COMBINING ABILITY AND HETEROSIS ANALYSIS IN

Brassica rapa

BY

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CERTIFICATE

This is to certify that the thesis entitled, "COMBINING ABILITY HETEROSIS AND ANALYSIS IN *Brassica rapa*)." 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 **MD. EKTIAR UDDIN**, Registration No. 00920 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.

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Dedicated to
My Reverend Parents & Teachers
Whose Earnest Efforts and Teaching
have Brought me Today up to this Level

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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

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ABSTRACT

An experiment on oleiferous *Brassica rapa* L. was conducted to evaluate the combining ability and heterosis of different characters on seed yield. 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 action was predominant for the expression of these characters. 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, thousand 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 siliqua, number of seeds per siliqua and thousand seed weight.The hybrid $P_6 \times P_{10}$ was found to be the best for number of primary branches per plant. While the cross $P_6 \times P_{11}$ produced maximum number of secondary branches per plant. The cross $P_7 \times P_3$ produced maximum number of siliquae per plant. The hybrids $P_5 \times P_{10}$, showed positive heterosis over mid parent and better parent on length of siliqua, thousand seed weight and number of seeds per siliqua. The cross $P_7 \times P_{11}$ showed desirable heterosis for seed yield per plant. The cross $P_7 \times P_3$, $P_7 \times P_{10}$, $P_5 \times P_{11}$ and $P_2 \times P_{11}$, were also good for seed yield per plant. The parent P_5 was good general combiner for days to flowering, maturity and number of seeds per plant. The parent P_6 was also good general combiner for number of primary branches, number of siliquae per plant, length of siliqua and thousand seed weight. The parent P_7 was also good general combiner for number of seeds per siliqua. The parent P_{10} and P_5 were good general combiner for plant height. The parent P_{10} was good general combiner for number of secondary branches. The hybrids $P_7 \times P_{11}$ and $P_6 \times P_{11}$ were good specific significant combiner for the number of primary branches. The hybrids $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$ and $P_2 \times P_{10}$ were good specific combiner for the secondary branches. The hybrids $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$ and $P_2 \times P_{10}$ were good specific combiner for the secondary branches. The hybrids $P_7 \times P_3$, $P_7 \times P_{11}$, $P_6 \times P_3$, and $P_5 \times P_2$ have also good sca effects on number of siliquae. The best specific combiner were $P_7 \times P_{11}$, $P_6 \times P_{11}$, and $P_5 \times P_{10}$ and $P_2 \times P_{11}$ for number of seeds per siliqua; $P_6 \times P_{11}$, $P_5 \times P_{11}$, $P_3 \times P_{11}$ and $P_2 \times P_{10}$ also for length of siliqua; $P_7 \times P_5$, $P_7 \times P_{10}$, $P_6 \times P_2$ and $P_6 \times P_{11}$ for thousands seed weight and $P_5 \times P_2$, $P_6 \times P_{11}$, $P_7 \times P_3$, $P_7 \times P_{10}$ and $P_6 \times P_3$ for seed yield per plant.

Chapter 1
Introduction

CHAPTER 1

INTRODUCTION

Mustard and rape seed are important oil crops of Bangladesh. *Brassica* is an important genus of plant kingdom consisting of over 3200 species with highly devise morphology. Rapeseed (*Brassica rapa*) is a cross pollinated oil crop belonging to the family Brassiceae. According to FAO (2005), the oil yielding crop *Brassica* hold the second position in the world oil seeds in respect of production and about 16% of the world's oilseed is obtained from this crop. The crop was grown in about 0.297 million hectares of land and the total production was 0.218 million tons in 2004.

The oleiferous *Brassica* is important source of vegetable fat and are mainly represented by rape, turnip rape and mustard. This is the fourth most important source of vegetative oil in the world after soybean, palm, and sunflower. The component of mustard group includes *B. juncea* Czern and Cross (2x =36), *B. nigra* koch, *B. carinata* Braun (2x =34) while rapeseed includes *B. rapa* L. (turnip rape, 2x =20) and *B. napus* L. (rape, 4x = 38) (Yarnell, 1965). 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 purposes, viz, *B. campestris, B. juncea* and *B. napus.*

In Bangladesh, total oil seed crops cover 3.02 lakh ha of land. However, rapeseed and mustard cover 2.17 lakh ha 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. Oilseed 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).

For human health in balanced diet 20-25% of calories should come from fats and oils. Although oilseed crops play a vital role in human diet the consumption rate of oil in our country is far below than that of balanced diet (6 g oil per day per capita against the optimum requirement of 35 g per head per day).

There is plenty of scope to increase yield per unit of area through breeding superior varieties. The production potential of rapeseed and mustard may be well exploited if the varieties can be identified with early maturity, rapid response to high fertility, has large seed size and high oil content. The oil content of mustard in Bangladesh varied 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 mustards by combining and selecting for the desirable character(s). The most important aspects are the choice of parents for hybridization and selection of best lines from hybrid progenies. Information on heritability of materials in early generations, gene actions involved and heterosis of different degrees is very useful for the purpose of selection among the hybrid populations.

A prerequisite of successful hybrid breeding work of rape plant is available heterotic germplasm. Mustard and rapeseed contributes major proportion of oil requirement in our country we have a limitation of accelerate total yield due to lack of poor performance of our cultivated varieties. So we have ample scope to improve our cultivated varieties by exploiting heterosis for different yield contributing characters. Heterosis should be leads to increase yield, reproduction ability, adaptability, disease and insect resistance, general vigor, quality etc.

Combining ability studies are more 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 actions involved in the expression of quantitative traits. Genetic information about the combining ability helps in the selection of suitable parents for hybridization and in isolating the promising early generation hybrids for further exploitation in breeding programs. Combining ability studies provide better estimates of general and specific combining abilities (GCA, SCA) which are useful in classifying parental lines in terms of their hybrid performance. In cross pollinated crops like rapeseed (*Brassica rapa)* these studies are useful in assessing the nicking ability of the parents which, when crossed, would give more desirable segregates. This, in turn, helps in choosing the parents for hybridization. There fore, the present work was undertaken with the following objectives.

1. To study the gene action and the inheritance of seed yield and yield components.
2. To study the extent of heterosis in the genotypes of *Brassica rapa.*
3. Identification of potential parent and promising cross combinations to develop HYV and hybrid varieties.

Chapter 2
Review of Literature

CHAPTER 2

REVIEW OF LITERATURE:

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

2.1 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.

Griffing (1956a) proposed a more general procedure for diallel analysis which makes provision for non-allelic interaction. In this approach mean measurement of a cross is partitioned into two major components, a part from a general mean 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 and epistatic component of variation.

Trivedi and Mukharjee (1986) repoted that non additive component in Indian mustard *Brassica juncea* L. is important for all the traits studied except for oil content and days to maturity, for which non additive and additive components were important. Dominance deviation for oil yield, seed yield, 1000 seed weight, seeds per siliqua and days to maturity was due to asymmetrical proportion of genes with positive and negative effects at the loci showing the highest dominance for oil content. The expression of oil content, 1000 seed weight and days to maturity was governed by frequency of dominant alleles where as recessive alleles were preponderant for other traits.

Badwal and Labana (1987) working on seed yield per plant and 8 related traits from a 10×10 half diallel cross in *Brassica juncea* L. They observed that both additive and non additive components of variance controlled the inheritance of seed yield, number of seeds per siliqua, plant height, primary branches and length of siliqua. Non additive variance was significant for secondary branches only.

Gupta *et al.* (1987a) studied combining ability of *Brassica juncea* L. genotype with 8×8 diallel cross without reciprocal cross, 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, and number of seeds per siliqua and seed yield. While additive gene effects were apparently predominant for plant height. Parents with high GCA were found the best general combiner for seed yield and the best crosses for future selection were high × high GCA parents.

Gupta *et al.* (1987b) performed on analysis in a 13×4, lien × tester cross in *Brassica juncea* L. Additive gene effects were found relatively more important than non additive for seed yield per plant and most of the yield components investigated.

Prakash *et al.* (1987a) evaluated analyzed data of the F_2 of an eight 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 seeds per siliqua, 1000 seed weight and seed yield indicating that dominance was possibly the predominant gene action for these traits. The parents DIR 146 and RCL 1017 were good general combiners for most of the characters studied.

Prakash *et al.* (1987b) observed 8 varieties with their 28 F_2s, the component of variance indicated the importance of both additive and dominance components for the character studied.

Rawat (1987) observed 12 females and 5 males' line of *Brassuca juncea* L. of diverse origin with a line × tester analysis. Variance components of GCA and SCA were significant for days to 50% flowering, number of primary branch, plant height, seed weight and seed yield per plant. The crosses showed high SCA effects for seed yield involving high × low GCA parents.

Singh and Chauhan (1987) worked with 60 triple test cross families produced by the crossing of 20 F_2 parents as males to the parents and F_1s. In Varuna × TM 9, 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 per plant. In Varuna×RW 75-80-1, additive genetic variance was estimated to be predominant for plant height and dominant for days to maturity, number of seeds per siliqua, 1000 seed weight and yield per plant.

Arya *et al.* (1989) worked on combining ability from data of 12 yield related component characters in parents and F_1s 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 DNS38×DISNS and N20-1×regent as good specific cross combinations.

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 Srivastava (1989) indicated that parents RK8202, KR1418, RH30, V10 and B30 were good general combiners for seed yield.

In another study Thakur and Zarger. (1989) studied yield components in 15 *Brassica juncea* lines and 3 testers and their F_1 hybrids. The lines gonad-3 and r71-2 had high GCA for yield.

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.

Pszczola (1993) inter crossed the varieties Bolko, Tor, Diadem, Arabeke, Panter and Libravo in one set of diallel crosses and the varieties boh1491 (Bor), falcon, Tapidor, Ofello and Lircus in another set. The characters evaluated were seed yield, 1000 seed weight, and others of importance. There were significant SCA effects in some crosses for all traits. Maternal (cytoplasmic) effect was apparent for all characters.

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 were significant differences in seed yield between genotypes. NDR8602, Krishna, Pusa Bold and TM9 showed good general combining ability.

Tamber *et al.* (1991) crossed 23 morphologically diverse *Brassica juncea* lines with 4 broad-based testers in 1987-88. The resulting 92 F_1 and parents, and F_2 and parents were sown in 1988-89, 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.

Rawat (1992) studied the reciprocal differences in the inheritance of 8 yield traits 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 of combined the basis of per se performance and of combining ability and F_1 performance were BICI624, BICI382, BICI439, BICI114 and BICI702. There was only one cross (BICI382×BICI702) in which reciprocal effects acted in a favourable 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.

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 BSH1×M27, B9×PT303 and PK×M27.

Kudal (1993) studied 9 maternal lines (5s3 and 4s4) 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 seeds/siliqua, but non-additive effects predominate in control of number of primary branches, seed yield/plant, and plant height and siliqua 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 seeds/siliqua, T1097 for number of primary branches and T996 and T1039 for plant height.

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 BCID for maturity traits. HC5 for seed attributes and CAR4-3, BCIDI, CAR3 and CAR8 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 progrmme.

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.

Chaudhary *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 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 the characters studied was Bell×Pusakalyani.

Chaudhary *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.

Singh *et al.* (1989) evaluated six *Brassica juncea* L. parents and their resultant 15 F_1 and F_2 population. Significant GCA and SCA variances were observed for all the 11 characters studied. Majority of the crosses showed high SCA effects for seed yield involving low × high GCA parents.

Verma *et al.* (1989) evaluated the nature and magnitude of combining ability and heterosis in a set of 7×7 diallel crosses (excluding reciprocals) of yellow sarson for yield, yield components and oil content. Predominance of additive gene action was observed for yield, primary and secondary branches per plant, siliquae on main shoot, 1000 seed weight and oil content, while it was non additive for siliquae per plant.

Wani and Srivastava (1989) studied combining ability in seven characters for 23 lines of *Brassica juncea* L. and their F_1 and F_2 hybrids and found that parents with high GCA were good general combiners for seed yield.

Siddique *et al.* (1990) studied a complete diallel cross involving four genotypes of *Brassica campestris* L. and their F_1s for nine characters including seed yield per 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 per plant, number of siliquae per plant, number of seeds per siliqua and non additive gene action for days to flowering, plant height, number of primary branches, and length of siliqua were found.

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. High GCA parents were identified as good combiners for seed yield, earliness, siliqua length, number of seeds per siliqua and 1000 seed weight. Majority of the crosses showed high SCA effects for seed yield involving either high × low or low × high general combiners.

Habetinek (1993) worked with *Brassica napus L.* and found higher GCA effects than SCA for all characters except seed per plant. The genotype of Darmor had the highest GCA for number of seeds per siliqua, siliqua length and 1000 seed weight, while sonata had the highest GCA for oil content. SCA for seed yield per plant was highest in crosses of high × low GCA parents.

Singh *et al.* (1996) worked with combining ability analysis of eight diverse cultivars for ten characters in *Brassica juncea* L. They reported that high magnitude most of the characters for plant height, siliqua length and 1000 seed weight for which high estimates of H2 were also recorded. The parent with high GCA effects was best general combiners for seed yield, oil content, 1000 seed weight, plant height, number of primary branches and length of siliqua. Glossy mutant, an early white flowered parent, showed desirable GCA for early flowering, reduced plant height and it was involved in crosses with high SCA for seed yield, oil content and seeds per sililqua but it's per SCA performance and GCA was low. Oil content was positively associated with 1000 seed weight and seed yield indicating the possibility of simultaneous improvement for these characters. Yellow color of corolla was dominant over white and segregated in 15:1 ratio, indicating control of duplicate genes.

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.

Thakur and Sagwal (1997) evaluated combining ability analysis in nine parent diallel analysis of *Brassica napus.* They reported that mean squares due to general and specific combining ability were significant, suggesting the importance of both additive and dominance components. Parents GSL, 8809, HPN-1, GSL, 1501 and HNS 8803 were good combiners for seed yield and some of its components and oil content. Estimates of heterosis over better parent (BP) for various traits indicated significant magnitude for seed (-14.8 to 82.8%), primary branches (-26.0 to 193.6%) and siliquae per plant (-21.9 to 162.6%). Unidirectional dominance was observed for most of the traits studied. The cross GSB 7027×HNS 8803 gave highest positive heterosis for seed yield per plant.

Varshney and Rao (1997) evaluated combining ability, heterosis and inbreeding depression in yellow sarson for 11 quantitative characters. Non additive genetic variance was preponderant for all characters in both F_1 and F_2 generations except for 1000 seed weight in F_2 generation. For seven characters, the best F_2s on the basis of SCA involves one parent with high GCA effects and the other with poor or average GCA effects. The hybrids which exhibited highest heterosis also showed higher inbreeding depression.

Sheikh and Singh (1998) observed combining ability analysis, including reciprocals in Indian mustard for ten characters is preponderance of non additive gene action for most of the characters including seed yield and oil content in 10×10 half diallel. Additive genetic variance was more important for plant height and length of siliqua for which high estimate of heritability was also observed. Majority of the crosses showed high SCA effects for seed yield involved high×low GCA parents.

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.

Singh *et al.* (2000) worked with genetic analysis in yellow saron, *Brassica campestris.* 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 component wee involving in the expression of all the traits. The parents with high GCA was showed good general combining ability for seed yield, days to maturity and siliquae 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 yields.

Matho and Haider (2001) worked with the magnitude of specific combining ability effects was much higher than the general combining ability 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.

Sarkar and Singh (2001) evaluated ten *Brassica juncea* L. parents and their 45 F_1 population. GCA and SCA variance were significantly different among parents and crosses for all the characters except for early vigor. The parents with high GCA effects was showed good general combining ability for plant height, number of primary and secondary branches, siliquae per plant and seeds per plant. Comparison of SCA effects in relation to GCA effects of respective parental lines indicated that crosses with high SCA effects involved high × low general combiners for yield and seeds per siliqua.

Singh *et al.* (2001) worked with a partial diallel analysis (S=7) involving 20 parents was studied in F_1 and F_2 generations in yellow sarson. The variances for general and specific combining ability were highly significant in both generations. The estimated components of variance revealed that additive gene action was more important for days to flowering, days to maturity and plant height in both generations. Primary branches per plant, secondary branches per plant, siliqua length and siliquae per plant showed additive gene action in F_1 but non additive in F_2. Non additive gene action played a major role in genetic variation for seeds per siliqua and seed yield per plant in both the generations. Parental performances as judged by GCA effects indicate that AJL 4, AJL 18, AJL 19, AJL 20, AJL 55, AJL 43 and YID 1 were promising genotypes may be used as potential source in hybridization programme.

In a line × tester analysis involving 29 promising female and seven male parents of 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 mustard 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) analyzed 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.

Aahrya and Swain (2004) observed combining ability analysis in a 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 days 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.

Chowdhury *et al.* (2004a) 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.

Yadav *et al.* (2005) found significant differences due to parents vs. crosses indicating the presence of heterosis in the crosses. They studied the nature of combining ability for seed yield and other yield-attributing characters through line × tester analysis in rape (*Brassica 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. 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 seed yield per plant which involved both good combining parents.

Nair *et al.* (2005) worked on combining ability in Indian mustard 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 the 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.

2.2 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.

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 siliquae/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, siliquae length and number of seeds/siliqua. Highest positive heterosis secondary branches, siliquae length and number of seeds/siliqua. Highest positive heterosis for seed yield was observed in the cross RLM198 x RH30 and was followed by the crosses RLM514 × Varuna; RL18 × Varuna and RS64 × Varuna, RLM198 × RH30 also recorded highest heterobeltiosis for secondary branches.

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 Heiko (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 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 delayed in maturity when compared with their parents.

A male sterile line, European-xinping 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 F_1 hybrids yielded 19.2-34.8% more than CV. Kunming-Gaoke.

Krzymanski *et al.* (1994) found significant heterosis for seed yield in F_1 over better parent in the first generation but not in the second.

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_1 hybrids. A number of hybrids expressed heterosis for seed yield and its component. The average heterosis over better parent for seed yield was 21.3%. The crosses showed significantly high positive heterosis for seed yield in all cases except had high negative heterosis for yield in DTS×YST151.

Ahmadi (1993) worked with parents and F_1 hybrids from crosses between resynthesized lines and improved double zero varieties. F_1 were early maturing than resynthesized lines and heterosis was observed for spring free growth and plant height. In trials, the best resyn. Line H128 could only produce 87% of the mean yield of the improved varieties.

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).

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.

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 YS 151×Tobin, YS151×Torch and PT 303×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.

Keishnapal 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 genotyoes 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.

Pradhan *et al.* (1993) found from the component character analysis concluded that characters such as number of primary and secondary branches, number of siliquae/plant and siliqua density contributed significantly to positive heterosis for yield.

Habetinek (1993) determined plant length, siliqua length, no. of seeds/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 (5s3 and 4s4) and their pollinator, taplidor and 9 F_1 hybrids derived by top crossing.

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.

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. Banga and Labana (1984) reported several important findings on heterosis of Indian mustard (*Brassica juncea*). They studied 139F_1 of two groups Indian and European lines. High heterosis was also estimated for number of secondary branches.

Bodwal and Labana (1987) studied *Brassica juncea* for seed yield/plant and other eight related characters. In F_1, they found positive and significant heterosis for almost all traits. In a study for heterosis and cytoplasmic-henetic 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 (1982) studied 140 F_1 hybrids of winter oil seed rape (*Brassica napus* L) and found that for seed yield average hybrid vigor 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 eraphasizes the interest of hybrid varieties for improving yield.

Schuster *et al.* (1978) reported heterosis of 203% for seed yield, 211% for number of seeds /siliqua and 178% for no. of siliquae/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 characters. According to them heterosis for different characters varied widely due to cross combination.

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.

Chapter 3
Methodology

CHAPTER 3

MATERIALS AND METHODS

Experimental site and duration

The experiment was conducted at the experimental farm of Sher-e- Bangla Agricultural University, Dhaka, during the period November 2007 to March 2008. The land was of medium high and sandy loam soil texture. The site was situated in the subtropical climatic zone, wet summer and dry winter is the general climatic feature of this region. The rainfall at the beginning of the experimental period was very high. Temperature was initially high. During the rabi season the rainfall generally is scant and temperature moderate with short day length (Fig. 1).

Plant Materials

Seven diverse genotypes of rapeseed namely P_7, P_6, P_5, P_3, P_2, P_{10} and P_{11} were selected as parents based on their performance evaluated in the previous experiments. The seeds of 21 F_1s obtained from seven parents crossed in all possible combinations excluding reciprocals were the materials of the experiment. The cultivars were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

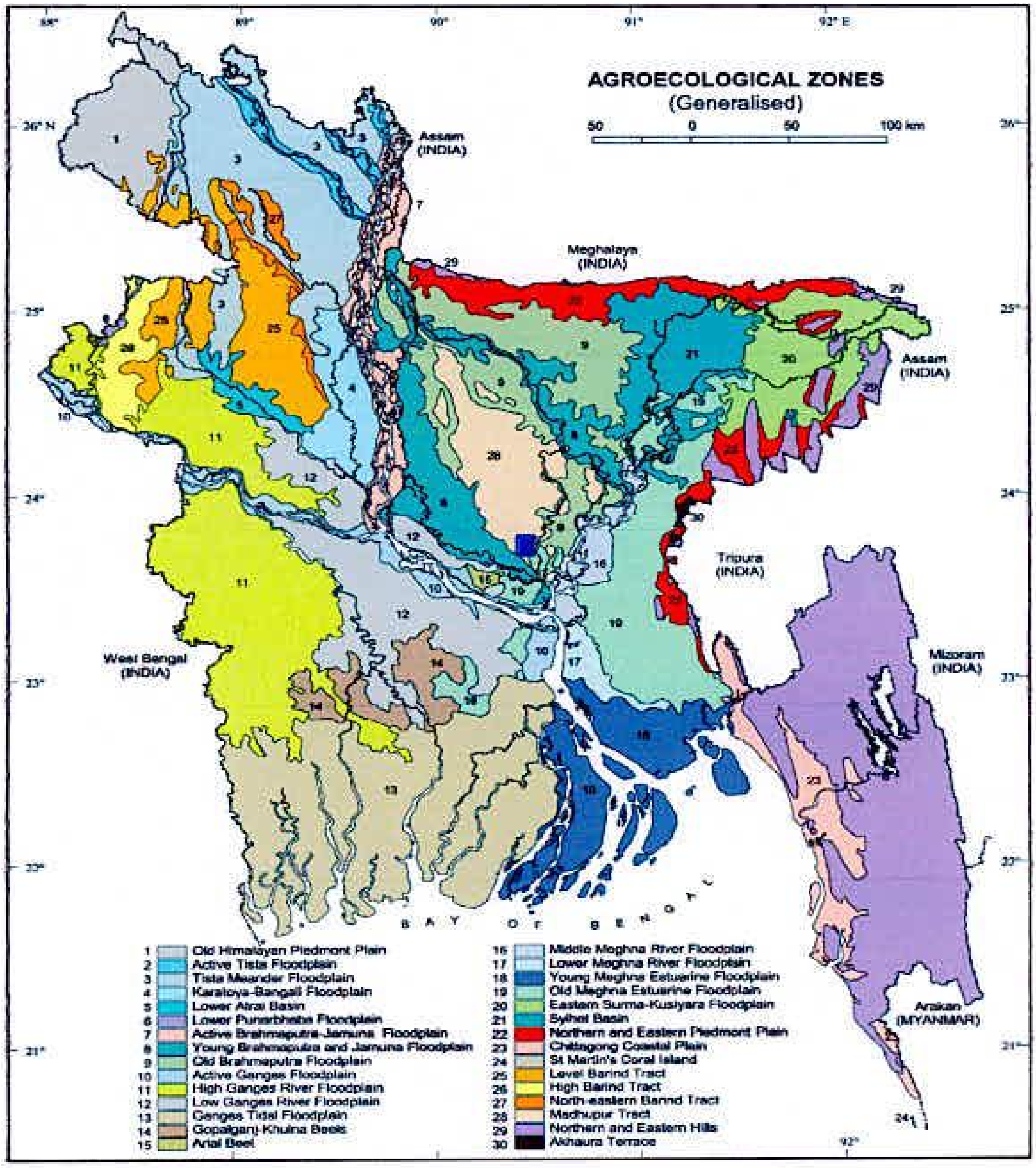


Figure 1. Location of the experimental field

Land preparation and fertilizer application

The experimental plots were prepared with tractor ploughing followed by harrowing and laddering to bring to the desired tilth. Chemical fertilizers were applied at the rate of 120-80-60-40-4 kg/ha of N-P-K-S-B from urea, triple super phosphate (TSP), Muriate of potash (MP), Gypsum and Boric acid were applied at the rate of 10 ton per ha. Cowdung, 50% urea and whole amount of TSP, MP, Gypsum and boric acid were applied during final land preparation. The remaining 50% urea was applied as top dressing during flower initiation stage.

Experimental design and layout

Twenty one F_1s along with their seven parents were grown on November 12, 2007. The seeds were sown continuously in a randomized block design with 3 replications. Each F_1 line and their parents comprised of single rows of 2.5m long with a spacing of 30 cm between rows and 10 cm between plants. The genotypes were randomly distributed to each row within the blocks in each replication. The seedling emerged three to four days after sowing. Plant spacing within the rows was maintained by thinning after 15 days of seedling emergence (Table 1).

Table 1. The treatment distributed in Randomized Block Design

B = Block

B1	B2	B3
$P_5 \times P_{11}$	$P_7 \times P_{11}$	$P_7 \times P_3$
$P_6 \times P_{10}$	$P_7 \times P_3$	$P_6 \times P_{10}$
$P_7 \times P_5$	$P_3 \times P_{10}$	$P_2 \times P_{11}$
$P_6 \times P_{11}$	P_{10}	$P_7 \times P_2$
$P_7 \times P_6$	$P_6 \times P_3$	P_6
P_2	P_5	$P_2 \times P_{10}$
$P_5 \times P_3$	$P_6 \times P_{11}$	P_{11}
$P_3 \times P_2$	$P_5 \times P_{10}$	$P_6 \times P_5$
$P_7 \times P_3$	P_7	$P_5 \times P_2$
$P_7 \times P_{10}$	$P_7 \times P_{10}$	P_5
P_5	$P_5 \times P_3$	$P_6 \times P_2$
$P_6 \times P_3$	P_{11}	P_{10}
$P_2 \times P_{11}$	$P_3 \times P_2$	$P_7 \times P_5$
$P_6 \times P_5$	$P_6 \times P_5$	$P_6 \times P_3$
$P_3 \times P_{10}$	$P_5 \times P_2$	P_2
P_{11}	$P_7 \times P_5$	$P_3 \times P_{10}$
$P_7 \times P_2$	P_3	$P_3 \times P_2$
$P_6 \times P_2$	$P_2 \times P_{11}$	$P_7 \times P_{10}$
P_3	P_6	P_7
$P_2 \times P_{10}$	$P_5 \times P_{11}$	$P_6 \times P_{11}$
$P_5 \times P_2$	$P_6 \times P_{10}$	P_3
P_6	P_2	$P_7 \times P_{11}$
P_7	$P_7 \times P_6$	$P_{10} \times P_{11}$
$P_{10} \times P_{11}$	$P_{10} \times P_{11}$	$P_5 \times P_3$
$P_5 \times P_{10}$	$P_3 \times P_{11}$	$P_7 \times P_6$
P_{10}	$P_6 \times P_2$	$P_5 \times P_{10}$
$P_7 \times P_{11}$	$P_7 \times P_2$	$P_3 \times P_{11}$
$P_3 \times P_{11}$	$P_2 \times P_{10}$	$P_5 \times P_{11}$

Seed sowing

Sowing of seeds was done in the dry soil. Seeds of each genotype were sown in single row on November 12, 2007 by hand uniformly. After sowing, the seeds were covered with soil carefully so that no clods on the seeds.

Irrigation and drainage

One post sowing sprinkler irrigation was given 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 field 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 of seedlings was done during first weeding after 10 days of germination. The second weeding was done before flowering followed by top dressing of urea. Aphid infestations were found in the crop during the siliquae development stage. To control aphid's diazinon 60 EC at the rate of 1ml per liter was applied. No remarkable disease attack was observed.

Crop harvesting

The plants of each block were harvested when 80% of the plants showed symptoms of maturity (straw color of leaves, stem and desirable seed color in the matured siliquae). Ten randomly selected matured plants from each line were cut at the base with the help of sickle and kept separately to avoid seed mixture between lines. Data were collected from these ten plants.

Data collection

Observations were made on the following quantitative characters:

1. Days to 50% flowering: when more than 50 percent plants had at least one open flower.

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

3. Plant height (cm): mean height in cm measured from top of the soil to top of the main stem.

4. Number of primary branches per plant: mean number of branches originated from the main stem from ten randomly selected plants from each F_1s and parents at maturity.

5. Number of secondary branches per plant: mean number of branches originated from the primary branch from ten randomly selected plants from each F_1s and parents at maturity.

6. Siliquae per plant: mean number of siliquae obtained from ten randomly selected plants from each F_1s and parents at maturity.

7. Length of siliqua (cm): mean length of siliqua in cm measured from bottom of the stalk to the top of the siliqua.

8. Seeds per siliqua: mean number of seeds counted from ten randomly selected siliquae.

9. 1000-seed weight (g): weight in grams of 1000-seed was recorded from ten randomly selected plants of each F_1s and parents.

10. Seed yield per plant (g): mean seed weight in grams of ten randomly selected plants from each F_1s 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 calculated 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 was 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, ... p

K = 1,2, ... b

L = 1,2, ... 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:

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

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

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.)

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

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

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

Front view

Close view

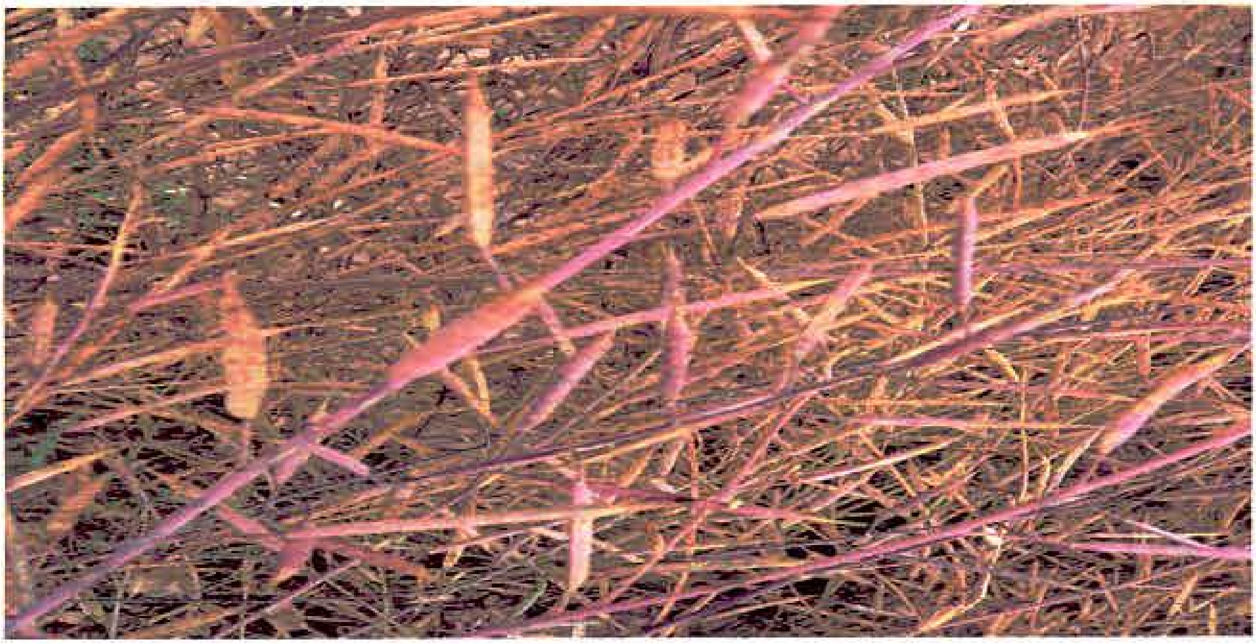
Plate 1. Field view at hybridization stage (front and close view)

Front view

Close view

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

Front view



Close view

Plate 3. Field view at maturity stage (front and close view)

Chapter 4
Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

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 2) revealed highly significant variation among the parents and hybrid indicating the presence of variability in the material. Variance due to genotype was significant for all the traits except plant height and number of seeds per siliqua. In case of cross-only number of seeds per siliqua showed significant variation. Variance due to parents was 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 3). 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 3). 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 Yellow sarson

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 per siliqua 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 yellow sarson.

Table 2: Analysis of variance for seed yield per plant and its component characters in *Brassica rapa* genotypes

Source of Variation	df	Days to 50% flowering	Days to maturity	Plant height	Number of primary branch	Number of secondary branch	Number of siliquae per plant	Length of siliqua	Number of seeds per siliqua	Thousand seed weight	Seed yield per plant
Replication	2	0.08	2.51	190.00**	0.47	5.72	6807.21	0.21	10.65**	0.20	9.78**
Genotype	27	10.76**	28.09**	437.09**	1.69*	39.28*	12517.52	1.04	14.58**	0.30**	19.42**
Cross	20	11.55	28.36**	532.56**	1.72	29.37	10348.85	0.72	18.15	0.33	20.40**
Parent	6	6.86**	22.16	182.20	1.63	10.78	1138.28	0.04	4.43	0.27	3.61**
Patent vs cross	1	18.35	58.10	56.95	1.39	408.46*	124166.38	13.59	4.01	0.04**	94.54
Error	54	0.65	4.03	102.79	0.57	9.73	2352.46	0.39	6.68	0.06	2.63

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

Table 3. Analysis of variance for general and specific combining ability for seed yield and yield contributing components in *Brassica rapa* genotypes

Source of Variation	df	Days to 50% flowering	Days to maturity	Plant height	Number of primary branch	Number of secondary branch	Number of siliquae per plant	Length of siliqua	Number of seeds per siliqua	Thousand seed weight	Seed yield per plant
GCA effects	6	2.81*	13.57**	307.85**	0.46	6.11**	1457.98*	0.14	6.64**	0.13	5.55*
SCA effects	21	3.81**	8.16**	99.37**	0.59	15.09*	4948.09*	0.41	4.35*	0.09	6.74**
Error	54	0.22	1.34	34.26	0.19	3.24	784.15	0.13	2.23	0.02	0.88

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

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 pollen 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 (-0.04) ware provided by P_2 for days to fifty percent flowering followed by P_{11}. Hence the parent $P_2$and P_{11} was desired as general combiner in crosses aimed at promoting earliness in rapeseed (Table 4). The parent P_5 showed positive significant GCA effects that ware undesirable general combiners to promote the earliness in *Brassica juncea.* The parents P_6 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 4. GCA effect of 7 parents for 10 charecters in half diallel cross of *Brassica rapa* genotypes

Parent	Days to 50% flowering	Days to maturity	Plant height	Number of primary branch	Number of secondary branch	Number of siliquae per plant	Length of siliqua	Number of seeds per siliqua	Thousand seed weight	Seed yield per plant
P_7	-0.15	0.01	5.77*	0.16	-0.47	-9.56	0.15	1.35*	-0.06	0.77*
P_6	1.14	2.49**	9.78**	0.33*	-1.22	14.76	-0.22	-1.38*	0.18**	-0.81*
P_5	0.14**	-1.54**	-5.39*	-0.15	0.22	0.30	0.07	0.06	-0.02	0.97*
P_3	-0.56	0.01	0.72	-0.24	-0.03	-2.24	-0.04	0.42	0.04	-0.77*
P_2	-0.04**	-0.03	-3.09	-0.01	0.84	15.33	-0.04	-0.48	0.11*	0.47
P_{10}	-0.45	-0.51	-5.74*	-0.26	1.16	1.89	-0.04	-0.37	-0.15**	0.19
P_{11}	-0.08*	-0.43	-2.04	0.17	-0.51	-20.47	0.12	0.41	-0.09	-0.82*
SEgi	0.14	0.36	1.81	0.13	0.56	8.64	0.11	0.46	0.04	0.29

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

b. Days to maturity:

Parent P_5 showed highest significant and negative gca effects (-1.54) and hence P_2, P_{10} and P_{11} cultivars showed insignificant general combiners for early maturity in *Brassica juncea L.* The parent P_6 provided highest significant positive gca effects for days to maturity (2.49) and hence the parent was undesirable general combiners to promote the earliness (Table 4). The parents P_7 and P_3 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 P_{10} exhibited significant negative effects (-5.74) for the parameter followed by P_5 and was good general combiners for breeding dwarf plant type. The highest significant and positive gca effect (9.78) was observed in P_{10} and followed by P_7 these were parents dwarf plant type (Table 4). 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 P_6 provided significant and positive gca effects (0.33) on the primary branches. Other parents showed insignificant positive and negative effects. So the parent P_6 was found good for using in the breeding programme for more primary branches (Table 4) Chowdhury *et al.* (2004) obtained more primary branches on sampad in

Brassica rapa L. Sheikh and Singh (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:

All the parents showed insignificant positive and negative gca effects for this trait. Number of secondary branches per plant was higher in parent P_{10} showed positive gca effects (1.16) for the character (Table 4). The other four parents were undesirable for producing more number of secondary branches. These four 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 exhibited insignificant gca effects. The parents P_6 exhibited positive gca effects for the character, so it was desirable to use in hybridization programme to improve number of siliquae per plant in *Brassica rapa* L. (Table 4). 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 siliqua:

All the parents found insignificant negative and positive gca effects on length of siliquae, Length of siliqua was highest in parent P_6 which showed positive gca effects (1.16) for the character (Table 4). So there was no opportunity except P_7 to improve the length of siliqua 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 P_7 (1.35). Thus this parent was found best general combiners to increase the number of seeds per siliquae in these parents (Table 4). The parent P_6 showed significant but negative gca effects, so it is undesirable to improve this trait. Other parents showed insignificant positive and negative 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. Thousand seed weight:

Significant and positive gca effects for hundred seed weight was observed in P_6 (0.18) followed by P_2. The parent P_3 showed insignificant positive effects for the trait. The parent P_{10} exhibited significant negative gca effect. The other three parents exhibited insignificant negative gca effect (Table 4). 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 P_5 (0.97) parent followed by P_7. On the other side, P_3, P_6 and P_{11} showed higher significant negative value for this character, which indicates that these parents were not fit to increase seed yield? Other parents showed insignificant gca effect for the character (Table 4) 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 *Brassica 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 seven different characters studied are presented in (Table 5). 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:

a. Plant height:

Significant and positive sca effects was observed in the cross combinations, $P_6 \times P_5$ (18.53) and followed by the combination of $P_6 \times P_2$ and $P_7 \times P_3$ on plant height. The crosses $P_5 \times P_2$ and $P_3 \times P_{10}$ showed significant negative sca effects on plant height (Table 5). 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 $P_7 \times P_6$ (-2.70), $P_7 \times P_3$ (-1.67), $P_6 \times P_2$ (-1.81), $P_6 \times P_{11}$ (-2.11), $P_5 \times P_2$ (-1.81) and $P_2 \times P_{11}$ (-1.59) for days to fifty percent flowering (Table 5). Significant and positive sca effects was observed in the cross combinations, $P_7 \times P_2$ (4.48), $P_6 \times P_{10}$ (2.93) and $P_3 \times P_{11}$ (3.59). Thus, the cross combinations, $P_7 \times P_2$provide opportunity for earliness in mustard *(Brassica rapa* 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.

Table 5. SCA effects for 10 characters in half diallel cross of *Brassica rapa*

Cross	Days to 50% flowering	Days to maturity	Plant height	Number of primary branch	Number of secondary branch	Number of siliqua per plant	Length of siliqua	Number of seed per siliqua	Thousand seed weight	Seed yield per plant
P 7 x P 6	-2.70**	-2.99**	-8.52	-0.09	0.99	3.67	0.00	0.09	-0.46**	-0.66
P 7 x P 5	1.30**	-0.95	0.80	0.46	-1.16	-47.28	-0.15	-2.12	0.25**	-1.41
P 7 x P 3	-1.67**	3.49**	14.51*	0.40	4.49*	143.13**	-0.29	1.00	0.11	2.97**
P 7 x P 2	4.48**	-0.14	-7.81	0.40	1.24	8.12	-0.38	0.13	-0.15	-1.32
P 7 x P 10	0.22	-0.32	4.14	0.67	-3.19	-46.86	-0.21	-0.27	0.39**	2.78**
P 7 x P 11	-0.81	-0.73	5.45	-1.06*	1.92	53.78*	0.08	2.90*	-0.14	1.80*
P 6 x P 5	1.33**	2.90*	15.83*	0.21	-1.58	13.81	-0.65	-2.56	0.35**	-0.96
P 6 x P 3	-0.63	0.34	-0.06	0.23	3.96**	83.16**	0.11	0.62	-0.19	1.75*
P 6 x P 2	-1.81**	1.05	14.34*	0.58	-1.57	46.50	-0.22	-4.26**	0.45**	-1.35
P 6 x P 10	2.93**	0.53	8.16	0.67	2.88	10.74	-0.94**	-0.57	-0.09	0.14
P 6 x P 11	-2.11**	-3.21**	1.44	-1.23**	2.67	29.47	0.45	5.63**	-0.38**	3.38**
P 5 x P 3	0.04	-3.29**	1.70	-0.34	0.62	27.60	0.12	-0.92	0.08	0.58
P 5 x P 2	-1.81**	0.08	20.82**	0.22	4.34*	93.10**	-0.12	1.07	-0.52**	7.57**
P 5 x P 10	-0.07	-0.44	-0.62	0.39	1.90	35.18	0.76*	3.86**	0.47**	0.95
P 5 x P 11	-0.11	5.16**	-0.28	-0.70	3.01	-1.70	-0.95**	-1.47	-0.27*	0.65
P 3 x P 2	-0.44	3.53**	-6.15	-1.59	0.20	-68.83*	-0.56	0.68	-0.22	-0.46
P 3 x P 10	0.30	-2.66*	-13.44*	-0.81	-2.19	-45.49	-0.37	-0.80	-0.35**	-3.66**
P 3 x P 11	3.59**	4.27	0.28	-0.24	1.20	18.54	-0.67*	-0.15	0.39**	-0.10
P 2 x P 10	1.11*	2.38*	-4.47	0.60	8.72**	109.56	-0.72*	-0.50	0.20	1.45
P 2 x P 11		-3.36**	1.44	0.30	-1.36	-32.73	0.55	2.79*	0.09	0.57
P 10 x P 11			2.12	0.43	-2.10	19.05	-0.05	-0.50	-0.24	0.87
SEsij			5.25	0.39	1.62	25.13	0.32	1.34	0.12	0.84

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

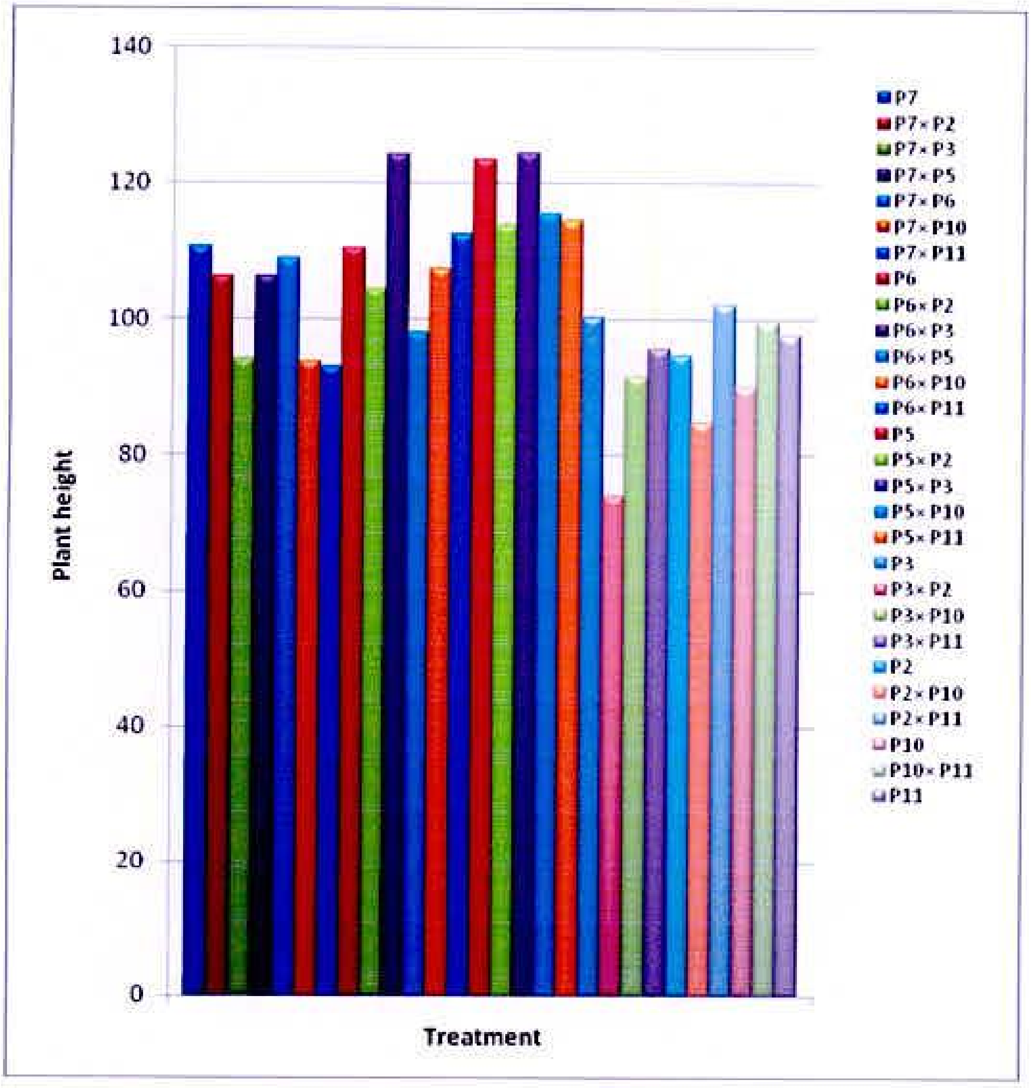


Figure 2. Graphical representation of treatment vs plant height

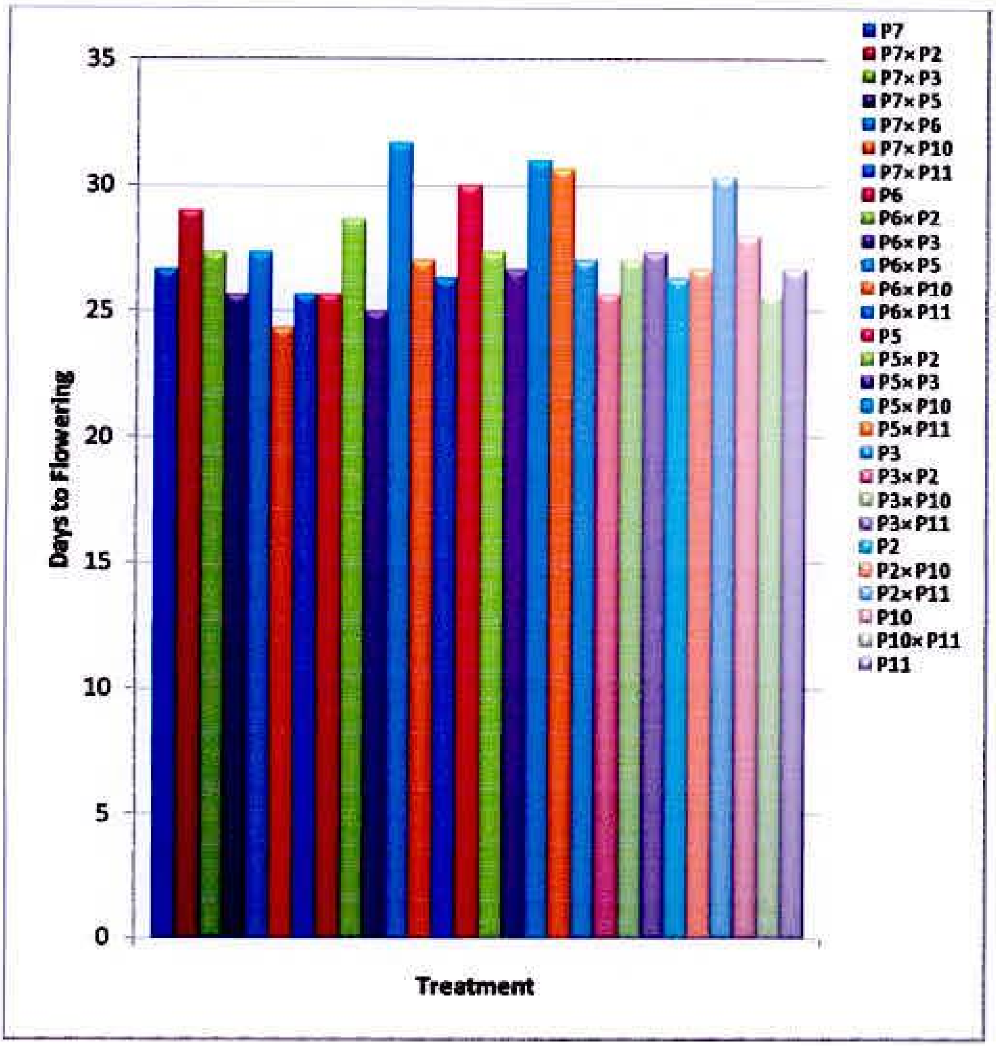


Figure 3. Graphical representation of treatment vs days to 50% flowering

c. Days to maturity:

The cross combination $P_7 \times P_6$, $P_6 \times P_{11}$, $P_5 \times P_3$, $P_3 \times P_{10}$ and $P_2 \times P_{11}$ showed significant and negative sca effects, provides opportunity for early maturity in *Brassica rapa* L. (Table 5). Significant and positive sca effects was observed in the cross combinations, $P_7 \times P_3$, $P_6 \times P_5$, $P_5 \times P_{11}$, $P_3 \times P_2$ and $P_2 \times P_{10}$.While other hybrids exhibit insignificant positive and negative value form the parameter. Chowdiiury *et al.* (2004) observed earliness in M-27 × Din-2 in *Brassica 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.

d. Number of primary branches per plant:

The cross combinations $P_7 \times P_{11}$ and $P_6 \times P_{11}$ were found to be the specific combiner to improve plants with less number of primary branches as they showed significant negative sca effects for this trait (Table 5). 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.

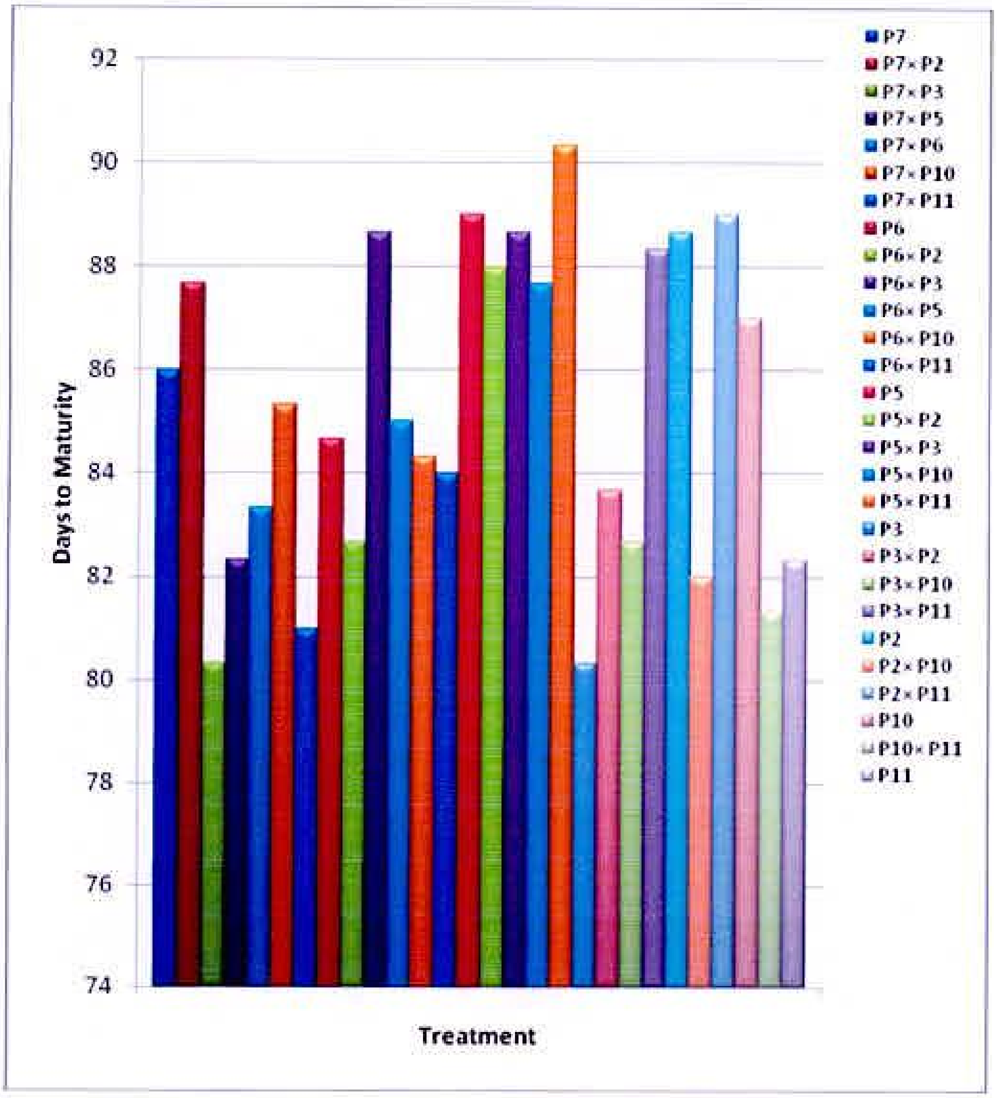


Figure 4. Graphical representation of treatment vs days to maturity

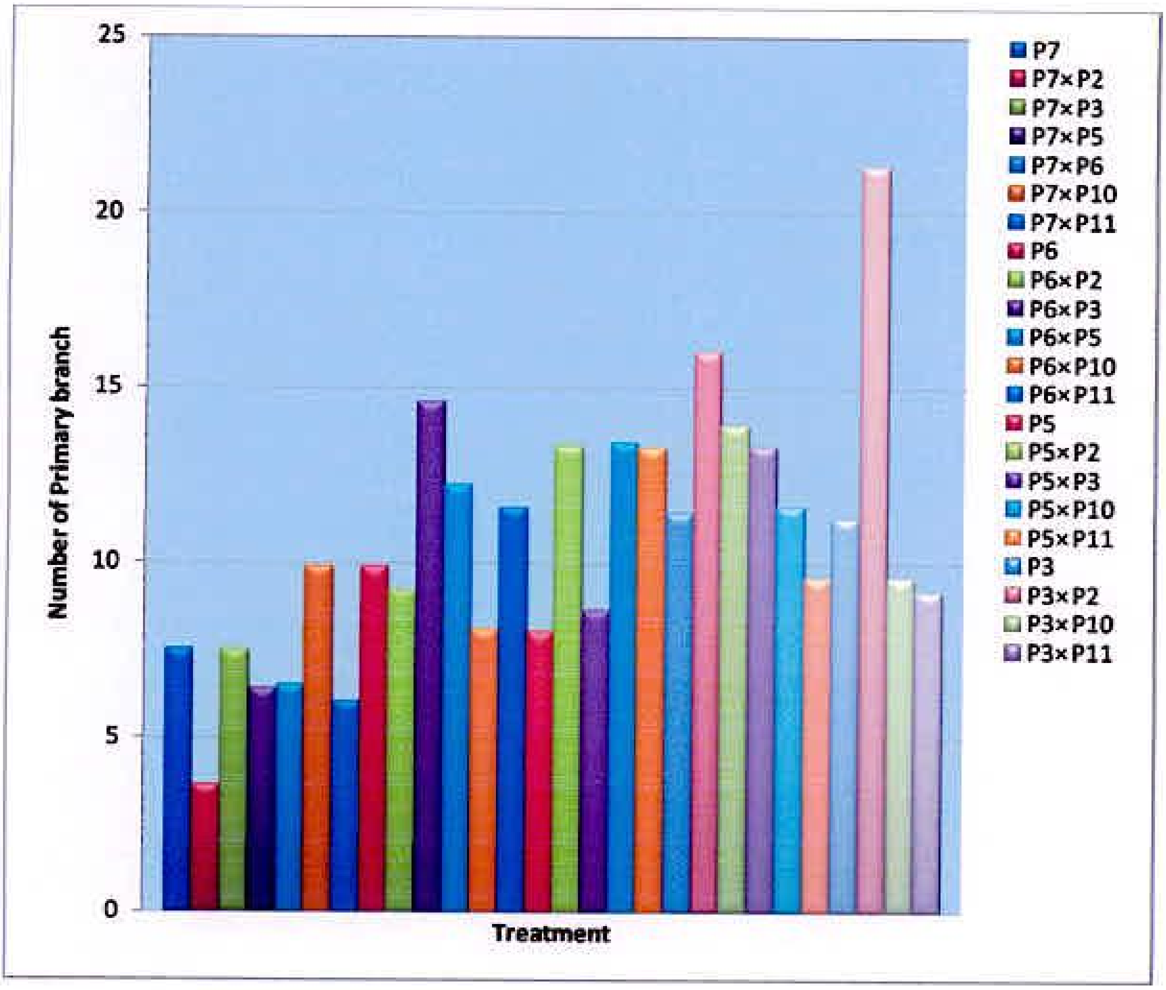


Figure 5. Graphical representation of treatment vs primary branches

e. Number of secondary branches per plant:

The cross $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$ and $P_2 \times P_{10}$ exhibited significant positive sca effects for this trait, rest of the crosses showed insignificant positive and negative sca effects (Table 5). Thus $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$ and $P_2 \times P_{10}$ 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.

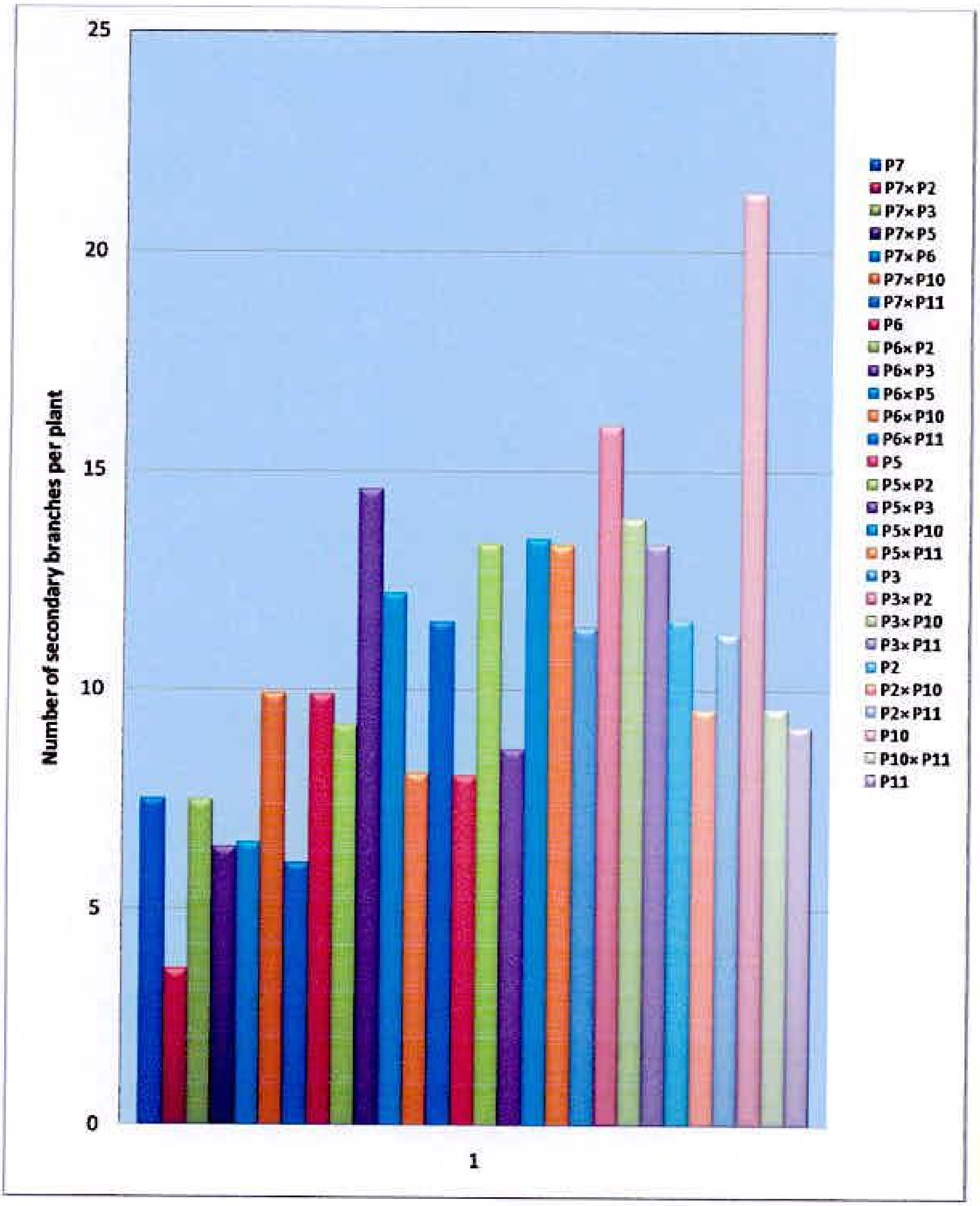


Figure 6. Graphical representation of treatment vs secondary branches

f. Number of siliquae per plant:

Among the cross combinations, $P_7 \times P_3$, $P_7 \times P_{11}$, $P_6 \times P_3$ and $P_5 \times P_2$ showed significant and positive sca effects and produced maximum siliquae and the cross combination $P_3 \times P_2$ and rest of the crosses showed significant negative sca effects (Table 5). 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 $P_7 \times P_{11}$, $P_6 \times P_{11}$, and $P_5 \times P_{10}$ and $P_2 \times P_{11}$ exhibited significant and positive sca effects for seeds per siliquae. The cross $P_6 \times P_2$ combinations showed significant negative sca effects (Table 5). The other crosses exhibited insignificant positive and negative 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.

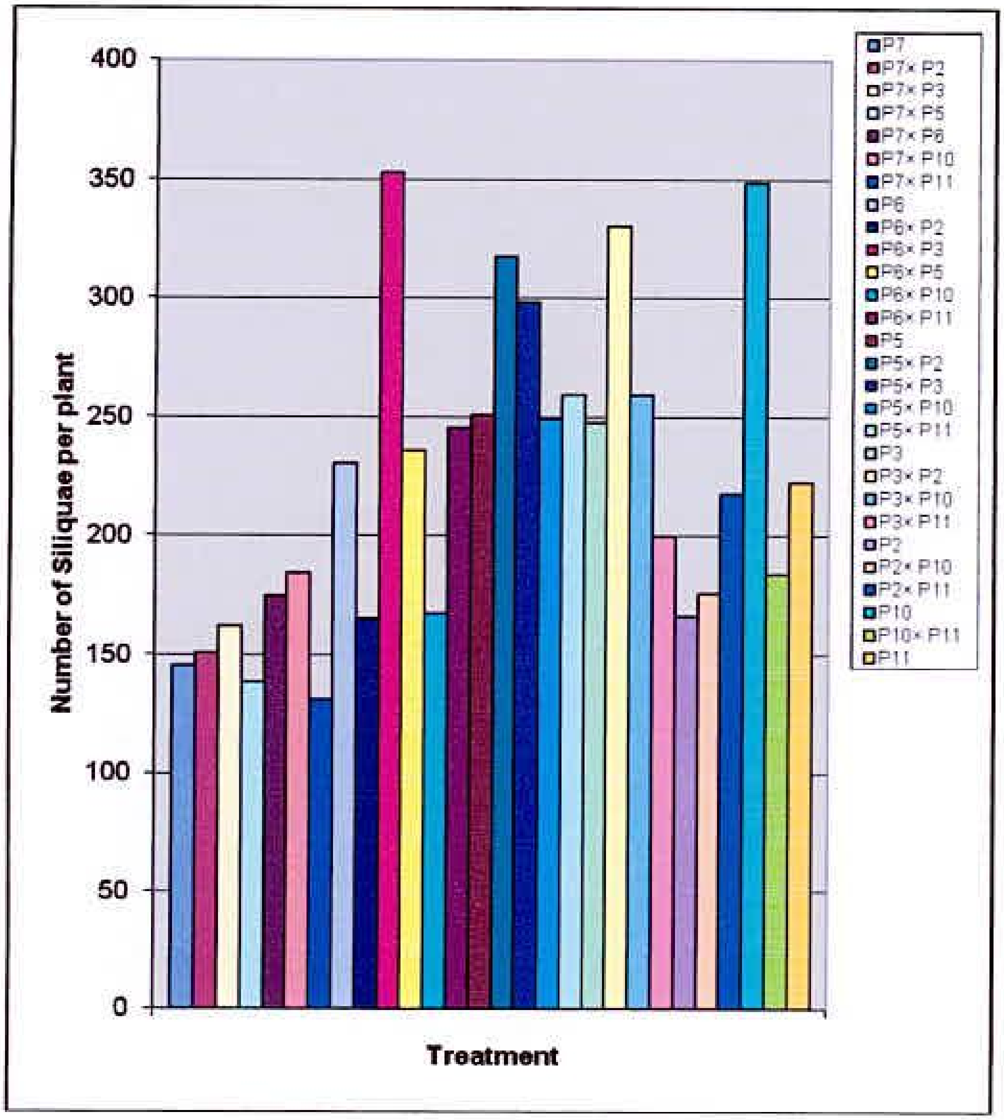


Figure 7. Graphical representation of treatment vs siliquae/plant

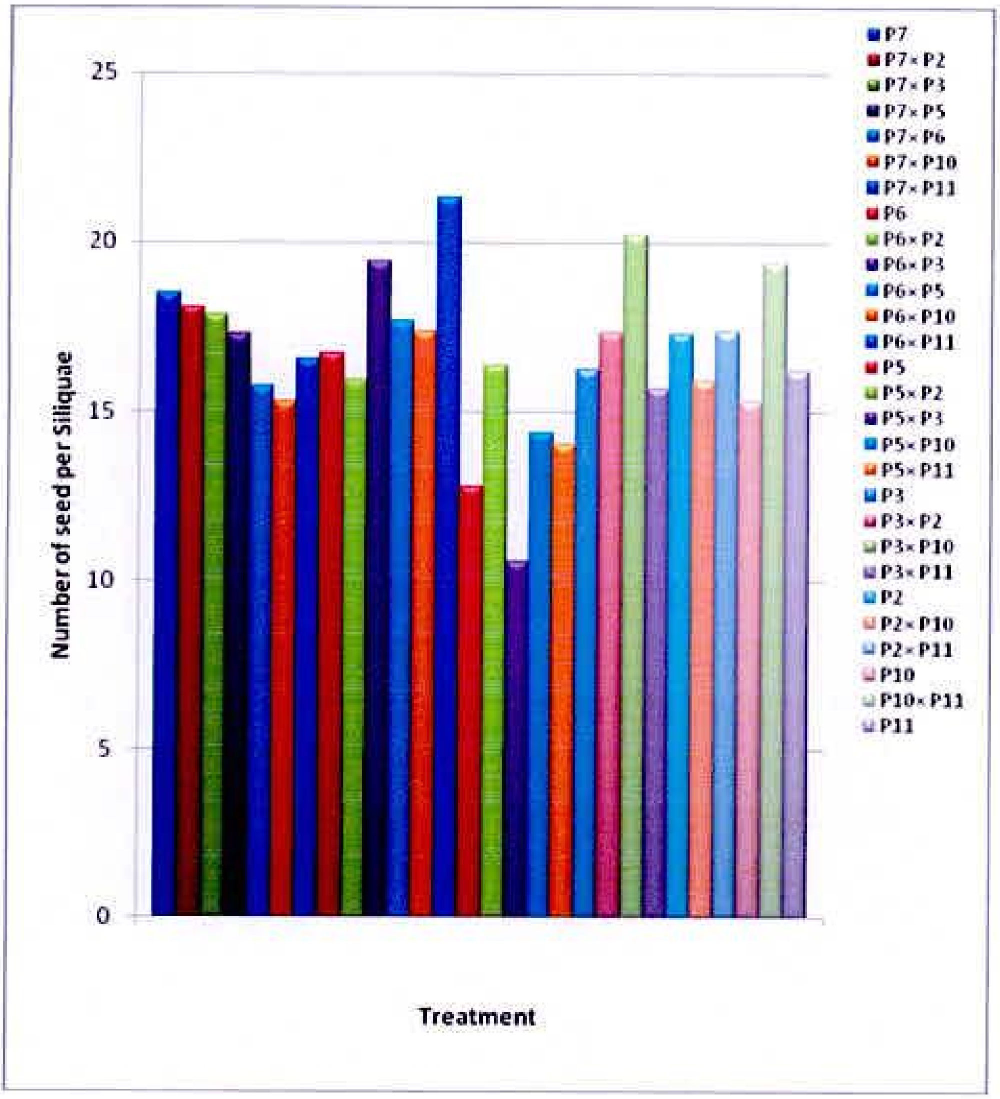


Figure 8. Graphical representation of treatment vs seeds/siliquae

h. Length of siliqua:

Among the cross combinations, $P_6 \times P_{11}$, $P_5 \times P_{11}$, $P_3 \times P_{11}$ and $P_2 \times P_{10}$ showed significant and negative sca effects. Others showed positive and negative insignificant sca effect (Table 5). 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 $P_7 \times P_5$, $P_7 \times P_{10}$, $P_6 \times P_2$ and $P_6 \times P_{11}$ exhibited significant and positive sca effect (0.272). The crosses $P_7 \times P_3$ $P_5 \times P_3$, $P_2 \times P_{10}$ and $P_2 \times P_3$ showed positive insignificant sca effect for the character (Table 5). 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 campestris* 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.

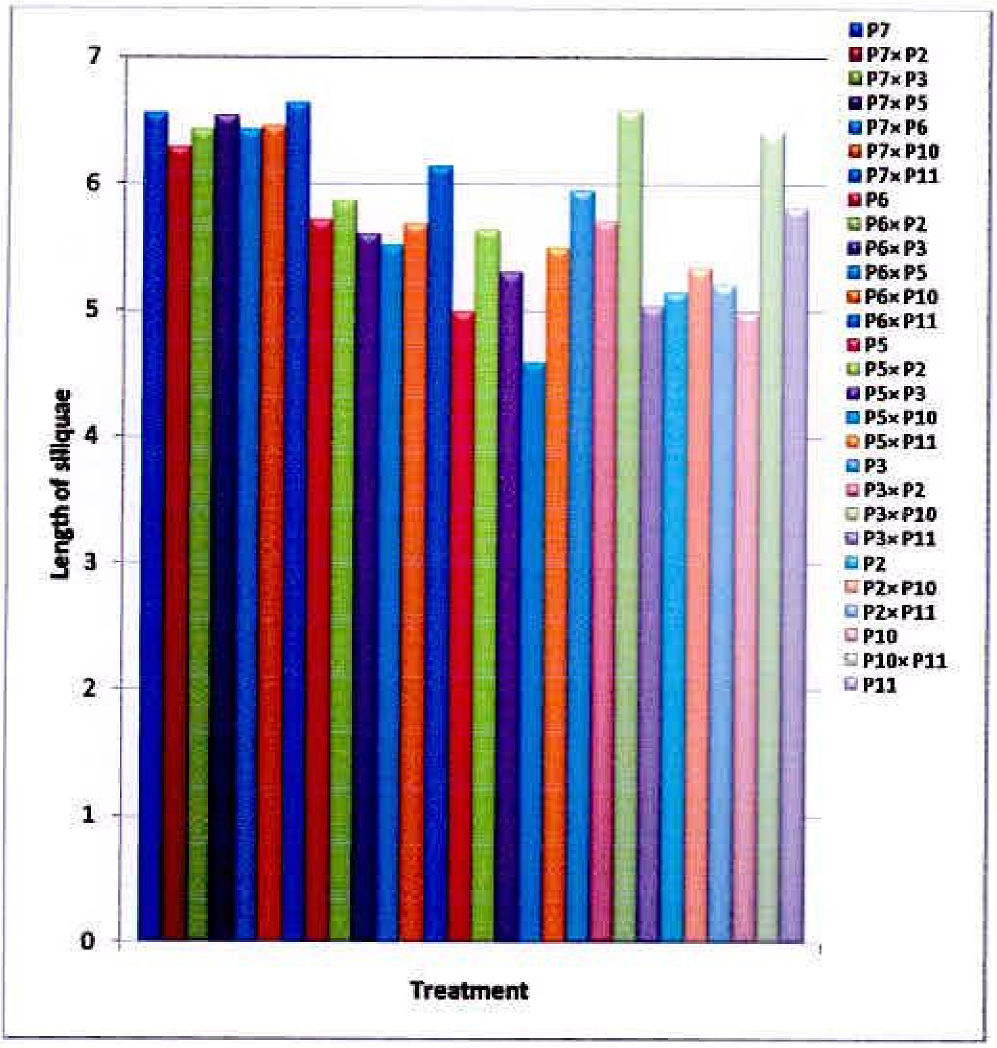


Figure 9. Graphical representation of treatment vs length of siliquae

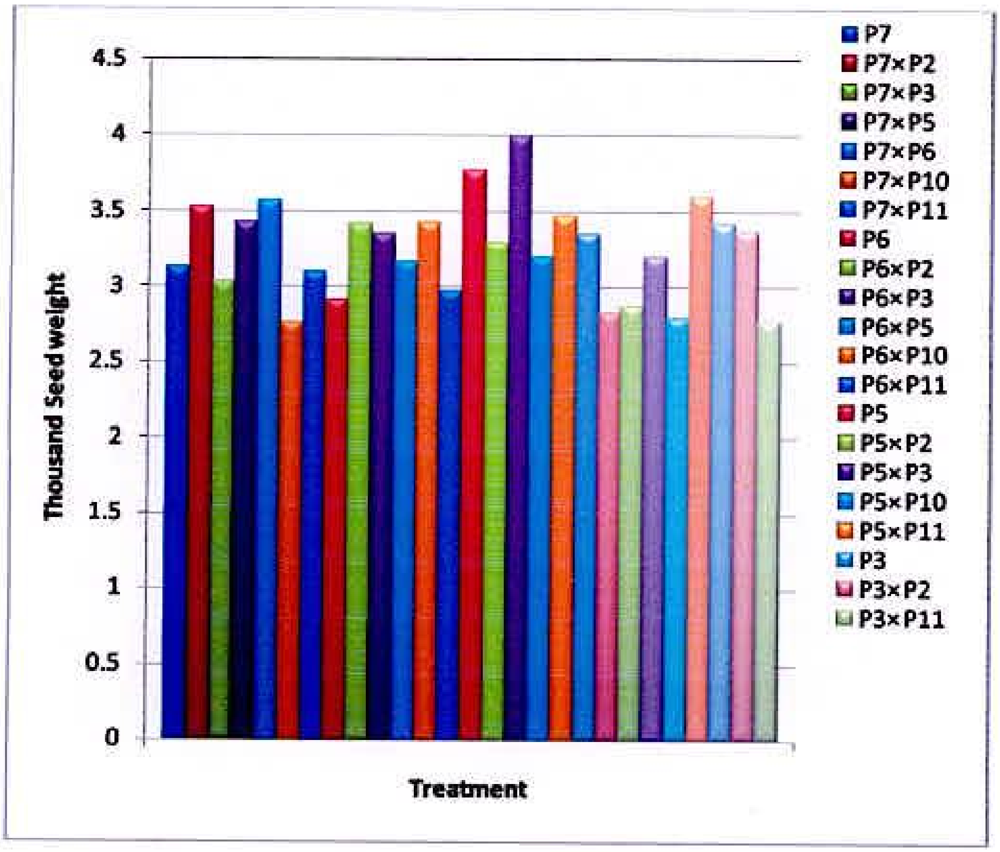


Figure 10. Graphical representation of treatment vs thousand seed weight

j. Seed yield per plant:

The cross combinations $P_5 \times P_2$ exhibited highest significant and positive sca effect (7.57) followed by $P_6 \times P_{11}$, $P_7 \times P_3$, $P_7 \times P_{10}$ and $P_6 \times P_3$ for seed yield per plant. The cross combinations $P_3 \times P_{10}$ exhibited significant and negative sca effect. Thus, $P_5 \times P_2$, $P_6 \times P_{11}$, $P_7 \times P_3$, $P_7 \times P_{10}$ and $P_6 \times P_3$ were the best specific combinations for the improvement of seed yield per plant in *Brassica rapa* L. (Table 5). 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.

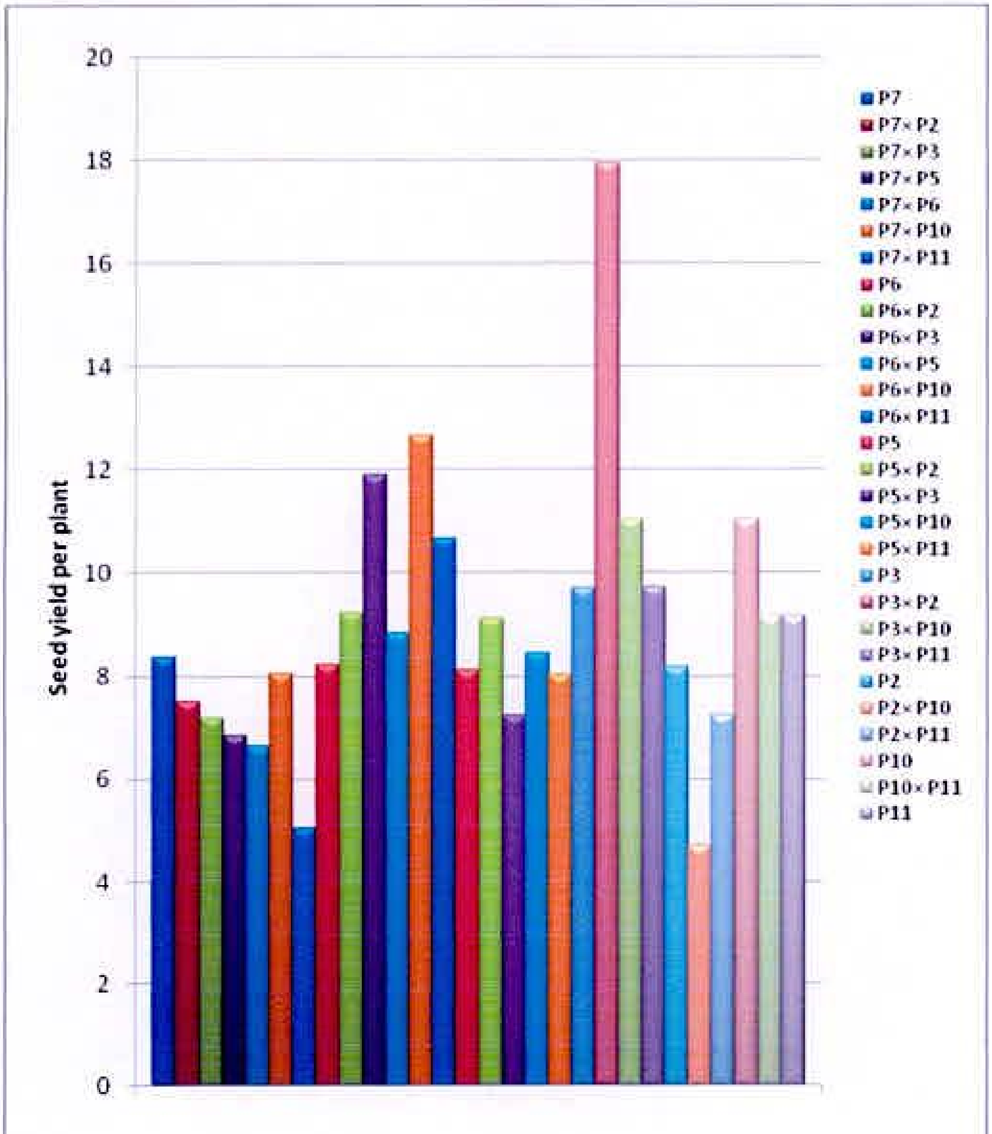


Figure 11. Graphical representation of treatment vs yield/plant

HETEROSIS

Percent heterosis in F_1 over mid parent and pollen parent were estimated for plant height, no. of primary branch, no. of secondary branch, siliqua/plant, length of siliqua, no. of seed/siliqua, 1000 seed wt. date of maturity and seed yield/plant. Positive and negative, significant and insignificant values were obtained. The results have been presented in the Table 6. Only the desirable heterotic values and crosses have been marked and discussed.

a. Days to 50% flowering:

Highly negative significant heterosis was provided by the hybrid $P_7 \times P_6$ (-7.78%) for days to first flowering over mid parent (Table 6). It was followed by the crosses $P_5 \times P_2$ showed significant negative heterosis over mid parent and the other hybrids showed non significant heterosis over mid parent which was not desirable. The hybrids $P_7 \times P_2$, $P_6 \times P_{10}$, $P_6 \times P_{11}$ and $P_3 \times P_{11}$ showed highly positive significant heterosis. It was followed by the crosses $P_2 \times P_{10}$ showed significant positive heterosis over mid parent and the other hybrids showed non significant positive heterosis over mid parent which was desirable. The hybrids $P_7 \times P_6$ showed highly negative significant heterosis pollen parent, $P_5 \times P_2$ also showed significant negative heterosis over pollen parent and the other hybrids showed non significant heterosis over pollen parent which was not desirable. The hybrids $P_7 \times P_2$, $P_6 \times P_{10}$, $P_6 \times P_{11}$, $P_3 \times P_{11}$ and $P_2 \times P_{10}$ showed highly positive significant heterosis over pollen parent and the other hybrids showed non significant positive heterosis over pollen parent which was 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.

Table 6. Percent heterosis over mid parent and better parent for 10 characters in intervarietal hybrids of oleiferous *Brassica rapa*

Cross	Days to 50% flowering		Days to maturity		Plant height		Number of primary branches/plant		Number of secondary branches/plant	
	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent
$P_7 \times P_6$	-7.78**	-11.49***	-2.50	-3.42	1.76	3.80	12.39	17.47	77.65	172.75*
$P_7 \times P_5$	6.17*	4.88	-0.60	2.90	2.05	10.90	12.03	15.41	22.56	22.83
$P_7 \times P_3$	-4.46	-2.60	5.35*	7.69**	14.64	16.91	0.00	-5.64	109.37**	127.30*
$P_7 \times P_2$	17.28***	15.85***	0.39	2.00	-10.52	-9.82	12.12	14.14	74.12	87.62
$P_7 \times P_{10}$	5.88*	10.96**	-1.56	-1.17	5.15	14.49	25.23*	44.51**	-6.99	-18.24
$P_7 \times P_{11}$	0.64	2.60	0.60	3.70	10.50	20.91	-15.49	-19.50	70.20	90.81
$P_6 \times P_5$	6.51*	9.76**	5.95**	10.79***	23.21*	31.12**	15.65	14.06	44.62	7.39
$P_6 \times P_3$	0.00	6.49*	3.53	6.88**	7.00	6.98	4.16	-5.54	165.03**	107.47*
$P_6 \times P_2$	-5.33*	-2.44	3.70	6.40*	15.58	14.22	23.28*	20.21	70.83	33.06
$P_6 \times P_{10}$	16.25***	27.40***	1.35	2.73	15.40	23.04*	34.89**	48.34**	98.28*	35.44
$P_6 \times P_{11}$	12.20***	19.48***	7.11**	11.52***	14.82	23.01*	21.86*	11.50	174.51**	119.59*
$P_5 \times P_3$	1.89	5.19	-1.23	-2.43	0.06	-5.64	-13.90	-20.93	64.35	78.00
$P_5 \times P_2$	-6.10*	-6.10*	2.24	0.40	-27.13**	-32.03**	7.12	5.90	128.85**	146.01**
$P_5 \times P_{10}$	4.52	10.96**	-0.20	-3.12	-2.65	-2.47	18.08	31.86	59.65	40.07
$P_5 \times P_{11}$	3.14	6.49*	9.50***	9.05***	2.11	2.76	-12.11	-18.55	96.90*	120.20*
$P_3 \times P_2$	-0.63	-3.66	7.04**	6.40*	-11.91	-12.93	-32.40**	-26.73*	79.85	78.61
$P_3 \times P_{10}$	6.67*	9.59**	-2.19	-3.91	-15.25	-9.63	-15.89	4.05	16.92	-3.69
$P_3 \times P_{11}$	18.18***	18.18***	8.98***	9.88***	2.59	9.93	-13.86	-13.00	80.82	86.30
$P_2 \times P_{10}$	8.39**	15.07***	3.16	1.95	-11.22	-4.13	23.28	39.45*	159.58***	114.98***
$P_2 \times P_{11}$	-3.14	0.00	-1.01	0.41	-1.32	7.07	5.15	-1.50	52.59	58.34
$P_{10} \times P_{11}$	6.67*	3.90	-1.00	1.65	4.48	4.96	14.24	-3.35	14.73	51.35

*, **, *** significant at 5%, 1% and 0.1% level of probability, respectively

Table 6. Percent heterosis over mid parent and better parent for 10 characters in intervarietal hybrids of oleiferous *Brassica rapa* (contd.)

Cross	Number of siliquae per plant		Length of siliqua		Number seed per siliqua		Thousand seed weight		Seed yield per plant	
	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent	Over mid parent	Over better parent
P7x P 6	55.73	52.93	-11.10	-9.17	-8.57	-7.55	-12.60*	-17.55*	3.59	9.69
P 7x P 5	7.50	1.99	-9.85	-8.92	-12.24	-10.67	11.03	12.86	18.94	28.94
P 7x P 3	148.96***	155.39***	-14.55	-14.42	8.59	12.41	2.03	-2.43	56.28**	73.77**
P 7x P 2	47.30	34.99	-15.21	-14.35	3.11	12.06	-5.47	-11.21	17.69	33.03
P 7x P 10	1.41	-9.33	-12.85	-12.17	2.76	13.47	16.52*	24.40**	54.21**	57.37**
P 7x P 11	77.78*	87.69*	-7.12	-7.68	21.72	28.94	-4.81	-4.30	59.09**	111.76**
P 6x P 5	60.23*	54.69	-21.54*	-22.40*	-28.81*	-28.34	14.72*	24.18**	10.74	13.24
P 6x P 3	119.63***	129.61***	-12.21	-13.91	-7.67	-5.51	-5.65	-4.27	26.92	32.94
P 6x P 2	83.38**	70.90*	-16.64	-17.56	-37.64**	-33.02*	12.68*	12.15	2.33	8.87
P6x P 10	48.62	35.07	-28.23**	-29.19**	-14.08	-6.26	1.69	15.94	8.66	4.93
P 6x P 11	84.05**	98.11*	-15.10	-17.36	-18.99	-15.18	4.52	11.83	27.82	58.96
P 5x P 3	64.80*	78.97*	-8.48	-9.27	-7.63	-6.09	3.71	-2.33	38.45	41.75
P 5x P 2	96.36***	89.30**	-11.43	-11.45	3.03	9.89	-14.14*	-20.56**	159.50	169.77
P 5x P 10	49.58*	40.48	2.02	1.75	21.91	32.06	22.55**	28.62**	44.98*	37.09
P 5x P 11	36.53	52.81	-23.05**	-24.28*	-8.88	-5.24	-6.52	-7.53	59.19*	92.86**
P 3x P 2	6.15	-4.89	-20.78*	-20.10*	4.67	9.72	-8.67	-10.37	21.04	22.86
P 3x P 10	9.03	-4.62	-17.99*	-17.48	-2.32	3.98	-9.58	1.45	-37.02	-41.72*
P 3x P 11	61.75	66.34	-21.18*	-21.78*	2.60	4.91	10.20	16.13*	21.86	43.69
P 2x P 10	94.14***	88.94**	-22.82**	-23.00*	-1.39	0.07	8.01	23.79**	50.22*	37.13
P 2x P 11	20.44	40.59	-1.96	-3.51	20.03	17.22	1.00	8.60	56.61*	81.56*
P 10 x P 11	40.98	69.89	-11.29	-12.49	1.79	-1.99	-5.57	-10.75	40.04	81.82*

*, **, *** significant at 5%, 1% and 0.1% level of probability, respectively

b. Days to maturity:

The hybrids $P_5 \times P_{11}$, $P_3 \times P_{11}$, $P_6 \times P_{11}$, $P_6 \times P_5$ and $P_7 \times P_3$ showed significant positive heterosis over mid parent (Table 6). The other hybrids showed non significant heterosis over mid parent for days to maturity. Highly negative significant heterosis was provided by the hybrid $P_6 \times P_{11}$, $P_6 \times P_5$, $P_3 \times P_{11}$ and $P_5 \times P_{11}$ for days to maturity over better parent. The hybrids $P_7 \times P_3$, $P_6 \times P_5$ and $P_3 \times P_2$ also showed significant positive heterosis over better parent and the other hybrids showed non significant heterosis which was 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.

c. Plant height:

Plant height is an important character for increasing seed yield. Higher plant height might offer a better yield, so significant positive heterosis was desirable. Out of twenty one materials fourteen showed positive heterosis over mid parent values and seven showed negative heterosis (Table 6). These crosses showed negative heterosis and it ranged from -1.32% in $P_6 \times P_{11}$ to -27.13 $P_5 \times P_2$. All negative values were insignificant. The positive heterosis values ranged from 0.06% in $P_5 \times P_3$ to 23.27% in $P_6 \times P_5$. Significant heterosis was found in 2 crosses $P_6 \times P_5$ and $P_5 \times P_2$. Sohoo *et al.* (1993) found heterosis 29.13% over percent for plant height in the crosses of *Brassica juncea* cv. RLM240 with strain 3 of *Brassica napus.*

Out of twenty one materials fifteen showed positive heterosis over better parent values and seven showed negative heterosis over better parent values (Table 6). These crosses showed negative heterosis and it ranged from -32.03% in $P_5 \times P_2$ to -

2.47% in $P_5 \times P_{10}$. All negative values were insignificant. The positive heterosis values ranged from 3.80% in $P_7 \times P_6$ to 31.12% in $P_6 \times P_5$. Significant heterosis was found in 2 crosses $P_6 \times P_5$ and $P_5 \times P_2$.

d. Number of primary branches per plant:

Number of primary branches per plant can play a vital role for developing a high yielding variety. For this trail positive significant heterosis was desirable. Out of twenty one crosses only six crosses such as $P_7 \times P_{11}$, $P_5 \times P_3$, $P_5 \times P_{11}$, $P_2 \times P_{10}$ and $P_2 \times P_{11}$, showed negative heterosis over mid parent for number of primary branches per plant (Table 6). The five negative heterosis values were not significant but only one is significant. Fifteen cross expressed positive heterosis but only four of them were significant. The significant heterosis was observed in the crosses $P_7 \times P_{10}$, $P_6 \times P_2$, $P_2 \times P_{10}$ and $P_6 \times P_{11}$. The negative heterosis values ranged from -12.11% in $P_5 \times P_{11}$ to 32.40% in $P_3 \times P_2$. The positive heterosis values ranged from 0.00% in $P_7 \times P_3$ to 34.83% in $P_6 \times P_{10}$. Kumar *et al.* (1990) found positive heterosis for number of primary branches per plant.

Out of twenty one crosses only seven crosses such as $P_7 \times P_3$, $P_7 \times P_{11}$, $P_5 \times P_3$, $P_5 \times P_{11}$, $P_3 \times P_2$, $P_3 \times P_{10}$ and $P_3 \times P_{11}$ showed negative heterosis over better parent for number of primary branches per plant (Table 6). The five negative heterosis values were not significant but only one is significant. Fifteen cross expressed positive heterosis but only four of them were significant. The significant heterosis was observed in the crosses $P_7 \times P_{10}$, $P_6 \times P_2$, $P_6 \times P_{10}$ and $P_6 \times P_{11}$. The negative hetersis values range from -12.11% in $P_5 \times P_{11}$ to 32.40% in $P_3 \times P_2$ and the positive hetersis values range from 0.00% in $P_7 \times P_3$ to 34.83% in $P_6 \times P_{10}$. Kumar *et al.* (1990) found positive heterosis for number of primary branches per plant.

e. Number of secondary branches per plant:

The hybrid $P_7 \times P_3$, $P_6 \times P_3$, $P_6 \times P_{11}$, $P_5 \times P_2$, $P_5 \times P_{11}$ and $P_2 \times P_{10}$ showed significant heterosis over mid parent and better parent. The cross $P_6 \times P_{10}$ showed significant heterosis over mid parent (Table 6). The cross $P_7 \times P_6$ showed significant heterosis over better parent. Insignificant negative heterosis over mid parent and better parent was observed in the crosses $P_7 \times P_{10}$. The hybrids $P_3 \times P_{10}$ created insignificant negative heterosis over better parent and 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.

f. Number of siliquae per plant:

Number of siliquae per plant has direct contribution towards seed yield. So, positive and significant heterosis is desirable. The highly significant and positive heterosis for siliquae per plant was found in $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$, and $P_2 \times P_{10}$ over mid parent and better parent. The F_1s viz:, $P_7 \times P_{11}$, $P_6 \times P_2$, $P_6 \times P_{11}$ and $P_5 \times P_3$ expressed significant positive heterosis for siliquae per plant over mid parent and better parent (Table 6). The hybrids $P_6 \times P_5$ and $P_5 \times P_{10}$ 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 except $P_7 \times P_{10}$, $P_3 \times P_2$ and $P_3 \times P_{10}$. 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 pollen 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 an average 28.02% (0.93-97.87%) more siliquae per plant.

g. Length of siliqua:

Higher siliqua length offers higher number of seed per fruit and increased seed yield per plant. So, positive heterosis is desirable in this character. There was no significant positive heterosis over mid parent and better parent. The hybrids $P_5 \times P_{10}$ showed positive heterosis over mid parent and better parent. All hybrids showed negative heterosis over mid parent and over better (Table 6). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea.*

h. Number of seeds per siliqua:

The nine hybrids expressed positive heterosis over mid parent as well as over better parent and $P_{10} \times P_{11}$ expressed positive heterosis only over mid parent. The hybrid $P_3 \times P_{10}$ and $P_2 \times P_{10}$ showed positive heterosis over better parent only. The hybrids $P_6 \times P_5$ showed significant negative heterosis over mid parent and better parent incase of number of seeds per siliqua. The hybrids $P_6 \times P_5$ showed significant negative heterosis over mid parent. Eight hybids express negative heterosis over mid parent as well as over better parent (Table 6). Kumar *et al.* (1990) reported positive heterosis for number of seeds per siliqua in *Brassica juncea*. Yadav *et al.* (2004) reported that 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.

i. Thousand seed weight:

The cross $P_7 \times P_{10}$, $P_6 \times P_5$ and $P_5 \times P_{10}$ showed significant positive heterosis over mid parent and better parent. The hybrids $P_7 \times P_6$ and $P_5 \times P_2$ showed significant negative heterosis over mid parent and better parent. The cross $P_6 \times P_2$ expressed significant positive heterosis over mid parent. The hybrids $P_3 \times P_{11}$ and $P_2 \times P_{10}$ showed significant positive heterosis over better parent. The five hybrids showed positive heterosis over mid parent and better parent. Negative heterosis found in $P_7 \times P_2$, $P_7 \times P_{11}$, $P_6 \times P_3$, $P_5 \times P_{11}$, $P_3 \times P_2$ and $P_{10} \times P_{11}$ over mid parent and better parent which indicate lower performance than mid and better parent for these 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 6). Yadav *et al.* (2004) observed the highest heterosis for thousand seed 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 pollen parent heterosis (3.57 to 20.48%) in thousand seed weight.

j. Seed yield per plant:

The cross $P_5 \times P_2$ exhibited highly significant positive heterosis over mid and better parent (Table 6). The hybrids $P_7 \times P_3$, $P_7 \times P_{10}$, $P_5 \times P_{11}$, $P_2 \times P_{11}$, showed significant positive heterosis over mid parent and better parent. The presence of high levels of mid and high better parent heterosis indicates a considerable potential to embark on breeding of hybrid or synthetic cultivars. The cross $P_5 \times P_{10}$ and $P_2 \times P_{10}$ showed significant positive heterosis over mid parent only. The cross $P_{10} \times P_{11}$ showed significant positive heterosis over mid parent only and other crosses showed insignificant positive heterosis over mid parent and better parent (Table 6). Moreover, significant positive heterosis value ranged from 2.33% to 159.50% over mid parent and 4.93% to 169.77% over better parent for seed yield per plant. 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 highest relative mid parent heterosis in Ethiopian mustard for seed yield/plant 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.

Chapter 5
Summary and Conclusion

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A seven parents (P_7, P_6, P_5, P_3, P_2, P_{10} and P_{11}) half diallel cross hybrids were evaluated for estimating the magnitude of combining ability, and heterosis over mid parent and better parent of different genotypes.

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 P_5 was good general combiner for days to 50% flowering and days to maturity. The parent P_6 was also good general combiner for number of primary branches; number of siliquae per plant, length of siliqua and thousands seed weight. The parent P_7 was also good general combiner for number of seeds per siliqua. The parent P_{10} and P_5 were good general combiner for plant height. The parent P_{10} was good general combiner for number of secondary branches. The parent P_5 was good general combiner for seed yield per plant.

The sca estimates of various characters revealed that cross $P_7 \times P_6$ (-2.70), $P_7 \times P_3$ (-1.67), $P_6 \times P_2$ (-1.81), $P_6 \times P_{11}$ (-2.11), $P_5 \times P_2$ (-1.81) and $P_2 \times P_{11}$ (-1.59) were good specific combiner for days to 50% flowering. The combination $P_7 \times P_6$, $P_6 \times P_{11}$, $P_5 \times P_3$, $P_3 \times P_{10}$

and $P_2 \times P_{11}$ were good specific combiner for days to maturity. The hybrids $P_7 \times P_{11}$ and $P_6 \times P_{11}$ were good specific combiner for the number of primary branches. The hybrids $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$ and $P_2 \times P_{10}$ were good specific combiner for the secondary branches. The hybrids $P_7 \times P_3$, $P_7 \times P_{11}$, $P_6 \times P_3$, and $P_5 \times P_2$ have also good sca effects on number of siliqua. The best specific combiner were $P_7 \times P_{11}$, $P_6 \times P_{11}$, and $P_5 \times P_{10}$ and $P_2 \times P_{11}$ for number of seed per siliqua; $P_6 \times P_{11}$, $P_5 \times P_{11}$, $P_3 \times P_{11}$ and $P_2 \times P_{10}$ also for length of siliqua; $P_7 \times P_5$, $P_7 \times P_{10}$, $P_6 \times P_2$ and $P_6 \times P_{11}$ for thousands seed weight and $P_5 \times P_2$, $P_6 \times P_{11}$, $P_7 \times P_3$, $P_7 \times P_{10}$ and $P_6 \times P_3$ 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 given on these traits. This parent could be effectively used in future for developing varieties of rapeseed (*Brassica rapa L)*.

It was observed that the hybrids obtained performed well for many of the important 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 $P_7 \times P_6$ showed significant negative heterosis for the characters days to 50% flowering over both mid and better parent. The hybrid $P_7 \times P_2$, $P_6 \times P_{10}$, $P_6 \times P_{11}$ and $P_3 \times P_{11}$ showed significant positive heterosis for the characters days to 50% flowering over both mid and better parent. The cross $P_5 \times P_{11}$, $P_3 \times P_{11}$, $P_6 \times P_{11}$, $P_6 \times P_5$ and $P_7 \times P_3$ exhibit significant positive heterosis for days to maturity and rest almost all the hybrids showed insignificant positive heterosis which were desirable for these characters. The hybrid $P_6 \times P_{10}$, $P_7 \times P_{10}$, $P_6 \times P_2$,

$P_2 \times P_{10}$ and $P_6 \times P_{11}$ was found to be the best for number of primary branches per plant, while the cross $P_6 \times P_{11}$ produced maximum number of secondary branches per plant. The cross $P_7 \times P_3$, $P_6 \times P_3$, $P_5 \times P_2$, and $P_2 \times P_{10}$ however, produced maximum number of siliqua per plant. There was no significant positive heterosis over mid parent and better parent for length of siliqua. The hybrids $P_5 \times P_{10}$ showed positive heterosis over mid parent and pollen parent on length of siliqua. There was no significant positive heterosis over mid parent and better parent on number of seeds per siliqua. The cross $P_7 \times P_{10}$, $P_6 \times P_5$ and $P_5 \times P_{10}$ showed insignificant positive heterosis over mid parent and better parent. For seed yield per plant the cross $P_7 \times P_{11}$ found to be the best one followed by cross $P_7 \times P_3$, $P_7 \times P_{10}$, $P_5 \times P_{11}$ and $P_2 \times P_{11}$. Thus, selection out of these crosses in the subsequent generations might produce some suitable segregates.

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Appendices

APPENDICES

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	Percent (%)	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, 2007 to 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. Mean performance of of 7 parents and 21 F_1s for 10 quantitaive characters in *Brassica rapa* genotypes

Cross	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches
P_7	26.67	86.00	110.52	6.03	7.52
P_6	29.00	87.67	106.27	5.53	3.63
P_5	27.33	80.33	94.18	5.69	7.49
P_3	25.67	82.33	106.30	6.80	6.42
P_2	27.33	83.33	108.82	5.82	6.51
P_{10}	24.33	85.33	93.84	4.61	9.92
P_{11}	25.67	81.00	93.00	6.67	6.06
P 7 x P 6	25.67	84.67	110.30	6.50	9.91
P 7 x P 5	28.67	82.67	104.45	6.57	9.20
P 7 x P 3	25.00	88.67	124.28	6.42	14.60
P 7 x P 2	31.67	85.00	98.13	6.65	12.22
P 7 x P 10	27.00	84.33	107.44	6.67	8.11
P 7 x P 11	26.33	84.00	112.45	5.37	11.56
P 6 x P 5	30.00	89.00	123.49	6.49	8.04
P 6 x P 3	27.33	88.00	113.72	6.42	13.33
P 6 x P 2	26.67	88.67	124.30	7.00	8.67
P 6 x P 10	31.00	87.67	115.47	6.84	13.44
P 6 x P 11	30.67	90.33	114.40	7.43	13.30
P 5 x P 3	27.00	80.33	100.30	5.38	11.43
P 5 x P 2	25.67	83.67	73.96	6.17	16.02
P 5 x P 10	27.00	82.67	91.52	6.08	13.90
P 5 x P 11	27.33	88.33	95.57	5.43	13.34
P 3 x P 2	26.33	88.67	94.75	4.27	11.63
P 3 x P 10	26.67	82.00	84.81	4.80	9.56
P 3 x P 11	30.33	89.00	102.23	5.80	11.28
P 2 x P 10	28.00	87.00	89.97	6.43	21.33
P 2 x P 11	25.67	81.33	99.58	6.57	9.59
P 10 x P 11	26.67	82.33	97.61	6.44	9.17

Appendix III. (Contd.)

Cross/ Parents	No. of siliquae/ plant	Length of siliqua (cm)	No. of seeds/ siliqua	Thousands seed weight	Seed yield/ plant
P_7	145.42	6.56	18.52	3.13	8.38
P_6	150.83	6.29	18.11	3.53	7.50
P_5	162.04	6.43	17.88	3.03	7.18
P_3	138.27	6.54	17.30	3.43	6.85
P_2	174.61	6.43	15.78	3.57	6.65
P_{10}	184.49	6.46	15.32	2.76	8.05
P_{11}	130.83	6.64	16.55	3.10	5.04
P 7 x P 6	230.68	5.71	16.74	2.91	8.23
P 7 x P 5	165.27	5.86	15.97	3.42	9.25
P 7 x P 3	353.13	5.60	19.45	3.35	11.90
P 7 x P 2	235.70	5.51	17.68	3.17	8.85
P 7 x P 10	167.28	5.68	17.39	3.43	12.67
P 7 x P 11	245.56	6.13	21.34	2.97	10.68
P 6 x P 5	250.67	4.99	12.81	3.77	8.13
P 6 x P 3	317.48	5.63	16.35	3.29	9.11
P 6 x P 2	298.40	5.30	10.57	4.00	7.24
P 6 x P 10	249.19	4.58	14.36	3.20	8.45
P 6 x P 11	259.20	5.49	14.04	3.47	8.02
P 5 x P 3	247.46	5.94	16.25	3.35	9.71
P 5 x P 2	330.53	5.70	17.34	2.83	17.94
P 5 x P 10	259.17	6.58	p20.24	3.55	11.04
P 5 x P 11	199.93	5.03	15.69	2.87	9.73
P 3 x P 2	166.07	5.14	17.31	3.20	8.17
P 3 x P 10	175.96	5.33	15.93	2.80	4.69
P 3 x P 11	217.63	5.20	17.37	3.60	7.25
P 2 x P 10	348.58	4.98	15.33	3.42	11.04
P 2 x P 11	183.93	6.41	19.40	3.37	9.16
P 10 x P 11	222.27	5.81	16.22	2.77	9.17