HETEROSIS, INTERGENOTYPIC VARIABILITY, CORRELATION AND PATH ANALYSIS OF QUANTITATIVE CHARACTERS OF OLEIFEROUS *Brassica campestris* L.

BY

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Registration No. 23936/00178

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

IN

GENETICS AND PLANT BREEDING

SEMESTER: JULY - DECEMBER, 2006

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CERTIFICATE

This is to certify that the thesis entitled, "HETEROSIS, INTERGENOTYPIC VARIABILITY, CORRELATION AND PATH ANALYSIS OF QUANTITATIVE CHARACTERS OF OLEIFEROUS ***Brassica campestris* L.**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE in GENETICS AND PLANT BREEDING**, embodies the result of a piece of bona fide research work carried out by **MD. ASHADUZZAMAN SIDDIKEE**, Registration No. 23936/00178 under my supervision and my guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December, 2006
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(Professor. Dr. Md. Shahidur Rashid Bhuiyan)
Supervisor

Dedicated to

My

Parents & Wife

SYMBOL AND ABBREVIATIONS

ABBREVIATIONS	:	FULL WORD
%		Percentage
PH	:	Plant height
NPB/P	:	Number of primary branches per plant
NSB/P	:	Number of secondary branches per plant
S/S	:	Number of seed per siliqua
S/P	:	Number of siliqua per plant
LS	:	Length of siliqua
D 1st F	:	Days to first flowering
D 50% F	:	Days to 50% flowering
DM	:	Days to maturity
TSW	:	Thousand (1000) seed weight
POC	:	Percent (%) oil content
Y/P	:	Seed yield/plant
DMRT	:	Duncan's Multiple Range Test
LSD	:	Least significant different test
e.g.	:	Exempli gratia (by way of example)
et al.	:	et alu=other people
etc.	:	et cetera (means and the rest)
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
cm	:	Centimetre
i.e.	:	ed est (means That is)
BARI	:	Bangladesh Agricultural Research Institute
SAU	:	Sher-e-Bangla Agricultural University
J.	:	Journal
No.	:	Number
NS	:	Not significant
var.	:	Variety
via	:	By way of
viz.	:	Namely
S.V	:	Source of variation
D.F	:	Degrees of freedom
σ^2_g	:	Genotypic variance
σ^2_p	:	Phenotypic variance
σ^2_e	:	Environmental variance
GCV	:	Genotypic coefficient of variation
PCV	:	Phenotypic coefficient of variation
ECV(%)	:	Environmental coefficient of variaton
h^2_b	:	Haritability in broad sense
G.A.	:	Genetic advance
rg	:	Genotypic correlation co-efficient
rp	:	Phenotypic correlation co-efficient

SYMBOL AND ABBREVIATIONS (CONTD.)

R	:	Residual effect
Rep.	:	Replication
Gen.	:	Genotype
Err.	:	Error
MP	:	Mid parent
F_1	:	The 1st generation of a cross between two dissimilar homozygous parents
F_2	:	The 2nd generation of a cross between two dissimilar homozygous parents
BP	:	Better parent
P^H	:	Negative logarithm of hydrogen ion concentration (-log $[H^+]$)
UNDP	:	United Nations Development Programme
T. S. P.	:	Triple Super Phosphate
M. P.	:	Muriate of Potash
EC	:	Emulsifiable concentrate
@	:	At the rate
ml/L	:	Milligram per litre
g/L	:	Gram per litre
WP	:	Wet able powder
RCBD	:	Randomized Complete Block Design
LSR	:	Least significance range
SSR	:	Significant studendize range
$S\bar{d} = S\bar{x}$	:	Standard deviations
$\overline{F_1}$	:	Mean of F_1 individuals or Mean of reciprocal individuals
$\overline{BP}$	:	Mean of the Better parent values
$\overline{MP}$	:	Mean of the mid parent values
MSG	:	Mean square of the genotypes
MSE	:	Mean square of the error
r	:	Number of replications
σPh	:	phenotypic standard deviation
K	:	Selection intensity which is equal to 2.06 at 5% selection intensity
$\bar{x}F_1$	:	Population mean of F_1
g	:	Gram
BBS	:	Bangladesh Bureau of Statistics
ANOVA, anova	:	Analysis of variance
FAO	:	Food and Agriculture Organization
Kg	:	Kilogram

ACKNOWLEDGEMENTS

Alhamdulillah. Allah, the merciful, Who has created everything in this universe and kindly enabled me to present this thesis for the degree of Master of Science (M.S.) in Genetics and Plant Breeding.

I have great pleasure in expressing my deepest sense of gratitude to Professor Dr. Md. Shahidur Rashid Bhuiyan, Supervisor of my research work for the suggestion of the thesis topic, inspiring guidance, scholarly suggestions, constructive criticism and constant encouragement throughout the course of the investigation and spending valuable time to go through the manuscript. I owe a lot to him for his sustained interest and tireless help and no amount of rhetoric would suffice to express my indebtedness to him.

It gives me immense pleasure to express my profound sense of gratitude and sincere thanks to my research Co-supervisor Dr. Md. Aziz Zilani Chowdhury, Principal Scientific Officer, Bangladesh Agricultural Research Council (BARC), for the precious encouragement, constructive suggestions, invaluable guidance, expert evaluation and keen interest that helped me to overcome every problem that came to my way during the course of this investigation and preparation of the manuscript.

I am highly grateful to Associate Professor Dr. Md. Sarowar Hossain, Chairman, Department of Genetics and Plant Breeding of Sher-e-Bangla Agricultural University for his scholarly suggestions, constructive criticism, support and encouragement during the course of my studies and for providing unforgettable help at the time of preparing the thesis.

I express my sincere gratitude, hearty respect, immense indebtedness and profound appreciation to Professor Abu Akbar Mia, Department of Genetics and Plant Breeding of Sher-e-Bangla Agricultural University for his scholastic guidance, constructive criticism and immense technical help in preparing the thesis.

I am thankful to Professor Dr. A. M. Farooque, Honarable Vice Chancellor, Sher-e-Bangla Agricultural University, Co-ordinator of Advance Studies and Research, Professor Shadat Ulla for providing necessary facilities and conducive atmosphere to accomplish my research work. I feel pleasure in expressing my special thanks to M. Mahbubur Rahman Scientific officer, oil seed Division for providing me laboratory facility for knowing percent oil content.

I feel to express my sincere appreciation and indebtedness to my esteemed teacher Assistant Professor Mst. Nahid Zeba and Firoz Mahmood, Dept. of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka for her valuable teaching, direct and indirect advice, encouragement and cooperation during the whole study period.

I feel much pleasure to convey the profound thanks to My Brother in law Kazi Abdul Bari, my collegues, friends and well wishers for their active encouragement and inspiration. There are many others who, in various ways helped and supported me. I sincerely thank all of them and request their forgiveness for not mentioning them here by name.

(Md. Ashaduzzaman Siddikee)

Dated: December, 2006.

Place: Dhaka, Bangladesh.

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ABSTRACT

An experiment on oleiferous *Brassica campestris* L. was conducted to evaluate the heterosis, intergenotypic variability, character associations and direct and indirect effect of different characters on seed yield. Desirable heterosis was shown by different hybrids in different characters. On the basis of desirable heterotic values the hybrids were scored for individual characters. On the basis of average score and rank position the hybrid SS 75 x Tori 7 was superior for number of primary branches per plant, number of siliquae per plant and seed yield per plant; BARIsar-6 x BARIsar-9/SS 75 x BARIsar-9 for seeds per siliqua; SAU YC x Tori 7 for number of secondary branches per plant; BARIsar-6 x BARIsar-9 for length of siliqua, SS 75 x Tori 7/BARIsar-6 x BARIsar-9 for thousand seed weight and BARIsar-9 x SAU YC were superior for percent (%) oil content. The hybrid Tori 7 x SS 75 showed desirable negative heterosis for the characters days to first flowering, 50% flowering and maturity. Mean squares for all the characters were highly significant and variations among the genotypes were wide. In general, environmental influences were minimal on yield and its component characters indicating that they were less responsive to environmental factors for their phenotypic expression. The values of phenotypic coefficient of variation and genotypic coefficient of variation indicated that there were considerable variations for all the traits except days to maturity and length of siliqua. Heritability, genetic advance and genetic advance in percent of mean were high for almost all the characters indicating superior performance of the genotypes were due to genetical reasons. The genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients, with the indication of a strong inherent association between the characters studied. Yield per plant had highest significant positive correlation with number of siliquae per plant followed by number of secondary branches per plant, seeds per siliqua, thousand seed weight, length of siliqua, number of primary branches per plant, plant height and days to first flowering and nonsignificant positive correlation with days to maturity in both genotypic and phenotypic level. Path coefficient analysis revealed that thousand seed weight had the highest positive direct effect on seed yield per plant followed by seeds per siliqua, number of siliquae per plant, number of secondary branches per plant and plant height.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Brassica is an important genus of plant kingdom consisting of over 3200 species with highly diverse morphology. *Brassicas* have great economic and commercial value and play a major role in feeding the world population. They range from nutritious vegetables, condiments and oil producing oleiferous *Brassica*.

From nutritional point of view fats and oils in our diets are mostly needed for calories and vitamin absorbent. It produces highest amount of calories per unit in comparison with carbohydrate and protein diets. For human health, in a balanced diet 20-25% of calories should come from fats and oils. Although, oilseed crops play a vital role in human diet the consumption rate of oil in our country is far below than that of balanced diet (6 g oil per day per capita against the optimum requirement of 37g per head per day, Rahman, 1981).

Among the oleiferous *Brassica*, the rapeseed groups includes, turnip rape (*Brassica campestris*, 2n = 20 AA), rape (*Brassica napus*, 2n = 38 AACC), Indian mustard (*Brassica juncea*, 2n = 36 AABB) and Ethiopian mustard (*Brassica carinata*, 2n = 34, BBCC) and *Brassica nigra* (2n = 16 BB), (Yarnell, 1956). Though there are several species of oleiferous *Brassica*, the short duration's varieties of *Brassica campestris* are mainly cultivated in Bangladesh.

Among the oil seed crops rapeseed and mustard is the third highest source of edible oil supply in the world after soybean and palm (FAO 2000, Piazza and Foglia 2001, Walker and Booth 2001). The oil yielding crop *Brassicas* hold the fourth and second position in the world oilseeds in respect of area and production, respectively and about 16% of the world's oilseed production is obtained from this crop (FAO, 2003).

Bangladesh is predominantly an agricultural country. Oilseed crops have always been an important segment in Bangladesh agriculture. About ten oilseed crops are grown in the country. These are mustard, sesame, groundnut, linseed, coconut, niger, castor, saffe flower, soybean and sunflower. Among these, *Brassica* oil crop is the most important group of species that supplies major edible oils in Bangladesh (BBS, 2000). Total oil seed crops cover 3.99 lakh hectare of land. However, rapeseed and mustard cover 2.97 lakh hectares of land and produce about 2.18 lakh Mt of oil seeds. This crop covers about 74.5% area of the total edible oil crops cultivated in Bangladesh. Oil seed crop covers about 4.04% area of the total cultivable land in Bangladesh (BBS, 2004).

Average yield per hectare of mustard and rapeseed crop is 850-900 kg (BBS, 2004) in Bangladesh compared to the world average of 1,575 kg, while it was 2,658 kg in Europe, 1,739 kg in south America, 1,436 kg in North America, 1,188 kg in Asia and 1,054 kg in Africa (FAO, 2003).

The shortage of edible oil has become a chronic problem for the nation. Bangladesh requires 0.29 million tons of oil equivalent to 0.8 million tons of oilseeds for nourishing her people. But, the oilseed production is about 0.254 million tons, which covers only 40% of the domestic need (FAO, 2001). As a result, more than 60% of the requirement of oil and oil seed has been imported every year by spending huge amount of foreign currency involving over 2,500-3,000 core taka.

The production of rapeseed and mustard should be increased to fulfill the consumption need and at the same time to save foreign exchange. To increase the production there can be increase in area under cultivation and of increasing per hectare yield. The feasibility of the former one is very little, rather the area will get decreased in course of time due to heavy population pressure and need for cereal grains. So, the remaining way to increase production is to increase per hectare yield and that can be achieved through adoption of high yielding varieties.

Meanwhile, about 24 mustard and rapeseed varieties have been released among these 15 from Bangladesh Agricultural Research Institute (BARI), 4 from Bangladesh

Institute of Nuclear Agriculture (BINA), 3 from Bangladesh Agricultural University (BAU) and 1 from Sher-e-Bangla Agricultural University (SAU) and 1 from Bangladesh Agricultural Development Corporation (BADC) but most of them are not popular to the farming community because of their long duration, low to moderate yield and susceptibility to severe biotic and abiotic stresses. It is, therefore, needed to develop improved mustard and rapeseed varieties with high yield potential, late planting, shorter growth duration which could be fit into cropping pattern T-Amon-Mustard-Boro.

There is plenty of scope to increase yield per unit of area through breeding superior varieties. The production potential of rapeseed and mustard may be well exploited if the varieties can be identified with early maturity, rapid response to high fertility, large seed size and high oil content. The oil content of mustard in Bangladesh varies from 30 to 40 percent depending on the variety, climate and production condition (Rahman *et al.*, 1993).

The seed yield is contributed by many morphological characters of the plant. So, increase of yield needs a careful assessment of the degree of inheritance and association between characters of plants and hybrid progenies for the selection of promising varieties. Intra-species hybridization is a good way of improving the varieties of different natures by combining characters followed by selecting of desired types. The most important aspects for hybridization are the choice of parents and selection of best lines from hybrid progenies. Information on heritability and heterosis of hybrid progenies early generations are very useful for the purpose of selection.

Based on the information above, the present research was undertaken to find out the

1. Extent of heterosis for different yield contributing characters
2. Magnitude of intergenotypic variation for different yield contributing characters
3. Association of different characters of 17th genotype of *Brassica* oil crops and their F_1s and
4. Identification of potential parent and promising cross combinations to develop HYV and hybrids

CHAPTER II

REVIEW OF LITERATURE

Oleiferous *Brassica campestris* L. is an important oil crop of tropical and sub-tropical agriculture, as it provides available nutrition to human. In Bangladesh the average productivity of mustard is low in comparison to the developed countries. Identification of superior parents, promising cross combination and suitable breeding methodology are the important pre-requisites for development of high yielding genotypes. The heterosis and variability studies are frequently utilized to understand breeding potential of parent as well as different cross combinations which helps in formulating proper breeding methodology. The estimation of different genetic parameters with nature and magnitude of direct and indirect effect on yield is an important factor in developing an efficient breeding programme. Therefore, relevant information available in the literature pertaining to the heterosis, variability, heritability and associations of characters of rapeseed and mustard are reviewed in this section.

2.1 Heterosis

The term heterosis refers to the phenomenon in which F_1 population generated by crossing of two dissimilar parents showed increased or decreased vigour over the mid parental value or the better parental value. The intraspecific crosses showed some heterotic effect and both positive and negative heterosis were found.

Adefris and Becker (2005) conducted an experiment to generate information on heterosis. Nine inbred parents and their 36 F_1s, were evaluated for 12 traits at three locations in Ethiopia. Analysis of variance showed the presence of significant heterosis for all the traits. Seed yield showed the highest relative mid parent heterosis that varied from 25 to 145% with a mean of 67%. Relative high parent heterosis for seed yield varied from 16 to 124% with a mean of 53%. The presence of high levels of mid and high parent heterosis indicates a considerable potential to embark on breeding of hybrid or synthetic cultivars in Ethiopian mustard.

Shen *et al.* (2005) observed significant differences in seed yield per plant and seed oil content among the F_1 hybrids and between F_1 progenies and their parents of *Brassica campestris*. However, the heterosis for seed yield per plant was much greater than that for seed oil content. Mid parent heterosis and high parent heterosis of seed yield per plant ranged from 5.50 to 64.11% and from −2.81 to 46.02%. while those of seed oil content ranged from −1.55 to 7.44% and −3.61 to 6.55%, respectively.

Katiyar *et al.* (2004) carried out a study on heterosis for the seed yield in ninety intervarietal crosses of *Brassica campestris*. Twenty one crosses (23.3%) showed significant positive heterosis over better parent while only four crosses (4.4%) were over the best commercial variety (MYSL-203). The crosses, YST-151 x Pusa gold (dwarf), and MYSL–203 x EC–333596 showed highest heterosis upto 150.33 and 43.38 percents over best parent and commercial variety respectively. Line GYSG–1 (female parent) and Pusa gold (dwarf) were the most potential ones for giving largest proportions of crosses with high degree of heterosis.

Yadav *et al.* (2004) had undertaken an investigation to estimate heterosis for seed yield and its components in Indian mustard. Hybrids Siifolia x NDRE-4 (-18.5%) and Trachystoma x NRCM-40 (-6.1%) exhibited the highest heterosis for days to flower initiation and days to maturity over better parent, respectively. The magnitude of heterosis was highest for plant height in Trachystoma x SK 93-1 (27.7%) over BP and (25.8%) over SV both. For the number of primary branches per plant Trachystoma x PR 905 showed 106.5 and 100.0% heterosis over BP and SV, respectively. Trachystoma x PHR-1 (125.1%) showed maximum heterosis over BP and Moricandia x NRCM-79 (9.6%) over SV for the number of secondary branches per plant. Siifolia x SM-1 showed 54.1% heterosis over BP and negative heterosis (-9.2%) over SV for seeds per siliqua. The highest heterosis for thousand seed weight was observed in Moricandia x PHR-1 (48.80%), followed by Trachystoma x NRCM 69 (20.6%) over BP and SV, respectively. Significant and positive magnitude of heterosis for oil content was observed in Trachystoma x NDYR-8 (10.1%) over BP and Siifolia x NRCM 79 (8.5%) over SV, respectively. The cross, Moricandia x NRCM 86 exhibited significant and positive heterosis over BP (82.8%) for seed yield per plant, followed by Siifolia x NRCM 86 (76.0%) and Moricandia x NRCM 98 (52.5%).

Mahak and Lallu (2004) performed an experiment on Indian mustard strains/cultivars Varuna, Shekhar, Vardan, Laha 101, Pusa Bold, RH-30, Pusa Basant, NDR-8501 and Kranti were crossed in a diallel mating design excluding reciprocals. The parents along with 36 F_1s and 36 F_2s were grown data recorded for plant height, branches per plant, siliquae on main raceme, seed yield per plant, thousand seed weight, seed oil content, de-fatted seed content and protein content. The crosses exhibited highly significant heterosis for most of the characters studied.

Goswami *et al.* (2004) conducted an experiment and estimated heterosis for yield and yield components in 30 crosses of Indian mustard. Results showed that the cross RH9404 x RH30 had the maximum heterosis for seed yield per plant (92.88 and 106.23%) during E_1 and E_2, respectively. This cross also showed high heterosis for thousand seed weight. The crosses RH9617 x RWH1 and RH9621 x RWH1 were selected because of high heterosis for all the parameters tested.

Satyendra *et al.* (2004) evaluated twenty-one Indian mustard hybrids and their parents for eight quantitative traits: days to flowering, days to maturity, plant height, number of primary branches, length of the main raceme, seed yield, thousand seed weight and oil content percentage, in an experiment. High heterosis (15.99, 15.51 and 12.37%) was obtained for seed yield in the crosses Basanti x NDR 8501, Basanti x Kanti and Basanti x RH 30, respectively. These hybrids showed high heterosis over the best cultivar.

Among the crosses, Basanti x Kranti may be used for selecting for seed yield and quality traits.

Mahak *et al.* (2003) studied heterosis for days to flowering, plant height, number of primary and secondary branches, length of main raceme, days to maturity, thousand seed weight, harvest index, oil content, protein content, and seed yield in 10 Indian mustard cultivars and 45 F_1 and F_2 hybrids. High heterosis for seed yield was observed in Varuna x Rohini (56.74%), Vardan x Rohini (53.43%), Varuna x RK 9501 (52.86%), Vardan x NDR 8501 (36.73%), Pusa Bold x Rohini (37.68%), and Varuna x NDA 8501 (32.54%).

Qi *et al.* (2003) made 66 crosses in a diallel design of 12 parental varieties of *Brassica napus* to study heterosis of seed and its components. Twenty-one crosses showed a significant heterosis in seed yield per plant. The average yield heterosis over their parents was 70.24% (30.70-218.10%). Eight crosses showed better parent heterosis (3.57-20.48%) in thousand seed weight, while the parents of 7 cross showed low thousand seed weights. Forty-seven crosses gave on average 28.02% (0.93-97.87%) more siliquae per plant in parents, while 13 crosses showed 11.67% more seeds per siliqua in parents.

Pankaj *et al.* (2002) studied heterosis of parents for seed yield, oil content and protein content in an 8 x 8 diallel cross in toria (*Brassica campestris* var. toria). Trait data were recorded on five plants of each of the 28 F_1s and 28 reciprocal F_1s (RF_1s). 24 F_1s and 21 RF_1s showed significant positive heterosis for seed yield over mid parent (MP) and 16 F_1s and 21 RF_1s over the better parent (BP).

Kumar *et al.* (2002) crossed three lines and twelve testers of Indian mustard and the resulting 36 F_1's and 15 parents were grown. Physiological data were determined from 5 plants per entry and the range of heterosis given for all crosses. The five hybrids with the highest heterosis for seed yield were RN-505 x RN-490, RN-505 x PCR-43, RN-393 x

RN-481, RN-393 x RN-453 and RN-505 x RN-481, and these crosses offer the best possibilities of further exploitation for the development of high yielding varieties.

Ghosh *et al.* (2002) carried out a line x tester analysis involving 29 promising female and seven male parents for 10 quantitative traits in Indian mustard. The crosses YSRL-10 x Pusa bold, DBS-10 x Pusa bold showed high heterosis for seed yield and some of the yield contributing traits.

Tyagi *et al.* (2001) evaluated forty-five hybrids of Indian mustard obtained from crossing 10 cultivars for seed yield and yield components. The relative heterosis was desirable for plant height, number of primary and secondary branches per plant, seeds per siliqua, number of siliquae on main shoots, biological and seed yields, and oil content. Heterobeltiosis was desirable for primary and secondary branches per plant; siliquae on main shoots, and biological and seed yields. Standard heterosis was desirable for the number of primary and secondary branches per plant, siliqua length, seeds per siliqua, number of siliquae on main shoots, biological and seed yields and oil content. The mean level of heterosis was highest for biological yield. The highest standard heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant was recorded in the cross BIO 772 x Rohini. This cross was the best heterotic combination for all the three types of heterosis for seed yield.

Swarnkar *et al.* (2001) carried out heterosis analyses using 36 F_1 hybrids, 36 F_2 generations and parents obtained from 9 x 9 diallel mating design for 11 quantitative traits, viz. days to flowering, plant height (cm), number of primary branches, number of secondary branches, length of main raceme (cm), number of siliquae on main raceme, days to maturity, yield per plant (g), thousand seed weight (g), oil content (%) and protein content (%). High economic heterosis for seed yield was observed to be present in four crosses, KR-5610 x PR-15 (58.38%), YRT-3 x PR-15 (54.33%), RK-1467 x T-6342 (52.60%) and KR-5610 x KRV-Tall (36.70%). The hybrids showing high heterosis over best cultivar can be successfully grown up to 2 or 3 early generations, which may prove beneficial for the Indian mustard growers.

Qi *et al.* (2000) investigated heterosis in hybrids of 6 cultivars of *Brassica campestris*. They found that yields of the hybrids ranged from 46 to 125 kg. Significant heterosis for yield was found in some hybrids with the highest being 96.4%. Most hybrids showed lower levels of heterosis, with the lowest being 1.4%.

Agrawal and Badwal (1998) studied the extent of heterosis for yield and other characters in 19 F_1 hybrids of *Brassica juncea* and compared to 5 commercial cultivars. Eighteen hybrids out yielded the best control variety RLM514. Three of them (MS x Plant Rai 1002, MS x RH848 and MS x RLC1047) were superior over the best control in seed yield by 81.19, 50.65 and 64.94%, respectively. Overall heterosis (taking all hybrids and check into account) for seed yield was very high (59.69%). The agronomic superiority of the 3 hybrids was reflected by 1.5 to 2.0 fold increase in oil yield and one week earliness in flowering as compared to RLM514.

Yadav *et al.* (1998) studied some 27 crosses of female and 3 male sarson (*Brassica campestris) parents* for 7 yield components. Of these, 18 hybrids exhibited significant positive heterosis. Highest heterotic response for seed yield was observed in DB_1 x Pusa kalyani and BSKI x BSI K_2

Yadav *et al.* (1997) studied heterosis in toria (*Brassica campestris var. toria*). He used 6 lines and their 15 F_1 hybrids and studied on 8 yield components. The cross White flower x TC113 had the highest negative heterosis (being desirable) for plant height. The crosses White flower x TS61, TH68 x TC113, White flower x Sangam and White flower x TS61 were superior for seed yield.

Thakur and Segwal (1997) estimated heterosis in rapeseed (*Brassica napus L.*) and showed that heterosis over better parent for the various triats were significant for seed yield (-14.8 to 82.8%), primary branches (-26.0 to 193.6%) and siliqua per plant (21.9 to

162.6%). The cross GSB7027 x HNS8803 gave highest positive heterosis for seed yield per plant.

Varshney and Rao (1997) estimated combining ability, heterosis and inbreeding depression in yellow sarson (*Brassica camperstris*) for 11 quantitative characters. The hybrids, which exhibited highest heterosis also showed higher inbreeding depression. Heterosis over better parent was highest for siliquae per plant (162.9%), followed by economic yield per plant (129.4%), Biological yield per plant (118.7%), primary branches per plant (118.7%) and secondary branches per plant (88.1%).

Singh *et al.* (1996) studied heterosis for yield and oil content in *Brassica junce L.* Heterosis over better parent was recorded in the crosses PR1108 x BJ-679 by 77.6% and BJ-1257 x Glossy mutant by 13.1% for seed yield and oil content, respectively. Oil content was positively associated with thousand seed weight and seed yield indicating the possibility of simultaneous improvement for these characters.

Information on heterosis have also been recorded by Rai and Singh (1994) from data on 6 yield component in 8 *Brassica campestris* varieties and their 28 F_1 hybrids. A number of hybrids expressed heterosis for seed yield and its component. The average heterosis over better parent for seed yield was 21.3%. The crosses showed significantly high positive heterosis for seed yield in all cases except had high negative heterosis for yield in DTS x YST151.

Krzymanski *et al.* (1993) found significant heterosis for seed yield, oil content and some flowering traits in 10 parental strains and their 45 hybrids. The mean heterosis for seed yield over the mid parent was 24.7%. The highest heterosis for this was seen in the cross of PN2595/91 x PN2870/91 (71.81% relative to the mid parental value).

Zheng and Fu (1991) worked with eight F_1 hybrids of *Brassica napus* L. They evaluated 17 agronomic traits with 4 heterosis standards. Off all traits, Investigated seed yield per plant and siliquae per plant showed significant heterosis, their heterosis (over mean value of the parents) ranges being 80.21 and 51.47 percent, respectively.

Hirve and Tiwari (1991) evaluated 28 elite *Brassica juncea* genotypes produced 28 F_1 and F_2 progenies together with the parents, for siliquae and seed yield per plant and siliqua length. The highest heterosis for seed yield was obtained in the cross RAU x RPU18 (161%). RLM 198 x Veruna, RAU RP_4 x Varuna and Tm 7 x Varuna also gave good seed yield heterosis and gave high heterosis for other yield contributing characters. In general, crosses containing Varuna as one parent gave high heterotic values.

Schuster *et al.* (1978) reported heterosis of 203% for seed yield, 211% for number of seed per siliqua and 187% for number of siliquae per plant in crosses between diverse lines in each generation of black mustard (*Brassica nigra* L.) . There was lower heterosis for thousand seed weight.

2.2 Variability

The representative varieties used in many different studies under certain agroecological conditions of production have expressed different degrees of varation. Parts of these were genetic and part non-genetic. It is therefore, important to review the varabilities that have been found in different materials for some specific characters of interest.

Katiyar *et al.* (2004) carried out a study on variability for the seed yield in ninety intervarietal crosses of *Brassica campestris.* Existence of significant variation among parents and crosses indicated the presence of adequate genetic variance between parents which reflected in differential performance of individual cross combinations.

Tyagi *et al.* (2001) evaluated forty-five hybrids of Indian mustard obtained from crossing 10 cultivars for seed yield and yield components. Variation was highest for plant height of parents and their hybrids. The seed yield per plant exhibited the highest coefficient of variation (41.1%).

Masood *et al.* (1999) studied seven genotypes of *Brassica campestris* and standard cultivar of *Brassica napus* to calculate genetic variability. The co-efficient of variation was high for thousand seed weight, pod length and number of seeds per pod for both genotypic and phenotypic variability.

Lekh *et al.* (1998) conducted an experiment with 24 genotypes of *Brassica juncea* and 10 genotypes each of *Brassica campestris, Brassica carianata* and *Brassica napus* during the rabi season of 1992-93 and 93-94. The highest genotypic co-efficient of variation was calculated for secondary branches. High genotypic and phenotypic coefficient of variation was recorded for days to 50% flowering. Shen *et al.* (2002) tested 66 F_1 hybrids of *Brassica campestris* and significant differences were found between F_1s and their parents for yield per plant and seed oil content.

Usually higher the siliqua number higher is the seed yield. This trait has high variation and a considerable part of which appeared to be of environmental. Yin (1989) studied 8 cultivars of *Brassica napus* and observed high genetic variation in number of siliquae per plant. Similar results of high variation for this trait has also been observed and reported by Kumar *et al.* (1996). According to Tak and Patnaik (1977) genotypic co–efficient of variation (GCV %) and phenotypic co-efficient of variation (PCV %) of this trait in yellow sarson were as high as 55.4% and 53.2% respectively. The same values in Toria were 27.1% and 23.5%. Further variable result of GCV and PCV for this character 25.41 and 29.15%, respectively was observed by Singh *et al.* (1987) in *Brassica campestris*. GCV was reported to be also as 18.85% by Yadava (1973) and 97.3% by Bhardwaj and Singh (1969). These review indicated that there exists sufficient variation in number of siliquae per plants and the same is variable with variable production conditions and genetic materials as used by different authors.

In general, high number of seeds per siliqua is desirable. A good number of literatures are available on the variability of this character. Kumar *et al.* (1996) reported the presence of significant variability in the genotypes of *Brassica napus, Brassica campestris* and *Brassica juncea* they studied. Similar significant variability in number of seeds per siliqua in oleiferous *Brassica* materials of diverse genetic base have also been observed by Kudla (1993) and Kumar and Singh (1994). In case of genotypes of *Brassica campestris* the value of GCV was 35.85% as observed by Bhardwaj and Singh (1969). According to Tak and Patnaik (1977) values of GCV and PCV were found to be 13.1% and 18.5% respectively in yellow sarson. While the value of the same for toria were 16.3% and 22.6%. Low values of GCV and PCV were also observed in *Brassica juncea* by Singh *et al.* (1987). According to them values were 6.46% and 9.5% for GCV and PCV respectively. Labana *et al.* (1987) also observed GCV and PCV of 9.82% and 15.96% respectively in genotypes of *Brassica juncea* for number of seeds per siliqua. These indicate that the genotypes of *Brassica juncea* are less variable than those of *Brassica campestris.*

Thousand seed weight is also an important trait of *Brassica* oil crops, where highest consideration is on the seed yield. This trait has been found to vary widely from genotypes to genotypes and from environment to environment including macro and micro environments. A good number of literatures are available on the variability of this character. According to Chowdhury *et al.* (1987) in *Brassica campestris*, Yin (1989) in *Brassica campestris* Labowitz (1989) in *Brassica campestris*, Biswas (1989) in *Brassica campestris*, Andrahennadi *et al.* (1991) in brown mustard, Kudla (1993) in sewede rape and Kumar and Singh (1994) in *Brassica juncea* reported different degrees of significant variations of thousand seed weight due to variable genotypes. In case of *Brassica campestris* (toria ecotypes), GCV and PCV, two important parameters of breeding values were found to be 11.8% and 18.9% respectively (Bhardwaj and Singh, 1969). The respective values of the same were 13.1% and 16.5% in brown sarson as reported by Tak and Patnaik (1977).

Labowitz (1989) studied *Brassica campestris* population for siliqua length and observed high geneic variation in theis trait.

Yield is the most important trait for all crops in every breeding program. This is a complex trait influenced largely by a number of component characters and factors of production. A good number of research works have been conducted on this character. Significant genetic variability in genotypes belonging to toria ecotype of *Brassica campestris* was reported by Thakral (1982). Similar high variability in different genotypes of *Brassica campestris* was reported by Sharma (1994). Khera and Singh (1988) also reported significant variation in yield due to genotypes of *Brassica napus*. A high degree of variation for seed yield per plant was reported by Yin (1989) in *Brassica campestris*, Kudla (1993) in *Brassica napus* and Kumar *et al.* (1996) in *Brassica juncea*. According to Bhardwaj and Singh (1969), the value of GCV was found to be 96.99% among different strains of brown sarson (*Brassica campestris*). This value appeared to be very high for yield as because 48.76% GCV was found by Yadava (1973) among 29 strains of *Brassica juncea*. While, Singh *et al.* (1987) observed GCV and PCV values of 44.04% and 46.9% in *Brassica juncea*. The same values were only 9.6% and 19.47% among different genotypes of *Brassica juncea* Labana *et al.* (1987). The comparative position of the genotypes of these two species indicates the presence of high variability due to difference in species and genotypes.

2.3 Heritability

Sheikh *et al.* (1999) studied with 24 diverse genotypes of toria in two different environments in 1996-97. They observed high heritability coupled with high genetic advance for seed yield per plant, secondary branches per plant, siliquae per plant, 1000 seed weight and primary branches per plant.

Lekh *et al.* (1998) conducted an experiment with 24 genotypes of *Brassica juncea* and 10 genotypes each of *Brassica campestris*, *Brassica carianata* and *Brassica napus* during the rabi season of 1992-93 & 93-94. He evaluated 10 yield components under 3 sowing dates. The highest genotypic co-efficient of variation were calculated for secondary branches. High heritability estimates were observed for all the characters under all environments except harvest index and biological yield. Highest genetic advance and high genotypic and phenotypic co- efficient of variation was recorded for days to 50% flowering.

Benna *et al.* (1998) studied variability in mustard. Information was tabulated on mean, range, genotypic and phenotypic co-efficient of variation and heritability for 6 yield related traits in 22 mustard (*Brassica juncea*) genotypes grown at Nagpur during the rabi season of 1997-1998.

Yadav *et al.* (1996) studied 8 x 8 diallel analysis (excluding reciprocals). They found that both additive and dominance genetic component were important for seed yield and yield components in *Brassica campestris* var. toria. They reported higher heritability for days to maturity and thousand seed weight.

Diwakar and Singh (1993) studied heritability and genetic advance in segregating populations of yellow seeded Indian mustard (*Brassica juncea* L. Czern and Coss.). They used data on yield and 5 component traits in 8 cultivars and their 28 F_3 hybrids. They observed a wide range of phenotypic variation for most of the measured traits. They also reported that narrow sense heritability and genetic advance were high for days to flowering and plant height.

Singh (1986) studied 22 genotypes of *Brassica napus, Brassica campestris* and *Brassica juncea* and reported high heritability and genetic advance in seed yield per plant and number of seeds per siliqua.

2.4 Correlation and path co-efficient

Characters associations among different characters are important in breeding programme. Many workers have reported their studies on characters association among characters of *Brassica* sp. Some of these information are reviewed here.

Khulbe and Pant (1999) studied correlations from data on 12 yield related traits in 8 Indian mustard (*Brassica juncea*) parents and their 28 F_1 hybrids. The result indicated that siliquae per plant, siliqua length, seeds per siliqua, thousand seed weight and harvest index were positively associated with seed yield. Path coefficient analysis revealed that harvest index, siliqua per plant, siliqua length, thousand seed weight, seeds per siliqua and days to initial flowering were the major characters influencing seed yield.

Patel *et al.* (1999) derived correlations from 12 yield related traits in the parents and 60 F_1 progeny of a 20 line x 3 tester cross of *Brassica juncea*. Based on path analysis, siliquae per plant, primary branches per plant and plant height made in greatest contribution to seed yield.

Masood *et al.* (1999) studied those seven genotypes of *Brassica campestris* and standard cultivar of *Brassica napus* to calculate genetic variability, correlation and path co-efficient. The co-efficient of variation was high for thousand seed weight, siliqua length and number of seeds per siliqua for both genotypic and phenotypic variability. The genotypic and phenotypic correlation coefficients showed that seed yield per plant were significantly positively correlated with plant height, number of siliquae per plant and number of seeds per siliqua. Path analysis of yield with the traits indicated that number of seeds per siliqua exerted the highest effect on seed yield.

Sheikh *et al.* (1999) assessed the direct and indirect influence of seven quantitative and developmental traits on seed yield in 24 diverse genotypes of toria under two environments at Khudwani, pooled analysis revealed highly positive direct effects of thousand seed weight and siliquae per plant on seed yield. These characters can be used to maximize genetic gain for yield.

Thakral *et al.* (1999) studied genotypic and phenotypic correlation co-efficient on seed yield and yield contributing characters in 8 Indian mustard (*Brassica juncea*) parents and their 28 F_1 hybrids grown at Hisar. The data indicated that higher seed yields could be obtained by selecting for increased plant height.

Kumar *et al.* (1999) studied 12 yield related traits in 15 genotypes at *Brassica juncea*, 3 of *Brassica napus*, 4 of *Brassica campestris* and one of *Brassica chinensis*. For most characters studied, genotypic correlation coefficients were higher in magnitude than their corresponding phenotypic correlation coefficients. Seed yield was positively correlated with plant height, siliquae on main shoot, siliquae per plant and thousand seed weight.

Gurdial and Hardip (1998) conducted a field trial during the rabi season of 1988-89 and 1989-90 in a loamy sand irrigated soil with gobhi sarson (*Brassica nigra*) cv. GSLS to study the relationships among different growth parameters and seed yield. Results indicated positive correlations of number of branches per plant, number of siliquae per plant, siliqua length , seed yield , harvest index (HI), LAI, chlorophyll content, DM, photo synthetically active radiation (PAR) interception and seed yield were positively correlated among themselves. However, Plant height was negatively correlated with LAI, chlorophyll content, dry matter, yield components and seed yield. Thus dwarf plant gave higher yields.

Phenotypic correlation between yield and its components were estimated by Zajac *et al.* (1998). The range of yield and its component values indicated a great variability within them. The strong positive correlation occurred between seeds per siliqua and actual yield. Positive, though a weaker correlation was observed between seed yield and siliquae per plant. However, correcting actual yield, seeds per siliqua had the greatest influence and stand density and siliquae per plant had the smallest effect on yield.

Das *et al.* (1998) studied 8 genotypes of Indian mustard (*Brassica juncea*) they reported the presence of high positive genotypic correlations by siliqua length and seeds per siliqua with seed yield per plant.

Dileep *et al.* (1997) found that seed yield was correlated positively with characters including number of siliquae per plant, seed weight per plant and thousand seed weight.

Tyagi *et al.* (1996) studied correlations with 6 yield components in 3 cultivars of mustard grown during 1992-93, plant height, siliquae per plant, siliqua length, seed yield per plant, seed weight and seeds per siliqua had positive and significant effects on yield.

Yadav *et al.* (1996) evaluated correlations from path coefficient analysis of 6 yield components of 25 diverse varieties of Indian mustard. He observed that number of siliquae per plant had the highest positive direct effect on seed yield per plant.

Gill and Narang (1995) carried out a field trails with gobhi sarson (*Brassica campestris* var sarson) in winter 1986-1988. The result showed that seed yield was positively correlated with DM, number of primary and secondary branches, number of siliquae per plant, thousand seed weight an LAI but not plant height, Dry matter showed the highest direct contribution towards seed yield followed by secondary branches, siliquae number and thousand seed weight.

Uddin *et al.* (1995) observed considerable genotypic and phenotypic coefficients of variation for thousand seed weight, seed yield per plant and siliquae per plant in 13 Indian mustard (Brassica *juncea*). Correlation analysis revealed that seed yield per plant had high positive and significant correlations with plant height and thousand seed weight, but high negative and significant correlations with seeds per siliqua, at both the genotypic and phenotypic levels. Seeds per siliqua, thousand seed weight had high positive direct effects on seed yield per plant.

Correlation and regression studies were made by Arthamwar *et al.* (1995) for *Brassica juncea.* Weight of siliquae per plant showed the highest correlation with seed yield followed by number of siliquae per plant, number of seeds per siliqua and thousand seed weight. Path analysis revealed that the contribution of plant characters to yield was of siliquae per plant, thousand seed weight, number of siliquae per plant and number of seeds per siliqua.

Character association and path coefficient analysis were used to determine relationships between growth and yield parameters in 28 lines of yellow and brown sarson *(Brassica campestris)* by Saini and Kumar (1995). Results revealed that seeds per siliqua and thousand seed weight had direct positive effect on yield.

Ghosh and Mukhopadhyay (1994) evaluated seed yield and 5 seed yield related characters in toria *Brassica campertris* var. toria during the winter seasons of 1987-1989 at Sriniketan. Seed yield was significant and positively correlated with plant height, siliquae per plant, seeds per siliqua and thousand seed weight.

Chaudhury *et al.* (1993) evaluated 7 *Brassica juncea* cultivars, 2 *Brassica carinata* cultivars and 1 cultivar each of *Brassica campestris* and *Brassica tournefortii* in 1979-1980 at Hisar, Haryana. Seed yield was positively correlated with siliqua length. Similar results were obtained with analysis by multiple correlation coefficients.

Ahmed (1993) studied nature and degree of inter relationships among yield components in 8 cv. *Brassica campestris* and *Brassica juncea.* According to him siliqua length, number of siliquae per plant, number of seeds per siliqua and seed weight per siliqua was positively and linearly associated with seed yield per plant, and these 4 component characters of yield were also interrelated with plant height. Seed oil content was positively correlated with seed weight, but negatively correlated with number of seeds per siliqua.

Zaman *et al.* (1992) studied several yield contributing traits of Swedish advanced rape lines. Results showed seeds per siliqua to be negatively correlated with siliquae per plant.

Reddy (1991) conducted an experiment during the rabi season of 1983-84 and 1984-85 and studied correlation in Indian mustard (*Brassica juncea* L.). He observed positive and significant correlation between seed yield and leaf area index, primary branches per plant, secondary branches per plant, siliquae per plant, seeds per siliqua and weight of siliquae and seed yield per plant.

Kachroo and Kumar (1991) reported at *Brassica juncea* found that thousand seed weight had positive direct effect, but days to 50% flowering and primary branches had negative indirect effect via seeds per siliqua on seed yield. But Chauhan and Singh (1995) observed high positive direct effect of plant height, siliquae per plant and seeds per siliqua on yield.

Dhillor *et al.* (1990) observed the highest positive direct effect of plant height on seed yield per plant. While Han (1990) working with *Brassica napus* observed negative direct effect of number of siliquae per plant, siliqua length and positive direct effect of seeds per siliqua and plant height on yield.

Swain (1990) studied correlations of yield components in 15 genotypes of brown sarson (*Brassica campestris var* dichotoma). Siliquae per plant was found the most important characters contributing to yield.

Gupta *et al.* (1987) studied with 51 *Brassica juncea* genotypes of diverse origin and observed that harvest index, oil percentage and seed yield were positively correlated with oil yield both at the genotypic and phenotypic levels. The genotypic correlations being generally higher than phenotypic ones. Seed yield and oil percentage had the highest direct effect on oil yield.

Chowdhury *et al.* (1987) studied with 42 strains of mustard and showed that yield per plant was positively and significantly correlated with days to maturity, plant height, number of primary branches, number of siliquae on the main raceme, number of siliquae on lateral branches, siliqua length, and thousand seed weight. Number of primary branches had the highest positive correlation with yield. Path coefficient analysis revealed that the highest positive direct effect on yield was contributed by siliqua length. Number of primary branches had the highest negative direct effect on yield.

Correlation and path coefficient analysis by Hari *et al.* (1985) using data on seed yield per plant and 11 related traits from 38 cultivars of *Brassica juncea* revealed that siliquae number per plant and thousand seed weight were significantly and positively correlated with yield and these characters showed considerable direct effects on yield.

Kumar *et al.* (1984) observed the negative indirect effect of days to flowering via plant height and siliqua length on yield in *Brassica juncea*. Singh *et al.* (1978) found negative direct effect of these traits.

CHAPTER III

MATERIALS AND METHODS

To conduct the experiment five selected cultivars were used as parents. The cultivars and line were Tori 7, SS 75, BARIsar-6, BARIsar-9 and SAU YC. The promising line SAU YC was collected from *Brassica* breeding Project of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh. The other four cultivars were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. Twelve crosses includes six reciprocals were done among parents in *Rabi* season 2002-2003. In 2004-2005 *Rabi* season, the parents, F_1s and reciprocals were grown in the experimental farm of Genetics and Plant Breeding Department of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

3.1 Experimental site and duration

The research work was conducted at the experimental farm of Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh, during the period from November 2002 to March 2003 and November 2004 to March 2005. The soil of the experimental plots were clay loam, land was medium high with medium fertility level. The site was situated in the subtropical climatic zone, wet summer and dry winter is the general climatic feature of this region. During the rabi season the rainfall generally is scant and temperature moderate with short day length. Meterogical data on rainfall, temperature, relative humidity from November 2002 to March 2003 and November 2004 to March 2005 were obtained from the Department of Metrological centre, Dhaka-1207, Bangladesh (Appendix II).

3.2 Plant materials used

Five parental genotypes and their twelve intervarietal hybrids with reciprocals were used in experiment. The present status, source of the materials and characteristics of the parents used in the intraspecific crosses and the attemted cross combinations are presented in Table 1 and Table 2. The parents were crossed in partial diallel to produce 12 F_1's including 6 reciprocal during winter 2003 at the experimental farm of SAU, Dhaka, Bangladesh.

3.3 Land preparation and fertilizer application

The land was ploughed well by power tiller followed by laddering. The stubbles and weeds were removed carefully. Chemical fertilizers were applied at the rate of 220-140-80-150-5 kg/ha of urea, Triple Super Phosphate (TSP), Muriate of Potash (MP), Gypsum and Zinc sulphate respectively. Cowdung was applied at the rate of 5 t/h. The whole amount of TSP, MP, Gypsum, Zinc sulphate and 50% urea were applied as basal dose. The remaining 50% urea was applied as top dressing at flower initiation stage.

3.4 Experimental design and layout

The seeds of twelve F_1's including reciprocals and five parents were grown in Randomized Complete Block Design (RCBD) with three replications. Each plot consisted of single row of 3m length spaced 40cm apart and 10cm between plants. The seeds were sown in separate line in the experimental field on 3 November 2004 by hand uniformly. The seeds were sown at a soil depth of 2.5 to 3.5 cm. After sowing the seeds were covered with soil carefully so that no clods were on the seeds. Seed germination started after 3 days of sowing on 7th November 2004. Treatment was distributed in the experimental unit through randomization by using the random number.

3.5 Irrigation and drainage

One post sowing irrigation was given by sprinkler after sowing of seeds to bring proper moisture condition of the soil to ensure uniform germination of the seeds. A good drainage system was maintained for immediate release of rainwater from the experimental plot during the growing period.

Table 1. Particulars of the parents of *Brassica campestris* L. used in the intraspecific crosses

Parent	Line or Variety	Sources	Seed color	Seed size	Maturity period (days)	Yield (Kg/ha)
BARIsar-9	Variety	BARI	Brown	Medium	78-85	1200-1300
BARIsar-6	Variety	BARI	Yellow	Medium	90-95	2000-2200
Tori 7	Variety	BARI	Brown	Small	75-80	900-1100
SS 75	Variety	BARI	Yellow	Bold	95-100	1800-2000
SAU YC	Line	SAU	Yellow	Medium	80-90	1400-1600

Note: SS 75 = Sonali Sarisha 75, SAU YC = Sher-e-Bangla Agricultural University Sharisha yellow color

Table 2. Showing the cross combinations with reciprocal system of five parents/ varieties of *Brassica campestris* L.

Cross	Reciprocal cross
Tori 7 x BARIsar-6	BARIsar-6 x Tori 7
Tori 7 x SAU YC	SAU YC x Tori 7
Tori 7 x SS 75	SS 75 x Tori 7
BARIsar-9 x BARIsar-6	BARIsar-6 x BARIsar-9
BARIsar-9 x SS 75	SS 75 x BARIsar-9
BARIsar-9 x SAU YC	SAU YC x BARIsar-9

3.6 Intercultural operation, Insect and disease control

Necessary intercultural operations were done during the crop period to ensure normal growth and development of the plants. Thinning and first weeding were done after 15 days of sowing. Top-dressing, weeding and necessary thinning were done after 25 days of sowing. Malataf was sprayed 2 times one just before flowering and the other at the middle of flowering for protecting the crop from the attack of aphids and Rovral-50 WP was sprayed @ 20-g/10L water first one at the time of siliqua setting of fruiting and second one after 15 days of 1st spraying to control *Alternaria* leaf spot. No remarkable disease attack was observed.

3.7 Harvesting of sample plants

When 80% of the plants showed symptoms of maturity i.e.; straw color of siliquae, leaves, stem and desirable seed color in the matured siliquae, the crop was assessed to attain maturity. At maturity, ten plants were selected at random from the middle row of each plot. The sample plants were harvested by uprooting and then they were tagged properly. Data were recorded from these ten plants.

3.8 Data Recorded

1. Days to first flowering: Determined the number of days required from the date of sowing to the blooming of the first flower in the plant. Number of days required for opening the first flower in each F_1's or parents was recorded. The average of three plants blooming of a plot was considered as the days to first flowering for one replication.

2. Days to 50% flowering: Days to 50% flowering was counted when near about 50 percent plants had at least one open flower of each F_1's or parents.

3. Days to maturity: Number of days required from sowing to siliquae maturity of 80% plants of each row.

4. Plant height: During harvesting, the plant height was measured in cm from the ground level of the plant to the top of the plant. It was the longest inflorescence of the tallest raceme.

5. Number of primary branches per plant: Mean numbers of branches originated from the main stem from ten randomly selected plants from each F_1's and parents at maturity.

6. Number of secondary branches per plant: Number of branches originated from the primary branch from ten randomly selected plants from each F_1's and parents at maturity.

7. Number of siliquae per plant: Mean number of siliquae obtained from ten randomly selected plants from each F_1's and parents at maturity.

8. Length of siliqua: Ten siliqua was selected at random from every selected plant to measure the length of siliqua. The measurement was in cm. Distance between the end of the peduncle to the starting point of the beak was considered as siliqua length.

9. Number of seeds per siliqua: All siliqua from the sample plants was collected and 10 siliqua was randomly selected. Seeds obtained from them were counted and average numbers of seeds per siliqua was recorded.

10. Thousand-seed weight (g): Weight in grams of 1000-seed was recorded from ten randomly selected plants of each F_1's and parents.

11. Seed yield per plant (g): Mean seed weight in grams of ten randomly selected plants from each F_1's and parents after harvest.

12. Oil content: Percentage of oil in the seed sample was determined by extracting the oil with petroleum ether at 40-60^{0}C in a soxhelt's extraction apparatus. A random seed sample of approximately 40g was taken form the bulk yield of each of the line. The seeds of the individual genotype were grand to a fine powder in a porcelain mortar and pestle. The powder was then transferred into a Whatman's filter paper. The mortar and pestle were washed with petroleum ether to collect the traces of oil and powder sticking to them and the solution was transferred to the thimble in the socket. Approximately 125 ml of petroleum ether was taken into the distillation flask and the extraction set was fixed on an electrical water bath. Ten extraction sets were used so as to extract oil from the sample simultaneously for 5.5 hours. The distillation flask was later separated and the petroleum ether was distilled off. Last traces of it were removed by suction pressure. The extract or oil remain in the flask was accurately weighted and the percentage of extract in seed material was calculated.

3.9 Statistical analysis

Statistical analyses were done to calculate the analysis of variance and other parameters of the genotypes for the characters tested. The total variances of each character were partitioned into block, genotype, and error differences. The differences within the classes of effects were tested by F-test.

3.9.1 Estimation of heterosis: The amount of heterosis in the F_1's was analysed using the following formula:

$$\%\ \text{Heterosis in } F_1 \text{ over mid parent} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} X\ 100$$

$$\%\ \text{Heterosis in } F_1 \text{ over better parent} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} X\ 100$$

Where, $\overline{F_1}$ = Mean of F_1 individuals $\overline{BP}$ = Mean of the Better parent values.

$\overline{MP}$ = Mean of the mid parent values

3.9.2 Student t-test: Student t-test was employed to test the significance of heterosis. The general formula of t-test was

$$t = \frac{Difference\ \ of\ \ means\ \ (\overline{d})}{Standard\ \ Error\ \ of\ \ Difference\ \ (SED)}$$

t- Value was calculated and then compared with the tabulated t-value at the relevant degrees of freedom (d. f.) and probability (p) level.

3.9.3 Estimation of SED: For unequal samples with pooled variance the SED was used:

$$SED = \sqrt{\frac{\sigma^2}{n_1} + \frac{\sigma^2}{n_2}} \quad or \quad SED = \sqrt{\sigma^2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$$

3.9.4 Variability analysis: Duncan's Multiple Range Test (DMRT) was performed for judging differences among the genotypes mean for every character and the computation of

$$LSR = SSR \ X \ S\bar{d}$$

Where, LSR = Least significance range (t-1)

SSR = Significant studendize range (Tabulated value)

$S\bar{d} = S\bar{x}$ = Standard deviations

$$S\overline{X} = \sqrt{\frac{Error\ Mean\ Square}{No.\ of\ Replication}}$$

3.9.5 Estimation of heritability: Haritability in broad sense (h^2b) was estimated by the formula as suggested by Johnson *et al.* (1955).

$$\% h_b^2 = \frac{\sigma^2 g}{\sigma^2 p} x \ 100$$

Where, $\sigma^2 g$ = Genotypic variance $\sigma^2 p$ = Phenotypic variance

3.9.6 Estimation of genotypic and phenotypic variance: Genotypic and phenotypic variances were estimated according to the formula given by Johnson *et al.* (1955).

a. Genotypic variance,

$$\sigma^2 g = \frac{MSG - MSE}{r}$$

Where, MSG = Mean square of the genotypes

MSE = Mean square of the error r = Number of replications

b. Phenotypic variance, $\sigma^2 p = \sigma^2 g + \sigma^2 e$

Where, $\sigma^2 g$ = Genotypic variance,

$\sigma^2 e$ = Environmental variance = Mean square of error

3.9.7 Estimation of standard deviation and Coefficient of variation: Standard deviation and coefficient of variation were estimated according to the formula given by Singh and Chaudhary (1979).

$$S\bar{x} \text{ or } S\bar{d} = \sqrt{\sigma^2} \quad \text{and} \quad CV = \frac{S\bar{d}}{\bar{X}} X\ 100$$

3.9.8 Estimation of genetic advance (G.A.): The expected genetic advance (G.A.) for different characters under investigation was estimated according to the formula used by Johnson *et al.* (1955) and Allard (1960).

i. Genotypic Advance (G.A.) = h^2b. K. σph

Where, h^2b = Heritability in broad sense, σPh = phenotypic standard deviation

K = Selection intensity which is equal to 2.06 at 5% selection intensity

ii. Genetic advance in percent of mean $G.A.\ (\%) = \frac{GA}{\bar{x}F_1}\ X\ 100$

Where, GA = Genetic advance, $\bar{x}F_1$ = Population mean of F_1

3.9.9 Estimation of genotypic and phenotypic correlation coefficient: Genotypic and phenotypic correlation coefficients for different characters in all possible combinations were done with the formula given by Miller *et al.* (1958).

i. Genotypic correlation co-efficient $(r_g) = \frac{COV.\,g(XY)}{\sqrt{\sigma^2(g)X} \bullet \sqrt{\sigma^2(g)Y}}$

Where, COV. g(XY) = Genotypic covariance between the characters X and Y.

$\sigma^2(g)X$ = Genotypic variances of the characters X

$\sigma^2(g)Y$ = Genotypic variances of the characters Y

ii. Phenotypic correlation co-efficient $(r_p) = \frac{COV.\,p(XY)}{\sqrt{\sigma^2(p)X} \bullet \sqrt{\sigma^2(p)Y}}$

Where, COV. p(XY) = Phenotypic covariance between the characters X and Y.

$\sigma^2(p)X$ = Phenotypic variances of the characters X

$\sigma^2(p)Y$ = Phenotypic variances of the characters Y

3.9.10 Estimation of path co-efficient: Path coefficient analysis was done according to the procedure stated by Singh and Chaudhury (1985) and Dabholkar (1992) which was originally suggested by Dewey and Lu (1959). The following sets of simultaneous equations were obtained depending upon the cause and effect relationship:

$$r_{1y} = P_{1Y} + r_{12} P_{2Y} + r_{13} P_{3Y} + r_{14} P_{4Y} + r_{15} P_{5Y} + r_{16} P_{6Y} + r_{17} P_{7Y} + r_{18} P_{8Y}$$

$$r_{2y} = P_{2Y} + r_{21} P_{1Y} + r_{23} P_{3Y} + r_{24} P_{4Y} + r_{25} P_{5Y} + r_{26} P_{6Y} + r_{27} P_{7Y} + r_{28} P_{8Y}$$

$$r_{3y} = P_{3Y} + + r_{31} P_{1Y} + r_{32} P_{2Y} + r_{34} P_{4Y} + r_{35} P_{5Y} + r_{36} P_{6Y} + r_{37} P_{7Y} + r_{38} P_{8Y}$$

$$r_{4y} = P_{4Y} + r_{41} P_{1Y} + r_{42} P_{2Y} + r_{43} P_{3Y} + r_{45} P_{5Y} + r_{46} P_{6Y} + r_{47} P_{7Y} + r_{48} P_{8Y}$$

$$r_{5y} = P_{5Y} + r_{51} P_{1Y} + r_{52} P_{2Y} + r_{53} P_{3Y} + r_{54} P_{4Y} + r_{56} P_{6Y} + r_{57} P_{7Y} + r_{58} P_{8Y}$$

$$r_{6y} = P_{6Y} + r_{61} P_{1Y} + r_{62} P_{2Y} + r_{63} P_{3Y} + r_{64} P_{4Y} + r_{65} P_{5Y} + r_{67} P_{7Y} + r_{68} P_{8Y}$$

$$r_{7y} = P_{7Y} + r_{71} P_{1Y} + r_{72} P_{2Y} + r_{73} P_{3Y} + r_{74} P_{4Y} + r_{75} P_{5Y} + r_{76} P_{6Y} + r_{78} P_{8Y}$$

$$r_{8y} = P_{8Y} + r_{81} P_{1Y} + r_{82} P_{2Y} + r_{83} P_{3Y} + r_{84} P_{4Y} + r_{85} P_{5Y} + r_{86} P_{6Y} + r_{87} P_{7Y}$$

Where, r_{iy} = Genotypic correlation coefficient between the ith characters (i = 1..... 2, 8.) and

Y = Seed yield per plant

P_{iy} = Path coefficient y to ith character (i = 1, 2, 3............8.)

1 = Plant height
2 = Number of primary branches per plant
3 = Number of secondary branches per plant
4 = Number of siliquae per plant
5 = Number of seeds per siliqua
6 = Length of siliqua
7 = Thousand seed weight
8 = Days to first flowering
9 = Days to maturity
10 = Seed yield per plant

Total genotypic correlation was thus partitioned as follows:

P_{1Y} = The direct effect of 1 only

$r_{12} P_{2Y}$ = The direct effect of 1via 2 on Y only

$r_{13} P_{3Y}$ = The direct effect of 1via 3 on Y only

$r_{14} P_{4Y}$ = The direct effect of 1via 4 on Y only

$r_{15} P_{5Y}$ = The direct effect of 1via 5 on Y only

$r_{16}\,P_{6Y}$ = The direct effect of 1via 6 on Y only

$r_{17}\,P_{7Y}$ = The direct effect of 1via 7 on Y only

$r_{18}\,P_{8Y}$ = The direct effect of 1via 8 on Y only

After calculating the direct and indirect effects of the characters, residual effect (R) was calculated by using the following formula (Singh and Chaudhary, 1985)

$P^2 R_Y = 1 - \sum P_{Iy}\, r_{iY}$

Where, $P^2 R_Y = R^2$ and P_{iY} = Direct effect of the characters on yield

r_{iY}= Correlation coefficient on the characters with yield

Therefore, Residual effect R = $\sqrt{P^2}\,RY$

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Heterosis

Twelve yield contributing characters including percent oil content of *Brassica campestris* were studied in five parental genotypes and their twelve hybrids with reciprocals obtained from a partial diallel cross. Percent heterosis for different characters of the F_1 hybrids and reciprocals over their respective mid and better parental values are shown in Table 3a and 3b. The results on heterosis of 12 F_1s including reciprocals are described below character wise:

Days to first flowering

Highly negative significant heterosis (-21.57%) was provided by the hybrid Tori 7 x SS 75 for days to first flowering over mid parent (Table 3). It was followed by the crosses SS 75 x Tori 7, Tori 7 x BARIsar-6, BARIsar-9 x SS 75 and Tori 7 x SAU YC and the other hybrids showed significant positive heterosis over mid parent which was not desirable. All the hybrids showed the significant positive heterosis over better parent except Tori 7 x SS 75 which showed -4.76% heterosis. Positive heterosis value ranged from 4.0% to 20.0% in BARIsar-9 x SS 75 and BARIsar-9 x SAU YC; BARIsar-6 x BARIsar-9; SAU YC x BARIsar-9, respectively. Hence the hybrids bearing negative or positive value might produce some suitable segregants in the next generations. Kumar *et al.* (2002) and Mahak *et al.* (2003) found significant heterotic values for days to first flowering over mid-parent and better parent.

Days to 50% flowering

The highly significant and negative heterosis (-19.30%) for the parameter was found in Tori 7 x SS 75 followed by SS 75 x Tori 7, Tori 7 x BARIsar-6, BARIsar-9 x SS 75 and Tori 7 x SAU YC over the mid parent. Thus the hybrid might produce suitable segregants in the next generations. All the hybrids showed positive heterosis over the better parent except Tori 7 x SS 75 (-4.17%) which was not desirable for this character (Table 3a). Low in magnitude but significant heterosis over better parent has been observed for days to 50% flowering in F_2 by Pathak *et al.* (2002).

Days to maturity

All the hybrids showed significant positive heterosis except Tori 7 x SS 75 and the positive heterosis value over mid parent ranged from 0.58% to 7.03% in Tori 7 x BARIsar-6 and BARIsar-6 x BARIsar-9, respectively for days to maturity (Table 3a). Positive heterosis over better parent value ranged from 6.27% in BARIsar-9 x SAU YC and SAU YC x BARIsar-9 to 18.86% in BARIsar-6 x Tori 7 which was not desirable for this character and no negative heterosis was observed there (Table 3a). Kumar *et al.* (2002), Mahak *et al.* (2003) and Das *et al.* (2004) found significant heterosis values for days to maturity over mid parent and better parent.

Plant height

The highly significant negative heterosis (–6.74%) for plant height was found in SAU YC x BARIsar-9 followed by BARIsar-9 x SAU YC and BARIsar-6 x BARIsar-9 for this characters (Table 3a). Thus these hybrids might produce suitable dwarf plant in the next generation. All the negative values were significant except BARIsar-9 x SAU YC. The positive heterosis values ranged from 2.91% to 40% in BARIsar-9 x SS 75 and SS75 x Tori 7 respectively (Table 3a). However, the highly positive heterobeltiosis (7.69%) was observed in SS 75 x Tori 7 followed by SS 75 x Tori 7, SS 75 x BARIsar-9 and BARIsar-9 x SS 75 and significant negative heterobeltiosis ranged from -2.78% to -16.48% in BARIsar-9 x BARIsar-6 and Tori 7 x SAU YC respectively (Table 3a). Sohoo *et al.* (1993) found 29.13% heterosis over better parent for plant height in the crosses of *Brassica juncea* cv. RLM240 with strain 3 of *Brassica napus*. Yadav *et al.* (2004) observed the magnitude of heterosis was highest for plant height in Trachystoma x SK 93-1 (27.7%) over BP and (25.8%) over CV both.

Table 3(a). Percent heterosis over mid parent and better parent for different characters in intervarietal hybrids of oleiferous *Brassica campestris*

Characters → / Hybrids ↓	Days to first flowering		Days to 50% flowering		Days to maturity		Plant height (cm)		Number of primary branches per plant		Number of secondary branches per plant	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
Tori 7 x SS 75	-21.57**	-4.76**	-19.30**	-4.17**	-3.41**	11.84**	20.00**	-7.69**	116.77**	106.92**	293.89**	137.91**
Tori 7 x BARIsar-6	-8.33**	4.76**	-7.41**	4.17**	0.58**	13.16**	19.51**	-9.26**	14.50**	6.85**	76.88**	58.34**
Tori 7 x SAU YC	-4.17**	9.52**	-3.70**	8.33**	2.81**	12.28**	3.40**	-16.48**	39.54**	27.27**	136.59**	40.05**
BARIsar-9 x SS 75	-5.45**	4.00**	-4.92**	3.57**	3.06**	12.15**	2.91**	1.92**	6.35**	-16.25**	19.85*	-31.84**
BARIsar-9 x BARIsar-6	7.69**	12.00**	6.90**	10.71**	5.92**	12.15**	0.00 ns	-2.78**	40.17**	21.25**	115.18**	63.78**
BARIsar-9 x SAU YC	15.38**	20.00**	13.79**	17.86**	3.23**	6.27**	-1.55*	-6.86**	57.27**	19.63**	255.01**	99.08**
SS 75 x Tori 7	-13.73**	4.76**	-12.28**	4.17**	0.37**	16.22**	40.00**	7.69**	140.17**	129.25**	271.85**	124.60**
SS 75 x BARIsar-9	1.82**	12.00**	4.92**	14.29**	4.44**	13.33**	6.80**	5.77**	-21.59**	-38.25**	287.14**	120.18**
BARIsar-6 x Tori 7	4.17**	19.05**	3.70**	16.67**	5.65**	18.86**	24.39**	-5.56**	29.17**	20.55**	-6.27 ns	-16.10**
BARIsar-6 x BARIsar-9	15.38**	20.00**	13.79**	17.86**	7.03**	13.33**	-3.81**	-6.48**	13.29**	-2.00 ns	96.80**	49.79**
SAU YC x Tori 7	4.17**	19.05**	3.70**	16.67**	2.81**	12.28**	6.12**	-14.29**	54.71**	41.11**	300.27**	136.95**
SAU YC x BARIsar-9	15.38**	20.00**	13.79**	17.86**	3.23**	6.27**	-6.74**	-11.76**	35.91**	3.37 ns	218.15**	78.41**
Mean	0.90	11.70	1.08	10.66	2.95	12.34	9.25	-5.48	43.86	26.64	172.11	71.76

*and ** indicate significant at 5% and 1% level of probability, respectively

Number of primary branches per plant

The hybrid SS 75 x Tori 7 showed the highest significant positive heterosis over the mid parent (140.17%) as well as better parent (129.25%) followed by Tori 7 x SS 75 and others incase of number of primary branches per plant. Thus all the hybrids were found good for producing more primary branches per plant than parent except SS 75 x BARIsar-9 over mid parent and SS 75 x BARIsar-9 and BARIsar-9 x SS 75 over better parent which showed significant negative heterosis (Table 3a). The hybrid BARIsar-6 x BARIsar-9 and SAU YC x BARIsar-9 showed insignificant negative and positive heterosis over better parent, respectively. Thakur and Segwall (1997) found a heterosis value ranging from -26.0 to 193.6% over better parent for the character primary branches in rapeseed (*Brassica napus* L.). Yadav *et al.* (2004) observed the number of primary branches per plant, Trachystoma x PR 905 showed 106.5% and 100.0% heterosis over BP and SV, respectively.

Number of secondary branches per plant

The hybrid SAU YC x Tori 7 showed outstanding heterotic effect over mid parent (300.27%) and over better parent (136.95%) followed by Tori 7 x SS 75, SS 75 x BARIsar-9, SS 75 x Tori 7, BARIsar-9 x SAU YC and SAU YC x BARIsar-9 (Table 3a) and others. Hence, all hybrids were found good for producing higher number of secondary branches per plant then parent except BARIsar-6 x Tori 7 (-6.27% ns) over mid parent and BARIsar-6 x Tori 7, BARIsar-9 x SS 75 over better parent which showed significant negative heterosis (Table 3a). Kumar *et al.* (1990) found positive heterosis for number of secondary branches per plant and they also recorded highest heterobeltiosis for number of secondary branches per plant. Yadav *et al.* (2004) observed maximum heterosis over BP in Trachystoma x PHR-1 (125.1%) and Moricandia x NRCM-79 (9.6%) over CV for the number of secondary branches per plant.

Number of siliquae per plant

The highly significant and positive heterosis for siliquae per plant was found in SS 75 x Tori 7 over mid parent (104.30%) as well as over better parent (93.88%) (Table 3b). Moreover, significant positive heterosis value ranged from 1.15% to 104.30% over mid parent and 5.94% to 93.88% over better parent and produced on an average 46.55% and 40.09% more siliquae per plant than mid and better parent respectively. Significantly negative heterosis was observed in cross SAU YC x Tori 7 for mid parent and SAU YC x Tori 7, SAU YC x BARIsar-9, BARIsar-9 x BARIsar-6 for better parent which indicated lower performance than mid and better parent for this traits and expressed their maternal effect as they showed higher heterosis values either in F_1s or in reciprocals. Zheng and Fu (1991) found positive heterosis of 51.47% over mid parent in the F_1 hybrids in *Brassica nigra* for number of siliquae per plant. Thakur and Segwal (1997) estimated positive heterosis over better parent ranging from 21.9 to 162.6% in rape seed for siliquae per plant. Qi *et al*. (2003) observed the forty-seven crosses gave on average 28.02% (0.93-97.87%) more siliquae per plant.

Number of seeds per siliqua

Incase of number of seeds per siliqua highly significant and positive heterosis was observed in BARIsar-6 x BARIsar-9 and SS 75 x BARIsar-9 over mid parent (27.78%) as well as over better parent (21.05%) followed by BARIsar-9 x BARIsar-6, Tori 7 x BARIsar-6 and BARIsar-6 x Tori 7 (Table 3b). Significantly negative heterosis was observed in SAU YC x Tori 7 followed by Tori 7 x SAU YC, BARIsar-9 x SAU YC, SAU YC x BARIsar-9 and Tori 7 x SS 75 over mid parent including with BARIsar-9 x SS 75 over better parent which indicate lower performance than mid and better parent for this traits (Table 3b). The hybrid BARIsar-9 x SS 75 and SS 75 x Tori 7 showed similar performance like mid and better parent respectively and expressed their maternal effect for seeds per siliqua as they showed higher heterosis values either in F_1s or in reciprocals

(Table 3b). Kumar *et al.* (1990) reported positive heterosis for number of seeds per siliqua in *Brassica juncea.* Yadav *et al.* (2004) observed the Siifolia x SM-1 showed 54.1% heterosis over BP and negative heterosis (-9.2%) over SV for seeds per siliqua. Qi *et al.* (2003) observed the crosses showed 11.67% more seeds per siliqua.

Length of siliqua

Highly Significant and positive heterosis was found in BARIsar-6 x BARIsar-9 over mid parent (24.21%) and better parent (16.60%) followed by BARIsar-9 x SS 75, SS 75 x BARIsar-9, BARIsar-9 x SAU YC and others (Table 3b). Out of twelve crosses three crosses expressed negative heterosis and only two of them BARIsar-9 x BARIsar-6 and BARIsar-6 x Tori 7 expressed significant heterosis ensuring short type siliqua compared with their mid and better parents and expressed their maternal effect for length of siliqua as they showed higher heterosis values either in F_1s or in reciprocals. Heterosis value ranged from -4.76% to 24.21% over mid parent and -11.07% to 16.60% over better parent and showed on an average 7.64% and 3.85% more siliqua length than mid and better parent respectively (Table 3b). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea.*

Thousand seed weight

The cross SS 75 x Tori 7 showed highly significant positive heterosis (21.18%) over mid parent followed by SS 75 x BARIsar-9, Tori 7 x SS 75, BARIsar-6 x BARIsar-9, BARIsar-9 x SS 75 and others except SAU YC x BARIsar-9 and BARIsar-9 x SAU YC (Table 3b). The hybrids BARIsar-6 x BARIsar-9 exhibited highly significant heterobeltiosis (9.83%) followed by SS 75 x BARIsar-9, BARIsar-9 x BARIsar-6 and others except SAU YC x BARIsar-9, BARIsar-9 x SAU YC, BARIsar-6 x Tori 7 and Tori 7 x BARIsar-6. Eight crosses showed mid (2.24% to 21.18%) and better parent (2.50 to 9.83%) heterosis in thousand seed weight while the parents of four crosses showed low thousand seed weights. Yadav *et al.* (2004) observed the highest heterosis for thousand

Table 3 (b). Percent heterosis over mid parent and better parent for different characters in intervarietal hybrids of oleiferous *Brassica campestris*

Characters ► / Hybrids ↓	Number of siliquae /plant		Number of seeds/siliqua		Length of siliqua (cm)	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
Tori 7 x SS 75	82.80**	73.47**	-5.88**	-15.79**	5.61**	2.13**
Tori 7 x BARIsar-6	65.08**	54.46**	17.65**	5.56**	-1.38ns	-7.91**
Tori 7 x SAU YC	71.10**	68.18**	-13.33**	-13.33**	8.17**	7.06**
BARIsar-9 x SS 75	56.15**	48.98**	0.00ns	-5.26**	13.79**	10.64**
BARIsar-9 x BARIsar-6	3.16**	-2.97**	22.22**	15.79**	-1.89**	-7.91**
BARIsar-9 x SAU YC	60.92**	57.30**	-12.50**	-17.65**	12.13**	10.36**
SS 75 x Tori 7	104.30**	93.88**	11.76**	0.00ns	12.21**	8.51**
SS 75 x BARIsar-9	58.29**	51.02**	27.78**	21.05**	12.47**	9.36**
BARIsar-6 x Tori 7	47.09**	37.62**	17.65**	5.26**	-4.76**	-11.07**
BARIsar-6 x BARIsar-9	12.63**	5.94**	27.78**	21.05**	24.21**	16.60**
SAU YC x Tori 7	-4.05**	-5.68**	-26.67**	-26.67**	3.57**	2.51**
SAU YC x BARIsar-9	1.15**	-1.12**	-6.25**	-21.05**	7.55**	5.86**
Mean	46.55	40.09	5.02	-2.61	7.64	3.85

Characters ► / Hybrids ↓	Thousand seed weight (g)		Seed yield per plant (g)		Percent oil content (g)	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
Tori 7 x SS 75	14.71**	-2.50**	128.11**	88.39**	-2.23**	-5.55**
Tori 7 x BARIsar-6	8.63**	-1.73**	72.73**	35.71**	-4.22**	-7.47**
Tori 7 x SAU YC	6.90**	-3.33**	33.54**	31.52**	-0.84**	-3.52**
BARIsar-9 x SS 75	12.33**	2.50**	98.80**	69.04**	-0.37 ns	-2.77**
BARIsar-9 x BARIsar-6	6.51**	4.05**	57.08**	26.79**	-0.27 ns	-2.66**
BARIsar-9 x SAU YC	-4.76**	-9.09**	81.01**	77.33**	2.55**	0.82**
SS 75 x Tori 7	21.188**	3.00**	170.28**	123.22**	-0.74**	-4.12**
SS 75 x BARIsar-9	15.07**	5.00**	146.71**	109.78**	-2.17**	-4.52**
BARIsar-6 x Tori 7	2.24**	-7.51*	99.09**	56.43**	1.06**	-2.37**
BARIsar-6 x BARIsar-9	12.43**	9.83**	82.74**	57.50**	-1.34**	-3.72**
SAU YC x Tori 7	6.90**	3.33**	-1.54**	-3.03**	-3.15**	-5.76**
SAU YC x BARIsar-9	-11.11**	-15.15**	19.88**	17.44**	0.43 ns	-1.27**
Mean	7.58	-0.41	82.37	56.68	-0.94	-3.58

*and ** indicate significant at 5% and 1% level of probability, respectively

seed weight in Moricandia x PHR-1 (48.80%), followed by Trachystoma x NRCM 69 (20.6%) over BP and SV, respectively. Qi *et al.* (2003) observed eight crosses showed better parent heterosis (3.57 to 20.48%) in thousand seed weight.

Seed yield per plant

The cross SS 75 x Tori 7 showed highly significant positive heterosis over mid parent (170.28%) as well as over better parent (123.22%) followed by SS 75 x BARIsar-9, Tori 7 x SS 75 and other crosses except SAU YC x Tori 7 (Table 3b). Moreover, significant positive heterosis value ranged from 19.88% to 170.28% over mid parent and 17.44 to123.22.43% over better parent and produced on an average 82.37% and 56.68% more seed yield per plant than mid and better parent, respectively. Significantly negative heterosis found in SAU YC x Tori 7 over mid parent and better parent which indicate lower performance than mid and better parent for this traits and expressed their maternal effect as they showed higher heterosis values either in F_1s or in reciprocals. The presence of high levels of mid and high parent heterosis indicates a considerable potential to embark on breeding of hybrid or synthetic cultivars. Tyagi *et al.* (2001) found the highest standard heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant in the cross BIO 772 x Rohini. Adefris *et al.* (2005) observed seed yield showed the highest relative mid parent heterosis that varied from 25 to 145% with a mean of 67% and relative high parent heterosis varied from 16 to 124% with a mean of 53%. The presence of high levels of mid and high parent heterosis indicated a considerable potential to embark on breeding of hybrid or synthetic cultivars in mustard. Shen *et al.* (2005) observed mid parent heterosis and high parent heterosis of seed yield per plant ranged from 5.50 to 64.11% and from −2.81 to 46.02% respectively.

Percent (%) oil content

Highly significant positive heterosis (2.55%) found in the cross BARIsar-9 x SAU YC over mid parent (Table 3b). Three crosses showed positive heterosis for percent oil content but only two of them BARIsar-9 x SAU YC and BARIsar-6 x Tori 7 were significant. Out of twelve crosses nine crosses expressed negative heterosis. The negative heterosis values ranged from -0.27% to –4.22% in BARIsar-9 x BARIsar-6 and Tori 7 x BARIsar-6 respectively. The cross BARIsar-9 x SAU YC and BARIsar-6 x Tori 7 expressed their maternal effect for percent oil content as they showed positive significant heterosis values either in F_1s or in reciprocals. The only one cross BARIsar-9 x SAU YC showed significant positive heterosis (0.82%) over better parent (Table 3b). Negative heterosis value ranged from -1.27% to -7.47% in SAU YC x BARIsar-9 and Tori 7 x BARIsar-6 respectively. Shen *et al.* (2005) observed mid parent heterosis and high parent heterosis of seed oil content ranged from −1.55 to 7.44% and −3.61 to 6.55%, respectively. Yadav *et al.* (2004) observed heterosis for oil content in Trachystoma x NDYR-8 (10.1%) over BP and Sifolia x NRCM 79 (8.5%) over SV, respectively. Shen *et al.* (2002) observed the mid parent heterosis of this character ranged from 1.55% to -7.44% respectively.

4.2 Variability

Twelve characters of *Brassica campestris* such as days to first flowering, days to 50% flowering, days to maturity, plant height, number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, length of siliqua, number of seeds per siliqua, thousand seed weight, seed yield per plant and percent oil content were studied in five parental genotypes and their twelve hybrids including reciprocals obtained from a partial diallel cross.

Analysis of variance in Table 4; The mean values over three replications for the characters of all genotypes are presented in Table 5; Genotypic, phenotypic and environmental variance, genotypic, phenotypic and environmental coefficients of variation in Table 6; showed highly significant variation among the genotypes for all characters indicating wide scope of selection for these characters. i.e. the data revealed substantial

Table 4. Analysis of variance of twelve different characters of six parents and their 12 F_1s including reciprocals in rapeseed *Brassica campestris*

Sources of variation	D.F	Mean Sum of Squares of characters											
		Days to first flowering	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/ plant	Number of secondary branches /plant	Number of siliquae/ plant	Length of siliqua (cm)	Number of seeds/ siliqua	Thousand seed weight (g)	Seed yield/plant (g)	Percent oil content
Replication	2	0.529	0.765	1.961	39.078	3.323	3.749	147.235	0.030	0.412	0.062	0.124	0.170
Genotype	16	33.463**	34.456**	107.020**	623.498**	13.737**	106.893**	3081.750**	0.403**	40.853**	0.831**	20.669**	3.000**
Error	32	0.654	0.577	0.461	2.266	0.070	1.235	26.548	0.017	1.037	0.049	0.089	0.072
CV		3.31%	2.63%	0.75%	1.57%	3.65%	10.33%	4.33%	2.67%	5.77%	6.51%	4.69%	0.66%

** Denote significant at 1% level of probability variability and thus high possibility of improvement in most of the traits. The variability in the present study indicated the potentiality of the hybrids for selecting out desirable segregants in the subsequent generations for the development of new varieties would be effective. The phenotypic variance was partitioned into genotypic and environmental variances for clear understanding of the pattern of variations. In general environmental influences were minimal on yield and its component characters Table 6. The results on variability of five parental lines and twelve F_1s including reciprocals have been discussed in this chapter.

Days to first flowering

It appeared from the Table 4 that there were highly significant variations among the genotypes (31.456**) for days to first flowering. The days to first flowering was observed lowest in Tori 7 x SS 75 which was statistically significant and different from those of other crosses and parents except parent Tori 7 and hybrids Tori 7 x BARIsar-6 and SS 75 x Tori 7. The highest value was observed in parent SS 75 and in hybrids BARIsar-9 x SAU YC, BARIsar-6 x BARIsar-9 and SAU YC x BARIsar-9 which were statistically significant and different from those of other crosses and parents (Table 5).

Days to 50% flowering

From the Table 4 there were highly significant variations among the genotypes (32.426**) for days to 50% flowering. The days to 50% flowering was observed lowest in hybrid Tori 7 x SS 75 and in parent Tori 7 which was statistically similar with Tori 7 x BARIsar-6 and SS 75 x Tori 7 but significantly different from other crosses and parents. The highest value found in BARIsar-9 x SAU YC, BARIsar-6 x BARIsar-9 and SAU YC x BARIsar-9 hybrids and SS 75 parent which were statistically similar but significantly different from others (Table 5). Genotypic and phenotypic variance of days to 50% flowering was observed 11.29 and 11.87, respectively with minimum differences between them indicating that they were less responsive to environmental factors for their phenotypic expression and values of GCV and PCV were 11.64% and 12.19% respectively which indicate moderate variability present among the genotype for this character (Table 6). Lekh *et al.* (1998) recorded highest GCV and PCV for days to 50% flowering.

Days to maturity

Significant difference was observed among all genotypes (107.020**) studied for this character (Table 4). The days to maturity was observed lowest in Tori 7 which was statistically significant and different from those of 16 other genotypes. The highest value was in SS 75, which was statistically significant and different from those of 17 other genotypes (Table 5).Genotypic and phenotypic variance of days to maturity was observed 35.52 and 35.98 respectively with minimum differences between them indicating that they were less responsive to environmental factors for their phenotypic expression. Similarly values of GCV and PCV were 6.62% and 6.66%, respectively which indicated that the genotype has relatively less variation (Table 6). Higher genotypic variances indicate the better transmissibility of a character from parent to the offspring (Ushakumari *et al.* 1991).

Plant height (cm)

The character plant height displayed significant variation in genotype mean squares 623.539** in Table 4. Highest plant height was observed in SS 75 x Tori 7 which was statistically significant and different from those of 16 other genotype except SS 75 x BARIsar-9. The lowest plant height was observed in Tori 7, which was statistically significant and different from those of 16 other genotypes (Table 5). Plant height showed high genotypic (207.08) and phenotypic (209.34) variance with relatively high difference between them indicating large environmental influences on these character as well as moderate GCV (15.023%) and PCV (15.106%) indicating presence of considerable variability among the genotype (Table 6). Tyagi *et al.* (2001) observed highest variation in plant height among parent and their hybrids. Higher genotypic variances indicate the better transmissibility of a character from parent to the offspring (Ushakumari *et al.* 1991).

Table 5. Mean performance of twelve different characters of six parents and their 12 F_1s including reciprocals in rapeseed *Brassica campestris*.

Genotype	Days to first flowering	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary Branches/ plant	Number of secondary Branches/ plant	Number of siliquae/ plant	Number of seeds/ siliqua	Length of siliqua (cm)	Thousand seed weight (g)	Seed yield/ plant (g)	Percent oil content (g)
Tori 7	21.0f	24.0g	76.00f	56.00j	5.07h	6.24f	88.00g	15.0fg	4.39g	2.80g	3.20j	39.55i
BARIsar-9	25.0d	28.0e	85.00e	102.0e	8.00d	9.44e	89.00fg	17.0de	4.44fg	3.46cde	3.44j	40.39fgh
BARIsar-6	27.0bc	30.0cd	95.00b	108.0bc	5.84g	4.94f	101.0e	19.0bc	5.06bc	3.30def	6.0g	42.43a
SS 75	30.0a	33.0a	100.0a	104.0de	4.60hi	1.30g	98.00ef	19.0bc	4.70de	4.00a	4.91h	42.44a
SAU YC	27.0bc	30.0cd	90.00c	91.00h	4.17i	1.15g	85.00g	15.0fg	4.30g	3.00fg	3.30j	41.81bc
Tori 7 x SS 75 (c)	20.0f	23.0g	85.00e	96.00fg	10.47b	14.83d	170.0b	16.0ef	4.80d	3.90ab	9.25c	40.08h
Tori 7 x BARIsar-6 (c)	22.0ef	25.0fg	86.00e	97.67f	6.24fg	9.87e	156.0c	20.0b	4.66def	3.40def	7.60e	39.26i
Tori 7 x SAU YC (c)	23.0e	26.0f	85.33e	75.67i	6.44f	8.74e	148.0cd	13.0h	4.70de	3.10efg	4.34i	40.34gh
BARIsar-9 x SS 75 (c)	26.0cd	29.0de	95.33b	105.7cd	6.70ef	6.44f	146.0d	18.0cd	5.20b	4.10a	8.30d	41.26de
BARIsar-9 x BARIsar-6 (c)	28.0b	31.0bc	95.33b	105.0d	9.70c	15.45cd	98.00ef	22.0a	4.66def	3.60bcd	7.10f	41.30de
BARIsar-9 x SAU YC (c)	30.0a	33.0a	90.33c	94.67g	9.57c	18.78b	140.0d	14.0gh	4.90cd	3.00fg	6.10g	42.15ab
SS 75 x Tori 7 (R)	22.0ef	25.0fg	88.33d	111.7a	11.60a	14.00d	190.0a	19.0bc	5.10bc	4.12a	10.96a	40.69fg
SS 75 x BARIsar-9 (R)	28.0b	32.0ab	96.33b	109.7ab	4.94h	20.77a	148.0cd	23.0a	5.14b	4.20a	10.30b	40.52fgh
BARIsar-6 x Tori 7 (R)	25.0d	28.0e	90.33c	102.0e	7.04e	5.24f	139.0d	20.0b	4.50efg	3.20defg	8.76cd	41.42cd
BARIsar-6 x BARIsar-9 (R)	30.0a	33.0a	96.33b	101.3e	7.84d	14.13d	107.0e	23.0a	5.90a	3.80abc	8.26d	40.85ef
SAU YC x Tori 7 (R)	25.0d	28.0e	85.33e	77.67i	7.14e	14.77d	83.00g	11.0i	4.50efg	3.10efg	3.20j	39.40i
SAU YC x BARIsar-9 (R)	30.0a	33.0a	90.33c	90.33h	8.27d	16.83c	88.00g	15.0fg	4.70de	2.80g	4.04i	41.28de
Grand mean	25.824	28.882	90.020	95.784	7.271	10.758	119.0	17.647	4.821	3.395	6.346	40.894
LSD value	1.345	1.263	1.299	2.492	0.5153	1.848	8.569	1.694	0.2168	0.3682	0.4962	0.4463
S_d value	0.4669	0.4386	0.4509	0.8651	0.1789	0.6416	2.975	0.5879	0.07528	0.1278	0.1722	0.1548

Note: Means separated by uncommon letters in order of alphabetic preferences are significantly different from each other at $p = 0.05$.

Number of primary branches per plant

The genotype mean square for number of primary branches per plant was found significant 13.7471** (Table 4). The DMRT test indicated the existence of both significant and insignificant differences in different means. The number of primary branches was recorded highest in the cross SS 75 x Tori 7 which was statistically different with 16 other genotypes and the lowest mean value was in SAU YC for this trait which was statistically different with that of 16 other genotypes except SS 75 (Table 5). Number of primary branches per plant showed low values and little differences between genotypic (4.56) and phenotypic (5.63) variance indicating that they had some short of interaction with environment and relatively high GCV (29.26%) and PCV (32.56%) which indicate that the genotype has high variability (Table 6). Chawdhury *et al.* (1987) found significant differences for number of primary branches per plant.

Number of secondary branches per plant

The number of secondary branches showed significant variation among genotypes mean square 106.893** (Table 4). Among the parents, number of secondary branches per plant ranges from 1.15h to 9.43e in SAU YC and BARIsar-9 respectively. Among the hybrids number of secondary branches ranged from 6.43fg to 18.78ab in BARIsar-9 x SS 75 and BARIsar-9 x SAU YC and among the reciprocals ranged from 5.23g to 20.77a in BARIsar-6 x Tori 7 and SS 75 x BARIsar-9 respectively (Table 5). The highest mean for number of secondary branches was observed in SS 75 x BARIsar-9 which was statistically different with 16 genotypes except BARIsar-9 x SAU YC. The lowest mean was observed in SAU YC which was statistically different with 15 genotypes except SS 75 (Table 5). Number of secondary branches showed high values and little difference between genotypic (35.22) and phenotypic (36.46) variance indicating that they had some short of interaction with environment and highest GCV (55.12%) and PCV (56.14%) indicating that the genotypes are highly variable (Table 6). Lekh *et al.* (1998) reported similar results.

Number of siliquae per plant

The number of siliquae per plant also showed significant variation among genotypes mean square 3081.750** (Table 4) i.e, the genotypes tested here differed highly significant for this character. Significantly highest number of siliquae per plant was observed in SS 75 x Tori 7 followed by Tori 7 x SS 75 which were statistically different with 15 other genotypes. The lowest number of siliquae per plant was found in SAU YC x Tori 7 which was statistically similar with Tori 7, BARIsar-9, SAU YC and SAU YC x BARIsar-9 but different with other 11 genotypes (Table 5). Yin (1989) studied 8 cultivars of *Brassica napus* and observed high genetic variation in number of siliquae per plant. Highest genotypic and phenotypic variance was observed 1018.40 and 1044.95 respectively in number of siliquae per plant with considerable environmental influence and moderate GCV (26.82%) and PCV (27.17%) indicating existence of adequate variation among genotype (Table 6). Singh *et al.* (1987) found 25.41% and 29.15% of GCV and PCV respectively in *Brassica campestris*. Higher genotypic variances indicate the better transmissibility of a character from parent to the offspring (Ushakumari *et al.* 1991).

Number of seeds per siliqua

Genotype mean square for number of seeds per siliqua was found significant (40.853**) as shown in Table 4. The number of seeds per siliqua was found highest in BARIsar-6 x BARIsar-9 and SS 75 x BARIsar-9 followed by BARIsar-9 x BARIsar-6 which were statistically similar but significantly different from all other genotypes. The number of siliqua was lowest in SAU YC x Tori 7 which was statistically dissimilar with all other genotypes used in the study (Table 5). The difference in magnitudes in between genotypic (13.27) and phenotypic (15.37) variances was relatively high for number of seeds per siliqua indicating large environmental influence on these characters (Table 6). According to Table 6, GCV and PCV of 20.69% and 21.42% respectively for number of

Table 6. Genetic parameters for yield and yield contributing characters of the *Brassica campestris* parents and their hybrids

Genetic parameters → / Characters ↓	σ^2_g	σ^2_p	σ^2_e	GCV (%)	PCV (%)	ECV (%)
Days to 50% flowering	11.29	11.87	0.58	11.64	12.19	0.56
Days to maturity	35.52	35.98	0.46	6.62	6.66	0.75
Plant height	207.08	209.34	2.26	15.023	15.106	1.60
No. of primary branches per plant	4.56	5.63	1.07	29.26	32.56	3.64
No. of secondary branches per plant	35.22	36.46	1.24	55.12	56.14	1.03
No. of siliquae per plant	1018.40	1044.95	26.55	26.82	27.17	0.36
No. of seeds per siliqua	13.27	15.37	2.04	20.69	21.42	0.75
Length of siliqua	0.13	0.15	0.017	7.47	7.89	0.42
Thousand seed weight	0.26	0.31	0.049	14.75	16.23	1.47
Seed yield per plant	6.86	7.95	1.089	41.33	44.34	2.99

** Denote significant at 1% level of probability seeds per siliqua which indicate that sufficient variation exist among different genotypes. Bhardwaj and Singh (1969) observed 35.85% GCV in *Brassica campestris.*

Length of siliqua

Significant difference was observed among all genotypes (0.403**) studied for this character (Table 4). Length of siliqua was observed highest in BARIsar-6 x BARIsar-9 which was statistically significant and different from those of 16 other crosses and parents. The lowest value was in SAU YC which was statistically different with that of 12 genotypes except parents Tori 7, BARIsar-9 and hybrids BARIsar-6 x Tori 7 and SAU YC x Tori 7 (Table 5). Length of siliqua showed minimum amount of genotypic and phenotypic variance with minimum difference between them indicating that they were less responsive to environmental factors for their phenotypic expression and relatively low GCV (7.47%) and PCV (7.89%) indicating that the genotype has less variation for this traits (Table 6). Labowitz (1989) studied *Brassica campestris* population for siliqua length and observed high genetic variation in this trait.

Thousand seed weight (g)

Significant difference was observed among all genotypes (0.831**) studied for this character (Table 4). The weight for thousand seed was observed highest in SS 75 x BARIsar-9 which was similar to genotypes namely SS 75 x Tori 7, BARIsar-9 x SS 75, SS 75, Tori 7 x SS 75 and BARIsar-6 x BARIsar-9 but statistically significant and different from those of 11 other crosses and parents. The lowest value was in Tori 7 and SAU YC x BARIsar-9 which was statistically different with that of nine other genotypes except parents SAU Shorisha-1 and hybrids Tori 7 x SAU YC, BARIsar-9 x SAU YC. BARIsar-6 x Tori 7 and SAU YC x Tori 7 (Table 5). Thousand seed weight exhibited very low genotypic and phenotypic variance with minimum differences indicating that they were less responsive to environmental factors and moderate GCV (14.75%) and PCV (16.23%) indicating that the genotype has considerable variation for this traits (Table 6). Bhardwaj and Singh (1969) reported values 11.8% and 18.9% of GCV and PCV for thousand seed weight in *Brassica campestris* similarly Tak and Patnaik (1977) reported values 13.1% and 16.5% of GCV and PCV for *Brassica campestris*.

Seed yield per plant (g)

In the present experiment the genotype mean square for seed yield per plant was found significant 20.669** (Table 4). The DMRT test indicated the existence of both significant and insignificant differences in different means. The seed yield per plant was recorded highest in the cross SS 75 x Tori 7 which was statistically different with 16 other genotypes and the lowest mean value was in Tori 7 and SAU YC x Tori 7 for this trait which was statistically similar with BARIsar-9 and SAU YC but different from other parents and hybrids (Table 5). Shen *et al*. (2002) observed significant differences between F_1s and their parents for yield per plant. Katiyar *et al*. (2004) found significant variation among parents and crosses indicated the presence of adequate genetic variance which reflected in differential performance of intervarietal cross combinations of *Brassica campestris*. Seed yield per plant showed low values of genotypic (6.86) and phenotypic (7.95) variance with little differences indicating that they had some short of interaction with environment and higher GCV (41.33%) and PCV (44.34%) indicating that the genotype are highly variable for this character (Table 6). Bhardwaj and Singh (1969) reported GCV of seed yield per plant was 96.99% in *Brassica campestris* and Singh (1987) reported values 44.04% and 46.9% of GCV and PCV respectively for *Brassica juncea*.

Percent (%) oil content

Statistically significant difference was observed among all genotypes (2.999**), studied for the character percent oil content (Table 4). The height value was 42.44g in SS 75 which was statistically significant and different from those of 13 other cross and parents except BARIsar-6, SAU YC, and BARIsar-9 x SAU YC. The lowest value was 39.26g in Tori 7 x BARIsar-6, which was statistically different with that of 14 genotypes except Tori 7 and SAU YC x Tori 7 (Table 5). Shen *et al.* (2002) were observed significant differences were found between F_1s and their parents for seed oil content.

4.3 Heritability and genetic advance

The heritability estimates, genetic advance and genetic advance in percent of mean are presented in Table 7. Heritability in broad sense were ranged from 80.98% to 98.92% in plant height and number of primary branches per plant respectively which indicated that selection based on phenotypic expression of any character for breeding could be effective. High heritability along with high genetic advance and genetic advance in percentage of mean was observed in number of secondary branches per plant followed by seed yield per plant, number of siliquae per plant and number of seeds per siliqua, number of primary branches per plant which indicated that these characters is governed by additive gene. Panse (1957) stated that if heritability was mainly due to additive effects, it could be associated with high genetic advance but if it was due to non additive effects the genetic advance would be low by following this breeder could perform selection. However, in most of the cases high heritability estimates have been found to be helpful in making selection of superior genotypes on the basis of phenotypic performance. Days to maturity, days to 50% flowering, length of siliqua and thousand seed weight had low values of genetic advance and genetic advance in percentage of mean but high values of heritability this showed that the high values of heritability are not always and indication of high genetic advance i.e, these characters is governed by non-additive gene. Liang and Walter (1968) reported that the character with high values of heritability and low genetic advance may be due to non-additive gene action which includes dominance and epistasis. Johnson *et al.* (1955) suggested that heritability estimates along with genetic gain were more useful in prediction selection of the best individual. Seed yield per plant, number of secondary branches per plant, number of siliquae per plant and number of primary branches per plant showed high GCV and heritability together with high genetic advance in percentage of mean suggesting better scope for selection.

Table 7. Heritability, Genetic advance and Genetic advance in percent of means for yield and yield contributing characters of the *Brassica campestris* parents and their hybrids

Genetic parameters → Characters ↓	h^2_b	Genetic advance		GA in percent of means	
		1%	5%	5%	(1%)
Days to 50% flowering	95.14	8.65	6.89	23.38	29.96
Days to maturity	98.72	15.63	12.20	13.55	17.37
Plant height	98.92	37.93	29.59	30.79	39.57
No. of primary branches per plant	80.98	5.59	3.96	54.31	76.87
No. of secondary branches per plant	96.60	15.40	12.02	111.702	143.15
No. of siliquae per plant	97.46	79.89	64.90	54.55	65.48
No. of seeds per siliqua	86.68	8.41	6.75	38.23	47.79
Length of siliqua	88.33	0.86	0.692	14.34	26.12
Thousand seed weight	84.33	1.96	0.96	28.19	39.00
Seed yield per plant	86.30	6.34	4.99	78.89	104.10

Akanda *et al.* (1997) opined that the characters with high values of GCV and heritablilty accompanied by high genetic advance in percentage of mean indication that they might transmit to their hybrid progenies and therefore, phenotypic selection based on these characters would be effective. Kudla (1993) found considerable non-additive gene action in the inheritance of siliqua length. But Gupta and Labana (1989) observed dominance for the inheritance of this character. However, genetic advance value of yield indicated that yield can be improved upto 4.99g per plant with a selection pressure of 5% intensity. This improvment in yield would be 78.89% of mean yield. If selection is made on the basis of yield character of genotypes used there may have enough scope for yield improvement of oleiferous *Brassica.*

4.4 Character association

Yield is a complex product being influenced by several interdependent quantitative characters. Breeders always look for genetic variation among traits to select desirable types. Some of these characters are highly associated among themselves and with seed yield. The analysis of the relationships among these characters and their associations with seed yield is essential to establish selection criteria. When more characters are involved in correlation study it becomes difficult to ascertain the characters which really contribute toward yield. The path coefficient analysis under such situations helps to determine the direct contribution of these characters and their indirect contributions via other characters. Selection for yield *per se* may not be effective unless the other yield components were having direct or indirect influence on it and are taken into consideration. When selection pressure is exercised for improvement of any character highly associated with yield, it simultaneously affects a number of other correlated traits. Genotypic and phenotypic correlation coefficients were calculated as according to Miller *et al.* (1958).

Correlation coefficient

Genotypic and phenotypic correlation coefficients between pairs of characters in the present study are presented in Table 8. It is evident that in majority of the case, the genotypic correlation coefficients were higher than the corresponding phenotypic

Table 8. Correlation coefficients among different characters of the *Brassica campestris* parents and their hybrids

Characters		Days to maturity	Plant height	Number of primary branches per plant	Number of secondary branches per plant	Number of siliquae per plant	Length of siliqua (cm)	Number of seeds per siliqua	Thousand seed weight (g)	Seed yield per plant (g)
Days to 50% flowering	rg	0.547**	0.307**	-0.176 ns	0.347**	0.258*	0.284**	0.181 ns	0.254*	0.246*
	rp	0.546**	0.309**	-0.173 ns	0.341**	0.260*	0.260*	0.183 ns	0.247*	0.249*
Days to maturity	rg		0.492**	-0.452**	-0.309**	-0.336**	0.204 ns	-0.042 ns	0.208 ns	0.176 ns
	rp		0.490**	-0.455**	-0.304**	-0.336**	0.184 ns	-0.042 ns	0.199 ns	0.177 ns
Plant height	rg			0.270**	0.124 ns	0.135 ns	0.691**	0.516**	0.619**	0.348**
	rp			0.266**	0.120 ns	0.135 ns	0.631**	0.503**	0.596**	0.346**
Number of primary branches per plant	rg				0.588**	0.543**	0.434**	0.663**	0.362**	0.598**
	rp				0.590**	0.540**	0.381**	0.627**	0.344**	0.591**
Number of secondary branches per plant	rg					0.916**	0.396**	0.578**	0.423**	0.864**
	rp					0.901**	0.329**	0.579**	0.398**	0.845**
Number of siliquae per plant	rg						0.372**	0.543**	0.513**	0.925**
	rp						0.336**	0.555**	0.514**	0.924**
Length of siliqua (cm)	rg							0.869**	0.896**	0.655**
	rp							0.825**	0.792**	0.593**
Number of seeds per siliqua	rg								-0.709**	0.768**
	rp								-0.684**	0.744**
Thousand seed weight (g)	rg									0.745*
	rp									0.729**

*and ** indicate significant at 5% and 1% level of probability, respectively

ns = Not Significant

rg = Genotypic correlation coefficients

rp = Phenotypic correlation coefficients correlation coefficients. This indicates that of a strong inherent association between the characters studied and suppressive effect of the environment modified the phenotypic expression of these characters by reducing phenotypic correlation values. In few cases, however, phenotypic correlation coefficients were same with or higher than their corresponding genotypic correlation coefficients suggesting that both environmental and genotypic correlation in these cases act in the same direction and finally maximize their expression at phenotypic level.

Seed yield per plant had highest significant positive correlation with number of siliquae per plant followed by number of secondary branch per plant, seeds per siliqua, thousand seed weight, length of siliqua, number of primary branches per plant, plant height and days to 50% flowering and insignificant positive correlation with days to maturity at both genotypic and phenotypic level. Khulbe and Pant (1999) found similar results for number of siliquae per plant, number of seeds per siliqua, thousand seed weight and length of siliqua, Kumar *et al*. (1999) for number of siliquae per plant, thousand seed weight and plant height, Masood *et al*. (1999) for number of siliquae per plant and number of seeds per siliqua, Reddy (1991) for number of primary branches and secondary branch per plant, Das *et al*. (1998) for number of seeds per siliqua and length of siliqua, Tyagi *et al*. (1996) and Thakral *et al*. (1999) for increased plant height, Chowdhury *et al*. (1987) and Gill and Narang (1995) for days to maturity. Among the yield contributing characters days to maturity was found to have highly significant and positive association with days to 50% flowering and plant height which indicates that late matured genotypes would be late flowered and tall. Days to maturity showed highly significant negative correlation with number of primary branches per plant which indicate if days to maturity increase the number of primary branches per plant decrease and it showed similar relationship with number of siliquae per plant and number of secondary branches per plant. Days to 50% flowering showed significant positive correlation with number of secondary branches per plant which indicate with increasing days to 50% flowering the number of secondary branches per plant would increase and it showed similar relationship with plant height, siliqua length, number of siliquae per plant and thousand seed weight. Plant height showed highest significant positive correlation with length of siliqua followed by thousand seed weight, number of seeds per siliqua indicating with increase plant height the thousand seed weight, number of seeds per siliqua would increase. Number of primary branches per plant showed highly significant positive correlation with number of seeds per siliqua followed by number of secondary branches per plant, number of siliquae per plant and length of siliqua at both genotypic and phenotypic level which indicated that more primary branches producing genotype produce more seeds per siliqua and more secondary branches per plant. Number of secondary branches per plant showed highly significant positive correlation with number of siliquae per plant followed by number of seeds per siliqua, thousand seed weight and length of siliqua which suggest that number of secondary branches per plant might be considered for the selection of siliquae per plant. Reddy (1991) reported similar results. Length of siliqua had highly significant positive correlation with seeds per siliqua such positive correlation indicates that seeds per siliqua were highly dependent on length of siliqua. Das *et al.* (1998), Gurdial and Hardip (1998) and khulbe and pant (1999) were found similar relationship between them. Highly significant negative correlation was found in seeds per siliqua with thousand seed weight which indicate that more seeds per siliqua reduce seed weight. A significant positive association of thousand seed weight with length of siliqua indicating that with increase siliqua length seed weight increase. Chowdhury *et al.* (1987) also found positive correlation between them.

4.5 Path coefficient analysis

Association of character determined by correlation coefficient may not provide an exact picture of the relative importance of direct and indirect influence of each of yield components on seed yield per plant. As a matter of fact, in order to find out a clear picture of the interrelationship between seed yield per plant and other yield attributes, direct and indirect effects were worked out using path analysis at genotypic level which also measured the relative importance of each component. Seed yield per plant was considered as a resultant (dependent) variable and days to 50% flowering, days to maturity, plant height, number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, length of siliqua, number of seeds per siliqua and thousand seed weight were causal (independent) variables. Path coefficient analysis was estimated according to method suggested by Dewey and Lu (1958).

Estimates of direct and indirect effect of path coefficient are presented in Table 9. The cause and effect relationship of yield per plant and yield related characters have been presented diagrammatically in Figure 1. Residual effects of their independent variables, which have influenced yield to a small extent, have been denoted as 'R' in the diagram. The results are discussed briefly as follows:

Path coefficient analysis revealed that thousand seed weight had the highest positive direct effect on seed yield per plant followed by number of siliquae per plant, number of seeds per siliqua, number of secondary branches per plant and plant height. Kakroo and Kumar (1991) assessed similar results for thousand seed weight, Khulbe and Pant (1999) for thousand seed weight, seeds per siliqua, siliquae per plant, Sheikh *et al.* (1999) for siliquae per plant and thousand seed weight, Chauhan and Singh (1995) for plant height, seeds per siliqua and siliquae per plant, Patel *et al.* (1999) for plant height, secondary branches per plant and siliquae per plant. Thousand seed weight followed by seeds per siliqua, number of siliquae per plant, number of secondary branches per plant and plant height showed positive direct effect its indirect effect through others character which finally made highly significant positive correlation with seed yield per plant indicating that for increasing these characters other causal factor must be considered simultaneously. Moreover, number of siliquae per plant had higher positive direct effect

Table 9. Partitioning of genotypic correlation with seed yield per plant into direct (Diagonal/bold) and indirect components

Characters	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches per plant	Number of secondary branches per plant	Number of siliquae per plant	Length of siliqua (cm)	Number of seeds per siliqua	Thousand seed weight (g)	Total correlation to seed yield per plant (g)
Days to 50% flowering	**-0.046**	-0.035	0.028	0.025	0.102	0.082	-0.153	0.096	0.147	0.246*
Days to maturity	-0.025	**-0.064**	0.044	0.164	-0.091	-0.040	0.221	-0.022	-0.011	0.176 ns
Plant height (cm)	-0.014	-0.032	**0.090**	-0.038	0.037	0.044	-0.372	0.274	0.359	0.348**
Number of primary branches per plant	0.008	0.029	0.024	**-0.141**	0.173	0.176	-0.234	0.352	0.210	0.598**
Number of secondary branches per plant	-0.016	0.020	0.011	-0.083	**0.295**	0.297	-0.213	0.307	0.246	0.864**
Number of siliquae per plant	0.022	-0.265	-0.112	0.120	0.212	**0. 560**	-0.344	0.188	0.122	0.503**
Length of siliqua (cm)	-0.013	-0.013	0.062	-0.061	0.117	0.121	**-0.538**	0.462	0.520	0.655**
Number of seeds per siliqua	-0.008	0.003	0.046	-0.093	0.171	0.176	-0.468	**0.531**	0.411	0.768**
Thousand seed weight (g)	-0.012	-0.013	0.056	-0.051	0.125	0.166	-0.482	0.377	**0.580**	0.745**

- Bold figures indicate direct effects
- Residual effect = 0.10
- ns = Not significant
  *and ** indicate significant at 5% and 1% level of probability, respectively

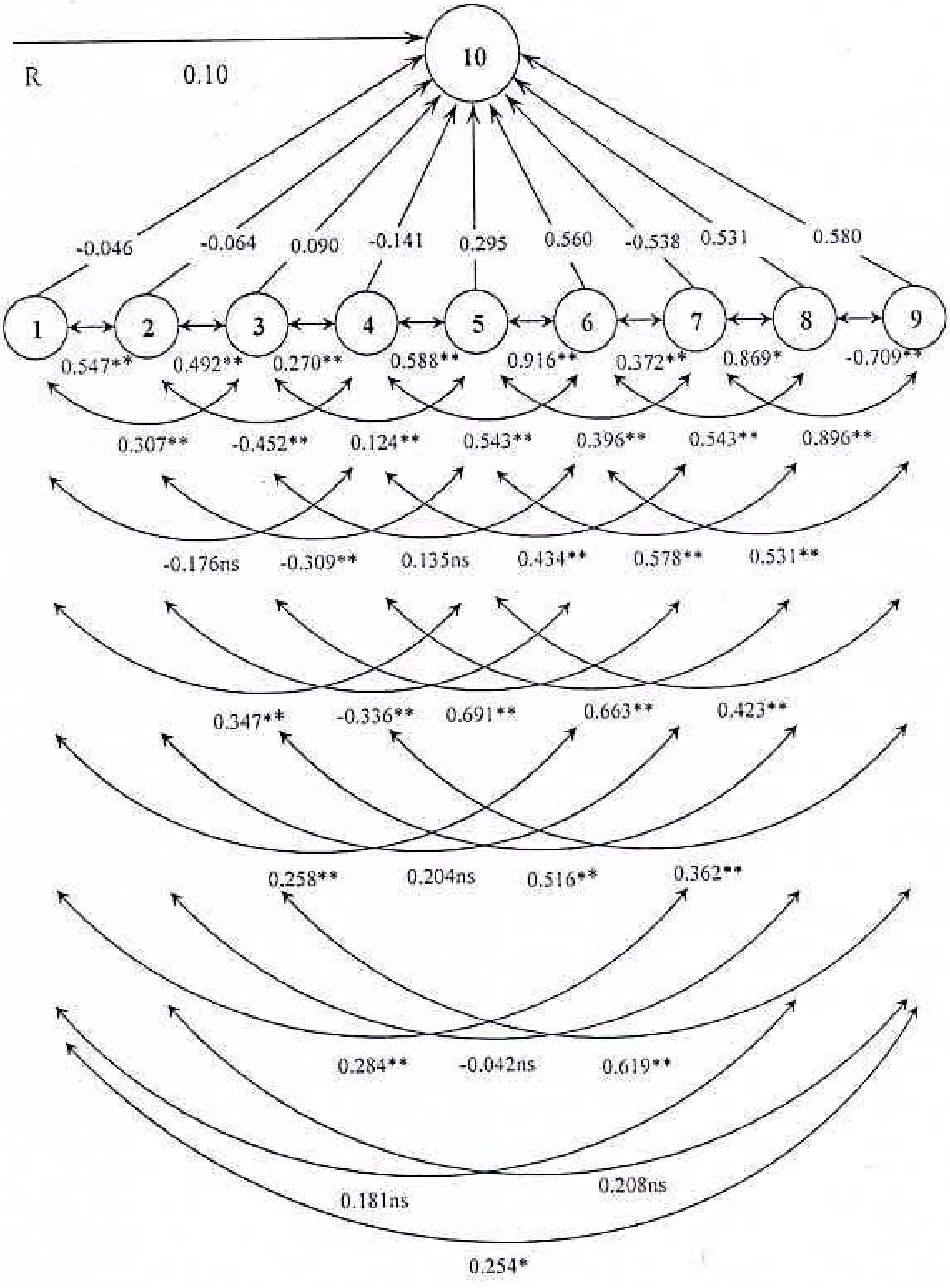

Fig 1. Path diagram of yield contributing traits in 5 parents and 12 hybrids of *Brassica campestris*

1= Plant height, 2= No. of primary branches/plant, 3= No. of secondary branches/plant, 4= No. of siliquae/plant, 5= No. of seeds/siliqua, 6= Length of siliqua, 7= Thousand seed weight, 8= Days to 50% flowering, 9= Days to maturity, 10= Seed yield/plant, R = Residual effects.

than their highly significant positive correlation with seed yield per plant indicating that selection based on these characters would be effective. Days to maturity had negative direct effect but most of its indirect effects through other characters were positive and relatively high which finally made insignificant positive correlation between days to maturity and seed yield. Although number of primary branches per plant showed negative direct effect, its indirect effect through seeds per siliqua was relatively higher followed by thousand seed weight, number of siliquae per plant, secondary branches per plant, days to maturity, plant height and days to 50% flowering which finally made highly significant positive correlation with seed yield per plant indicating that for increasing primary branches per plant, other causal factor must be considered simultaneously. Kakroo and Kumar (1991) found that primary branches had negative indirect effect via seeds per siliqua on seed yield. Days to 50% flowering and length of siliqua also showed negative direct effect but resulted positive correlation with seed yield indicating that for increasing these characters, other causal factor must be considered simultaneously. Singh *et al.* (1978) found similar results negative direct effect for days to 50% flowering and Khulbe and Pant (1999) for siliqua length. The direct effect of plant height was negligible though it showed positive significant association with seed yield per plant. The indirect effect of plant height through thousand seed weight and number of seed per siliqua were also much appreciable indicating that these characters played an important role in determining yield.

The residual effect observed in path analysis was low (0.10) indicating that the character under study contributed 90.0% of the seed yield per plant. It is suggested that there are some other factors/characters those contributed 10.0% to the seed yield per plant not included in the present study may exert insignificant effect on seed yield (Fig. 1). Correlation and path analysis revealed that thousand seed weight, number of seeds per siliqua, siliquae per plant and secondary branches per plant were the most important yield contributing characters as they showed highly significant positive correlation with grain yield as well as high direct and indirect effect through other characters on seed yield except days to maturity. They had also high genotypic coefficient of variation and heritability coupled with high genetic advance and genetic advance in percentage of mean. The results therefore, suggest that thousand seed weight, number of seeds per siliqua, siliquae per plant and secondary branches per plant appeared as an important yield components and selection based on these traits would give better response for improving seed yield in *Brassica campestris*.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A five parents (Tori 7, SS-75, BARI 6, BARI 9 and SAU YC) partial diallel cross hybrids were evaluated for estimating the magnitude of heterosis over mid parent and heterobeltiosis, intergenotypic variability, heritability, genetic advance, character associations, direct and indirect effect of different characters on yield.

It was observed that all the hybrids did not perform well for all the characters and to find out the desirable hybrids for certain character the crosses were scored on the basis of desirable heterotic values. Out of twelve crosses, only the hybrid Tori 7 x SS 75 showed desirable negative heterosis for the characters days to first flowering, 50% flowering and maturity and almost all the hybrids showed positive heterosis which was not desirable for these characters. The hybrid SS 75 x Tori 7 was found to be the best one for number of primary branches per plant. The cross SS 75 x Tori 7 produced maximum number of siliquae per plant. The cross BARIsar-6 x BARIsar-9 and BARIsar-6 x BARIsar-9/SS 75 x BARIsar-9 showed maximum length of siliqua and number of seeds per siliqua. The cross SS 75 x Tori 7 and BARIsar-6 x BARIsar-9 were best for thousand seed weight. Most of the hybrids showed negative heterosis for percent oil content, however, the highest significant heterosis was found in the cross BARIsar-9 x SAU YC over mid parent and over better parent. For seed yield per plant the cross SS 75 x Tori 7 found to be the best one followed by cross SS 75 x BARIsar-9 and Tori 7 x SS 75. So, selection out of these crosses in the subsequent generations may produce some suitable segregants.

From ANOVA it was observed that highly significant variation exists among all the genotypes used in the character studied. Through DMRT test, the day to first flowering was observed lowest in hybrid Tori 7 x SS 75 and highest in parent SS 75 and hybrids BARIsar-9 x SAU YC, BARIsar-6 x BARIsar-9 and SAU YC x BARIsar-9. Lowest days to maturity observed in parent Tori 7 and cross Tori 7 x SAU S-1. The days to 50% flowering was observed lowest in hybrid Tori 7 x SS 75 and in parent Tori 7. The number of primary branches per plant was recorded highest in the cross SS 75 x Tori 7 and lowest in parent SAU YC. Similar results was observed for number of secondary branches per plant in hybrid SS 75 x BARIsar-9 and parent SAU YC; for number of siliquae per plant in hybrid SS 75 x Tori 7 and SAU YC x Tori 7; for length of siliqua in hybrid BARIsar-6 x BARIsar-9 and parent SAU YC; for number of seeds per siliqua in hybrids BARIsar-6 x BARIsar-9, SS 75 x BARIsar-9 and SAU YC x Tori 7. The weight for thousand seed was observed highest in SS 75 x BARIsar-9 and lowest value was in Tori 7 and SAU YC x BARIsar-9. The highest value was 42.44g in SS 75 and lowest value was 39.26g in Tori 7 x BARIsar-6 for percent oil content. The seed yield per plant was recorded highest in the cross SS 75 x Tori 7 and the lowest mean value was in Tori 7 and SAU YC x Tori 7. The difference between genotypic and phenotypic variances was relatively high for number of siliquae per plant, plant height and number of seeds per siliqua indicating large environmental influence other characters, however, showed little difference between genotypic and phenotypic variance. The values of PCV and GCV indicated that there were considerable variations for all the traits except days to maturity and length of siliqua. ANOVA, DMRT test and genetic parameter study revealed substantial genetic variability among genotype and thus high possibility of improvement in most of the traits.

Heritability in broad sense was moderate to high for all the characters studied and it ranged from 80.98% to 98.92% which indicated that selection based on phenotypic expression of any character for breeding could be effective. The genetic advance, genetic advance in percent of mean were high for almost all the characters except length of siliaua and thousand seed weight. Thus, the hybrids which performed well in various characters were due to genetic reasons and have a possibility for improvement through selection in the subsequent generations.

Seed yield was positively and significantly correlated with number of siliquae per plant followed by number of secondary branches per plant, seeds per siliqua, thousand seed weight, length of siliqua, number of primary branches per plant, plant height, days to

50% flowering and insignificantly with days to maturity. Number of secondary branches per plant had strong positive association with number of siliquae per plant. Length of siliqua had highly significant positive correlation with seeds per siliqua such positive correlation indicates that seeds per siliqua were highly dependent on length of siliqua. Highly significant negative correlation was found in seeds per siliqua with thousand seed weight which indicate that more seeds per siliqua reduce seed weight.

Path coefficient analysis revealed that thousand seed weight had the highest positive direct effect on seed yield per plant followed by number of siliquae per plant, number of seeds per siliqua, number of secondary branches per plant and plant height. Thousand seed weight had the highest positive direct effect on seed yield per plant and the number of siliquae per plant had higher positive direct effect than their highly significant positive correlation with seed yield per plant.

More than 50% heterobeltiosis were observed among the crosses Tori 7 x SS 75, BARIsar-9 x SS 75, BARIsar-9 x SAU YC, SS 75 x Tori 7, SS 75 x BARIsar-9, BARIsar-6 x Tori 7 and BARIsar-6 x BARIsar-9 which could be utilized for commercial purposes if suitable male sterility system would become available. The hybrid Tori 7 x SS 75 was good for short duration which might produce suitable segregants in the next generations where selection could be applied for shorter duration. Number of secondary branches per plant, seed yield per plant, number of primary branches per plant and number of siliquae per plant had high GCV and PCV values indicating the presence of high amount of genetic variability among the genotypes, therefore, in a breeding programme maximum emphasis should thus be given on these traits. Correlation and path analysis revealed that number of siliquae per plant followed by thousand seed weight was the most important yield contributing traits and selection based on these traits would give better response for the improvement in seed yield in oleiferous *Brassica*.

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APPENDICES

APPENDICES

Appendix I. Monthly record of year temperature, rainfall, relative humidity and sunshine of the experimental site during the period from October 2004 to March 2005

Year	Month	*Air temperature (°c)			Relative humidity (%)	Rainfall (mm)	**Sunshine (hr)
		Maximum	Minimum	Mean			
2004	October	30.97	23.31	27.14	75.25	208	208.9
	November	29.45	18.63	24.04	69.52	00	233.2
	December	26.85	16.23	21.54	70.61	00	210.5
2005	January	24.52	13.86	19.19	68.46	04	194.1
	February	28.88	17.98	23.43	61.04	03	221.5
	March	32.22	21.78	27.00	66.69	155	210.2

*Monthly average

** Monthly total

Source: Bangladesh Meteorological Department (Climate division)

Agargoan, Dhaka - 1212

Appendix II. Mean performance of parents and hybrids for different quantitative characters in oleiferous *Brassica campestris*

Characters → / Parents and Hybrids ↓	Plant height (cm)	Number of primary branches per plant	Number of secondary branches per plant	Days to first flowering	Days to 50% flowering	Days to maturity	Siliquae per plant	Seeds per siliqua	Length of siliqua (cm)	Thousand seed weight (g)	Seed yield per plant (g)	Percent oil content
Tori 7	56	5.06	6.23	21.00	24	76	152	15	4.44	3	6.70	39.55
BARIsar-9	102	8	9.43	25.00	28	85	158	16	4.91	3.3	7.53	40.39
BARIsar-6	108	5.84	4.93	27.00	30	95	156	15	4.66	3.6	8.17	42.43
SS 75	104	4.6	1.3	30.00	33	100	148	14	4.75	3.8	7.64	42.44
SAU YC	91	4.17	1.15	27.00	30	90	168	15	4.61	3.2	7.25	41.81
Tori 7 x SS 75	96	10.47	14.83	21.00	24	85.00	312	15	4.86	3.97	17.34	40.08
Tori 7 x BARIsar-6	98	6.24	9.87	22.00	25	86.00	292	14.70	4.68	3.4	13.44	39.26
Tori 7 x SAU YC	76	6.44	8.73	23.00	26	85.33	244	13	4.55	3.2	9.64	40.34
BARIsar-9 x SS 75	106	6.7	6.43	26.00	29	95.33	336	17	5.2	4.03	22.39	41.26
BARIsar-9 x BARIsar-6	105	9.7	15.45	28.00	31	95.33	272	14	5.9	3.8	14.11	41.30
BARIsar-9 x SAU YC	95	9.57	18.78	30.00	33	90.33	277	13.3	4.92	3.5	12.65	42.15
SS 75 x Tori 7	112	11.6	14	22.00	25	88.33	268	18.6	5.09	4.06	19.31	40.69
SS 75 x BARI 9	110	4.94	20.77	28.67	32	96.33	281	19.4	5.13	4.02	21.36	40.52
BARIsar-6 x Tori 7	102	7.04	5.23	25.00	28	90.33	286	15	4.48	3.3	12.81	41.42
BARIsar-6 x BARIsar-9	101	7.84	14.13	30.00	33	96.33	315	14.3	4.65	3.5	15.65	40.85
SAU YC x Tori 7	78	7.14	14.77	25.00	28	85.33	218	14	4.5	3.3	8.98	39.40
SAU YC x BARIsar-9	90	8.27	16.83	30.00	33	90.33	244	11.36	4.56	3.2	10.56	41.28
Mean	25.824	28.882	90.020	95.784	7.271	10.758	119.0	17.647	4.821	3.395	6.346	40.894