HETEROSIS AND COMBINING ABILITY ANALYSIS IN INDIAN MUSTARD (*Brassica juncia* L.).

BY

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Registration No. 00927

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: JANUARY-JUNE, 2008

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CERTIFICATE

*This is to certify that the thesis entitled, "HETEROSIS AND COMBINING ABILITY ANALYSIS IN INDIAN MUSTARD (**Brassica juncia L.**)." 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, embodies the result of a piece of bona fide research work carried out by SHAMIMA NASRIN, Registration No. 00927 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: June, 2008
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Dedicated to
My Reverend Parents & Teachers
Whose Earnest Efforts and Teachings
have Brought me Today up to this Level

ACKNOWLEDGEMENTS

All praises are due to the almighty "Allah", the merciful, great and gracious, Who has created everything in this universe and kindly enabled her to present this thesis for the degree of Master of Science (M.S.) in Genetics and Plant Breeding.

It is proud privilege to express the deepest sense of gratitude, immense indebtednes and sincere appreciation to supervisor, Dr. Md. Shahidur Rashid Bhuiyan, Professor, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka, 1207, Bangladesh for his keen interest, scholastic guidance, constructive criticism, valuable suggestion, continuous inspiration constant encouragement and providing of facilities needed to under taken this research work. He took much pain to edit the thesis thoroughly and offered valuable suggestion for its improvement. His scholastic supervision and constant inspiration brought this thesis up to its present standard.

The author expresses her heartfelt thanks and extreme gratitude to her co-supervisor, Dr. Md.sarowar Hossain, Professor, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh for his precious advice, instruction, inspiration and cordial help to complete the research work succesfully.

Cordial thanks and honors to Md. Firoz Mahmud, Chairman and Associate Professor, 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 studies and for providing unforgettable help at the time of preparing the thesis.

The author also expresses her cordial thanks and honour to Ex Chairman of Department of Genetics and Plant Breeding Professor Abu Akber Mia for providing necessary facilities and scholastic guidance during the period of research.

The author specially thankful to Md. Kamal Hossain, Scientific Officer, Plant Breeding Division , BRRI, Gazipur for his helpful co-operation in compiling data and valuable suggestion to analysis the data.

The author feel much pleasure to convey the profound thanks to her Friends and Brother specially Nasim, Asad, Baishakhi, Nahar, Kakan, Popi, Hana, Sumi, Gaffer, Immu, Ektear, Samim, Abdullah and all other friends, and all 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.

The author sincerely thanks to all field, laboratory, library and office staffs of the Depertment of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh for their direct and indirect help to complete this thesis.

Last but not least, the autor express her supreme gratitude and profound feelings to her beloved mother, father, brothers and husband who have been constant some of inspiration, blessing and well wishers for her higher study.

Dhaka, Bangladesh
Date: June, 2008

The Author

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LIST OF SYMBOLS AND ABBREVIATIONS

FULL WORD	ABBRE-VIATION
Percentage	%
Critical Difference	CD
Specific Combining Ability	sca, SCA
General Combining Ability	gca, GCA
Exempli gratia (by way of example)	e.g.
and others (at ell)	*et al.*
Food and Agriculture Organization	FAO
Centimeter	cm
Metric ton	Mt
Bangladesh Agricultural Research Institute	BARI
Sher-e-Bangla Agricultural University	SAU
Journal	*J.*
Number	No.
Parent	P
Cross	C
Variety	var.
Namely	viz.
Degrees of freedom	df.
Mid parent	MP
The 1st generation of a cross between two dissimilar homozygous parents	F_1
The 2nd generation of a cross between two dissimilar homozygous parents	F_2
Better parent	BP
Triple Super Phosphate	TSP
Muriate of Potash	MP
Emulsifiable concentrate	EC
At the rate of	@
Milliliter	ml
Randomized Complete Block Design	RCBD
Mean of F_1 individuals or Mean of reciprocal individuals	$\overline{F_1}$
Mean of the better parent values	$\overline{BP}$
Mean of the mid parent values	$\overline{MP}$
Gram	g
Bangladesh Bureau of Statistics	BBS
Analysis of variance	ANOVA
Kilogram	Kg
Bangladesh Institute of Nuclear Agriculture	BINA
Error mean sum of square	EMS
Heterosis over better parent	HBP
Heterosis over mid parent	HMP
North	N
East	E
Negative logarithm of hydrogen ion concentration (-log [H+])	pH
High yielding varieties	HYV

MUSTARD (*Brassica juncia* L.)

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ABSTRACT

An experiment on oleiferous *Brassica juncia* L. was conducted to evaluate the heterosis and combining ability of different characters on seed yield. Out of 21 F_1s, the cross J-8 × J- 9 showed desirable heterosis for primary branch, secondary branch and seed yield per plant J-7 × J-9 for primary branches, seed yield per plant and thousand seed weight; J-7 × J-11 for days to maturity; J-10 × J-11for 50% flowering and maturity. The cross J-1 × J-2, J-1 × J-7, J-1 × J-10, J-1 × J-11 , J-2 × J-7 , J-2 × J-8, J-2 × J-11 and J-8 × J-11 were also good for seed yield per plant. The parent J-7 and J-9 were good general combiner for days to flowering and maturity; J-9 for plant height; J-7 for number of primary branch and seed yield per plant and J-8 for thousand seed weight. On the basis of average score and rank position, the hybrid J-8 × J-9 was superior specific combiner for number of primary branches per plant, number of secondary branch per plant, number of siliquae per plant and seed yield per plant; J-1 × J-2 for maturity, primary branches per plant, number of siliquae per plant and siliqua length per plant; J-7 × J-9 for number of primary branches per plant and number of secondary branches per plant, J-7 × J-11 and J-10 × J-11 for maturity, J-2 × J-8,J-7 × J-8 and J-8 × J-10 for thousand seed weight; J-1 × J-10, J-2 × J-8, J-2 × J-11 and J-7 × J-8 also good for seed yield per plant. The mean sum of square due to general combining ability (gca) was significant for plant height ,days to 50% flowering, days to maturity and thousand seed weight indicating that the additive gene actions was predominant for the expression of these character. The significant mean sum of square due to specific combining ability (sca) was also observed for plant height, days to maturity, number of primary branches/plant, number of secondary branches/plant , number of siliquae/ plant, thousands seed weight and seed yield/plant indicating that the non-additive gene actions were predominant for the expression of these characters. The higher magnitude of gca variance was observed than that of sca variance for plant height, days to 50% flowering, days to maturity, length of siliquae, number of seeds per siliqua and thousand seed weight.

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. 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 head per day is consumed 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). All these species have many cultivated varieties suited to different agro-climatic conditions. In this sub-continent, three species of *Brassica* are cultivated for oil purpose, viz *Brassica juncea, Brassica napus* and *Brassica campestris*. Indian mustard (*Brassica juncea)* has comparatively high yield potentiality (1-2.4 t/ha). The yield of its varieties are stable even when it is late planted and can tolerate both drought and salinity to some extent. It is mostly nonshattering in behabiur but the duration of this crop is long.

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 and 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).

Total oil seed crops cover 7.47 lakh acres of land. However, rapeseed and mustard cover 5.36 lakh acres of land and produce about 5.95 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, 2006a).

Average yield per hectare of mustard and rapeseed crop is 850-900 kg (BBS, 2006b) 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 317 cores taka (BBS, 2006c).

Meanwhile, about 26 mustard and rapeseed varieties have been released in Bangladesh, among these 15 from Bangladesh Agricultural Research Institute (BARI), 5 from Bangladesh Institute of Nuclear Agriculture (BINA), 2 from Bangladesh Agricultural University (BAU) and 2 from Sher-e-Bangla Agricultural University (SAU) and 2 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.

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).

Intra-species hybridization is a good way of improving the varieties of different natures by combining desired traits followed by selection of desired types. The most important aspects for hybridization are the choice of parents and the selection of best genotypes from hybrid progenies.

Combining ability studies are reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene action involved in the expression of quantitative traits. Genetic information helps in the selection of suitable parents for hybridization and in isolating the promising early generation hybrids for further exploitation in breeding programs.

Information on Heterosis and combining ability of hybrid progeniesat its early generations are very usefulinformation for the purpose of selection critaria the present research was pland to the following investigation:

1. To study the extent of heterosis for different yield contributing characters
2. Identification of potential parent and promising cross combinations to develop high yielding and hybrid varieties
3. To estimate the nature and extent of gene action involved in controlling the trait.

Chapter 2
Review of Literature

REVIEW OF LITERATURE

In the field of *Brassica* breeding, many researchers have conducted research works on heterosis over mid parental values or better parental values and combining ability. A large volume of literature is available on topics. However, attempt has been made to review some of the literatures relevant to the present study on mustard in this chapter.

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 vigor over the mid parental values or the better parental values. Both intra and inter-specific crosses showed some heterotic effect and both positive and negative heterosis were found.

Beena *et al.* (2005) worked on Heterosis in Indian mustard. Hybridization was done in Indian mustard with Pusa bold, Rohini, T.M.-17, ACN-9 and Pusa bold as male parents; and Seeta, BIO-902 as female parents. The mean squares due to genotypes were significant for all the characters under study. The cross Bio-902 × Rohini was identified as the best cross amongst all the crosses evaluated. It exhibited the highest mean, and the highest useful heterosis for seed yield per plant, number of siliquae per plant number of branches per plant and significant negative heterosis for days to maturity.

Huq (2006) conducted an experiment on *Brassica rapa* involving 7x7 half diallel cross. Heterosis and combining ability were estimated for seed yield and other releted characters such as days to flowering, days to maturity, plant height, number of primary and secondary branches, length of siliquae, seeds per siliquae, seed yield per plant, thousand seed weight. Out of twenty one crosses Agroni × BARIsar-6, Agroni × Tori-7, Shafal × BARIsar-6 and Agroni × Tori-7 showed significant heterosis over mid and better parent. Agroni × Tori-7 best for number of primary branches/plant and siliquae/plant.

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.

Heterosis over the mid parent, better parent and commercial, check variety pusa bold was estimated for plant height, days to maturity, number of branches per plant, number-1 of siliquae per plant, seed yield per plant (gm) and 1000-seed weight (g) in 17 crosses of B. juncea by Patil *et al.* (2005). The crosses ACN-9 × MCN-126 and ACN-9 × MCN-128 were the best performers for seed yield and number of siliquae plant-1. The maximum magnitude of significant positive heterosis for all the three types were also exhibited by these crosses and hence can be exploited for further utilization in a breeding programme.

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.

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

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 × 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 × RWH1 and RH9621 × RWH1 were selected because of high heterosis for all the parameters tested.

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 × Pusa gold (dwarf), and MYSL–203 × EC–333596 showed highest heterosis up to 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.

Liersch *et al.* (2004) conducted a breeding approach known as CMS ogura system of oilseed rape hybrid cultivars in Poland to evaluate yield and yield component variability of F_1 hybrids and their parental lines also heterosis effect, and qualitative traits such as oil and glucosinolate content in seeds. They found that composite hybrid cultivars yielded higher than restored hybrids. They stated that the yield of hybrids and qualitative traits such as oil and glucosinolate content in seeds are significantly dependent on genotypes and environmental conditions.

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.

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 × NDR 8501, Basanti × Kanti and Basanti × RH 30, respectively. These hybrids showed high heterosis over the best cultivar. Among the crosses, Basanti × Kranti may be used for selecting for seed yield and quality traits.

Mahak *et al.* (2003a) 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 × Rohini (56.74%), Vardan × Rohini (53.43%), Varuna × RK 9501 (52.86%), Vardan × NDR 8501 (36.73%), Pusa Bold × Rohini (37.68%), and Varuna × NDA 8501 (32.54%).

An investigation was conducted by Pourdad *et al.* (2003) to study heterosis and inbreeding depression in rapeseed (*B. napus, [B. napus* var. *oleifera]*) and For this they planted Forty-two F_1s along with seven parents over three environments and found that TERI(OE)R15 × TERI(OE)R983 showed high negative heterobeltiosis for days to 50% flowering and days to maturity, it is suitable hybrid for development of early cultivars. TERI(OE)R983 × HNS9801 exhibited high negative heterobeltiosis for plant height. By the result of this experiment they concluded that heterosis breeding was not suitable for development of dwarf cultivars. The highest positive heterobeltiosis for seed yield per plant over three environments was observed in GSC3A00 × HNS9801 with mean performance of 14.3 g. The mean of inbreeding depression was 45.63% in this hybrid. Results showed that heterosis breeding was a suitable method to increase seed yield. In most of the hybrids, oil content showed negative heterobeltiosis over three environments. The mean of inbreeding depression in this character was 2.39%. Selection for high oil content was more effective than hybrid production. The highest negative heterobeltiosis for glucosinolate concentration over three environments was observed in GSC3A00 × NPN02. The lowest glucosinolate concentration was observed in GSC3A00 × TERI(OE)R983, with mean performance of 80.6 micro mol/g. The highest negative heterobeltiosis for linolenic acid content was observed in HNS9802 × NPN01, with a mean performance of 10.7%. The highest negative heterobeltiosis for erucic acid content was observed in TERI(OE)R983 × GSC3A00, with a mean performance of 2.3%. Heterosis breeding was not suitable for developing single zero cultivar. Characters with low and high inbreeding depression could be basically controlled by additive and non-additive gene action, respectively.

Qi *et al.* (2003) carried an experiment out in 1997, 66 crosses were made 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/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 1000-seed weight, while the parent of 7 crosses showed low 1000-seed weights. Forty-seven crosses gave on average 28.02% (0.93-97.87%) more pods/plant in parents, while 13 crosses showed 11.67% more seeds/pod in parents. By this experiment they concluded that there is large potential heterosis in seed yield with heterosis of pod number/plant making the biggest contribution.

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

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 × RN-490, RN-505 × PCR-43, RN-393 × RN-481, RN-393 × RN-453 and RN-505 × RN-481, and these crosses offer the best possibilities of further exploitation for the development of high yielding varieties.

Pankaj *et al.* (2002) studied heterosis of parents for seed yield, oil content and protein content in an 8 × 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).

Zhang *et al.* (2002) crossed three double low cytoplasmically male sterile (CMS) and five double low restorer lines of *Brassica napus* and they analysed resulting 15 hybrids for 8 yield components. In this experiment they found that the CMS F_1 had significant heterosis, particularly for yield, but that predicted for the F2 was lower. They also suggested that the major yield components, total pod number/plant had the highest heterosis and would be of more value in a breeding programme than trying to increase seed number per pod or 1000-seed weight.

Lu *et al.* (2001) proposed that heterosis is proportional to genetic divergence between respective parents in many crops. They evaluate heterosis in interspecific hybrids between *Brassica napus* (AACC, 2n=38) and *Brassica rapa* (*B. campestris)* (AA, 2n=20) for ten agronomic characteristics and compared to heterosis in hybrids of *B. napus*. They characterized fifteen inter-specific crosses for their cross ability, germination rate, morphology, pollen fertility, and seed production. They found cross ability ranged from 0.8 to 16.7 seeds per flower pollinated, with 7.5 seeds on average; Germination of the F_1 seeds varied with combinations from 20.7 to 89.8%; highly significant high-parent heterosis in the number of secondary branches and pod number per plant and significant mid-parent heterosis in plant height, length of main inflorescence, and the number of primary branches. They also found that seed number per pod in inter-specific hybrids was significantly lower than both parents' and varied with different combinations and Inter-specific hybrids showed higher vegetative heterosis than intra-specific hybrids.

Swarnkar *et al.* (2001) carried out heterosis analyses using 36 F_1 hybrids, 36 F_2 generations and parents obtained from 9 × 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 × PR-15 (58.38%), YRT-3 × PR-15 (54.33%), RK-1467 × T-6342 (52.60%) and KR-5610 × 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.

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, and 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 × Rohini. This cross was the best heterotic combination for all the three types of heterosis for seed yield.

Wu *et al.* (2001) evaluate the heterosis of 80 hybrid combinations from TGMS line 402S and its original parent Xiangyou 91S, and the combining ability of 40 test cross lines. The results of identification test showed that among 47 combinations yielding over the control Xiangyou 15, seventeen ones with 402S and three ones with Xiangyou 91S overyielded more than 20%, reaching the significant level of 1%; and among 51 combinations yielding over their corresponding higher yield parents, 18 ones with 402S and nine ones with Xiangyou 91S over yielded at 5 or 1% significant level.

Tyagi *et al.* (2000) reported data on Heterosis in intervarietal crosses in mustard (Brassica juncea (L.) Czern & Coss.). Desirable significant and negative heterosis for plant height was observed in seven crosses, with Varuna × SKNM-90-14 exhibiting the most negative value (-14%). Maximum positive heterosis was recorded for seed yield per plant (-48.0 to 93.3%), with crosses PCR-7 × SKNM90-13, RH-30 × TM18-8 and PCR7 × JM90-12 giving values of 93.3, 81.3 and 77.3%, respectively. In general, positive heterosis for seed yield was accompanied by positive heterosis for siliqua length, seeds per siliqua, 1000-seed weight, biological yield and harvest index.

Katiyar *et al.* (2000a) Information on heterosis and combining ability is derived from data on seed yield and 3 yield components in 6 lines, 16 testers and their 96 F_1 hybrids from a line × tester mating design. Of the hybrids, 64 and 38 showed heterosis for seed yield over the better parent and standard cv. Varuna, respectively.

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 × Plant Rai 1002, MS × RH848 and MS × 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 cheek 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 × Pusa kalyani and BSK1 × BSI K_2

Thakur *et al.* (1997) evaluated nine diverse inbreds and their 36 F_1 hybrids from a diallel cross for yield and its components and for oil content. They observed that estimates of heterosis over better parent (BP) for the various traits were significant for seed yield (-14.8 to 82.8%), primary branches (-26.0 to 193.6%) and siliquae per plant (-21.9 to 162.6%). They also observed unidirectional dominance for most of the traits studied and the cross GSB7027 × 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%).

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 × TC113 had the highest negative heterosis (being desirable) for plant height. The crosses White flower × TS61, TH68 × TC113, White flower × Sangam and White flower × TS61 were superior for seed yield.

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 × BJ-679 by 77.6% and BJ-1257 × 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.

Ali *et al.* (1995) investigated the association between genetic distance and mid-parent heterosis and they found that the correlation between genetic distance and heterosis was positive and highly significant for seed yield, pods/plant and seeds/pod. They estimated genetic distance among canola [rape] cultivars through multivariate analysis. They analysed thirty cultivars from various sources and clustered into three distinct clusters based upon five morphological characteristics and yield components (crown diameter, branches/plant, pods/plant, seeds/pod and yield/plant). Two cultivars from each cluster were selected as parents and 15 partial-diallel inter- and intracluster crosses were made between the six selected parents and evaluated at two locations in Michigan, USA in 1990-91.

Hari *et al.* (1995) conducted an experiment to derived information on heterosis from data on 8 yield components in 7 rape (*Brassica napus*) genotypes and their 21 F_1 hybrids grown during winter 1992 in Haryana. They found that hybrid HNS9002 × N20-7 had high positive heterosis for primary and secondary branches, pods on main shoot and seeds per pod. They also found another hybrid, HNS9005 × N20-7, exhibited appreciable heterosis over the better parent (HNS9005) for seed yield and oil content. They also proposed that these hybrids were promising for exploitation of heterosis. They informed that Parent N20-7 developed from Japanese material Norin 20 was a promising parent for exploitation in the hybrid breeding programme.

Information on heterosis has also been recorded by Rai and Singh (1994) from data on 6 yield component in 8 *Brassica campestris* varieties and their 28 F, 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 xYST151.

Ahmad (1993) worked with parents and F_1 hybrids from crosses between resynthesized lines and improved 00 varieties. F_1 were earlier maturing than resynthesized lines andheterosis was observed for spring regrowth and plant height. In trials, the best resyn. line H128 could only produce87% of the mean yield of the improved varieties.

Gupta *et al.* (1993) studied 56 hybrids from a half diallel set of crosses involving 8 genetic stocks with 28 hybrids being derived from crosses of the initial S_0 population and the rest from crosses of S_1 families from each of the parents. The use of S_1 families generally gave hybrids with a higher degree of commercial heterosis (over the best open pollinated commercial variety) than hybrids using S_0 materials, though the $S_0 \times S_0$ crosses gave high commercial heterosis for yield in many cases.

Habetinek (1993) determined plant length, siliqua length, no. of seed/siliqua, 1000 seed weight in 5 varieties of the 00 type and their F_1 hybrids from a diallel set of crosses. The greatest heterosis over the better parent was for seed weight/plant. Sonata × SL502 had the-highest heterosis value for seed weight/plant. Kudla (1993) also found high heterosis for seed yield/plant and was shown by all hybrids (10.2 - 62% over the better parent) in a study of 9 maternal lines ($5S_3$ and $4S_4$) and their pollinator, Taplidor and 9 F_1 hybrids derived by top crossing.

Krzymanski (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 parental mean was 24.71%. The highest heterosis for this trait was seen in the cross of PN2595/91 × PN2870/91 (71.81%relative to the mid parental mean).

Pradhan *et al.* (1993) found from the component character analysis concluded that characters such as no. of primary and secondary branches, number of siliqua/plant and siliqua density contributed significantly to positive heterosis for yield.

Srivastava and Rai (1993) tested heterosis for seed yield and 3 of its component in hybrids from a half diallel set of 15 crosses involving 3 Indian and 3 foreign varieties. The highly heterotic hybrids YST151 × Tobin, YSTI5l × Torch and PT303 × Torch, each had one Indian and one foreign parent and in general the Indian × foreign hybrids showed a higher degree of heterosis than the Indian × Indian and Foreign × Foreign.

Krishnapal and Ghose (1992) investigated the relationship between heterosis and genetic diversity in the F_1 from crosses involving five genotypes of rapeseed *(Brassica campestris)* and six mustard *(Brassica juncea)*. Cross combinations in genotypes having mediums *djk* values (ranging from 2.52 to 7.79) exhibited positive and significant heterosis for most characters in rapeseed but in mustard, heterosis for seed yield was positive and significant in all cross combination regardless of which genotypes had high or low *djk* value. In mustard more heterosis for seed yield/plant and 1000 seed weight were observed. However, combinations with a medium heterosis for seed yield and some of its component, high heterosis in cross combinations of genotypes of low *djk* value may result from cancellation of the mean of one character by that of the other characters). Therefore, dissimilarity/variation between genotypes is not always positively associated with heterosis.

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 × RPU18 (161%). RLM 198 × Veruna, RAU RP_4 × Varuna and Tm 7 × 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.

Heterosis and epistasis in spring oil seed rape *(Brassica napus)* was analysed by Engqvist and Becker (1991) by comparing generation means for 10 agronomic traits. Parents, F_2, F_3 and F_6 generations of 4 crosses with Swedish and French material were investigated. The F_2 was 11% higher in yield, earlier in flowering time and slightly latter in maturation when compared with their parents.

A male sterile line, European - Xinping A, a maintainer line European - Xinping B and a -restorer line *74243-6*, were developed from a male sterile plant of *Brassica juncea* by Shi *et al.* (1991). The seedling stage of F_1 hybrids showed fairly strong heterosis; there was also heterosis in seed yield. The fi hybrids yielded 19.2-34.8% more than CV. Kunming -Gaoke.

Zheng and Fu (1991) worked with eight F_1 hybrids of *Brassica napus* L. They evaluated 17 agronomic traits with 4 heterosis standards. Of all the traits investigated, seed yield/plant and effective siliqua/plant showed significant heterosis, their mean heterosis (over mean value of the parents) rates being 80.21 and 51.47 percent, respectively.

Kumar *et al.* (1990) evaluated 16 parents and 39 F_1s for six traits. Crosses showing positive heterosis for seed yield also showed positive heterosis for primary branches, secondary branches, siliqua length and number of seeds/siliqua. Highest positive heterosis, secondary branches, siliqua length and number of seeds/siliqua. Highest positive heterosis for seed yield was observed in the cross RLM198 × RH30 and was followed by the crosses RJLMSH × Varuna; RL18 × Varuna and RS64 × Varuna. RLM198 × RH30 also recorded highest heterobeltiosis for secondary branches.

In a similar experiment conducted by Nasim (1990) with six cultivars of *Brassica campestris* crossed in half diallel fashion M-91 × TS-72 showed highest heterosis over mid parent for seed yield/plant.

In a study of combining ability and heterosis in *Brassica campestris* Siddique *et al.* (1990) found up to 117.21% heterosis over mid parent for seed yield.

Badwal and Labana (1987) studied *Brassica juncea* for seed yield/plant and other eight related characters. In Fi, they found positive and significant heterosis for almost all traits. In a study for heterosis and cytoplasmic-genetic male sterility in oil seed rape *(Brassica napus* L) through diallel cross of six Canadian and European cultivars. Grants (1985) found heterosis for seed yield up to 72% over better parents.

Lefort *et al.* (1987) while studying *Brassica napus* of-Asian and European parental lines and their hybrids, reported that plant height and seed yield showed positive heterosis in the hybrids.

Banga and Labana (1984) reported several important findings on heterosis of Indian mustard *(Brassica juncea).* They studied 139 F_1 of two groups Indian and European limes. The greatest heterosis over better parent was estimated for seed yield/plant. High heterosis was also estimated for number of secondary branches.

Lefort (1982) studied 140 F_1 hybrids of winter oil seed rape *(Brassica napus* L) and found that for seed yield average hybrid vigour was 23.5% on the basis of the mid parent. In a few cross combinations the value reached up to 50% in relation to the best parent value. This emphasizes the interest of hybrid varieties for improving yield.

Schuster *et al.* (1978) reported heterosis of 203% for seed yield, 211% for seed no./ siliqua and 187% of no. of siliqua/plant in crosses between diverse lines in each generation of black mustard *(Brassica nigra* L). There was lower heterosis for 1000 seed weight.

Zuberi and Ahmed (1973) studied six crosses of four strains *of Brassica campestris* var Toria for yield and its component characters. They estimated heterosis for different charaters. According to them heterosis for different characters varied widely due to cross combination.

2.2. COMBINING ABILITY

General combining ability is the average performance of a given genotype in hybrid combinations with other genotypes, while the specific combining ability is expressed through average performance of the cross in relation to the genotypes. For the characters studied, both significant and insignificant results were noted in the literatures discussed in this chapter.

Yadav *et al.* (2005) found significant differences due to parents vs. crosses indicating the presence of heterosis in the crosses through conducted an experiment during the rabi seasons of 1998-2000 to study the nature of combining ability for seed yield and other yield-attributing characters through line × tester analysis in rape (*Brassica napus* [*B. napus* var. *oleifera]*). They derived forty-five F_1s from the crosses of two cytoplasmic male sterile lines (Ogura, ISN-706a) and one normal fertile line (NDBN-1) used as females and 15 testers (Westar, FM-27, GSL-6267, GSL-8814, EC129120, PBN 9501, NRCG-7, GSL-6067, HNS-4, GSL-1, GSL-406, NRCG-2, GSL-6303, NRCG-13 and NRCG-14) as males. Among lines, they observed significant differences for plant height and number of secondary branches per plant. Higher magnitude of variances due to testers compared to lines were observed for seed yield per plant, plant height, primary branches per plant, days to flower initiation, days to maturity and oil content. They also found that the estimates of SCA variances were higher than GCA (average) for all the characters studied, indicating the preponderance of non-additive type of gene action in the inheritance of these traits and the cross Ogura × NRCG-13 showed high SCA effects for yield per plant which involved both good combining parents.

Nair *et al.* (2005) worked on combining ability in mustard [Brassica juncea]. to identify the better parents (Pusa Bold, Rohini, TM-17, ACN-9 and PCR-7) on the basis of their combining ability and to isolate superior crosses for studying them in further generations. The analysis of variances indicated that variances due to lines were significant for plant height and variances due to the testers were highly significant for all traits except days to maturity indicating significant genetic variation. Rohini was identified as the superior parent for the improvement of siliquae number per plant and hence, may be used in breeding programmes for the improvement of this trait. The cross Seeta × Rohini was identified as the promising cross for yield and yield contributing characters.

Achrya and Swain (2004) observed combining ability analysis in 9 × 9 half-diallel set of *Brassica juncea* L. They studied for nine traits revealed the preponderance of additive gene effects for seed yield, secondary branches per plant, siliquae on main stem, siliqua length, seeds per siliqua and 1000 seed weight. Pusa Bahar was best general combiner for seed yield and yield components except day's *to*-maturity. Majority of crosses showing high *per se* performance involving parents of high × high or high × low gca effects. Pusa Bold × Pusa Bahar, BM-20-12-3 × JC 26 and Pusa Bahar × JC 26 were promising cross combinations which exhibited high sca effects and high mean performance.

Heterosis for seedling, physiological and morphological traits in 3 rape crosses derived from 4 genotypes (Ester, Rainbow, Range and Shiralee) and grown under irrigated and non-irrigated conditions was determined in experiments conducted by Cheema *et al.* (2004) in Pakistan during 1999-2002. High heterosis for shoot length and fresh root weight of the crosses over the mid- and better parents was recorded under irrigated and non-irrigated conditions. The highest positive and significant heterosis for water potential over the better parent was recorded in Range × Ester under normal and drought conditions. Heterosis over the mid parent for chlorophyll was recorded in Range × Shiralee grown under normal and drought conditions. Range × Sheralee recorded high heterosis over the mid and better parent under drought conditions and high heterosis for yield over the mid parent under normal conditions.

Chowdhury *et al.* (2004) studied the nature and magnitude of combining ability of parents and crosses (F_1s) were estimated in a 7 × 7 diallel cross analysis in turnip rape for seed yield, its different contributing characters and oil content. Higher magnitudes of gca variances were observed than those of sca variances for all the characters except siliquae per plant, seeds per siliqua and seed yield per plant. Majority of the crosses showed high sca effects for seed yield involving high × low, average × average and average × low gca parents.

Pietka *et al.* (2003) proposed that the general combining ability (GCA) values in terms of individual glucosinolates are important in breeding. Eleven inbred lines of winter oilseed rape (*B. napus* [*B. napus* var. *oleifera*]) characterized by very low glucosinolate contents were studied by them. These lines were crossed with five cultivars used as testers. Hybrids were grown in the field, and statistical analyses of GCA values were performed separately for particular glucosinolates, as well as F_1 and F2 generations. Heritabilities of regression were estimated by determining the coefficients between both generations. Most of the coefficients were significant at alpha =0.01 or 0.05, proving that the GCA estimation used in the experiments was satisfactorily reproducible.

In a line × tester analysis involving 29 promising female and seven male parents Indian mustard Ghosh *et al.* (2002) observed high heterosis for seed yield and some of the yield contributing traits. For most the major characters including seed yield both additive and non additive gene action were of prime importance.

Prasad *et al.* (2002) evaluated combining ability of 21F_1 hybrids derived from a diallel cross of seven Indian cultivars along with the parents in a field experiment. The general and specific combining ability were significant for all the traits examined. The cultivar Varuna recorded high general combining ability for most of the characters and *per se* performance. The specific combining ability for early maturity, length of main raceme and yield per plant were observed in the crosses involving high × low gca parents.

Swarnker *et al.* (2002) analysed combining ability using 36 F_1 hybrids and their parents obtained from a diallel mating for 11 characters. Both the general and specific combining ability variances were highly significant for almost all the traits. Out of 36 crosses, only eight had desirable specific combining ability effects for seed yield.

Liu *et al.* (2001) combining ability and heritability of 8 main agronomic characters of the crosses obtained by crossing four double-low male sterile lines of rapeseed with glucosinolate lower than 30 micro mol/g and erucic acid lower than 1% with 4 good restorer lines based on North Carolina II design. They observed sterile line 121A, known as the sterile line of Shanyou 6, was shown to be most outstanding, with high general combining ability for many yield-contributing characters, thus having relatively high yield potential.

Matho and Haider (2001) worked with the magnitude of specific combining ability (sca) effects was much higher than the general combining ability (gca) effects for all the characters studied, except for number of secondary branches per plant. In most of the cases, the crosses showing high sca effects also exhibited high heterosis.

Pietka *et al.* (2001) conducted an experiment to establish the relationship of general (GCA) and specific combining abilities (SCA) with glucosinolate content in seeds collected from F_1 and F_2 hybrid generations of winter double low rapeseed. They examined that hybrids produced by crossing cultivars Mar, Polo, Silvia, Lirajet and Wotan with inbred lines extremely low in glucosinolate content. They also found the calculated GCA values which showed that both inbred lines and cultivars were highly and significantly differentiated in terms of glucosinolate content and composition. They also suggested that an effective selection for low glucosinolate content is possible for segregating hybrid populations and the possibility of using SCA in improving glucosinolate content was smaller than that of GCA.

Wu *et al.* (2001) evaluated the general combining ability (GCA) effect of all parents and found that 402S possessed a stronger combining ability than Xiangyou 91S on yield, siliquae of main inflorescence, total siliquae per plant, seed yield per plant and 1000-seed weight.

Tak and Khan (2000) conducted to estimate the combining ability, magnitude of variability and gene effect of the available germplasm resources of 15 Indian mustard (B. juncea) lines crossed to 3 genetically different testers. Estimates of genetic variance revealed that the days to flowering was predominantly governed by a non-additive gene action. However both additive and non-additive gene actions were important in the inheritance of most of the characters studied. The line KS-216 showed significant general combining ability effect for earliness, whereas KS-240 and KS-181 were superior general combiners for seed yield.

Verma (2000) studied Combining ability analysis of yield and its components through diallel crosses in indica coiza (Brassica juncea L.) Czern & Coss. the variance due to general (GCA) and specific combining ability (SCA) were estimated to assess the additive and non-additive gene action involved in the inheritance of nine characters in 8 parents and F_1 hybrids of Brassica juncea. The parents RC 870, RC 759, RC 751 and RC 792 have shown higher GCA effects for seed yield and other characters. The best five crosses are RC 832 × RC 788, RC 827 × RC 870, RC 827 × RC 751, RC 837 × RC 870 and RC 832 × RC 870. These crosses are likely to give better segregants in future generations.

Katiyar *et al.* (2000b) studied on heterosis for seed yield in Indian mustard (Brassica juncea (L.) Czern. and Coss.). Six varieties and 16 lines of B. juncea in a tester mating design, and the resulting 96 crosses were evaluated for yield components. Seven combinations exhibited >30% heterosis and 11 crosses showed 31.2-71.3% heterosis. It is concluded that there is adequate genetic divergence among Indian mustard lines to support a successful hybrid programme.

Huang *et al.* (2000) studied three rapeseed (*Brassica napus*) genotypes tolerant of resistant to Sclerotinia sclerotiorum and 3 susceptible genotypes differing in origin were used in reciprocal or complete diallel crosses and found that resistant genotype from China, 018, had the highest general combining ability (4.46) while the French variety Cobra had the lowest general combining ability (-10.54). They also found optimum cross combination in this study was Cobra 018, with high specific combining ability (10.41) and desirable agronomic characters.

Singh *et al.* (2000) worked with genetic analysis in yellow sarson, *Brassica campestris* L. They found significant differences for both sca and gca among the genotypes for all the characters indicating there by that both additive and non additive components were involving in the expression of all the trails. The parents with high gca was showed good general combining ability for seed yield, days to maturity and silique per plant in both F_1 and F_2 generation and for primary and secondary branches per plant in F_2 generation only. The cross with high × low gca effects showed significant sca for seed yield.

Singh *et al.* (1999) studied the combining ability in *Brassica campestris* L. Comparison of sca effects in relation to gca effects of the respective parental lines indicated that crosses with high sca effects involved low × high, high × low and low × low general combiners.

Sheikh and Singh (1998) analysed combining ability, in 10 × 10 half-diallel (excluding reciprocals) of Indian mustard for ten characters and found preponderance of non additive gene action for most of the characters including seed yield and oil content. They also observed that Additive genetic variance was more important for plant height and length of silliqua. Majority of the crosses showed high sca effects for seed yield involved high × low gca parents.

Satwinder *et al.* (1997) evaluated diallel crosses involving 8 varieties of *Brassica napus* for seed oil yield and 7 related components and they found high variation for SCA and GCA for all traits, suggesting both additive and non-additive gene effects. They also found combinations of varieties with high × low or high × average oil contents had high SCA effects.

Thakur *et al.* (1997) found that GSL8809, HPN1, GSL1501 and HNS8803 were good combiners for seed yield and some of its components and for oil content. They evaluated nine diverse inbreeds and their 36 F_1 hybrids from a diallel cross for yield and its components and for oil content. Mean squares due to general and specific combining ability were significant for all the traits studied, suggesting the importance of both additive and dominance components of variation.

In a study of 8 × 8 diallel analysis (excluding reciprocals), Yadav and Yadava (1996) reported that the presence of both additive and dominance genetic components for seed yield and yield components in Toria (*Brassica campestris* L. var. Toria). But the magnitude of dominance component was larger than the additive component for all the traits including seed yield. Heritability estimates were higher for days to maturity and 1000 seed weight.

Krzymanski *et al.* (1994) compared F_1 and F_2 generations from a diallel set of crosses between 10 best strains. SCA for seed yield was significant in the first generation, but not in the second.

Barua and Hazarika (1993) conducted a study during 1993 with 5 varieties representing 2 *Brassica napus* types and *Brassica campestris* var toria along with their hybrids from a half diallel set of crosses. According to them, heterosis mainly due to non-additive gene effect was important for dry matter and seed yield/plant. The important heterotic crosses were BSH_1 × M27, B9 × PT303 and PK × M27.

Habetinek (1993) worked on *Brassica napus* and found higher gca effects than sca effects for all characters except seed weight/plant. Darmor had the highest GCA for number of seeds/siliqua, siliqua length and 1000 seed weight, while Sonata had the highest GCA for oil content. SCA for seed weight/plant was highest in Sonata × SL502.

Krzymanski (1993) studied yield and oil quality in 10 parental strains and their 45 hybrids. Significant GCA and SCA effects were found for all 19 traits.

Kudla (1993) studied 9 maternal lines ($5S_3$ and $4S_4$), their pollinator (tester) Taplidor and 9 F_1 hybrids derived by top crossing. Additive gene effects were most important in control of 1000-seed weight and the number of seed/siliqua, but non-additive effects predominated in control of number of primary branches, seed yield/plant, plant height and silliqua length. Differences in GCA between parents were significant for all characters except siliqua length. The inbred lines T1057 and T6237 transmitted to the progeny high yield potential and T1057 had a good effect also on 1000 seed weight in the hybrids, but reduced seed/siliqua (which was increased by T6237). Favorable GCA effects were shown by T1080, T1097 and T1039 for seed/siliqua, T1097 for number of primary branches and T996 and T1039 for plant height.

Pszczola (1993) inter crossed the varieties Bolko, Tor, Diadem, Arabeke, Panter and Libravo in one set of diallel crosses and the varieties BOH 1491 (Bor), Falcon, Tapidor, Ofello and Lircus in another set. The characters evaluated were seed yield, 1000 seed weight, and others of importance. There was significant SCA effect in some crosses for all traits. Maternal (cytoplasmic) effect was apparent for all characters.

Rawat (1992) studied the reciprocal differences in the inheritance of 8 yield triats in progeny from a diallel set of cross involving 12 lines of *Brassica juncea.* GCA effects predominated in the control of all the traits. Reciprocal effects were more pronounced than SCA effects, though the later were significant for all traits. The most promising parent lines on the basis of *per se* performance and of combining ability and F_1 performance were BICI624, BICI3S2, BICI439, BICI114 and BICI702. There was only one cross (BICI382 × BICI702) in which reciprocal effects acted in a favorable direction for all traits. This allowed the selection of a maternal parent, which was capable of enhancing beneficial non-additive effects in a specific cross. The parents of this cross also showed high GCA for most of the traits, allowing the exploitation also of beneficial additive effects.

Singh *et al.* (1992) determined combining ability from data on 12 quantitative characters in the parents and F_1 hybrids from a 10 line × 4 tester cross of Ethiopian mustard. Several of the lines were identified as being good general combiners. These are HC1, BC2 and BCIDI for maturity traits. FC5 for seed attributes and CAJR4-3, BCIDI, CAR3 and CARS' for seed yield and several other desirable traits. The best specific combinations for yield improvement were CAR3 × BC2 and BCIDI × BC2 for using a pedigree selection programme.

Yadav *et al.* (1992) evaluated 45 F_1 hybrids of Indian mustard together with 10 parents for combining ability with respect to seed yield and its component characters. Varuna, Kranti, RIC1359 and RLCI357 were identified as good combiners for seed yield, earliness, siliqua length, number of seeds/siliqua and 1000 seed weight. The following varieties or parents ECI26743, EC126745 and EC126746-1 have emerged as good combiners for plant height, primary branch and secondary branch.

Tamber *et al.* (1991) crossed 23 morphologically diverse *Brassica juncea* lines with 4 broad-based testers in 1987-88. The resulting 92 fi and parents and F_2 and parents were sown in 1988-89 and 1989-90, respectively. Data were recorded on number of days to first flowering and maturity. Analysis of variance of combining ability in both generations revealed that GCA variance due to lines and testers were significant for all characters except for maturity in the F_1 and additive effects in the F_2 were greater than in the F_1. Among the lines, RSK11 was the best general combining parent and was seen to be a suitable parent for evolving lines having short period of maturity. Among the testers, Varuna was a good general combiner in the F_2 generation and an average general combiner in the F_1 generation.

In tests of up to 210 *Brassica juncea* germplasm lines by Chauhan *et al.* (1990), there was a wide variation in yield and its component. When 36 *Brassica juncea* crosses and their 15 parents were tested, there was significant difference in seed yield between genotypes. NDRS602, Krishna, Pusa Bold and TM9 showed good general combining ability.

Siddique *et al.* (1990) studied a complete diallel cross involving four genotypes of *Brassica campestris* and their F_1s for nine characters including seed yield/plant. Both additive and non additive gene action was found in the inheritance of characters except days to flower, plant height and primary branches. Preponderance of additive gene action for days to maturity, number of secondary branches/plant number of siliqua/plant, number seeds/siliqua and non additive gene action for days to flowering, plant height, number of primary branches, siliqua length were found. Among the parents M-27 was the best general combiner for siliqua/plant and seed yield/plant. The hybrids YS-52 × M-27 exhibited highest significant SCA effect for seed yield/plant.

Arya *et al.* (1989) worked on combining ability from data of 12 yield related component characters in parents and F_1 of a 13 line × 3 tester mating design of *Brassica napus*. The varieties Midas, Regent 3-1 and DB054 were identified as good general combiners and DNA38 × DISNI and N20-1 × Regent as good specific cross combinations.

Singh *et al.* (1989) worked with six *Brassica juncea* parents and their resultant 15 F_1 and 15 F_2 populations. They evaluated 11 quantitative and qualitative characters. GCA and SCA variance were significant for all characters. RLM198 showed good general combining ability for plant height, number of siliqua/plant, and seed yield. The parents, I RNS12 showed good general combining ability for no. of seeds/siliqua and seed weight I The cross RLM198 × R75-1 showed significant SCA for seed yield in both F_1 and F_2.

Information on combining ability derived from data on seven characters in 23 lines of *Brassica juncea* and their F_1 and F_2 hybrids by Wani and Srivasiava (1989) indicated that parents RK8202, KR5610, RK1418, RH30, V10 and B3U were good general combiners for seed yield.

In another study Thakur *et al.* (1989) studied yield components in 15 *Brassica juncea* lines and 3 testers and their F_1 hybrids. The lines Gonda-3 and R71-2 have had high GCA for yield.

Varma *et al.* (1989) studied 7 yellow sarson *(Brassica campestris)* lines and their hybrids for eleven yield component characters YST151 and PYS6 had high GCAs for all characters except 1000 seed weight.

Chawdhary *et al.* (1988) investigated 13 selected *Brassica juncea* genotypes and their 78 hybrids from a half diallel cross. Data were tabulated on genetic variance and combining ability. RH30, RH785 and Varuna showed good performance and GCA for yield/plant, and its component. KC781 × RH30 and RH7513 × Varuna were the hybrids with best SCA effects and mean performance for yield and its components.

Badwal and Labana (1987) analysed data on seed yield/plant and 8 related traits from a 10x10 half diallel cross in *Brassica juncea.* They reported that both additive and non-additive components of variance controlled the inheritance of seed yield, number of seeds/pod, plant height, primary branches, pod length; only non additive variance was significant for secondary branches.

Chaudhury *et al.* (1987) found significant differences for GCA and SCA variances indicating that both additive and non-additive components of gene effects influenced the expression of each characters in a trial of *Brassica chinensis* and 4 genotypes *of Brassica campestris* with their 10 possible combinations (excluding reciprocals). The dominance component was greater than the additive component for all characters except seed size and Siliqua length. The best general combiners for yield and its component were BSHI and. Pusa Kalyani. The hybrids with the highest *per se* performance and SCA effects were *Brassica chinensis* × Pusa Kalyani and *Brassica chinensis* × Span. The best overall cross for lhe characters studied was Bell × Pusakalyani.

Chauhan (1987) tabulated genetic variance parameters for yield/plant and 8 related traits from a 20 partial diallel cross *in Brassica juncea.* Variance due to GCA and SCA effects were highly significant for all traits. Additive genetic effects appeared predominant for 3 characters and non additive effects for the remainder, Varuna, RS3 and Cult.47 were good general combiners for yield as was RB85 for days to flowering and maturity.

Gupta *et al.* (1987a) worked with 8x8 diallel cross without reciprocals of *Brassica* genotype. GCA and SCA mean squares were significant for all characters studied. Non-additive gene effects appeared to be predominant for number of primary and secondary branches, siliqua length, number of seed/siliqua and seed yield, while additive-gene effects were apparently predominant for plant height. The best general combiner for seed yield was RLM198. The best crosses for further selection were RLM822 × Varuna and RLM19SxRH30.

Gupta *et al.* (1987b) performed an analysis in a 13 × 4 line × tester cross in *Brassica juncea.* Additive gene effects were relatively more important than non-additive for seed yield/plant and most of the 5 yield components investigated. Among females, the best general combiners were RLM29 for seed yield, P Rai-1 for plant height, RLM240 for no. of primary and secondary branches. Among males, RLM198 was the best general combiners for seed yield, number of primary branches. Varuna was best for plant height and RL18 for number of secondary branches. The cross PI 1/71 × RH-30 exhibited high performance for seed yield along with significant SCA for number of primary and secondary branches, RLM24xRH30 and RLM82 × Varuana showed desirable significant SCA effect for seed yield and plant height.

Prakash *et al.* (1987) analysed data of the F_2 of an 8 parent diallel cross and showed that GCA and SCA variances were significant for yield components. SCA variance were higher than GCA variance for number of seed/siliqua, 1000 seed weight, and seed yield indicating that dominance was possibly the predominant gene action for these traits. The parents DIR146 and RCL1017 were good general combiners for most of the characters studied.

Rawat (1987) observed a line × tester analysis involving 12 females and 5 males of *Brassica juncea* of diverse origin. Variance components of GCA and SCA were significant for days to 50% flowering. Number of primary branch, plant height, seed height and seed yield/plant. For secondary branches GCA was important. Pusa Rai 34 and Pusa Rai 45 among the female parents and Pusa Rai 30 among the male parents performed well and were good general combiners. The cross RLM514 × RLM198, RW336 × Pusa Rai30, Pusa Rai45 xBR40 and RH7710 × Pusa Rai30 showed significant SCA for increased seed yield.

Singh and Chauhan (1987) worked with 60 triple test cross families produced by the crossing of $20F_2$ parents as males to the parents and F_1s. In Varuna × TM9 additive genetic variance appeared to be predominant for days to maturity, number of primary branch while dominance seemed to be mainly involved in the control of seed yield/plant In Varuna × RW75-80-1, additive genetic variance was estimated to be predominant for plant height and dominant for days to maturity, number of seeds/siliqua, 1000 seed weight, yield/plant.

Singh *et al.* (1987) reported data on yield and 8 other agronomic characters from an eight parent diallel cross in yellow sarson to indicate the presence of both additive and non-additive gene action, in the inheritance of all traits, with non-additive gene action being predominant for all traits, except plant height. YSK4 and YSK5 were good general combiners for seed yield/plant while the best combinations were YSK5 × YST151 and K88 × YSK5.

Griffing (1956) proposed a more general procedure for diallel analysis which makes provision for non-alleic interaction. In this approach mean measurement of a cross is partitioned into two major components, a part from a general mean (μ) and an environmental component, (i) the contribution of the parents, the general combining ability (gca) effect analogous to main effect of a factorial designs, and (ii) the excess over and above the sum of the two gca effects called the specific combining ability (sca) effect, analogous to an interaction effect of a factorial design. The diallel approach has been extensively used, in cross pollinated crops. Griffing (1958) emphasized the statistical concepts of general and specific combining ability. Variance for general combining ability involves mostly additive gene effects which variance for specific combining ability depends on dominance.

Chapter 3
Methodology

MATERIALS AND METHODS

To conduct the experiment seven selected cultivars were used as parents and these were J-1, J-2, J-7, J-8, J-9, J-10 and J-11. The cultivars were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. Twenty crosses were done among parents in *Rabi* season 2006-2007. In 2007-2008 *Rabi* season, the parents and F_1s were grown in the experimental farm of Genetics and Plant Breeding Department of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

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 2006 to March 2007 and November 2007 to March 2008. 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 (Figure 1). 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 2007 to March 2008 were obtained from the Department of Metrological centre, Dhaka-1207, Bangladesh.

Plant materials used

Seven parental genotypes and their twenty intervarietal hybrids 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. The parents were crossed in half diallel to produce 21 F_1's during winter 2006 at the experimental farm of SAU, Dhaka, Bangladesh.

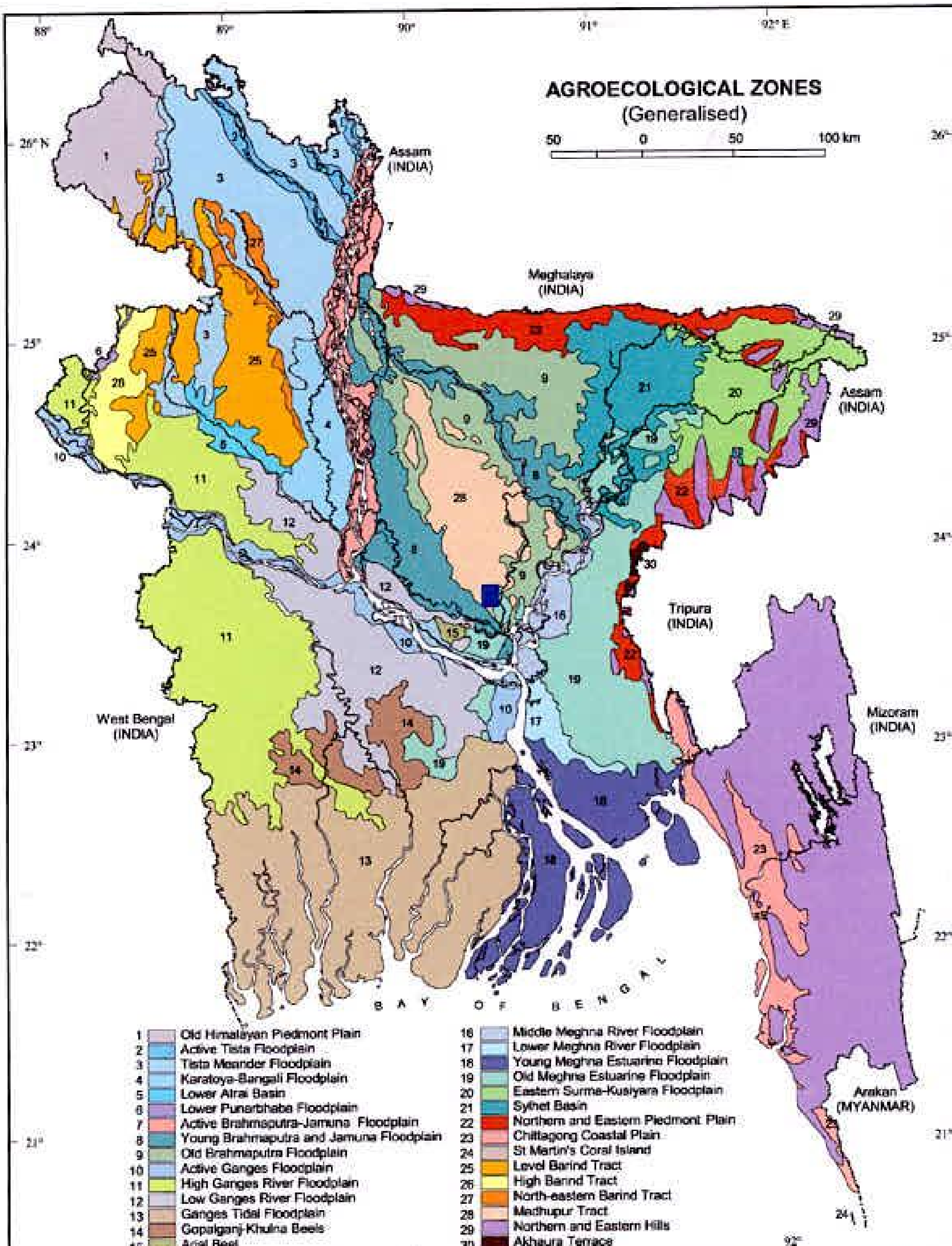


Figure 1. Location of the experimental field

Table1. Cross combinations in half diallel system of seven varieties of *Brassica juncia*

parents / parents	J-1	J-2	J-7	J-8	J-9	J-10	J-11
J-1	J-1	J-1 x J-2, (C-1)	J-1 x J-7 (C-2)	J-1 x J-8, (C-3)	J-1 x J-9, (C-4)	J-1 x J-10 (C-5)	J-1 x J-11 (C-6)
J-2		J-2	J-2 x J-7 , (C-7)	J-2 x J-8, (C-8)	J-2 x J-9, (C-9)	J-2 x J-10, (C-10)	J-2 x J-11, (C-11)
J-7			J-7	J-7 x J-8, (C-12)	J-7 x J-9, (C-13)	J-7 x J-10, (C-14)	J-7 x J-11, (C-15)
J-8				J-8	J-8 x J-9, C-16	J-8x J-10, C-17	J-8 x J-11, C-18
J-9					J-9	J-9 x J-10, C-19	J-1 x J-11, C-20
J-10						J-10	J-10 x J-11, C-21
J-11							J-11

P= Parent and C=Cross

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.

Experimental design and layout

The seeds of twentyone F_1's and seven 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 12 November 2007 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 15th November 2007. Treatment was distributed in the experimental unit through randomization by using the random number.

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.

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.

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.

Data Recorded

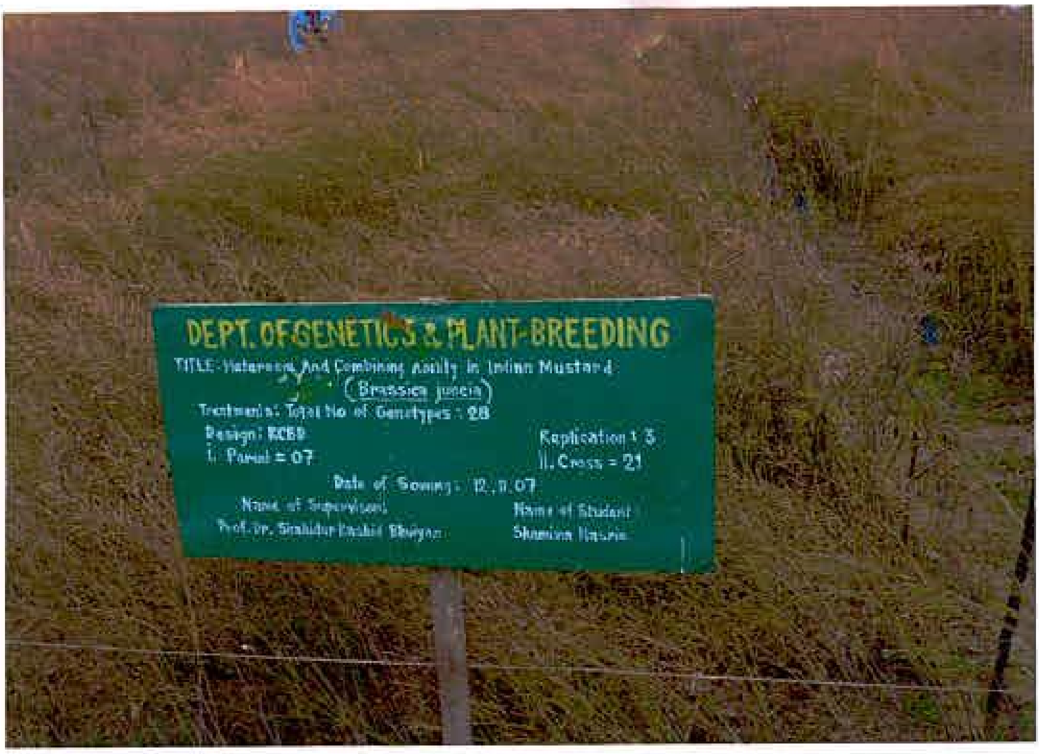
1. Days to 50% flowering: Days to 50% flowering was counted when near about 50 percent plants had at least one open flower of each F_1's or parents. Flowering stage was shown in Plate 1.

2. Days to maturity: Number of days required from sowing to siliquae maturity of 80% plants of each row. Maturity stage was shown in Plate 2.

Side view

Close view

Plate 1. Field view at early flowering stage (side and close view)



Front view

Close view

Plate 2. Field view at maturity stage (front and close view)

3. 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.

Statistical analysis

Statistical analyses were done to calculate the Analyses of variance and other parameters of the genotypes for the characters tested.

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

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

Here, $\overline{F_1}$ = Mean of F_1 individuals

$\overline{BP}$ = Mean of the better parent values.

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

Here, $\overline{F_1}$ = Mean of F_1 individuals

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

CD (Critical Difference) values were used for testing significance of heterotic effects.

$$\text{Critical Difference (CD)} = t \times \sqrt{\frac{2EMS}{r}}$$

Here, EMS= Error Mean Sum of square

r = No. of replication

t = tabulated t value at error df.

CD values were compared with the values come from (F_1 — BP) and (F_1 — MP) to test significance of respective heterotic effects.

Estimation of Combining ability

Griffing (1956) proposed 4 methods of analysis depending on the materials involved. Griffing has also considered Eisenhart's model I (fixed effect) and model II (random effect) situations in the analysis. In the present research work combining ability analysis were done following method 2 (excluding reciprocals) and model-1.

The mathematical model for the analysis was:

$$Y_{ij} = m + g_i + g_j + S_{ij} + \frac{1}{bc} + \sum\sum e_{ij}KL$$

Where,

$i, j = 1,2, \ldots\ldots\ldots\ldots p$

$K = 1,2, \ldots\ldots\ldots\ldots b$

$L = 1,2, \ldots\ldots\ldots\ldots c$

P = Number of parents

b = Number of blocks or replications

c = Number of observation in each plot

Y_{ij} = The mean of i×jth genotype over K and L

m = The population mean

g_i = The general combining ability (gca) effect of ith parent

g_j = The gca of jth parent

s_{ij} = The sca effect such that $s_{ij} = s_{ji}$

$\frac{1}{bc}\sum\sum e_{ij}KL$ = The mean error effect

The restriction imposed are $\sum_i g_i = 0$ and $\sum_i S_{ij} + S_{ij} = 0$ (for each i)

The analysis of variance for combining ability was carried out using replication mean of each entry (diallel family) as follows:

Item	d.f.	Sum of squares	Mean Squares
GCA	P-1	$\frac{1}{(p+2)}\left[\sum_{i}(Y_{i.}+Y_{ii})^2-\frac{4}{P}Y_{..}^2\right]$	Mg
SCA	P(P-1)/2	$\sum_{i}\sum_{j}Y_{ij}^2-\frac{1}{(p+2)}\sum(Y_{i.}+Y_{ii})^2+\frac{2}{(p+1)(p+2)}Y_{..}^2$	Ms
Error	(b-1)(e-1)	SSe	Me

Where,

gca = general combining ability

sca = specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

$Y_{i.}$ = Array total of the ith parent

Y_{ii} = Mean value of the ith parent

$Y_{..}$ = Grand total of the ½ p(p-1) crosses and parental lines

Y_{ij} = Progeny mean values in the diallel table

SSe = Sum of square due to error (obtained from preliminary ANOVA after dividing by the number of replications).

The gca and sca effects of each character were calculated as follows;

$$g_i = \frac{1}{(p+2)}\left[\sum_i (Y_{i.} + Y_{ii})^2 - \frac{2}{P} Y..\right]$$

$$s_{ij} = Y_{ij} - \frac{1}{(p+2)}\sum (Y_{i.} + Y_{ii} + Y_{.j} + Y_{jj}) + \frac{2}{(p+1)(p+2)} Y..$$

Standard error (SE) of an estimate was calculated as the square root of the variance of concerned estimate eg.

j Var(g;) and. jVar(s.)

$$\sqrt{\mathrm{Var}(g_i)} \text{ and } \sqrt{\mathrm{Var}(s_{ij})}$$

$$\mathrm{Var}(g_i) = \frac{(p-1)}{p(p+2)} \sigma^2 e$$

$$\mathrm{Var}(s_{ij}) = \frac{(p-1)}{(p+1)(p+2)} \sigma^2 e \; (i \neq j)$$

Chapter 4
Results and Discussion

RESULTS AND DISCUSSION

Heterosis

Ten yield contributing characters of *Brassica juncia* were studied in seven parental genotypes and their 21 hybrids obtained from a partial diallel cross. Percent heterosis for different characters of the F_1 hybrids over their respective mid and better parental values are shown in Table 2. The results on heterosis of 21 F_1s are described character wise below:

Days to 50% flowering

Highly negative significant heterosis (-4.53%) was provided by the hybrid J-10 × J-11 for days to first flowering over mid parent (Table 2). It was followed by the crosses J-1xJ-11and J-2 × J-11 showed significant negative heterosis over mid parent and the other hybrids showed non significant heterosis over mid parent which was not desirable. The hybrids J-9 × J-11 and J-10 × J-11 showed highly negative significant heterosis over better parent, J-2 × J-11 and J-2 × J-11 also showed significant negative heterosis over better parent, and the other hybrids showed non significant heterosis over better parent which was not desirable. 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.* (2003b) found significant heterotic values for days to first flowering over mid-parent and better parent.

Days to maturity

The hybrids J-10 × J-11, J-7 × J-11 and J-2 × J-11 showed significant negative heterosis over mid parent, the cross J-2 × J-7 also showed significant negative heterosis over mid parent (Plate 3). The other hybrids showed nonsignificant heterosis over mid parent for days to maturity (Table 2). Highly negative significant heterosis (-

(80.7 days) (78.3 days) (81.7 days)

Plate 3. Hybrid J-2 × J-11 and its parent at mature stage showing maturity

Table 2. Percent heterosis over mid parent and better parent for different characters in intervarietal hybrids of oleiferous *Brassica juncia*

Cross combination	Days to 50% flowering		Days to maturity		Plant height	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
J-1 × J-2	2.13	1.41	0.63	-1.69	10.69	9.91
J-1 × J-7	-0.36	-1.43	-1.07	-2.48	10.61	6.81
J-1 × J-8	1.42	0.70	0.63	-2.86*	8.30	6.97
J-1 × J-9	-1.08	-2.14	0.00	-0.47	4.72	-1.30
J-1 × J-10	-1.44	-2.14	1.29	0.47	11.24	6.94
J-1 × J-11	-3.81*	-6.71**	-0.84	-3.71*	7.11	3.52
J-2 × J-7	0.36	-1.41	-2.92*	-3.76*	8.45	5.47
J-2 × J-8	-1.41	-1.41	-1.63	-2.86*	3.29	2.77
J-2 × J-9	1.08	-0.70	-1.05	-2.93*	9.42	3.85
J-2 × J-10	-0.71	-2.11	-1.47	-2.93*	10.71	7.19
J-2 × J-11	-3.78*	-6.04**	-3.49**	-4.12**	9.30	6.39
J-7 × J-8	1.79	0.00	-0.41	-2.46	6.21	3.82
J-7 × J-9	0.00	0.00	-1.06	-2.06	6.18	3.52
J-7 × J-10	-0.36	-0.72	-0.63	-1.22	7.78	7.26
J-7 × J-11	-2.10	-6.04**	-3.52**	-4.94**	7.56	7.47
J-8 × J-9	1.79	0.00	1.04	-2.06	7.09	2.16
J-8 × J-10	1.43	0.00	0.21	-2.46	3.15	0.38
J-8 × J-11	-1.72	-4.03	-0.20	-0.85	-1.55	-3.68
J-9 × J-10	-0.36	-0.72	0.85	1.24	2.89	0.83
J-9 × J-11	-3.50	-7.38***	-0.42	-2.90*	8.91	6.13
J-10 × J-11	-4.53*	-8.05***	-3.75**	-5.75***	8.51	7.92

***$P<0.001$, **$p<0.01$, *$p<0.05$

Table 2. (Continued)

Cross combination	Number of primary branches per plant		Number of secondary branches per plant		Number of siliqua 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
J-1 × J-2	36.36*	35.14*	13.43	12.09	40.74*	32.00
J-1 × J-7	13.04	8.33	-8.33	-15.38	15.63	7.47
J-1 × J-8	14.29	8.11	-21.88	-24.24	8.08	3.13
J-1 × J-9	14.29	8.11	11.11	6.06	24.98	17.93
J-1 × J-10	-4.00	-14.89	31.25	27.27	33.53*	31.19
J-1 × J-11	4.35	0.00	41.94	33.33	31.32	29.30
J-2 × J-7	30.43*	25.00	6.85	0.00	28.23	27.01
J-2 × J-8	23.81	17.12	26.15	20.94	27.45	14.43
J-2 × J-9	14.29	8.11	-12.50	-17.40	13.85	13.12
J-2 × J-10	12.00	-0.71	20.00	15.04	29.76	23.74
J-2 × J-11	21.74	16.67	30.16	20.94	30.85	24.52
J-7 × J-8	36.36*	25.00	28.57	15.38	38.19*	23.02
J-7 × J-9	72.73***	58.33***	44.93*	28.21	37.56*	35.36*
J-7 × J-10	0.00	-7.80	22.86	10.26	26.67	19.68
J-7 × J-11	8.33	8.33	32.35	15.38	38.38*	30.48
J-8 × J-9	50.00**	51.52**	63.93**	61.81*	48.24**	33.86
J-8 × J-10	8.33	-7.80	-3.23	-2.91	39.80*	31.19
J-8 × J-11	9.09	0.00	30.00	26.21	45.22*	36.55
J-9 × J-10	8.33	-7.80	27.87	26.21	25.12	20.05
J-9 × J-11	9.09	0.00	28.81	26.67	27.74	22.31
J-10 × J-11	15.38	6.38	33.33	29.45	47.43**	47.09*

***P<0.001, **p<0.01, *p<0.05

Table 2. (Contd.)

Combination	Length of siliqua		Number of seeds/ siliqua	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
J-1 × J-2	10.21	9.52	-10.87	-16.16
J-1 × J-7	-3.31	-3.92	4.19	-0.92
J-1 × J-8	1.11	0.00	-8.89	-16.16
J-1 × J-9	1.05	-0.98	-6.67	-14.11
J-1 × J-10	6.29	1.96	-1.12	-10.02
J-1 × J-11	11.17	3.92	2.13	-1.84
J-2 × J-7	-5.24	-7.05	-5.75	-7.03
J-2 × J-8	0.28	0.76	4.76	2.56
J-2 × J-9	-1.57	-4.76	0.00	-2.10
J-2 × J-10	-2.01	-7.14	3.61	0.23
J-2 × J-11	4.64	-3.33	-2.27	-4.44
J-7 × J-8	1.46	-0.95	-3.53	-7.03
J-7 × J-9	6.29	5.86	5.88	2.04
J-7 × J-10	4.66	2.02	-4.76	-9.30
J-7 × J-11	9.57	4.04	-5.62	-6.67
J-8 × J-9	0.89	-2.86	5.41	5.16
J-8 × J-10	-2.02	-7.62	-18.96	-20.15
J-8 × J-11	7.77	-0.95	-6.98	-11.11
J-9 × J-10	1.58	0.63	1.23	-0.24
J-9 × J-11	5.83	2.08	4.65	0.00
J-10 × J-11	11.49	8.49	3.53	-2.22

***P<0.001, **p<0.01, *p<0.05

Table 2. (Contd.)

Cross combination	Seed yield /plant		Thousand seed weight	
	Heterosis over mid-parent	Heterosis over better parent	Heterosis over mid-parent	Heterosis over better parent
J-1 × J-2	47.01*	41.34*	2.14	-4.53
J-1 × J-7	58.17**	53.91**	3.10	2.18
J-1 × J-8	16.26	13.83	14.18*	7.36
J-1 × J-9	24.82	21.96	-0.14	-3.73
J-1 × J-10	58.55**	57.62**	-0.22	-8.27
J-1 × J-11	63.54***	58.93**	3.55	-2.80
J-2 × J-7	49.77**	40.86*	-0.28	-8.46
J-2 × J-8	74.64***	65.25**	24.84***	9.20
J-2 × J-9	27.71	20.58	3.00	-0.58
J-2 × J-10	39.80*	35.96	15.10	15.56
J-2 × J-11	49.18**	40.12*	12.52	10.30
J-7 × J-8	84.22***	83.05***	19.57**	14.48*
J-7 × J-9	56.05**	54.73**	-4.47	-9.62
J-7 × J-10	37.78*	33.87	6.32	-3.97
J-7 × J-11	58.37**	58.11**	-1.11	-8.85
J-8 × J-9	76.49***	76.13***	10.73	-0.34
J-8 × J-10	14.89	12.33	21.95**	5.06
J-8 × J-11	56.54**	55.35**	15.05*	1.03
J-9 × J-10	20.99	18.04	-0.38	-5.51
J-9 × J-11	31.85	30.58	-0.75	-3.77
J-10 × J-11	36.13*	32.10	-4.33	-7.88

***P<0.001, **p<0.01, *p<0.05

5.75%) was provided by the hybrid J-10 × J-11 for days to maturity over better parent (Table 2). The hybrids J-1 × J-8, J-1 × J-11, J-2 × J-7, J-2 × J-8 J-2 × J-9, J-2 × J-10, J-2 × J-11, J-7 × J-11 and J-9 × J-11 also showed significant negative heterosis over better parent, The other hybrids showed nonsignificant heterosis which was not desirable for this character. Kumar *et al.* (2002), Mahak *et al.* (2003a) and Das *et al.* (2004) found significant heterosis values for days to maturity over mid parent and better parent which is disagreement with the majority of the findings of the parent crosses.

Plant height

There is no significant heterosis over mid parent and better parent for plant height characters (Table 2). The hybrid J-8 × J-11 showed negative heterosis over both cases and J-1 × J-9 showed negative heterosis over better parent. The positive heterosis values ranged from 2.89% to 11.24% over mid parent and.83% to 9.91% over better parent. 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 × SK 93-1 (27.7%) over BP and (25.8%) over CV both.

Number of primary branches per plant

The hybrid J-7 × J-9 showed the highest significant positive heterosis over both the mid parent (72.73%) as well as better parent (58.33%) in case of number of primary branches per plant (Plate 4). The hybrids J-1 × J-2 and J-8 × J-9 showed significant positive heterosis over both parent while the hybrids J-2 × J-7 and J-7 × J-8 showed significant positive heterosis over mid parent only.Where as the hybrid J-1 × J-10 showed

(P:S=4:13) **(P:S = 6.3:16.7)** **(P:S = 3.3:10)**

Plate 4. Hybrid J-7×J-9 and its parent at mature stage showing branching status

insignificant negative heterosis over both parents and J-7 × J-10, J-8 × J-10 and J-9 × J-10 showed insignificant negative heterosis over better parent. The other parent showed insignificant positive heterosis and good for producing more primary branches per plant than parent. 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 × PR 905 showed 106.5% and 100.0% heterosis over BP and SV, respectively.

Number of secondary branches per plant

The hybrid J-8 × J-9 showed significant heterosis over mid parent and over better parent. The cross J-7 × J-9 showed significant heterosis over mid parent (Plate 4). The hybrids J-1 × J-7, J-1 × J-8, J-2 × J-9, J-8 × J-10 created insignificant negative heterosis over mid parent and better parent so were found not good for producing higher number of secondary branches per plant. Other hybrids expressed insignificant positive heterosis. 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 × PHR-1 (125.1%) and Moricandia × 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 J-8 × J-9 over mid parent (48.24%) (Plate 5). The F_1s J-7 × J-9 and J-10 × J-11 expressed significant positive heterosis for siliquae per plant over mid parent and better parent

J-8

J-9

J-8 X J-9

Plate No 5. Hybrid J-8 x J-9 and its parent at mature stage showing siliqua

(Table 2). The hybrids J-1 × J-2, J-1 × J-10, J-7 × J-8, J-7 × J-11, J-8 × J-10 and J-8 × J-11 expressed significant positive heterosis for siliquae per plant over mid parent. The rest of the crosses showed insignificant positive heterosis over mid parent and better parent. All hybrids produced more siliquae per plant than any parent.

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.

Length of siliqua

There was no significant heterosis over mid parent and better parent. The hybrids J-1 × J-7, J-2 × J-7, J-2 × J-9, J-2 × J-10 and J-8 × J-10 showed negative heterosis over mid parent and better parent. The hybrids J-1 × J-9, J-2 × J-11, J-7 × J-8, J-8 × J-9 and J-8 × J-11 showed negative heterosis over better parent. The cross J-1 × J-8 expressed no heterosis over better parent so here better parent had dominant gene effect. (Table 2). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea.*

Number of seeds per siliqua

All the hybrids showed insignificant heterosis over mid parent and better parent incase of number of seeds per siliqua. Maximum hybids express negative heterosis over mid parent as well as over better parent (Table 2). The hybrids J-2 × J-8, J-2 × J-10, J-7 × J-9, and J-8 × J-9 expressed positive heterosis over mid parent as well as over better parent and J-1 × J-7, J-9 × J-10, J-9 × J-11, and J-10 × J-11 express positive heterosis only over mid parent. Kumar *et al.* (1990) reported positive heterosis for number of seeds per siliqua in *Brassica juncea.* Yadav *et al.* (2004) observed the Siifolia × 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.

Thousand seed weight

The cross J-2 × J-8 showed highly significant positive heterosis (24.84%) over mid parent. The hybrids J-7 × J-8 showed significant positive heterosis (19.57%) over mid parent and (14.48%) over better parent. The crosses J-1 × J-8, J-8 × J-10and J-8 × J-11 expressed significant positive heterosis over mid parent. The hybrids J-1 × J-7, J-2 × J-10 and J-2 × J-11 showed insignificant positive heterosis over mid parent and over better parent. Negative heterosis were found in J-1 × J-9, J-1 × J-10, J-2 × J-11, J-7 × J-9, J-7 × J-11, J-9 × J-10, J-9 × J-11 and J-10 × J-11 over mid parent and better parent indicating lower performance than mid and better parent for the traits and expressed their maternal effect as they showed higher heterosis values in F_1s. The other hybrids showed insignificant positive heterosis over mid parent and insignificant negative heterosis over better parent (Table 2). The hybrids J-7 × J-8 exhibited best for thousand seed weight. Yadav *et al.* (2004) observed the highest heterosis for thousandseed weight in Moricandia × PHR-1 (48.80%), followed by Trachystoma × 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 J-7 × J-8 and J-8 × J-9 perfomed very well, they exhibited highly significant positive heterosis over both mid and better parent (Table 2). The hybrids J-1 × J-2, J-1

× J-7, J-1 × J-10, J-1 × J-11, J-2 × J-7, J-2 × J-8, J-2 × J-11 J-7 × J-9, J-7 × J-11 and J-8 × J-10 showed significant positive heterosis over mid parent and over better parent. The presence of high levels of mid and high parent heterosis indicates a considerable potential to embark on breeding for hybrid or synthetic genotypes. The cross J-2 × J-10showed significant positive heterosis over mid parent only and other crosses showed insignificant positive heterosis over mid parent and over better parent (Table 2). Moreover, significant positive heterosis value ranged from 36.13% to 84.22% over mid parent and 40.12% to 83.05% over better parent and produced on an average 40% and 38% more seed yield per plant than mid and better parent, respectively. 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 × 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 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.

COMBINING ABILITY

The general and specific combining ability effects are effective genetic parameters in the breeding program. Analysis of variances for yield and yield contributing characters (Table 3) revealed highly significant variation among the parents and hybrid indicating the presence of variability in the material. Varience due to genotype were significant for all the trait except plant height and number of seeds per siliqua. Incase of cross only number of seeds per siliqua showed significant variation. Variance due to parents were significant for the trait days to 50% flowering, days to maturity and thousand seed weight. Combining ability analysis of seven parents and twenty one F_1s in half diallel cross of ten quantitative traits. The variances due to general and specific combining ability were estimated for assessing the contribution of the additive and non-additive type of gene action involved in the inheritance of different characters. The mean sum of square due to general combining ability (GCA) was significant for plant height, days to 50% flowering, days to maturity and thousand seed weight indicating that the additive gene actions was predominant for the expression of these characters, others showed insignificant value. (Table 4). The significant mean sum of square due to specific combining ability (SCA) was also observed for plant height, days to maturity, number of primary branches/plant, number of secondary branches/plant, siliquae/ plant, thousands seed weight and seed yield/plant indicating that the non-additive gene actions was predominant for the expression of these characters (Table 4). The results showed the agreement with the findings of Malik *et al.* (1995); Thakur and Sagwal (1997) in rape seed. Similar findings were also reported by Acharya and Swain (2004), Tamber *et al.* (1991) in Indian mustard and Labana *et al.* (1978) in Yellowsarson.

The higher magnitude of gca variance was observed than that of sca variance for plant height, days to 50% flowering, days to maturity, length of siliquae, number of seeds per siliquae and thousand seed weight. In an earlier study of Verma (2000), reported that sca variance was higher than gca variance (non-additive type) for seed yield per plant. Verma *et al.* (1989) and Labana *et al.* (1978) reported non-additive type of gene action for siliquae per plant, seed yield per plant in yellowsarson.

Table 3. Analysis of variance for seed yield per plant and its component characters in *Brassica juncia* genotypes

Source of variation	Characters										
	df	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	No. of siliquae/ plant	Length of siliquae (cm)	No. of seeds/ siliquae	Thousand seed weight	Seed yield / plant
Rep	2	12.950	4.357	5.357	3.524	6.595	115.452	0.046	3.335	0.072	5.925
Gen	27	4558.808	73.952**	206.03**	31.333**	378.321*	135173.65 **	2.252*	88.384	10.192**	375.73**
Cross	20	2420.929	36.222	117.746	19.746	274.603	42173.937	1.208	68.02**	7.999	162.934
Parent	6	624.367	35.810*	80.952**	3.905	22.571	7454.286	0.866	19.143	1.750**	2.131
Patent vs cross	1	1513.512	1.921	7.337	7.683	81.147	85545.433	0.178	1.217	0.443	210.670
Err	54	5115.301	56.976	74.643	21.810	374.071	101783.88	2.459	160.61	2.048	132.712
Total	83	9687.059	135.286	286.036	56.667	758.988	237072.98	4.757	252.33	12.311	514.372

Table 4. Analysis of variance for GCA and SCA for seed yield and yield contributing components in *Brassica juncia* genotypes

Source of variation	Characters										
	df	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	No. of siliquae/ plant	Length of siliquae (cm)	No. of seeds/ siliquae	Thousands seed weight	Seed yield / plant
GCA	6	121.3988*	2.2874*	8.16402**	0.2839	3.1428	2.04316	0.05388	2.36910	0.45279**	2.509
SCA	21	37.6766*	0.5202	0.93783*	0.4162**	5.1071*	3.8927*	0.02035	0.72603	0.03240**	5.246**
Error	54	31.5759	0.3517	0.46075	0.1346	2.3090	0.8234	0.01517	0.99144	0.01263	0.819
GCA:SCA		3.222	4.395	8.70522	0.6821	0.6153	0.524869	2.64766	3.26308	13.975	0.4783

General combining ability (gca) effects

The additive nature and magnitude of gene action are controlled by gca effects. A parent with higher positive significant gca effects is considered as a good general combiner and higher significant sca effect considered as a good specific combiner. A parent showing high gca and sca variances is a better parent for creating high yielding specific combination. Parents with significant gca effect can be used in conventional breeding programme and crosses with significant sca effect can be used in hybrid development. The estimates of gca effects are presented in Table 4, The magnitude and direction of the significant gca effects for seven parents provide meaningful comparisons and would give clue to the future breeding programme. The results of gca effects of different characters are presented as follows:

a. Days to fifty percent flowering:

Highest negative significant gca effects (-0.534) ware provided by J-10 for days to fifty percent flowering followed by J-9 andJ-7. Hence the parent J-7, J-9 and J-10 were desired as general combiner in crosses aimed at promoting earliness in rapeseed (Table 5). The parent J-8 and J-11 showed positive significant gca effects that ware undesirable general combiners to promote the earliness in *Brassica juncea.* The parents J-1 and J-2 showed insignificant positive gca effects for this trait. Chowdhury *et al.* (2004) found earliness in Din-2 in *Brassica rapa L.* Singh *et al.* (2000) obtained earliness in YSK-8501 in *Brassica campestris/ rapa.* Verma (2000) observed earliness in RC 832 in *Brassica juncea* L.

Table 5. GCA effect of 7 parents for 9 charecters in half diallel cross of *Brassica juncia* genotypes

Parents	Characters				
	Days to 50% flowering	Days to maturity	Plant height(cm)	No. of primary branches	No. of secondary branches
J-1	-0.053	-0.799**	5.454**	-0.222*	-0.640
J-2	0.317	0.090	4.198*	0.037	-0.233
J-7	-0.423*	-0.540**	-0.658	0.296**	1.212**
J-8	0.614**	1.942**	-0.465	-0.148	-0.307
J-9	-0.497**	-0.577**	-5.247**	-0.037	-0.011
J-10	-0.534**	-0.503**	-1.657	0.148	-0.196
J-11	0.577**	0.386	-1.624	-0.074	0.175
Egi	0.183	0.209	1.734	0.113	0.469
SE (gi-gj)	0.280	0.320	2.649	0.173	0.716

Table 5. (Contd.)

Parents	Characters				
	No. of siliquae/ plant	Length of siliquae (cm)	No. of seeds/ siliquae	Thousands seed weight	Seed yield / plant
J-1	-15.878*	0.091*	0.784*	0.020	-0.197
J-2	6.196	0.072	-0.048	-0.088*	-0.357
J-7	13.048	-0.006	0.154	0.074	0.750**
J-8	-14.582	0.066	-0.639*	0.463**	0.498
J-9	5.899	-0.048	-0.039	-0.139**	-0.261
J-10	0.492	-0.100**	-0.610*	-0.173**	-0.734**
J-11	4.825	-0.076	0.397	-0.158**	0.301
Egi	7.735	0.038	0.307	0.035	0.279
SE(gi-gj)	1.552	0.058	0.469	0.053	0.427

b. Days to maturity:

Parent J-1 showed highest significant and negative gca effects (-0.799) followed by J-7, J-9 and J-10 and hence these four cultivars were the best general combiners for early maturity in *Brassica juncea L.* The parent J-8 provided highest significant positive gca effects for days to maturity (1.942) and hence the parent was undesirable general combiners to promote the earliness (Table 5). The parents J-2 and J-11 showed insignificant positive gca effects for days to maturity. Chowdhury *et al.* (2004) observed earliness in Din-2 in *Brassica rapa* L. Acharya and Swain (2004) obtained earliness in JC 26 in *Brassica juncea L.* Singh *et al.* (2000) found earliness in YSC-68 in *Brassica campestris* L.

c. Plant height:

The parent J-9 exhibited only significant negative effects (-5.247) for the parameter and was good general combiners for breeding dwarf plant type. The highest significant and positive gca effect (5.454) was observed in J-1and followed by J-2 these were parents dwarf plant type (Table 5). Chowdhury *et al.* (2004) found dwarfness in Din-2 in *Brassica rapa L.* Singh *et al.* (2000) obtained dwarfness in YSK-8501 in *Brassica campestris* L. Singh *et al.* (1996) observed dwarfness in glossy mutant in *Brassica juncea* L.

d. Number of primary branches per plant:

The parents J-7 provided significant and positive gca effects (0.296). The parents J-1 showed the significant but negative effects (-0.222) that indicated not good for promising primary branches. Other parents showed insignificant positive and negative effects. So the parent J-7 was found good for using in the breeding programme for more primary branches (Table 5) Chowdhury *et al.* (2004) obtained more primary branches on sampad in *Brassica rapa* L. Sheikh and Sing (1998) found more primary branches in poorbijayr in Brassica *juncea* L. Singh *et al.* (2000) observed maximum number of primary branches on YSP-842 in *Brassica campestris L*

e. Number of secondary branches per plant:

Number of secondary branches per plant was higher in parent J-7 showed significant and positive gca effects for the character. The parents J-11 provided insignificant and positive gca effects (Table 5). The other five parents were undesirable for producing more number of secondary branches. These five parents showed insignificant negative gca effects for this trait. Singh *et al* (1996) obtained highest secondary branches in BJ-1235 in Brassica *juncea* L. Singh *et al* (2000) found highest secondary branches in SS-1 in Brassica *campestris* L. Chowdhury et al (2004a) observed more secondary branches in Din-2 in *Brassica rapa* L.

f. Number of siliquae per plant:

All the parents except J-1 found insignificant gca effects. The parents J-1 exhibit negative significant gca effects for the character, so it is most undesirable to use in hybridization programme to improve number of siliqiiae per plant in Brassica *juncea* L. (Table 5). Chowdhury *et al.* (2004) found highest number of siliquae in Din-2 in *Brassica rapa* L. Acharya and Swain (2004) observed more siliquae in Pusa Bahar in *Brassica juncea* L. Singh and Murty (1980) obtained maximum number of siliquae per plant in SS-1 in *Brassica campestris* L.

g. Length of siliquae:

Only J-1 exhibited significant positive gca effect for this trait and J-10 showed significant negative effect. The other parents showed insignificant negative and positive effect (Table 5). So there was no opportunity except J-1 to improve the length of siliquae by using these parents due to their poor and negative gca effect. Sheikh and Singh (1998); and Acharya and Swain (2004) obtained maximum siliqua length in glossy mutant .

h. Number of seeds per siliqua:

Higher significant and positive gca effect was observed in J-1(0.784). Thus this parent was found best general combiners to increase the number of seeds per silique in these parents (Table 5). The parents J-8 and J-10 showed significant but negative gca effects, so they are undesirable for improve this trait. Other parents showed insignificant gca effects. Chowdhury *et al.* (2004) found maximum seeds per siliqua in Dhali in *Brassica rapa* L. Acharya and Swain (2004) observed highest seeds per siliqua in Varuna in *Brassica juncea* L. Singh and Murty (1980) obtained more seeds per siliqua in YPS-842 in *Brassica campestris* L.

i. Thousands seed weight :

Significant and positive gca effects for thousand seed weight was observed in J-8 (0.463). The parentsJ-1 and J-7 showed insignificant positive effects for the trait. The other four parent exhibited insignificant negative gca effect, not good for improved seed size (Table 5). Chowdhury *et al.* (2004a) found highest seed weight in Dhali in *Braasica rapa* L. Acharya and Swain (2004) obtained maximum seed weight in Pusa Bahar in *Brassica juncea L.* Singh *et al.* (2000) observed more seed weight in YSC-68 in *Brassica*

j. Seed yield per plant:

Higher significant and positive gca effects was observed in J-7 (0.750) parent. On the other side, J-10 showed higher significant negative value for this character. Negative value indicates parents were not fit for increase seed yield. Other parents showed insignificant gca effect for the character (Table 5) indicating the parents used in this experiment were not good general combiner for improved seed yield per plant. Swain (2004) found highest seed yield in Pusa Bahar in Brassica *juncea L.* Chowdhury *et al.* (2004a) found highest seed yield per plant in Pt-303 in *Braasica rapa* L.

Specific combining ability (sca) effects

The specific combining ability effects signify the role of non-additive gene action in the expression of the characters. It denotes the highly specific combining ability leading to highest performance of some specific cross combinations. For this reason it relates to a particular cross. The specific combining ability effects are also seen in relation to their size. High sca effects may arise not only in cross involving high × high combinations, but also in those involving low × high and also from low × low. Thus in practice, some of the low combiners should also be accommodated in hybridization programme. The specific combining ability effects of twenty one crosses for ten different characters studied are presented in (Table 6) The magnitude and direction of the significant effects for the seven parents provide meaningful comparisons and would give a clue to the future breeding programme. The results of sca effects of different characters are given below:

Table 6. SCA effects for 10 characters in half diallel cross of *Brassica juncia*

Cross	Characters				
	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches
J-1 × J-2	4.8294	1.09259*	0.9352	0.852**	1.028
J-1 × J-7	5.2191	-0.1667	-0.435	-0.074	-2.083
J-1 × J-8	5.2591	0.46296	0.0833	0.037	-3.231*
J-1 × J-9	-1.859	-0.4259	-0.398	-0.074	-0.194
J-1 × J-10	6.4183	-0.3889	0.8611	-0.259	2.324
J-1 × J-11	1.4517	-0.8333	-0.028	-0.037	2.620
J-2 × J-7	2.3413	0.12963	-0.991	0.333	-0.491
J-2 × J-8	-1.685	-0.9074	-0.806	0.111	1.694
J-2 × J-9	4.6302	0.53704	-0.287	-0.333	-2.935*
J-2 × J-10	5.7739	-0.0926	-0.361	0.148	0.917
J-2 × J-11	2.7072	-1.2037*	-0.917	-0.296	2.213
J-7 × J-8	3.1043	0.5	0.1574	0.519	1.583
J-7 × J-9	0.9465	-0.0556	-0.324	1.741**	2.954*
J-7 × J-10	2.3635	-0.0185	0.2685	-0.444	0.806
J-7 × J-11	2.8302	-0.1296	-1.287*	-0.222	1.102
J-8 × J-9	5.3598	0.57407	0.5278	0.852**	4.472**
J-8 × J-10	-0.73	0.61111	0.1204	0.000	-2.009
J-8 × J-11	-6.463	-0.1667	0.5648	-0.111	0.620
J-9 × J-10	-2.981	0.05556	0.6389	-0.111	0.694
J-9 × J-11	5.6191	-0.7222	0.4167	-0.222	-0.009
J-10 × J-11	4.4294	-1.0185	-1.991**	0.593	0.843
SEsij	25.436	0.53228	0.6092	-0.074	0.175
SE(sij-sik)	0.791	0.905	7.492	0.489	2.026

***P<0.001, **p<0.01, *p<0.05

Table 6. (Contd.)

Cross	Characters				
	No. of siliquae/ plant	Length of siliquae (cm)	No. of seeds/ siliquae	Thousands seed weight	Seed yield/ plant
J-1 × J-2	54.361*	0.296**	-1.290	-0.066	0.896
J-1 × J-7	-9.491	-0.193	0.992	0.042	1.373
J-1 × J-8	-30.861	-0.032	-0.699	0.111	-1.735*
J-1 × J-9	14.991	-0.050	-0.965	0.006	-0.326
J-1 × J-10	27.065	0.101	0.272	-0.074	2.526**
J-1 × J-11	17.065	0.144	0.599	0.049	2.228**
J-2 × J-7	19.102	0.0723	-0.660	-0.126	0.475
J-2 × J-8	8.398	-0.188	1.133	0.272**	2.537**
J-2 × J-9	-15.417	0.014	-0.133	-0.006	-0.277
J-2 × J-10	16.991	-0.065	0.770	0.167	0.882
J-2 × J-11	-5.009	-0.097	1.430	0.157	2.387**
J-7 × J-8	29.546	0.162	-0.069	0.263**	3.038**
J-7 × J-9	41.065	-0.006	0.665	-0.105	1.503
J-7 × J-10	5.806	0.031	-0.431	0.075	0.286
J-7 × J-11	29.472	0.173	-0.771	-0.066	1.214
J-8 × J-9	53.694*	0.097	0.865	0.047	3.312**
J-8 × J-10	25.769	0.140	-2.032*	0.237**	-1.319
J-8 × J-11	32.435	0.0663	-0.645	0.106	1.243
J-9 × J-10	3.954	0.008	0.096	-0.035	-0.103
J-9 × J-11	5.287	-0.108	0.422	-0.009	-0.005
J-10 × J-11	43.028	0.102	0.659	-0.162	0.591
SEsij	4.825	-0.048	0.397	0.010	0.660
SE(sij-sik)	0.8162	0.164	1.328	0.150	1.207

***P<0.001, **p<0.01, *p<0.05

a. Plant height:

All F_1 of crosses showed insignificant sca effects range -0.73 to 6.4183 respectively for plant height (Table 6). Thus, the cross combinations were not good to improve the character. Treatment VS plant hight is graphically represented in Figure 2. Chowdhury *et al.* (2004) observed dwarfness in PT-303 × Tori-7 in *Brassica rapa* L. Acharya and Swain (2004) obtained dwarfness in Varuna × Pusa Bahar in *Brassica juncea* L. Nair *et al.* (2005) observed significant variance for this trait in *Brassica juncea* L.

b. Days to 50% flowering:

The significant and negative value from the parameter was obtained from J-2 × J-11 (-1.2037) for days to fifty percent flowering (Table 6). Significant and positive sca effects was observed in the cross combinations, J-1 × J-2 (1.09259). Thus, the cross combinations, J-2 × J-11 provide opportunity for earliness in mustard *(Brassica juncea* L.). Treatment VS days to 50% flowering is graphically represented in Figure 3. Singh *et al.* (2000) obtained earliness on YSK.-S501 × SS-2 in *B. campestris/rapa.* Singh *et al.* (1996) observed earliness in PR-1108 × BJ-1235 in *Brassica juncea* L.

c. Days to maturity:

The cross combination J-7 × J-11 and J-10 × J-11 showed significant and negative sca effects, provides opportunity for early maturity in *Brassica juncea* L. (Table 6). While other hybrids exhibit insignificant positive and negative value form the parameter. Chowdiiury *et al.* (2004) observed earliness in M-27 × Din-2 in *Bmsaica rapa* L. Acharya and Swain (2004) found early maturity in JC 26 × Jai Idsan in *Brassica juncea* L. Singh *et al.* (2000) obtained earliness in SS-3 × SS-1 in *Brassica campestris* L. Treatment VS days to maturity is graphically represented in Figure 4.

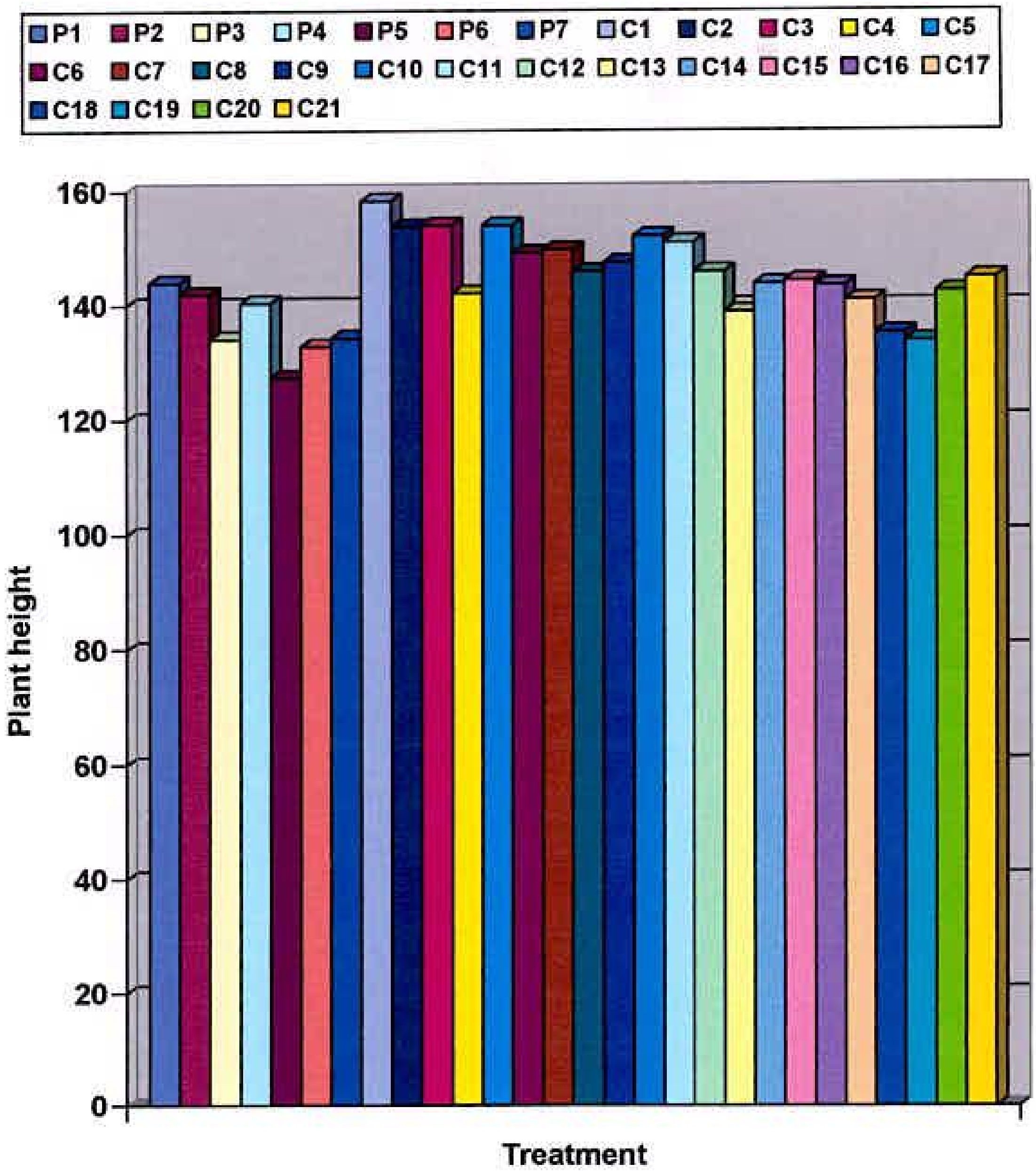


Figure 2. Graphical representation of treatment VS plant height

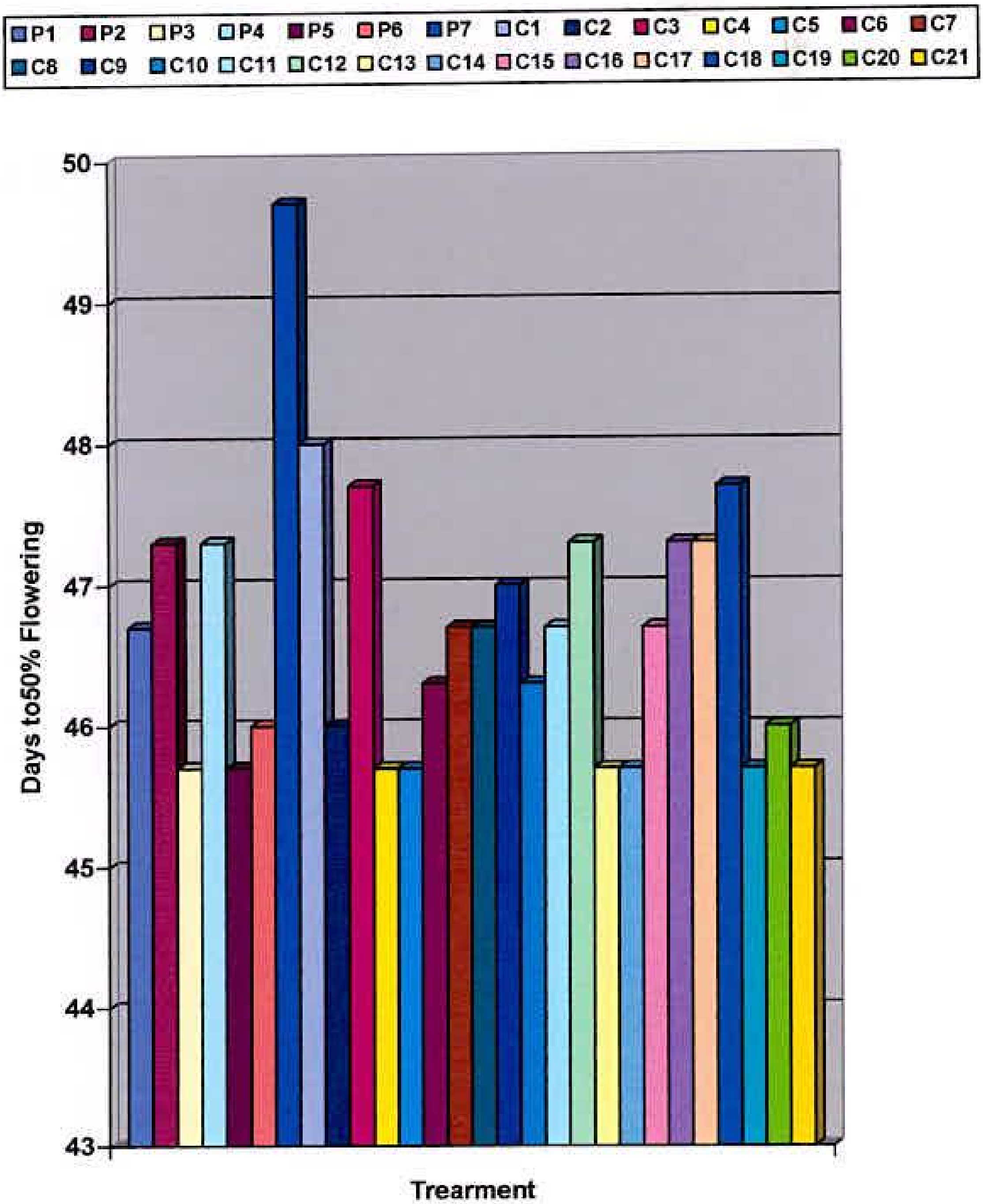


Figure 3. Graphical representation of treatment VS days to 50% flowering

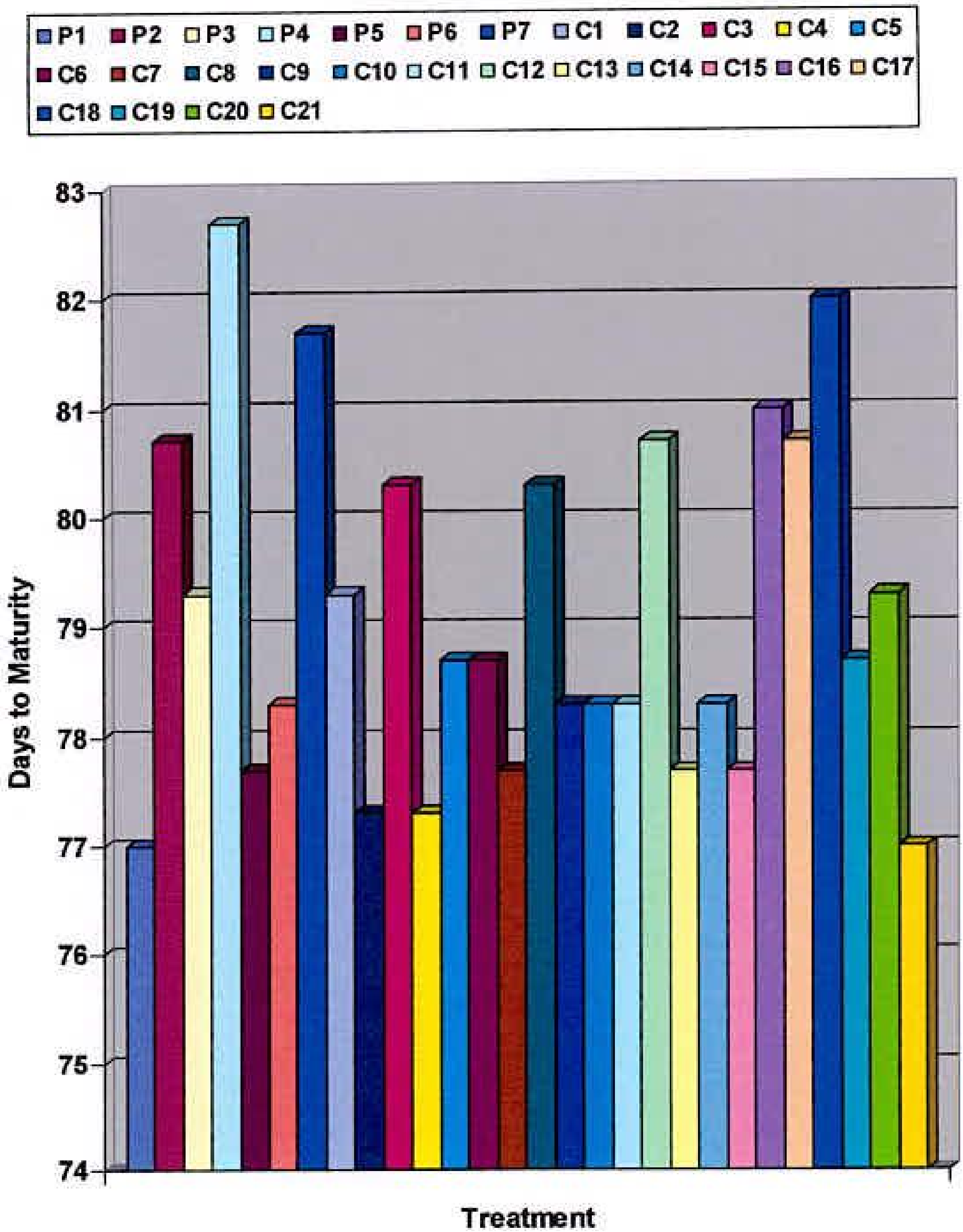


Figure 4. Graphical representation of treatment VS days to maturity

d. Number of primary branches per plant:

The cross combinations J-1 × J-2, J-7 × J-9 and J-8 × J-9 were found to be the best specific combiner to improve plants with more number of primary branches as they showed significant positive sca effects for this trait (Table 6). Chowdhury *et al.* (2004) found more primary branches in Sampad × Tori-7 in *Brassica rapa* L. Singh *et al.* (2000) obtained maximum number of primary branches per plant in YSK-8501 × SS-1 in *Brassica campestris* L. Sheikh and Singh (1998) observed best positive effect in Pusa × Barani in *Brassica juncea* L. Treatment VS number of primary branches per plant is graphically represented in Figure 5.

e. Number of secondary branches per plant:

The cross J-7 × J-8 and J-8 × J-9 exhibited significant positive sca effects for this trait, J-1 × J-8 and J-2 × J-9 exhibited significant negative sca effects and rest of the crosses showed insignificant sca effects (Table 6). Thus J-7 × J-8 and J-8 × J-9 were found to be the best specific combiner to improve plants with more number of secondary branches. Chowdhury *et al.* (2004a) found maximum secondary branches in Sampad × Din-2 in *Brassica rapa* L. Acharya and Swain (2004) obtained highest secondary branches per plant BM -20-12-3 × JC-26 in in *Brassica juncea* L, Singh and Murty (1980) observed more secondary branchrs per plant in YSC-68 × SS-2 in *Brassica campestris* L. Treatment VS number of secondary branches per plant is graphically represented in Figure 6.

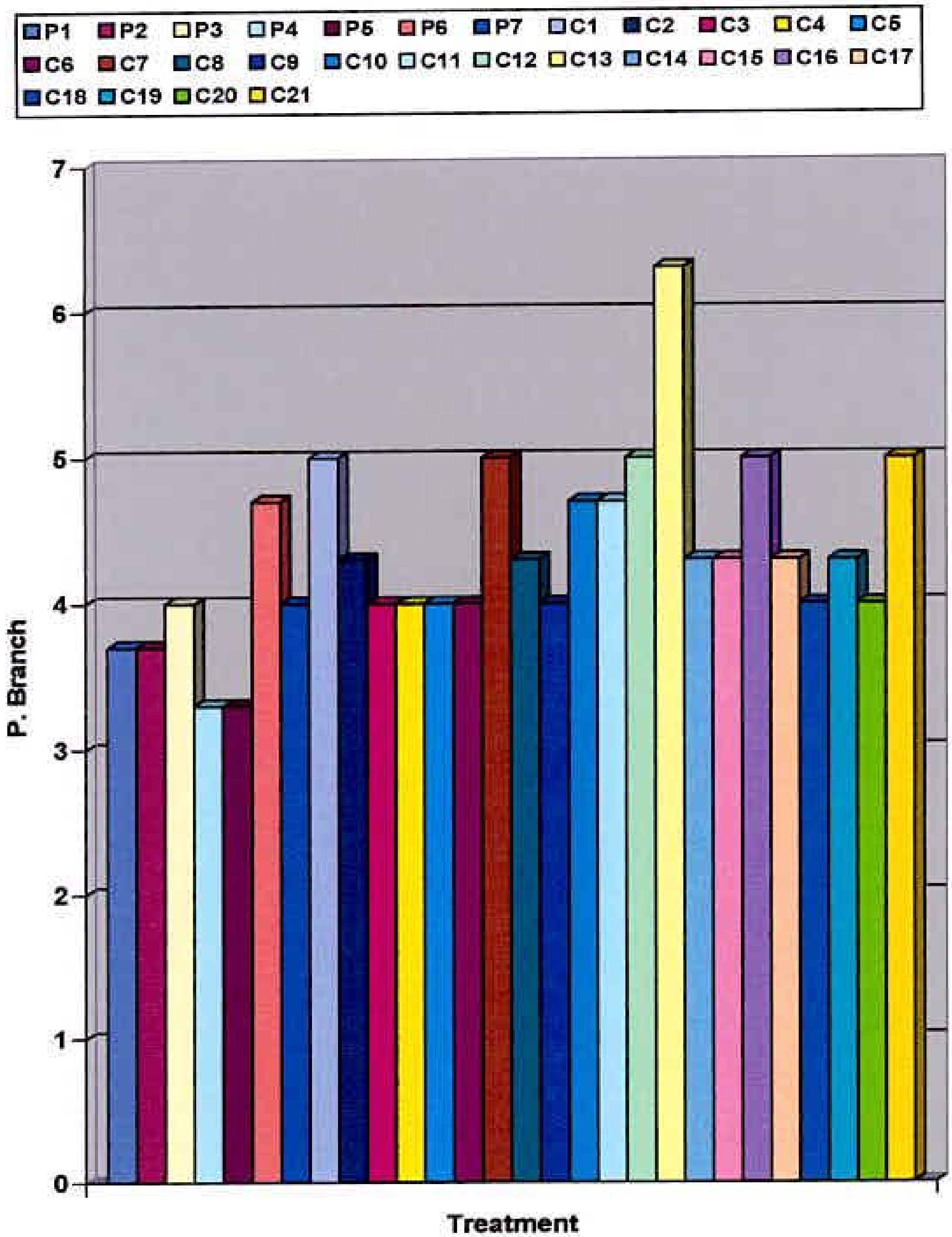


Figure 5. Graphical representation of treatment VS primary branches

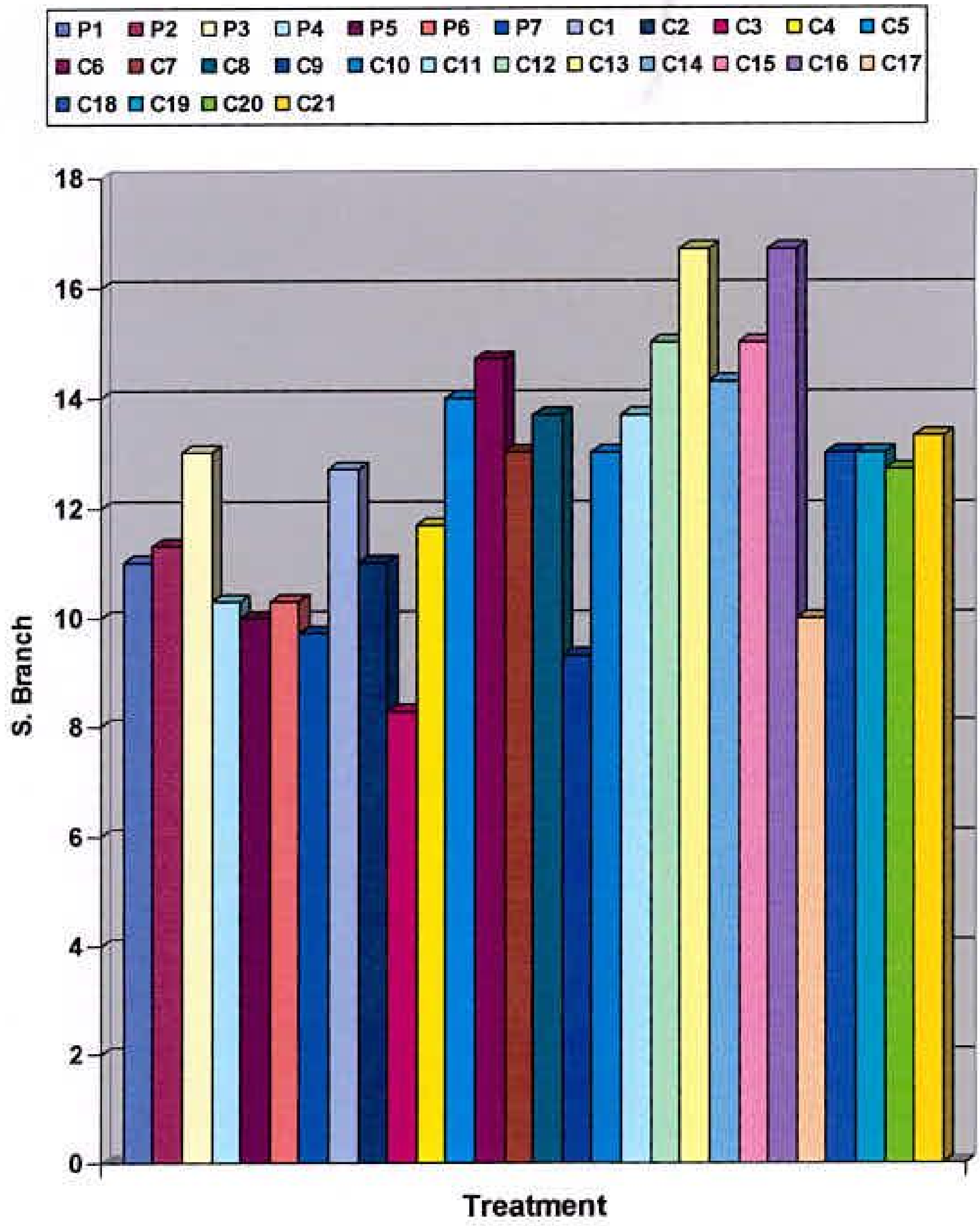


Figure 6. Graphical representation of treatment VS secondary branches

f. Siliquae per plant:

Among the cross combinations, J-1 × J-2 and J-8 × J-9 showed significant and positive sca effects and produced maximum siliquae and rest of the crosses showed insignificant sca effects (Table 6). Chowdhury *et al.* (2004) found maximum siliquae in Sampad × Din-2 in *Brassica rapa* L. Acharya and Swain (2004) obtained highest siliquae per plant in Pusa Bahar × JC 26 in *Brassica juncea* L. Singh and Murty (1980) observed more siliquae per plant in YSP-842 × SS-3 in *Brassica campestris* L. Treatment VS siliquae per plant is graphically represented in Figure 7.

g. Number of seeds per siliqua:

The cross combinations, J-8 × J-10 exhibited significant and negitive sca effects for seeds per siliquae. The cross J-1 × J-2, J-1 × J-8, J-1 × J-9, J-2 × J-7, J-2 × J-9, J-7 × J-8, J-7 × J-10, J-7 × J-11, J-8 × J-10 andJ-8 × J-11 combinations showed insignificant negative sca effects (Table 6). The other crosses exhibited insignificant and positive sca effects for seeds per siliquae. Enamul (2006) obtained BARIsar-6 × BINAsar-6 (C12) the best specific combiner to increase the number of seeds in the siliqua for yield improvement in *Brassica rapa* L. Chowdhury *et al.* (2004) found highest seeds per siliqua in Dhali × Sampad in *Brassica rapa* L. Acharya and Swain (2004) observed maximum seeds per siliqua in BM 20-12-3 × Pusa Bahar in *Brassica juncea* L. Singh *et al.* (2000) obtained more seeds per siliqua in YSP-842 × YSK-8501 in *Brassica campestris* L. Treatment VS number of seeds per siliqua is graphically represented in Figure 8.

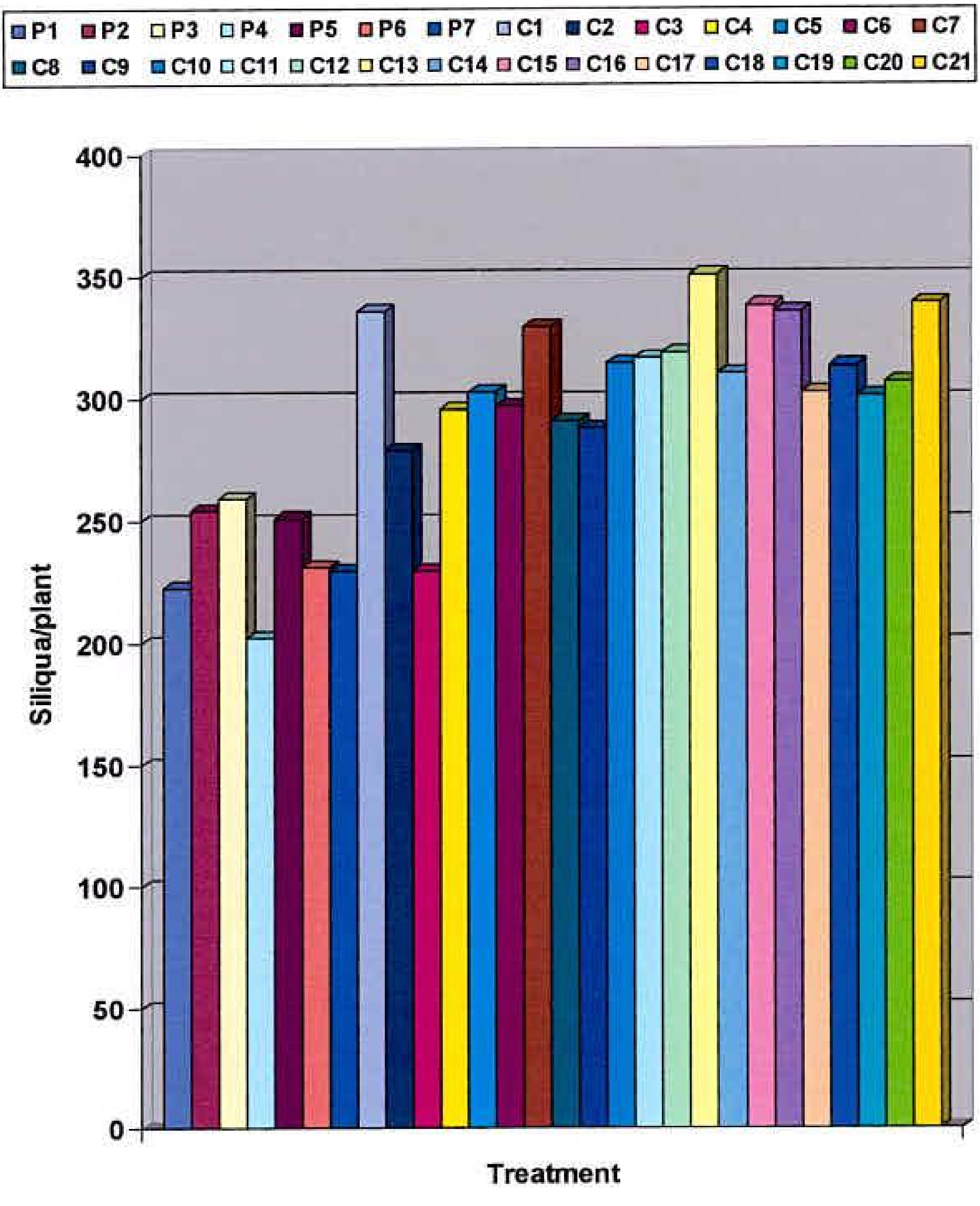


Figure 7. Graphical representation of treatment VS siliquae/plant

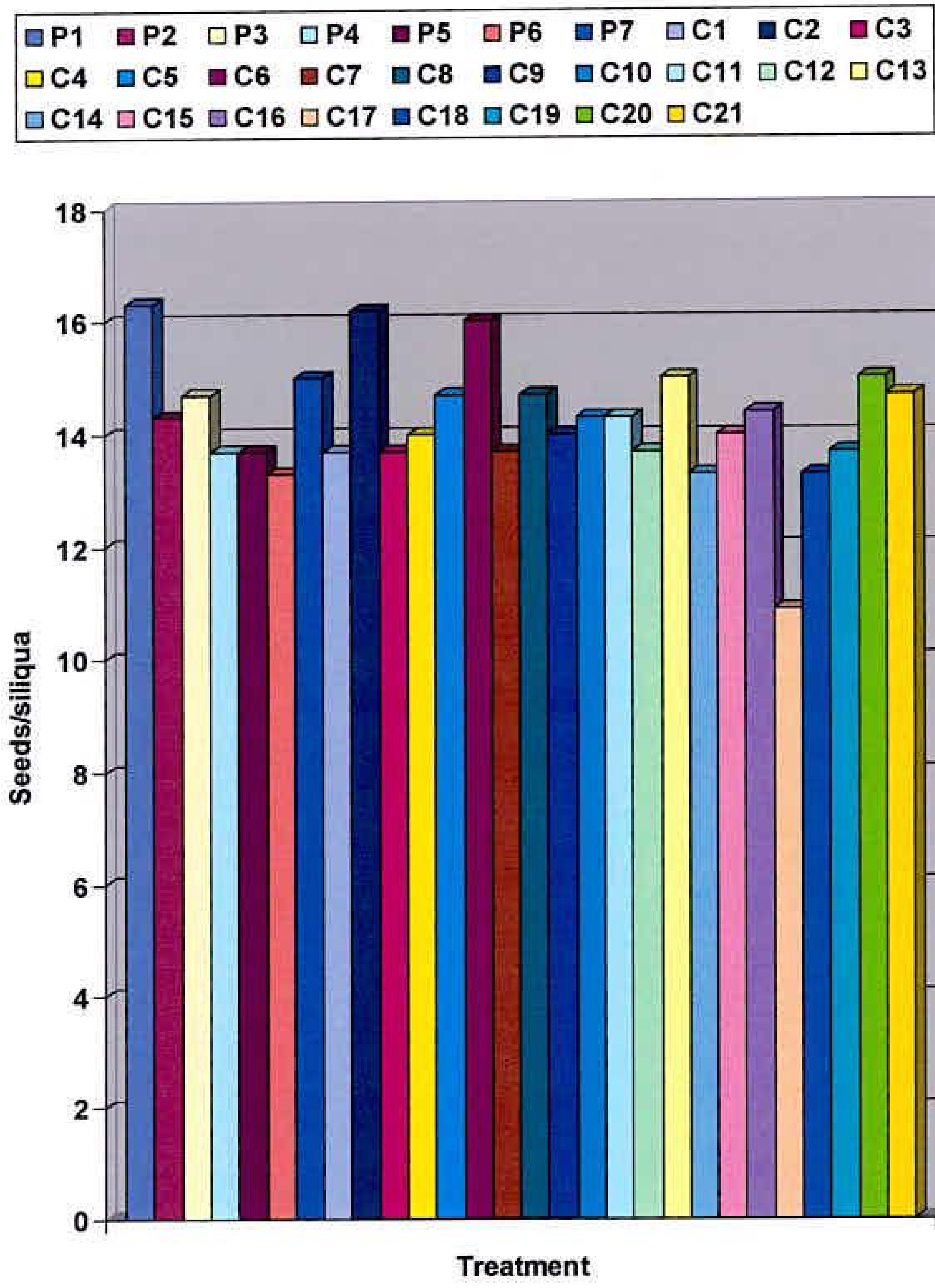


Figure 8. Graphical representation of treatment VS seeds/siliqua

h. Length of siliqua:

Among the cross combinations, J-1 × J-2 (0.296) showed highest significant and positive sca effects where J-1 × J-7, J-1 × J-8, J-1 × J-9, J-2 × J-8, J-2 × J-10, J-2 × J-11, J-7 × J-9 and J-9 × J-11 showed insignificant negative sca effects. Others showed positive but insignificant sca effect (Table 6). Huq(2006) showed BINAsar-6 × Tori 7 was not good for improve the trait. Sheikh and Singh (1998) and Acharya and Swain (2004) observed maximum siliqua length In Pusa Barani × Glossy mutant and BM 20-12-3 × Pusa Bahar respectively in *Brassica juncea.* Treatment VS length of siliqua is graphically represented in Figure 9.

i. Thousands seed weight:

The cross combinations J-2 × J-8 exhibited significant and positive sca effect (0.272) followed by J-7 × J-8 and J-8 × J-10. The crosses J-1 × J-7, J-1 × J-8, J-1 × J-9, J-2 × J-10, J-2 × J-11, J-7 × J-10, J-8 × J-9 and J-8 × J-11 showed positive insignificant sca effect for the character (Table 6). Enamul (2006) obtained all insignificant combinations range -0.0534 to 0.0363 in *Brassica rapa* L. Risul(2005) found DH-18 × Jun-536 and BARIsar-10 × BJ-18 were best combinations for thousands seed weight. Singh *et al.* (2000) observed more seed weight per plant in YSC-68 × SS-2 in *Brassica campeslris* L. Acharya and Swain (2004) found highest seed weight in Pusa Bold × Pusa Bahar in *Brassica juncea* L. Chowdhury *et al.* (2004a) obtained highest seed weight in Dhali × Sampad in *Brassica rapa* L. Treatment VS thousands seed weight is graphically represented in Figure 10.

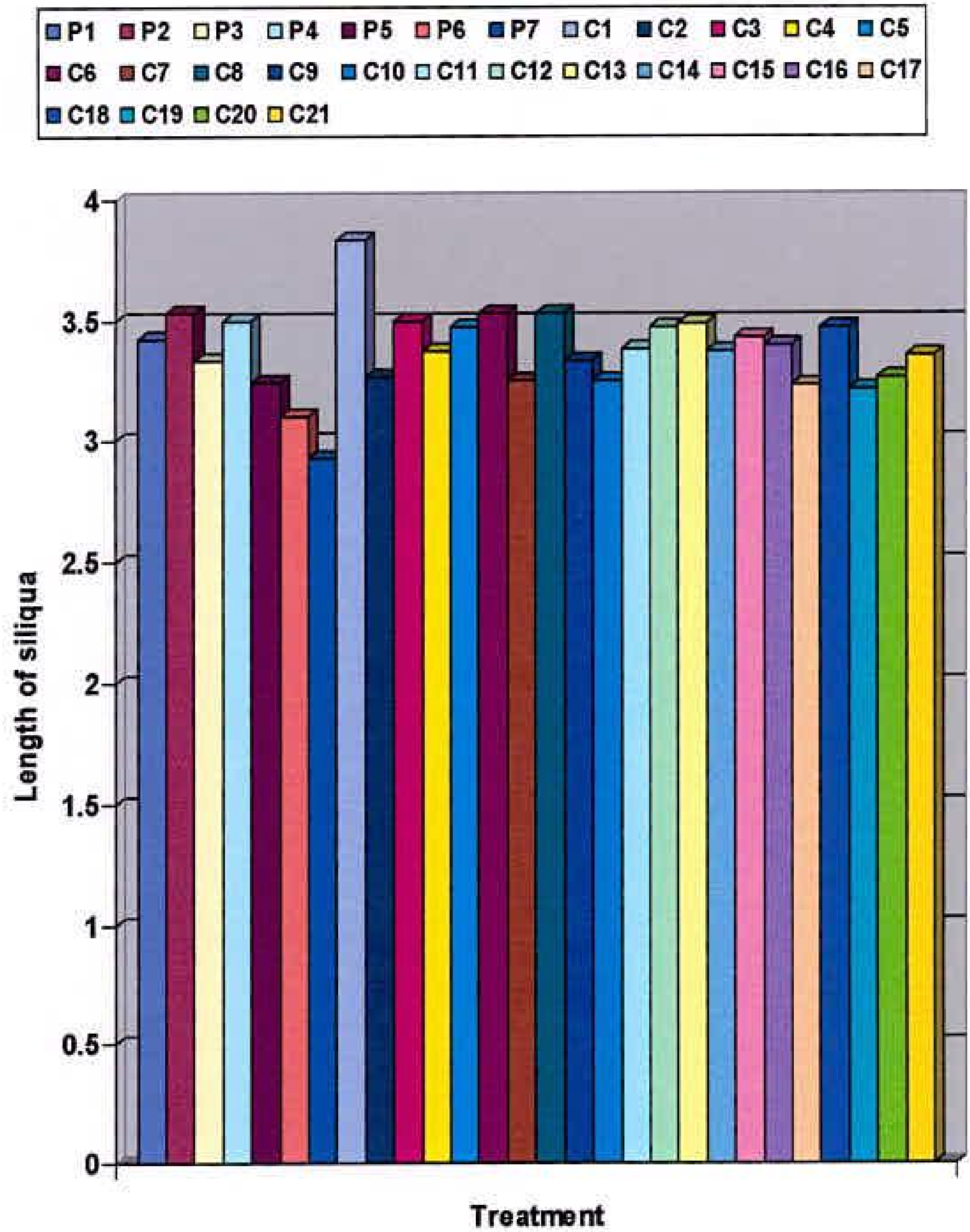


Figure 9. Graphical representation of treatment VS length of siliquae

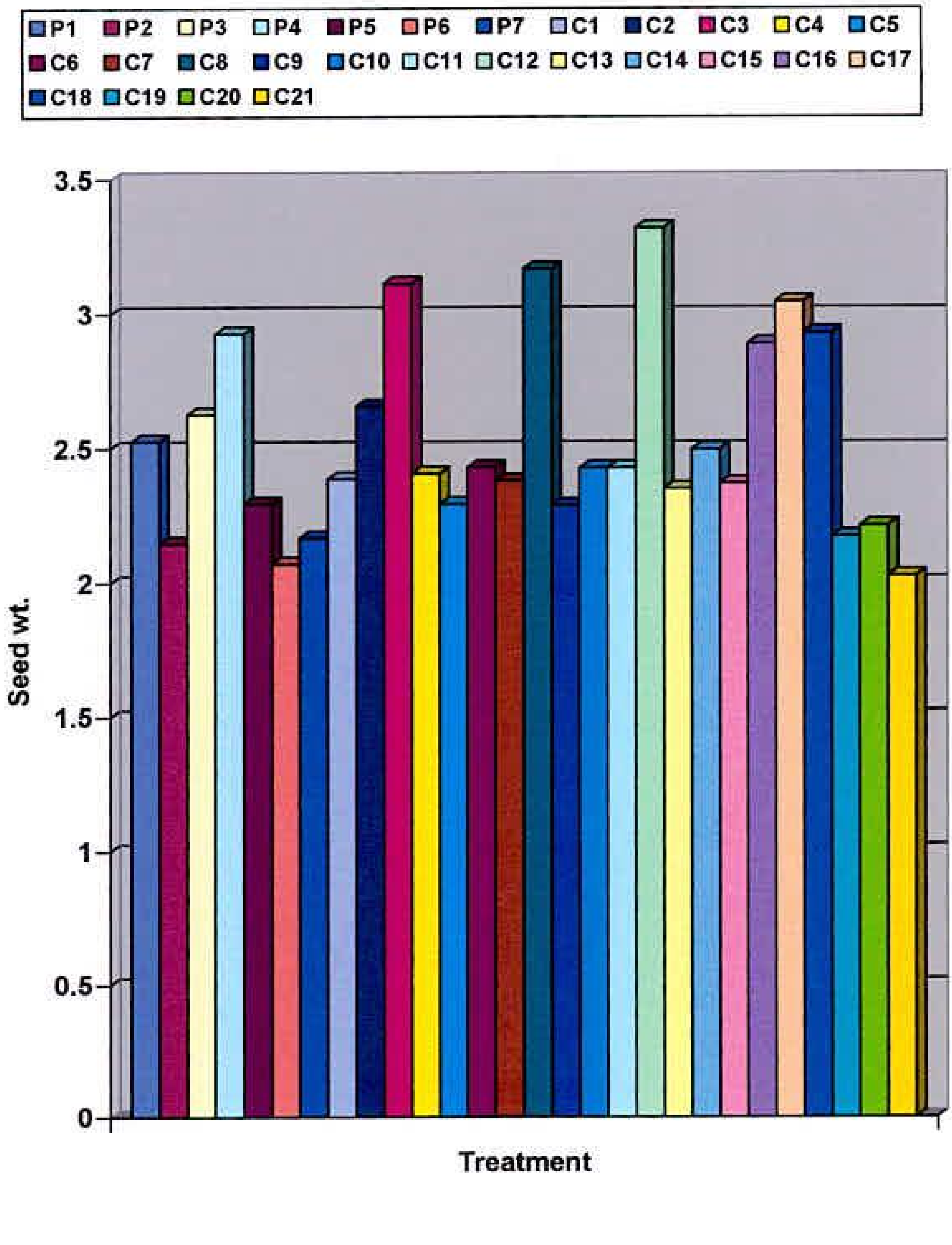


Figure 10. Graphical representation of treatment VS thousand seed weight

j. Seed yield per plant:

The cross combinations J-8 × J-9 exhibited highest significant and positive sca effect (3.312) followed by J -1 × J-10, J-1 × J-11 and J-7 × J-8 for seed yield per plant. The other combinations showed either significant negative (J-1 × J-8) or insignificant saa effects. Thus, J-8 × J-9, J -1 × J-10, J-1 × J-11 and J-7 × J-8 were the best specific combinations for the improvement of seed yield per plant in *Brassica rapa* L. (Table 6). Enamul (2006) obtained highest seed yield in Agroni × Tori 7, Agroni × BARIsar-6 and Shafal × BARIsar-6 in *Brassica rapa* L. Chowdhury *et al.* (2004) obtained highest seed yield in M-27 × Din-2 in *Brassica rapa* L. Acharya and Swain (2004) found maximum seed yield in Pusa Bold × Pusa Bahar in *Brassica juncea* L. Singh *et al.* (2000) observed more seed yield per plant in YSP-842 × YSK-8501 in *Brassica campeslris* L. Treatment VS yield per plant is graphically represented in Figure 11.

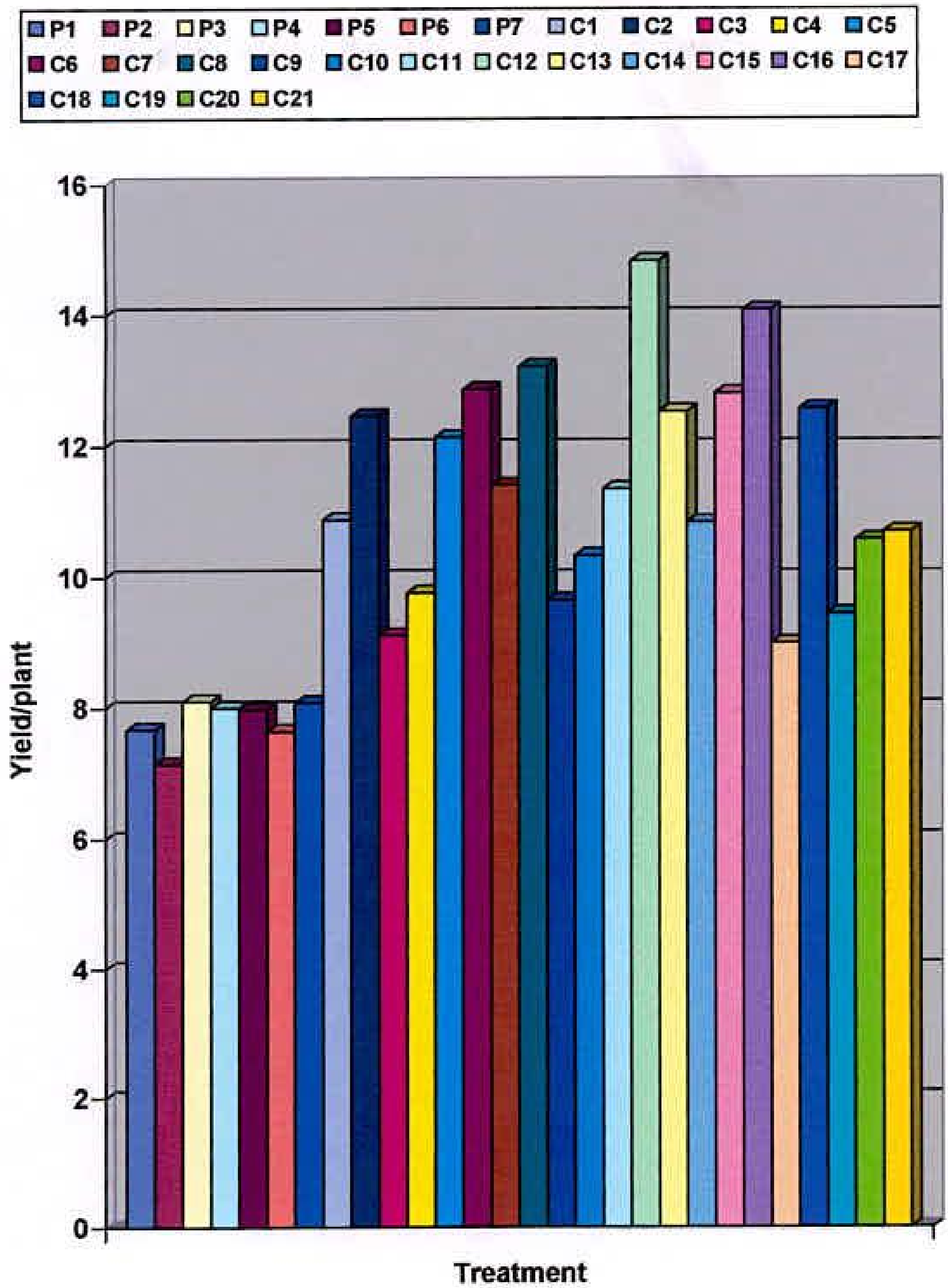


Figure 11. Graphical representation of treatment VS yield/plant

Chapter 5
Summary and Conclusion

SUMMARY AND CONCLUSION

A seven parents (J-1, J-2, J-7, J-8, J-9, J-10 and J-11) half diallel cross hybrids were evaluated for estimating the magnitude of heterosis over mid parent and better parent, and combining ability of different genotypes.

It was observed that all the hybrids obtained did not perform well for many of the importent characters and to find out the desirable hybrids, the crosses were scored on the basis of desirable heterotic values. Out of twenty one crosses, the hybrid J-1 × J-11, J-2 × J-11and J-10 × J-11 showed desirable negative heterosis for the characters days to 50% flowering over both mid and better parent. The cross J-2 × J-7, J-2 × J-11, J-7 × J-11and J-10 × J-11 exhibit desirable heterosis for days to maturity and rest almost all the hybrids showed insignificant positive or negitive heterosis which were not desirable for these characters. The hybrid J-7 × J-9 and J-8 × J-9 was found to be the best for number of primary branches per plant. While the cross J-8 × J-9 produced maximum number of secondary branches per plant. The cross J-7 × J-9and J-10 × J-11, however, produced maximum number of siliqua per plant. All the crosses showed insignificant performance for length of siliqua and number of seeds per siliqua. Only the hybrid J-7 × J-8 was best for thousand seed weight. For seed yield per plant the cross J-7 × J-8 found to be the best one followed by cross J-1 × J-2, J-1 × J-7, J-1 × J-10, J-1 × J-11, J-2 × J-7, J-2 × J-8, J-2 × J-11, J-7 × J-8, J-7 × J-9, J-7 × J-11, J-8 × J-9 and J-8 × J-11. Thus, selection out of these crosses in the subsequent generations might produce some suitable segregants.

Analysis of combining ability following Griffing approach showed significant gca and sca variance for most of the characters studied, indicating the role of both additive and non-additive components in the genetic system controlling these characters. The higher magnitude of gca variance was observed than that of sca variance for plant height, days to 50% flowering, days to maturity, length of siliqua, number of seeds/ siliquae and thousand seed weight, which indicated the preponderance of additive component in their expression. Estimates of gca effects for different characters suggested that parent J-7, J-9 and J-10 was good general combiner for days to 50% flowering and days to maturity. The parent J-1 was also good general combiner for days to maturity, number of primary branches, length of siliqua and number of seeds per siliqua. Only J-9 was good general combiner for plant height and J-8 for thousands seed weight. The parent J-7 was good general combiner for number of secondary branches and seed yield per plant.

The sca estimates of various characters revealed that cross J-2 × J-11 was the best specific combiner for days to 50% flowering. The combination J-7 × J-11 and J-10 × J-11 were good specific combiner for days to maturity. The hybrids J-7 × J-9 and J-8 × J-9 were good specific combiner for both number of primary and secondary branches. The hybrids J-1 × J-2 has also good sca effects. The best specific combiner were J-1 × J-2 and J-8 × J-9 for number of siliqua; J-1 × J-2 also for length of siliqua; J-2 × J-8, J-7 × J-8 and J-8 × J-10 for thousands seed weight and J-1 × J-10, J-2 × J-8, J-2 × J-11, J-7 × J-8, and J-8 × J-9 for seed yield per plant.

Among the genotypes, many parents had high gca effects and hybrids had high heterotic value and sca effect. So, in a breeding programme maximum emphasis should thus be given on these traits. This parent could be effectively used in future for developing varieties of Indian mustard (*Brassica juncia L)*.

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Appendices

APPENDIX

Appendix I. Morphological, physical and chemical characteristics of initial soil (0 – 15 cm depth)

I. A. Physical Composition of the Soil

Sl. No.	Soil Separates	%	Methods Employed
01	Sands	36.90	Hydrometer Methods (Day, 1915)
02	Silt	26.40	Same
03	Clay	36.66	Same
04	Texture Class	Clay Loam	Same

I. B. Chemical Composition of the Soil

Sl. No.	Soil Characteristics	Analytical data	Methods Employed
01	Organic Carbon (%)	0.82	Walkley and Black, 1947
02	Total Nitrogen (Kg/ha)	1790.0	Bremner and Mulvaney, 1965
03	Total S (ppm)	225.00	Bardsley and Lanester, 1965
04	Total Phosphorus (ppm)	840.0	Olsen and Sommers, 1982
05	Available Nitrogen (kg/ha)	54.0	Bremner, 1965
06	Available Phosphorus (kg/ha)	69.00	Olsen and Dean, 1965
07	Exchangeable K (Kg/ha)	89.50	Pratt, 1965
08	Available S (kg/ha)	16.00	Hunter, 1984
09	pH (1:2.5 Soil to Water)	5.55	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Appendix II. Monthly average temperature, number of rainy days, relative humidity and total rainfall of the experiment site during the period from October, 2007to April, 2008

Year	Months	*Air Temperature (^0C)			Number of Rainy Days**	Relative Humidity (%)	**Rainfall (mm)
		Max.	Min.	Mean			
2007	October	32.3	24.7	28.50	07	72	88
	November	31.8	16.8	67	111	5.7	31.8
	December	28.2	11.3	63	0	5.5	28.2
2008	January	29.0	10.5	61.5	23	5.6	29.0
	February	30.6	10.8	54.5	56	5.8	30.6
	March	34.6	16.5	61.5	45	5.8	34.6
	April	36.9	19.6	59.5	91	8.3	36.9

*Monthly Average
**Monthly Total
Source: Bangladesh Meteorological Department (Climate Division), Agargaon, Dhaka – 1212.

Appendix III. Treatment mean performance of different characters of 7 parents and 21 F_1s in *Brassica juncia*

Cross	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches
J-1	144.0	46.7	77.0	3.7	11.0
J-2	141.9	47.3	80.7	3.7	11.3
J-7	134.1	45.7	79.3	4.0	13.0
J-8	140.4	47.3	82.7	3.3	10.3
J-9	127.4	45.7	77.7	3.3	10.0
J-10	132.8	46.0	78.3	4.7	10.3
J-11	134.3	49.7	81.7	4.0	9.7
J-1 × J-2	158.3	48.0	79.3	5.0	12.7
J-1 × J-7	153.8	46.0	77.3	4.3	11.0
J-1 × J-8	154.0	47.7	80.3	4.0	8.3
J-1 × J-9	142.1	45.7	77.3	4.0	11.7
J-1 × J-10	154.0	45.7	78.7	4.0	14.0
J-1 × J-11	149.1	46.3	78.7	4.0	14.7
J-2 × J-7	149.7	46.7	77.7	5.0	13.0
J-2 × J-8	145.8	46.7	80.3	4.3	13.7
J-2 × J-9	147.4	47.0	78.3	4.0	9.3
J-2 × J-10	152.1	46.3	78.3	4.7	13.0
J-2 × J-11	151.0	46.7	78.3	4.7	13.7
J-7 × J-8	145.8	47.3	80.7	5.0	15.0
J-7 × J-9	138.8	45.7	77.7	6.3	16.7
J-7 × J-10	143.8	45.7	78.3	4.3	14.3
J-7 × J-11	144.3	46.7	77.7	4.3	15.0
J-8 × J-9	143.4	47.3	81.0	5.0	16.7
J-8 × J-10	140.9	47.3	80.7	4.3	10.0
J-8 × J-11	135.2	47.7	82.0	4.0	13.0
J-9 × J-10	133.9	45.7	78.7	4.3	13.0
J-9 × J-11	142.5	46.0	79.3	4.0	12.7
J-10 × J-11	144.9	45.7	77.0	5.0	13.3

Appendix III. (Contd.)

Cross/ Parents	No. of siliquae/ plant	Length of siliquae (cm)	No. of seeds/ siliquae	Thousands seed weight	Seed yield/ plant
J-1	222.7	3.42	16.3	2.527	7.67
J-2	254.3	3.53	14.3	2.147	7.14
J-7	259.3	3.33	14.7	2.627	8.10
J-8	202.3	3.50	13.7	2.927	8.00
J-9	251.0	3.24	13.7	2.293	7.97
J-10	230.7	3.10	13.3	2.070	7.64
J-11	229.7	2.93	15.0	2.167	8.08
J-1 × J-2	335.7	3.83	13.7	2.387	10.88
J-1 × J-7	278.7	3.27	16.2	2.657	12.47
J-1 × J-8	229.7	3.50	13.7	3.113	9.11
J-1 × J-9	296.0	3.37	14.0	2.407	9.76
J-1 × J-10	302.7	3.47	14.7	2.293	12.14
J-1 × J-11	297.0	3.53	16.0	2.430	12.87
J-2 × J-7	329.3	3.25	13.7	2.380	11.41
J-2 × J-8	291.0	3.53	14.7	3.167	13.22
J-2 × J-9	287.7	3.33	14.0	2.287	9.65
J-2 × J-10	314.7	3.25	14.3	2.427	10.33
J-2 × J-11	316.7	3.38	14.3	2.427	11.35
J-7 × J-8	319.0	3.47	13.7	3.320	14.83
J-7 × J-9	351.0	3.49	15.0	2.350	12.53
J-7 × J-10	310.3	3.37	13.3	2.497	10.84
J-7 × J-11	338.3	3.43	14.0	2.370	12.81
J-8 × J-9	336.0	3.40	14.4	2.890	14.09
J-8 × J-10	302.7	3.23	10.9	3.047	8.99
J-8 × J-11	313.7	3.47	13.3	2.930	12.58
J-9 × J-10	301.3	3.22	13.7	2.173	9.44
J-9 × J-11	307.0	3.27	15.0	2.213	10.58
J-10 × J-11	339.3	3.36	14.7	2.027	10.70