus1 × 1072	3.78**	4.58**	-0.33	9.69**	14.83**	-0.22	4.08	-38.31**	6.48	-333.19	-6.02**	0.07	2.71**
Napus1 × Napus2	-1.22	-1.19	-5.00	-7.53	-11.94**	1.67**	2.31	6.03	13.80**	-1073.08**	9.57	0.02	9.82**
Napus1 × Shora	1.11	-0.08	11.56*	-7.86	-18.83*	-1.22**	-7.25**	-7.86	-10.12**	-1095.86**	4.38	-0.09	-10.13**
Napus1 × UAF11	-3.67*	-3.31**	-6.22**	5.69**	15.94**	-0.22	0.86	40.14**	-10.17**	2502.14**	-7.92	0.00	-2.40**
Juncea1 × 1072	-8.06**	-9.50**	-13.08 **	-0.31	-45.58**	1.78	0.83	63.28**	-32.50**	1718.64	-4.73	-0.08	-6.90**
Juncea1 × Napus2	-1.06	-1.61	-5.75**	-0.19	26.64**	-2.33**	4.06	-23.06**	10.46**	1215.75**	-4.34	0.03	-4.94**
Juncea1 × Shora	-1.06	0.17	12.14**	-10.19 *	48.42**	3.78	4.83**	13.72**	16.98**	-640.36**	3.66	0.11	17.45**
Juncea1 × UAF11	10.17**	10.94**	6.69*	10.69**	-29.47**	-3.22**	-9.72**	-53.94**	5.06**	-2294.03**	5.41**	-0.06**	-5.61**

and varietal development, the GCA is more important than SCA. The GCA effects are controlled by fixable additive gene and the crosses of the parents having high GCA effects will provide good transgressive segregants when selection is done in later generations. Therefore selection of the parents may be done on the basis of GCA and mean performance (Singh and Dixit, 2007).

The SCA effects were greater than GCA effects in case of selected population and vice versa. Kalton and Leffel (1955) also indicated that GCA effects were more important in case of unselected population. The following conclusion may be drawn from the material used in this study. Different morphological traits are under control of different gene actions. Minimum numbers of days are required to develop short duration variety so that it may easily fit in our cropping pattern. All three species showed different behavior towards days to flowering initiation. *B. campestris* is the best species among the other to develop short duration varieties. Any lines having negative value of GCA can be used for the breeding program. These finding are in accordance with Marinkovic (1982) who gives the argument that during study of particular trait, the advantage should be given to a specific line that is good general combiner for the specific trait, any way value is positive or negative. The SCA revealed that for the yield improvement *B. juncea* is the best among the other two species and yield may be increased through hybridization within the species. For SCA the cross combination Juncea1 × Shora is the best for yield.

Manifestation of heterosis due to intra and interspecific hybridization

Substantial amount of relative heterosis and heterobeltiosis was noted for yield and other related characters (Table 4). All 12 hybrids were compared with mid parent and better parent for evaluation of heterosis. The results for morphological, phenological and yield related traits were presented as under.

Days to flowering initiation

Out of total 12 crosses, 6 hybrids were identified for significant and negative relative heterosis *i.e.* Toria × shora (-26.49**) Toria × Napus2 (-20.68**), Napus1 × UAF11 (-18.57**). Juncea1 × Shora (-13.06**) Juncea1 × 1072 (-12.66**) and Juncea1 × Napus2 (-8.44**) respectively.

Days to 50% flowering

Out of 12 combinations only 3 showed considerable negative heterosis over mid parent and 9 over better parent heterosis. Junce1 × 1072 (-8.72), Juncea1 × Napus2 (-5.02) and Juncea1 × Shora (-2.03) showed negative relative heterosis and combinations Toria × Shora (-22.68), Toria × Napus2 (-17.91) and Napus1 × UAF11 (-17.81) for heterobeltiosis.

Days to 50% siliquae formation

Out of 12 hybrids, two crosses (Toria × shora and Juncea1 × 1072) showed significant and negative relative heterosis while three (Toria × Shora, Napus1 × UAF11 and Toria × Napus2) for heterobeltiosis for days to 50% siliqua formation.

Table 4: Manifestation of heterosis for different traits of intra and interspecific crosses.

Class	Trait	Heterosis	Toria × 1072	Toria × Napus2	Toria × Shora	Toria × UAF11	Napus1 × 1072	Napus1 × Napus2	Napus1 × Shora	Napus1 × Shora	Juncea1 × 1072	Juncea1 × Napus2	Juncea1 × Shora	Juncea1 × UAF11
Phenological	DFI	MP	27.74**	11.24**	6.78*	5.56	16.95**	1.12	4.18	5.23	-8.68**	-6.87**	-6.24**	18.02**
Traits		BP	-5.26	-20.68**	-26.49**	-0.87**	16.67**	-4.64**	-7.09**	-18.57**	-12.66**	-8.44**	-13.06**	-11.35**
	D50%F	MP	28.29**	15.18**	11.11**	12.60**	12.25**	-0.97	1.12	4.91	-8.72**	-5.02*	-2.03	22.05**
		BP	-5.76**	-17.91**	-22.68**	2.14	11.34**	-4.85*	-6.53**	-17.81**	-10.00**	-8.21**	-8.94**	-4.80**
	D50%SF	MP	20.85**	11.62**	-50.66**	12.87*	4.26	-4.3	0	5.17	-8.77**	-4.51	1.18**	23.64**
		BP	-10.21**	-18.61**	-64.56**	3.64	3.52	-7.64*	-5.70**	-16.43**	-10.21**	-8.64	-5.38	-1.09
	DM	MP	12.48**	30.75**	38.89**	53.28**	5.23**	-3.79*	-1.02	33.24**	-12.34**	-9.21**	-11.74**	21.97**
		BP	-13.38**	-2.23	-1.69	48.73**	0.67	-4	-8.80**	1.56	-19.92**	-13.68**	-14.79**	-10.06**
Morphological	PH	MP	32.62**	-3.03	5.03	10.42	39.25**	13.17**	33.26**	29.98**	-20.34**	15.50**	59.55**	-21.95**
traits		BP	20.78**	-13.18**	-18.04**	-2.35	21.53**	5.89	0.53	10.32*	-27.45**	3.41	24.51**	-30.98**
	PB	MP	45.83*	-7.69	37.78	72.55**	-36.26**	-52.07**	-43.18**	-51.06**	36.84*	-51.72**	62.96**	-40.00*
		BP	34.62	-35.71**	34.78	51.72*	-55.39**	-55.39**	-61.54**	-64.62**	25.81	-62.50**	41.94*	-41.94*
	SB	MP	40.21	-10.39	198.67**	633.33**	-52.07**	-62.04**	-58.97**	-29.41*	-24.62	-31.55**	53.70**	-12.12
		BP	1.49	-44.36**	148.89**	303.33**	-65.33**	-65.33**	-73.33**	-64.00**	-26.87	-48.39**	31.75	-53.97**
	BY	MP	-26.03**	60.44**	-30.15**	-41.31**	-44.15**	18.79**	-30.09**	-11.35*	147.82**	15.36**	23.56**	-79.45**
		BP	-26.36	14.96*	-48.00**	-60.96**	-62.26**	8.07	-39.68**	-14.41**	72.14**	10	11.43	-81.08
	HI	MP	291.77**	-56.85**	163.95**	27.61**	66.12**	-46.03**	-21.7	-84.14**	-71.59**	-82.79**	118.98**	-69.18**
		BP	249.72**	-61.72**	134.62**	-11.01	51.23**	-50.55**	-41.22**	-87.22**	-78.48**	-87.02**	101.81**	-80.60**
Yield related	SL/P	MP	23.22*	59.02**	730.20**	78.01**	303.41**	88.48**	413.29**	585.96**	285.85**	175.76**	76.79**	-95.74**
traits		BP	-16.31	10.67	541.39**	20.91**	129.92**	8.65	340.38**	290.96**	254.29**	163.95**	9.05	-96.09**
	S/S	MP	1.24	-88.78**	-70.71**	-55.85**	-72.53**	-16.91**	6.69	-87.08**	-84.18**	-87.88**	-3.75	-43.18**
		BP	-2.72	-90.45**	-72.11**	-62.37**	-74.85**	-26.13**	-3.13	-88.50**	-85.06**	-90.45**	-8.27	-55.18**
	TW	MP	32.79**	-29.28**	42.40**	13.30**	10.56	-29.09**	-21.95**	-27.36**	-71.64**	-44.04**	44.53**	-64.32**
		BP	24.62**	-48.39**	30.88**	-15.52**	-7.29	-37.10**	-33.33**	-33.62**	-72.46**	-56.45**	43.48**	-71.55**
	Y/P	MP	190.67**	-34.10**	100.00**	-38.87**	-12.35**	-36.64**	-47.89**	-86.09**	-25.58**	-80.92**	157.26**	-94.14**
		BP	156.47**	-56.20**	65.00**	-65.54**	-43.40**	-46.85**	-65.01**	-89.07**	-38.46**	-84.18**	127.58**	-96.32**

Days to maturity

Three hybrids were at the top for significant negative relative heterosis (Juncea1 × 1072, Juncea1 × Shora and Juncea1 × Napus2) and six hybrids showed significant and negative heterobeltiosis for days to maturity.

Plant height

Out of 12 crosses, only one hybrid for mid parent heterosis and three showed significant and negative heterobeltiosis for plant height (Table 4).

Primary branches

Two crosses out of 12 showed positive relative heterosis and heterobeltiosis for primary branches. These crosses were Toria × UAF11, (72.55), (51.72) and Juncea1 × Shora (62.96), (41.94) revealed positive and significant relative heterosis and heterobeltiosis.

Secondary branches

Two crosses out of 12 showed positive and significant heterosis and heterobeltiosis for secondary branches *viz.* Toria × UAF11 (633.33 and 303.33) and Toria × Shora (198.67 and 148.89).

Green biomass and harvest index

Only two cross combinations showed considerable and positive heterosis and heterobeltiosis for green biomass (Table 4). Positive relative heterosis and heterobeltiosis is desirable for high yielding cultivar. The combination Juncea1 × 1072 (147.82, 72.14) and Toria × Napus 2 (60.44, 14.96) showed positive and significant heterosis and heterobeltiosis while four, Toria × 1072 (291.77, 249.72), Toria × Shora (163.95, 134.62), Juncea1 × Shora (118.98, 101.81) and Napus1 × 1072 (66.12, 51.23) crosses showed positive and significant heterosis and heterobeltiosis for harvest index.

Number of siliquae per plant and number of seed per siliqua

Seven hybrids showed positive and significant relative heterosis and heterobeltiosis for number of siliquae per plant and none of the 12 hybrids was significant for number of seed per plant.

Tested seed weight (100-seed)

Three cross combinations; Toria × 1072 (32.79, 24.62), Toria × Shora (42.40, 30.88) and Juncea1 × Shora (44.53, 43.48) hybrid showed positive and considerable heterosis and heterobeltiosis for tested seed weight.

Seed yield per plant

Only three hybrids out of 12 combinations showed positive and significant value for relative heterosis and heterobeltiosis (Table 4). The combination was Toria × 1072 (156.47), Juncea1 × Shora (127.58) and Toria × Shora (65.00) were at the top for the value of relative heterosis in yield per plant.

The heterosis obtained from hybridization between races or species gives an excessive increase in size, weight and growth rate in the interspecific or inter-racial hybrids. Such type of heterosis is called luxuriance and hybrids are luxuriant (Dobzhansky, 1940). There is no continuation due to poor seed setting in luxuriant hybrids.

Negative heterosis is preferred in *Brassica campestris* because it shows earliness in flowering. The crosses showing earliness can be used for further breeding program.

Synrem *et al*. (2015) also reported desirable negative and significant heterosis for days to 50% flowering in Brassica species. For early maturing cultivars negative heterosis for 50% days to siliquae formation is an advantageous trait.

The comparison of nap and mur cytoplasmic system showed negative heterosis for days to maturity (Riungu and McVetty, 2004). Early maturity is a useful trait in many plant species; however it is very important in Brassica species because late maturity causes the yield losses and quality of oil due to high temperature (Turi *et al.,* 2011). Negative heterosis is valuable in brassicas for early maturity (Yadava *et al.,* 2012).

Negative heterosis is also desirable for plant height in Brassica species. Dwarf and medium plant height resist to high wind velocity, logging and mechanical breakage. The heterosis studied in oilseed rape for plant height was none significant. Negative values were also noted for some crosses (Grant and Beversdorf, 1985). Significant and negative heterosis for plant height had also been described by Tyagi *et al*., (2000).

Plant with more branches will be vigorous and produces more yield. The highest value for heterosis and heterobeltiosis was identified for primary branches 24.25 vs. 12.30% in Brassica species by Nausheen and Amanullah (2015). Vigorous plant will provide opportunity for high yielding cultivar reported by Niranjana *et al*., (2014).

The use of plant biomass plays an important role for animal hay and biogas production. The estimation of heterosis for fresh biomass, dry matter and dry biomass, the average was greater of hybrids than parent genotypes; however dry biomass was greater in parents. It might be increased up to thirty per cent (Ofori *et al*., 2008).

Fornumber ofsiliquae per plant and seed per siliqua positive and significant heterosis is advantageous for the development of high yielding genotypes. Results were partially similar reported by Synrem *et al*. (2015). Positive heterosis is desirable for tested seed weight for the development of high yielding genotype.

The aim of the heterosis breeding is to attain the high yielding combinations with desirable quality traits. It has been reported that the genomic components introgressed from *B. rapa* can improve the seed yield of rapeseed (Qian *et al*., 2005). Significant and positive heterosis had also been reported by earlier workers (Meena *et al*. 2014; Synrem *et al*., 2015).

CONCLUSION

The crossing within the species is more fovourable than among the species for improvement in seed yield as depicted by higher SCA. Within the species two cross combinations Juncea1 × Shora (*B. juncea* × *B. juncea*) and Toria × 1072 (*B. campestris* × *B. campestris*) were found to be good on the basis of SCA, GCA and heterosis. These crosses may be desirable combinations for the improvement of respective traits.

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