COMBINING ABILITY AND HETEROSIS IN *Brassica napus* L. USING LINE-TESTER METHOD

BY

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CERTIFICATE

This is to certify that the thesis entitled, "COMBINING ABILITY AND HETEROSIS THROUGH LINE- TESTER ANALYSIS IN *Brassica napus* L." **submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of** MASTER OF SCIENCE **in** GENETICS AND PLANT BREEDING, **embodies the result of a piece of bonafide research work carried out by SABRINA ISMAIL,**
Registration No. 07-02220 under my supervision and 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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Dated: June 2014
Place: Dhaka, Bangladesh

Dedicated

to

My Beloved Son

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The Author

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LIST OF SYMBOLS AND ABBREVIATIONS

FULL WORDS	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 Agricultural Organization	FAO
Centimeter	cm
Metric ton	Mt
Bangladesh Agriculture Research Institute	BARI
Sher-e-Bangla Agricultural University	SAU
Journal	*J.*
Number	No.
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 better parent values	$\overline{BP}$
Mean of the mid parent values	$\overline{MP}$
Gram	g
Bangladesh Bureau of Statistics	BBS
Analysis of variances	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

COMBINING ABILITY AND HETEROSIS IN *Brassica napus* L. USING LINE-TESTER METHOD

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SABRINA ISMAIL

ABSTRACT

An experiment on oleiferous *Brassica napus* L. was conducted to evaluate seven female parents (line) and thirteen male parents (testers) in a line x tester design at the research field of Sher–e-Bangla Agricultural University, Dhaka during November 2012 to April 2013 to estimate their heterosis and gene action for ten different characters. Out of 91 of F_1s, no cross combinations showed desirable negative heterosis for the characters of shorter plant height and early maturity. NAP-9905 x NAP-2013 showed desirable negative heterosis for early flowering. NAP-9905 x NAP-9904 showed desirable positive heterosis for number of primary branches per plant, NAP-9905 x NAP-94006 for number of secondary branches per plant and number of siliqua per plant. The hybrids NAP-9908 x NAP-2001 were found to be the best heterosis for siliquae length but NAP-108 x NAP-179 and NAP-108 x NAP-2022 found to be best for seeds per siliqua. For thousand seed weight the hybrids NAP-9908 x NAP-2013 was best. For seed yield per plant the crosses NAP-108 x NAP-9901 was found to be the best. The parent Nap-248 was the best general combiner for early flowering. The parent NAP-108 was the best for desirable plant height, seeds per siliqua and yield per plant. The parent BS-13 was the best general combiner for early maturity while the parent NAP-248 was the best general combiner for 1000 seed weight. The cross NAP-9905 x NAP-9904 was good specific combiner for number of secondary branches and NAP-9905 x NAP-94006 for number of siliquae per plant. The cross NAP-205 x NAP-9901 was the best specific combiner for plant height. The combination BS-13 x NAP-2022 was the best specific combiner for early flowering and BS-13 x NAP-2066 for seed yield per plant while NAP-94006×NAP-248 was the best for early maturity. The hybrid NAP-248 x NAP-2001 was the best for number of primary branches per plant and NAP-205 x NAP-2012 for the number of seeds per siliqua and NAP-9908 x NAP-130 was best for 1000-seed weight.

Chapter 1

INTRODUCTION

INTRODUCTION

Rapeseed *(Brassica napus)* is a cross pollinated oil crop belonging to the family Brassiceae. The oleiferous *Brassica* is important source of vegetable fat and are mainly represented by rape. This is the fourth most important source of vegetative oil in the world after soybean, palm, and sunflower. 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 edaphic and climatic factors of Bangladesh are truly favorable for the cultivation of rapeseed and mustard. Almost all the cultivars are brown seeded and smaller in size (2-2.5 g/1000seed). Yellow seed contains 2-3% more oil than the same sized brown seeded type due to its thinner seed coat. Bold and yellow seeded rapeseed varieties may increase total edible oil production of Bangladesh. High yielding variety in late condition having early maturity may increase 12-15% area of total edible oil seed of Bangladesh, when it replaces the total rapeseed and mustard grown in the country. Although rape and mustard is most important oil crop in Bangladesh, farmer usually cultivates them in less fertile lands followed by low management with least investment. The above scenario dictates the major quantitative and agronomic modification of this crop.

Oilseed crop covers about 4.10% area of the total cultivable land in Bangladesh (BBS, 2012a) which covers 9.22 lakh ha of land. However, rapeseed and mustard cover 6.23 lakh ha of land produce about 3.49 lakh Mt of oil seeds. This crop covers about 74.5% area of the total edible oil crops cultivated in Bangladesh.

For human health in balanced diet requires 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).

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 371 cores taka (BBS, 2012b).

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 cultural practice of crop. 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 population.

There is also scope to increase yield per unit of area through cultivation of short duration high yielding varieties. The production potential of rapeseed and mustard will be 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 varies from 30 to 40 percent depending on the variety, climate and production condition.

Considering the above scenario, the present study was undertaken with the following objectives:

1. To estimate heterosis for different yield contributing characters of rapeseed,
2. To estimate the nature and extent of gene action involving in controlling the traits and
3. To identify the potential parents and promising cross combinations to select early maturing high yielding materials.

Chapter 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

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

2.1 GENERAL INFORMATION OF RAPESEED

Rapeseed, also known as rape, oilseed rape, rapa, rapaseed and double low rapeseed called canola (low erucic acid and glucosinolate contents rapeseed), belongs to the species of *Brassicae*, members of Cruciferae. The name rape derived from the Latin *rapum* meaning (Weiss, 1983).There are three basic species: *B.nigra, B oleracea,* and *B. campestris*. By hybridization and chromosome doubling, the three species: *B. carinata, B. juncea* and *B. napus* L. were synthesized. The botanical relationships among these species are illustrated by the "U Triangle" (Figure 1) which was proposed by a Japanese scientist, named U, IN 1935(U,1935).

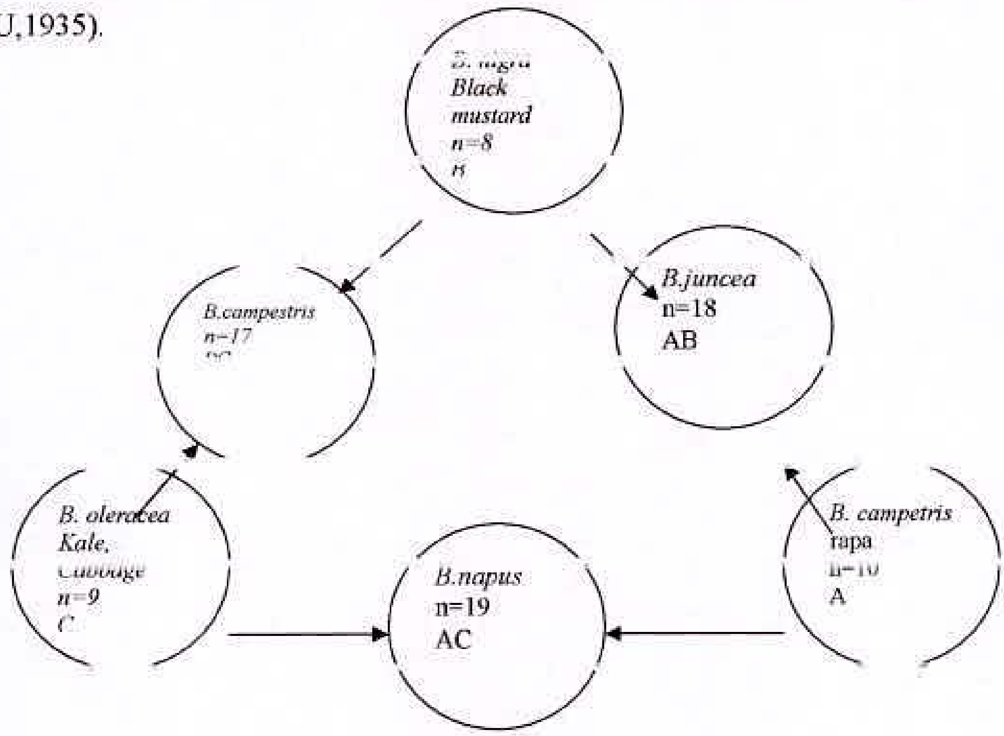

Figure 1: Relationships among important *Brassica* species shown by the triangle of U (1935)

Now *B. napus, B. campestris*, and *B. juncea* are the main species planted in the world. *B. juncea* has natural outcrossing rate below than 10 percent. Howevere some varieties may have more than 40 percent outcrossing in certain areas .*B. napus* L. has natural outcrossing rate of 10 to 30 percent, in general whereas *B. campestris* has 85 to 90 percent (Li,1999; Akow and Woods, 1987b). Their flower colors are bright yellow, sometimes orange yellow or pale yellow.Seed-coat color of rapeseed are different from species. In general, they are dark-brown to Black. We can find pure yellow seed in *B. campestris* and *B. juncea*, but not in *B. napus* . It was found that yellow –seeded rapeseed could have more oil and protein contents and lower fiber than brown and black rapeseed (Weiss,1983;Liu,1992).Yellow seed in *B. napus* L. was first found in artificially synthesized rapeseed in Sweden (Olsson,1960).

Rapeseed can be divided according to vernalization requirements into two types including winter and spring types (Wang *et al* 2007). Winter varieties of *B. napus* L. are grown predominantly in most of Europe , China and the eastern United States, Whereas spring varieties predominate in Canada, northern Europe, northwest of China .*B . rapa* has a shorter growing season than *B. napus* L. and this trait makes the spring varieties of this species suitable for the more severe climates. Spring type *B. rapa* has largely is the leading been replaced by more productive winter type *B. napus* . *B. juncea* is the leading *Brassica* oilseed in India and also produced in Canada, Europe and China (Sovero, 1993)

2.1 HETEROSIS

The term heterosis refers to the phenomenon in which F_1 population generated by crossing of two dissimilar parents showed increased or decreased vigor over the mid parental values or the better parental values. Both intra and inter-specific crosses showed some heterotic effect and both positive and negative heterosis were found.

Huq (2006) conducted an experiment on *Brassica rapa* involving 7×7 half diallel cross. Heterosis and combining ability were estimated for seed yield and other related characters such as days to flowering, days to maturity, plant height, number of primary and secondary branches, length of siliquae, seeds per siliqua, 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 berrer parent. Agroni × Tori-7 best for number of primary branches/plant and siliquae/plant.

Qian *et al.* (2005) reported the observation on the inter subgenomic heterosis for seed yield among hybrids between natural *Brassica napus* (AnAnCnCn) and a new type of *B. napus* with introgressions of genomic components of *Brassica rapa* (ArAr). This *B. napus* was selected from the progeny of *B. napus* x *B. rapa* and (*B. napus x B. rapa*) x *B. rapa* based on extensive phenotypic and cytological observation. Among the 129 studied partial intersubgenomic hybrids, which were obtained by randomly crossing 13 lines of the new type of *B. napus* to 27 cultivars of *B. napus* from different regions as tester lines, about 90% of combinations exceeded the yield of their respective tester lines, whereas about 75% and 25% of combinations surpassed two elite Chinese cultivars, respectively. This strong heterosis was further confirmed by reevaluating two out of the 129 combinations in a successive year and by surveying hybrids between 20 lines of the new type of *B. napus* and its parental *B. napus* in two locations. Some DNA segments from *B. rapa* were identified with significant effects on seed yield and yield components of the new type of B. *napus* and intersubgenomic hybrids in positive or negative direction. It seems that the genomic components introgressed from *B. rapa* contributed to improvement of seed yield of rapeseed.

Adefris and Heiko (2005) conducted an experiment to generate information on heterosis. Nine inbred parents and their 36 F_1s were evaluated for twelve 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 to145% with a mean of 67% Relative high parent heterosis for seed yield varied from 16 to 124% with a mean of 53%. The presence of high levels of mid and high parent heterosis indicates a considerable potential to embark on breeding of hybrid or synthetic cultivars in Ethiopian mustard.

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

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

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

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

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

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

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

Ripley and Beversdorf (2003) reported that cultivars in *Brassica napus* var. oleifera, a self-pollinating, self-compatible species, have traditionally been developed as open-pollinated lines or populations. Significant yield gains in this species have been realized through the exploitation of heterosis. They stated that commercial hybrid production had been possible as a result of the development of a number of pollination control systems. They found self-incompatibility was transferred from *B. oleracea* var. italica to *B. napus* var. oleifera through interspecific hybridization. The response to interspecific pollination, as measured by siliquae elongation and initial stages of ovule development, was genotype dependent, and two highly responsive *B. napus* genotypes were identified. They used embryo rescue to produce the interspecific hybrids. Isoelectric focusing of stigma proteins was used to identify S-alleles in the interspecific hybrids to facilitate backcrossing. Segregation of the S-locus through a series of back-crosses to *B. napus* was complicated by aneuploidy; however, the S-locus was found to segregate as a single gene. They discussed usefulness of *B. oleracea* as a source of S-alleles for pollination control in *B. napus.*

Mahak *et al.* (2003a) studied heterosis for days to flowering, plant height, number of primary and secondary branches, length of main raceme, days to maturity, thousand seed weight, harvest index, oil content, protein content, and seed yield in 10 Indian mustard cultivars and 45 F_1 and F_2 hybrids. High heterosis for seed yield was observed in Varuna× Rohini (56.74%), Vardan × Rohini (53.43%) Varuna × RK 9501 (52.86%), Vardan × NDR 8501 (36.73%), pusa Bold × Rohini (37.68%), and Varuna × NDA8501 (32.54%).

Qi *et al.* (2003) carried an experiment out in 1997, 66 crosses were made in a diallel design of twelve parental varieties of *Brassica napus* to study heterosis of seed and its components. Twenty-one crosses showed a significant heterosis in seed yield/ plant. The average yield heterosis over their parents was 70.24% (30.70-218.10%). Eight crosses showed better parent heterosis (3.57-20.48%) in 1000-seed weights,while the parent of seven crosses showed low 1000-seed weights. Forty-seven crosses gave on average 28.02% (0.93-97.87%) more siliquae / plant in parents, while thirteen crosses showed 11.67% more seeds/ siliqua in parents. By this experiment they concluded that there was large potential heterosis in seed yield with heterosis of siliquae number/plant making the biggest contribution.

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

Kumar *et al.* (2002) crossed three lines and twelve testers of Indian mustard and the resulting 36 F_1's and 15 parents were grown. Physiological data were determined from five plants per entry and the range of heterosis given for all crosses. The five hybrids with the highest heterosis for seed yield were RN-505 × RN-490, RN-505 × PCR-43, RN-393 × RN-481, RN-393 × RN-453 and RN-505 × RN-481, and these crosses offer the best possibilities of further exploitation for the development of high yielding varieties.

Pankaj *et al.* (2002) studied heterosis of parents for seed yield, oil content and protein content in an 8 × 8 diallel cross in toria (*brassica campestris* var. toria). Trait data were recorded on five plants of each of the 28 F_1's and 28 reciprocal F_1's (RF_1s). 24 F_1's and 21 RF_1s showed significant positive heterosis for seed yield over mid parent (MP) and 16 F_1's and 21 RF_1s over the better parent (BP).

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

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

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

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

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

Iftikhar *et al.* (2000) studied rape variety Tower and three stable M9 mutants for heterosis of yield components of inter-mutant crosses during 1997-99. F_1 generations expressed significant heterosis for number of primary branches, number and length of primary roots and siliquae, seeds/siliqua, yield/plant and oil content. It is concluded that these mutants are a good source of variation for future breeding programmes

Zhang *et al.* (2000) crossed three double low cytoplasmically male sterile (CMS) and five double low restorer lines of *brassica napus* and they analyzed resulting 15 hybrids for eight yield components. In this experiment they found that the CMS F_1 had significant heterosis, particularly for yield, but that predicted for the F_2 was lower. They also suggested that the major yield components, total siliquae number/plant had the highest heterosis and would be of more value in a breeding programme than trying to increase seed number per siliqua or 1000-seed weight.

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

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

Wang *et al.* (1999) analysed heterosis and combining abilities of 20 reciprocal cross combinations of five double low rape (*Brassica napus*) cultivars (lines) showing high seed yield. Positive mean heterosis varied among crosses. The positive mean heterosis of siliqua number/plant was 17.6% was highest, followed by seed number/siliqua and 1000-seed weight. Heterosis of F_1 generations were greatest when Zhihu 1 and Zhongyou 220 were used as parents.

Liersch *et al.* (1999) conducted a breeding approach known as CMS ogura system of oilseed rape hybrid cultivars in Poland to evaluate yield and yield component variability of F_1 hybrids and their parental lines also heterosis effect, and qualitative traits such as oil and glucosinolate content in seeds. They found that composite hybrid cultivars yielded higher than restored hybrids.They stated that the yield of hybrids and qualitative traits such as oil and glucosinolate content in seeds are significantly dependent on genotypes and environmental conditions.

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

Yadav *et al.* (1998) studied some 27 crosses of female and three male sarson (*Brassica campestris*) parents for seven yield components. Of these, 18 hybrids exhibited significant positive heterosis. Highest heterotic response for seed was observed in DB_1 × Pusa kalyani and BSKI × BSI k_2.

Thakur *et al.* (1997) evaluated nine diverse inbreds and their 36 F_1 hybrids from a diallel cross for yield and its components and oil content. They observed that estimates of heterosis over better parent (BP) for the various traits were significant for seed yield (-14.8 to 82.8%), primary branches (-26.0 to 193.6%) and siliquae per plant (-21.9 to 162.6%). They also observed unidirectional dominance for most of the traits studied and the cross GSB7027 × HNS8803 gave highest positive heterosis for seed yield per plant.

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

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

Sing and Verma (1997) discussed different aspects of heterosis breeding, including prerequisites for the development of hybrids, different existing hybrid systems, extent of of outcrossing, recent advances in India and abroad, limitations of hybrids in *Brassica*, and future strategies

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

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

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

Gupta and Labana (1995) provided information on combining ability and heterosis for seed, straw and chaff protein contents and nitrogen and protein harvest indexes was derived from data on distribution of nitrogen in plant parts as assessed in 8 *Brassica napus* cultivars and their 28 F_1 hybrids grown at Ludhiana in 1985-86. Protein contents were estimated from nitrogen content values. Topa was the best combiner for seed protein content.

Yu and Tang (1995) studied on seven inbred rape lines and their 21 F_1 hybrids which were compared at the seedling stage for acid phosphatase (APS) isoenzyme patterns by polyacrylamide gel electrophoresis (PAGE) analysis. All hybrids with hybrid band(s) in their zymograms showed heterosis in yield, and those without hybrid bands showed no heterosis. Hybrids with two or three hybrid bands and high APS activity showed great heterosis. Hybrids with 2-3 medium or weak hybrid bands had only moderate heterosis. Hybrids derived from parents with very different zymograms showed high heterosis even though they had only one strong hybrid band. When the parents had similar zymograms and the hybrid showed relatively low APS activity, heterosis was low. Since the isoenzymes of APS in *Brassica napus* appeared to be quite stable, they were recommended to serve as a biochemical indicator of heterosis at the seedling stage (the 2-3 leaf stage).

Information on heterosis has also been recorded by Rai and Singh (1994) from data on six yield component in eight *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 crossed showed significantly high positive heterosis for seed yield in all cases except had high negative heterosis for yield in DTS × YST151.

Ramsay *et al.* (1994) stated a complete diallel set of crosses, including selfs, was produced from eleven inbred lines of swedes and assessed in the field for both components of dry matter yield and neck length at Dundee, UK, during 1987. They found that there was a strong positive heterosis for dry matter yield with high yielding F_1s showing an improvement of more than 20% above the better parent. Reciprocal differences were also found. Both additive and non-additive genetic variation was found for dry matter yield and other quantitative traits. However a simple additive-dominance model with independence of action and distribution of the genes failed to describe the data adequately. Given the implications for the breeding of inbred or F_1 hybrid swede cultivars, further experiments, using triple test crosses are suggested.

Ahmad (1993) worked with parents and F_1 hybrids from crosses between resynthesized lines and improved 00 varieties. F_1 were earlier maturing than resynthesized lines and heterosis was observed for spring regrowth and plant height. In trails, the best resyn. line H128 could only produce 87% of the mean yield of the improved varieties.

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

Habetinek (1993) determind plant length, siliqua length, no. of seed/siliqua, 1000 seed weight in five varieties of the 00 types 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 nine maternal lines ($5S_3$ and $4S_4$) and their pollinator, taplidor and 9 F_1 hybrids derived by top crossing.

Krzymanski (1993) found significant heterosis for seed yield, oil content and some flowering traits in ten parental strains and their 45 hybrids. The mean heterosis for seed yield over the mid parental mean was 24.71%. The highest heterosis for this trait was seen in the cross of PN2595/91 × PN2870/91 (71.81% relative to the mid parental mean).

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

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

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

Hirve and Tiwari (1991) evaluated 28 elite *Brassica juncea* genotypes produced 28 F_1 and F_2 progenies together with the parents, for siliquae and seed yield per plant and siliqua length. The highest heterosis for seed yield was obtained in the cross RAU × RPU 18 (161%). RLM 198 × Veruna, RAU RP_4 × Varuna and Tm 7 × Varuna also gave good seed yield heterosis and gave high heterosis for other yield contributing characters. In general, crosses containing Varuna as one parent gave high heterotic values.

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

A male sterile line, European-Xinping A, a maintainer line European -Xinping B and a – restorer line 74243-6, were developed from a male sterile plant pf *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.

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

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

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

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

Badwal and Labana (1987) studied *Brassica juncea* for seed yield/plant and other eight related characters. In F_1, they found positive and significant heterosis for almost all traits. In a study for heterosis and cytoplasmic-genetic male sterility in oil seed rape (*Brassica napus* L.) through diallel cross of six Canadian and European cultivars.

Lefort *et al.* (1987a) 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.

Grants (1985) found heterosis for seed yield up to 72% over better parents

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

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

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

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

2.3 COMBINING ABILITY

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

Yadav *et al.* (2005) found significant differences due to parents vs. crosses indicating the presence of heterosis in the crosses through conducted an experiment during the rabi seasons of 1998-2000 to study the nature of combining ability for seed yield and other yield-attributing characters through line × tester analysis in rape (*Brassica napus*) [*B. napus* var. oleifera]). They derived forty-five F_1 from the crosses of two cytoplsmic male sterile lines (Ogura, ISN-706a) and one normal fertile line (NDBN-1) used as females and 15 testers (Westar, FM-27,GSL-6267,GSL-8814, EC129120, PBN 9501, NRCG-7, GSL-6067, HNS-4, GSL-1, GSL-406, NRCG-2, GSL-6303, NRCG-13 and NRCG-14) as males. Among lines, they observed significant differences for plant height and number of secondary branches per plant. Higher magnitude of variances due to testers compared to lines were observed for seed yield per plant, plant height, primary branches per plant, days to flower initiation, days to maturity and oil content. They also found that the estimates of SCA variances were higher than GCA (average) for all the characters studied, indicating the preponderance of non-additive type of gene action in the inheritance of these traits and the cross Ogura × NRCG-13 showed high SCA effects for yield per plant which involved both good combining parents.

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

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

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

Pietka *et al.* (2003) proposed that the general combining ability (GCA) values in terms of individual glucosinolates are important in breeding. Eleven inbred lines of winter oilseed rape (*B. napus* [var. oleifers]) characterized by very low glucosinolate contents were studied by them. These lines were crossed with five cultivars used as testers. Hybrids were grown in the field and statistical analyses of GCA values were performed separately for particular glucosinolates, as well as F_1 and F_2 generations. Heritabilities of regressions were estimated by determining the coefficients between both generations. Most of the coefficients were significant at alpha =0.01 or 0.05, providing that the GCA estimation used in the experiments was satisfactorily reproducible.

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

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

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

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

Gottman and Becker (2001) stated that because of the nutritional and antioxidative properties, tocopherol production is an interesting trait for the lipid quality of oil crops. Total tocopherol content in rapeseed (*Brassica napus L.*) is medium to low, and therefore, higher levels of tocopherol are desirable in this species. The objective of the present study was to determine the inheritance of alpha-, gamma-, and total tocopherol content and the alpha -/ gamma -tocopherol ratio in seed of rapeseed. Two diallel mating designs with six parents each were used. In Diallel I, the parents selected were high or low for total tocopherol content and in Diallel II, the parents were high or low for the alpha -/ gamma -tocopherol ratio. Parents and F_1 hybrids were tested in a screenhouse in 1998 and under field conditions in 1999 by means of a completely randomized design with two replications. In addition, 10 selected F_2 populations were grown along with their respective parents. Compared with the parents, the F_1 hybrids showed a significantly higher gamma -tocopherol content of about 6 mg kg-1 seed for Diallel I and 24 mg kg-1 seed for Diallel II. General combining ability effects in both diallels were highly significant ($P<0.01$) and much larger than specific combining ability effects for all traits studied. Reciprocal effects were not statistically significant. Gamma-Tocopherol was not correlated with alpha -tocopherol. The results indicate that tocopherol content and composition inheritances are strongly associated with additive gene action in rapeseed.

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

Wos *et al.* (2000) presented the results of the breeding studies on the development of winter and spring oilseed cytoplasmically male sterile (CMS) lines, restorers and composite hybrids performed at the Plant Breeding Station in Malyszyn (Poland) in collaboration with the Oil Crop Department of Plant Breeding and Acclimatization Institute in Poznan. Some breeding aspects of the CMS lines, restorers and composite hybrids, including general combining ability and specific combining ability, contents of glucosinolates and erucic acid, winter hardiness and yield, are analysed. The results obtained so far have allowed the introduction of eight winter and four spring composite hybrids of oilseed rape to the State Official Trials. In 1999, the first Polish-French composite hybrid of spring rape named Margo was listed on the Polish Variety List.

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

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

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

Singh *et al.* (2000) worked with genetic analysis in yellow sarson, *Brassica compestris* L. They found significant differences for both SCA and GCA among the genotypes for all the characters indicating there by that both additive and non-additive components were involving in the expression of all the traits. The parents with high GCA was showed good general combining ability for seed yield, days to maturity and siliqua per plant in both F_1 and F_2

generation and for primary and secondary branches per plant in F_2 generation only. The cross with high × low GCA effects showed significant SCA for seed yield.

Krzymanski *et al.* (1999) made diallel (13x13) crossings of double low oilseed rape cultivars and strains. Parental forms and F_1 combinations of diallel were compared in field trials in Poland. Two cultivars and four strains were the parental forms that most frequently occurred in F_1 combinations yielding considerably above the standard cultivar (Bor), two strains gave combinations of the highest fat contents, considerably differing from the standard. The yields oscillated between 126.5 and 209.1% of the standard (38.2 q/ha) and the fat content between 103 and 108% of the standard (47%). Calculations were made to estimate the expected values of seed yield of synthetic varieties, which could be obtained from tested cultivars and strains. Two or three component synthetics composed from the best combining cultivars and strains were taken into account by them.

Krzymanski *et al.* (1999) examined combining ability and heterosis for selected eleven winter double low rape inbred lines (PN 3181/95, PN 3451/95 PN 3455/95, PN 3462/95, PN 3707/95, PN 3710/95, PN 3734/95, PN 3999/95, PN 4043/95, PN 4272/95 AND PN 4297/95) with extremely low glucosinolate content. Three foreign cultivars, Lirajet, Silvia, and Wotan, and two Polish cultivars, Mar and Polo, were used as testers. Crosses were made in both directions. The results of calculations made for the F_1 generation concern general and specific combining abilities with regard to parental form and 55 hybrid combinations and reciprocal effects. The results enabled the determination of the best combination of crosses. It was also proved that combining effects depend in some combinations on the direction of crossing.

Wos *et al.* (1999) presented general combining ability (GCA) and specific combining ability (SCA) for 23 cytoplasmic male sterility (CMS) ogura lines. Field trials were executed in four localities (Malyszyn, Marwice, Borowo and Bakow) in Poland. The seed yield of hybrids, GCA and SCA of CMS lines and GCA of pollinators were significant. 23 CMS ogura lines were crossed using three pollinator cultivars Kana, Marita and MAH 1592. Obtained results were used to find the best combinations for hybrid production

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

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

Wos *et al.* (1998) presented the results of investigated general combining ability of 64 inbred lines and heterosis effects of winter oilseed rape F_1 hybrids. General combining ability was estimated by test topcrosses. Field experiments were designed in lattice design, in two replications (four rows per plot, three msuperscript two plot and sowing rate of 100 seeds per 1 msuperscript 2). The experiment was carried out in 1996-97. General combining ability (GCA) was significant for seed yield, 1000 seed weight, winter hardiness, beginning and end of flowering, oil and protein content. However, it has been proved that GCA was not significant for plant height. Results of these studies revealed: nine hybrids with significant higher yielding than tester (check) cv. Lirajet, 19 hybrids with significant better winter hardiness than tester, 35 hybrids with significant earlier beginning of flowering in comparison with Lirajet, 22 hybrids with significant earlier ending of flowering, three hybrids with significant higher 1000-seed weight, two hybrids with significant shorter plants than tester, 13 hybrids with significant higher oil content than tester Lirajet. The best hybrids out yielded about 40% higher than tester Lirajet. Nevertheless the average effect of heterosis with respect to the seed yield was 16% in comparison with the tester Lirajet. Moreover, Spearman coefficients of correlation between estimated traits were calculated. Positive significant correlations at P <less or => 0.01 Spearman coefficient of correlation rs = 0.48** was calculated between winter hardiness and yielding. Moreover, negative Spearman coefficients of correlation between winter hardiness as well as beginning and ending of flowering was noted.

Pietka *et al.* (1998) reported that winter hardiness of winter oilseed rape cultivars became very important trait after two strong winters which destroyed many plantations of this crop in

Poland. These two winters gave rape breeders an opportunity to estimate winter hardiness of breeding materials and to make effective selections. A field trial with an F_2 generation of a diallel cross (7 x 7) and with an F_1 generation of diallel cross (10 x 10) were sown in autumn 1996. Winter losses of plants on the plots differentiated the hybrids significantly, allowing more sophisticated analysis. Seeds used for sowing the first trial were harvested from F1 plants which survived the severe 1995-96 winter. The second trial was sown with seeds obtained by hand pollination after removing the anthers. The trials were made in a complete randomized block design with standard plots distributed systematically. Interblock variability was reduced with covariance analysis. The hybrids of both generations were examined in trials without parents. The number of plants which survived the winter were estimated in spring. Diallel analysis on transformed values was done according to Griffing method III. Effects of general (GCA) and specific combining abilities (SCA) and effects of reciprocal (RE) crosses were calculated. All effects except of reciprocal effects in F_1 generation are highly significant. Winter hardiness was shown to be a complicated character whose genetic control depends on additive effects of parent, interaction of parental genotypes and maternal cytoplasm.

Pu (1998) stated that a cytoplasmically male sterile line Ning A3 (MICMS), a *Brassica napus* line with a high level of sinaptic acid, was used as the basic breeding stock. The maintainer line Ning B3 was crossed with an elite cultivar with double low and fertile cytoplasm. Ning A6 and the maintainer line Ning B6 were bred after six generations of breeding. The combining ability of Ning A6 is high and the hybrids showed obvious heterotic vigour. Some hybrid combinations gave good performance in both yield and low content of sinaptic acid. The content of sinaptic acid in Ning A6 is 0.38% mu mol per g DW.

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

Wos *et al.* (1997) studied in the combining ability of 55 inbred lines of rape (*Brassica napus*) and heterosis effects of their 62 F_1 hybrids. GCA was significant for seed yield, 1000-seed weight, time to flowering and fat content. They found that some 24 hybrids had higher yields, 14 earlier onset of flowering, three shorter plants, 14 higher fat content and three had higher protein content than control Global. Average yield increase over Global was 10%. There was a significant positive correlation of seed protein content with 1000-seed weight, and a negative correlation with seed fat content.

Kudla (1997) stated that inbred lines T1170, T1162, T1148 and T1166 were crossed in a factorial design with cultivars Maxol, Mandarin and Silex. Parental forms and 12 F_1 hybrids were evaluated in 1994-95 in a field trial. GCA of inbred lines and cultivars was significant for height to first branch, number of primary branches, siliqua length, seeds/siliqua and 1000-seed weight. T1170 and T1166 transferred some high-yield traits to their progeny. Significant differentiation of SCA was found for height to first branch. Dominance effects appeared high and positive for seed yield/plant and plant height. Additive gene action played a predominant role in the inheritance of height to first branch and seeds/siliqua. Relation of additive and non-additive gene action was generally similar in the inheritance of number of primary branches, siliqua length and 1000-seed weight. F_1 hybrids showed positive heterosis, averaging 14% for seed yield/plant.

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

In a study of 8 × 8 diallel analysis (excluding reciprocals) Yadav *et al.* (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.

Kudla (1996) investigated the combining ability of winter oilseed rape (*Brassica napus*) inbred lines, and heterosis effects of F_1 and F_2 hybrids in the growing season of 1994-95. Analysis of variance showed that non-additive gene action had an advantage over additive gene action in the inheritance of plant height and number of primary branches. The significant effects of dominance genes in the F_1 for siliqua length, seeds/siliqua, seed yield/plant and 1000-seed weight did not occur in the F_2. The differentiation of GCA of inbred lines, based on F_1 hybrids, was significant for siliqua length, seeds/siliqua, seed yield/plant and 1000-seed weight. GCA based on the F_2 was significant for pod length and seeds/siliqua. Inbred lines T1056 and T1150 were good components for crossing to increase seed yield in the F_1. Both lines can be used for breeding high yielding oilseed rape hybrids varieties. In most of the F_1 and F_2 hybrids, significant positive effects of heterosis were found for plant height. F_1 of T1056 x Wotan showed the highest and significant heterotic effect (24.5%) for seed yield/plant. The mean heterotic effect in F_1 hybrids was 10% for seed yield, decreasing to 2% in the F_2 generation.

Patel *et al.* (1996) provided information that combining ability was derived from data on nine yield components in four parental genotypes (*Brassica juncea* cultivars Pusa Bold and TM17, *B. carinata* and *B. napus*) and their 12 F_1 hybrids grown during 1994-95. Variance due to GCA and SCA were significant for all the characters, except number of seeds/silique for GCA variance and 1000-seed weight for SCA variance. Non-additive gene action appeared to predominate for all characters except days to maturity, which was governed by additive gene action. *B. carinata* was the best general combiner for plant height, number of branches/plant, number of siliquae/plant and oil percentage. Among the hybrids, *B. napus* x Pusa Bold was the best specific combination, followed by the reciprocal.

Krzymanski *et al.* (1995) evaluated seed glucosinolate content in hybrids from a diallel set of crosses involving ten *Brassica napus* strains. Only three of the strains showed significant GCA effects for total content of aliphatic glucosinolates but their values were low. SCA effects for the trait were significant only for three of the 45 crosses and heterosis only for two, but their values were high. Most strains appeared to have the same alleles that controlled low glucosinolate content. Heterosis for content of glucosinolates was not correlated with heterosis for seed yield.

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

Barua and Hazarika (1993) conducted a study during 1993 with five varieties representing two *Brassica napus* types and *Brassica compestris* var toria along with their hybrids from a half diallel set of crosses. Accroding 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.

Habetinek (1993) worked on *Brassica napus* and found higher GCA effects than SCA effects for all characters except seed weight/ plant. Darmor had the highest GCA for number of seeds/siliqua, siliqua length and 1000 seed weight, while Sonata had the highest GCA for oil content. SCA for seed weight/plant was highest in Sonata × SL2502.

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

Kudla (1993) studied nine maternal lines (5S3 and 4S4), their pollinator (tester) Toplider and 9 F_1 hybrids derived by top crossing. Additive gene effects were most important in control of 1000-seed weight and the number of seed/siliqua, but non-additive effects predominated in control of number of primary branches, seed yield/plant, plant height and 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 seed/siliqua, T1097 for number of primary branches and 1996 and T1039 for plant heitht.

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

Rawat (1992) studied the reciprocal differences in the inheritance of eight 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 the basis of *per se* performance and of combining ability and F_1 performance were BICI624, BICI3S2, BICI439, BICI114 and BICI702. There was only one cross (BICI382 ×

BIC1702) in which reciprocal effects acted in a favorable direction for all traits. This allowed the selection of a maternal parent, which was capable of enhancing beneficial non-additive effects in a specific cross. The parents of this cross also showed high GCA for most of the traits, allowing the exploitation also of beneficial additive effects.

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

Yadav *et al.* (1992) evaluated 45 F_1 hybrids of Indian mustard together with ten parents for combining ability with respect to seed yield and its component characters. Veruna, Kranti, RIC1359 and RLC1357 were identified as good combiners for seed yield, earliness, siliqua length, number of seeds/siliqua and 1000 seed weight. The following varieties or parents EC126743, EC126745 and EC126746-1 have emerged as good combiners for plant height, primary branch and secondary branch.

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

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

Siddique *et al.* (1990) studied a complete diallel cross involving four genotypes of *Brassica compestris* and their F_1's for nine characters including seed yield/plant. Both additive and non-additive gene action was found in the inheritance of characters except days to flower, plant height and primary breaches. Preponderance of additive gene action for days to maturity, number of secondary branches/plant, number of siliqua/plant, number seeds/siliqua and non-additive gene action for days to flowering, plant height, number of primary branches, siliqua length were found. Among the parents M-27 was the best general combiner for siliqua/plant and seed yield/plant. The hybrids YS-52 × M-27 exhibited highest significant SCA effect for seed yield/plant.

Arya *et al.* (1989) worked on combining ability from data of 12 yield related component characters in parents and F_1 of a 13 line × 3 tester mating design of *Brassica napus*. The varieties Midas, Regent 3-1 and DB054 were identified as good general combiners and DNA 38 × DISNI and N20-1 × Regent as good specific cross combinations.

Singh *et al.* (1989) worked with six *Brassica juncea* parents and their resultant 15 F1 and 15 F_2 populations. They evaluated 11 quantitative and qualitative characters. GCA and SCA variance were significant for all characters. RLM198 showed good general combining ability for plant height, number of siliqua/plant, and yield. The parents, I RNS12 showed good general combining ability for no. of seeds/siliqua and seed weight. The cross RLM198 × R75-1 showed significant SCA for seed yield in both F_1 and F_2.

Information on combining ability derived from data on seven characters in 23 lines of *Brassica juncea* and their F_1 and F_2 hybrids by Wani and Srivasiava (1989) indicated that parents RK8202, KR5610, RK1418, RH30, V10 and B30 were good general combiners for seed yield.

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

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

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

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

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

Chauhan (1987) tabulated genetic variance parameters for yield/plant and eight 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 three characters and non-additive effects for the remainder, Varuna, RS3 and Cult47 were good general combiners for yield as was RB85 for days to flowering and maturity.

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

RLM198. The best crosses for further selection were RLM822 × Varuna and RLM19S×RH30.

Gupta *et al.* (1987b) performed an analysis in a 13 × 4 line × tester cross in *Brassica juncea.* Additive gene effects were relatively more important than non-additive for seed yield/plant and most of the five yield component investigated. Among females, the best general combiners were RLM29 for seed yield, P Rai-1 for plant height, RLM240 for no. of primary and secondary branches. Among males, RLM198 was the best general combiners for seed yield, number of primary branches. Varuna was best for plant height and RL18 for number of secondary branches. The cross PI 1/17 × RH-30 exhibited high performance for seed yield along with significant SCA for number of primary and secondary branches, RLM24 × RH30 and RLM82 × Varuna showed desirable significant SCA effect for seed yield and plant height.

Prakash *et al.* (1987) 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/siliqua, 1000 seed weight, and seed yield indicating that dominance was possibly the predominant gene action for these traits. The parents DIR146 and RCL1017 were good general combiners for most of the characters studied.

Rawat (1987) observed a line × tester analysis involving 12 females and five males of *Brassica juncea* of diverse origin. Variance components of GCA and SCA were significant for days of 50% flowering, number of primary branch, plant height, seed weight and seed yield/plant. For secondary branches GCA was important. Pusa Rai 34 and Pusa Rai 45 among the female parents and Pusa Rai 30 among the male parents performed well and were good general combiners. The cross RLM514 × RLM198, RW336×Pusa Rai 30, Pusa Rai 45 × BR40 and RH7710 × Pusa Rai30 showed significant SCA for increased seed yield.

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

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

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

Chapter 3

MATERIALS AND METHODS

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3.1 Experimental Site

The research work was conducted at the experimental farm of Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh, during the period from November 2012 to February 2013.

3.2 Soil and Climate

The soil of the experimental plots were clay loam, land was medium high with medium fertility level (SAU). The site was situated in the subtropical climatic zone, wet summer and dry winter is the general climatic feature of this region (Figure 2). During the robi season the rainfall generally is scant and temperature is moderate with short day length. Meterogical data on rainfall, temperature, relative humidity from November 2012 to April 2013 were obtained from the Department of Metrological Centre, Dhaka-1207, Bangladesh.

3.3 Parent Materials

Seven *Brassica* genotypes namely NAP-9905, BS-13, NAP-9908, NAP-205, NAP-9906, NAP-248 and NAP-108 were used as lines and thirteen *Brassica* genotypes namely NAP-9904, NAP-9901, NAP-2013, NAP-2022, NAP-2001, NAP-94006, NAP-2012, NAP-206, NAP-130, NAP-2057, NAP-2066, NAP-179 and NAP-2037 as tester for line-tester cross.

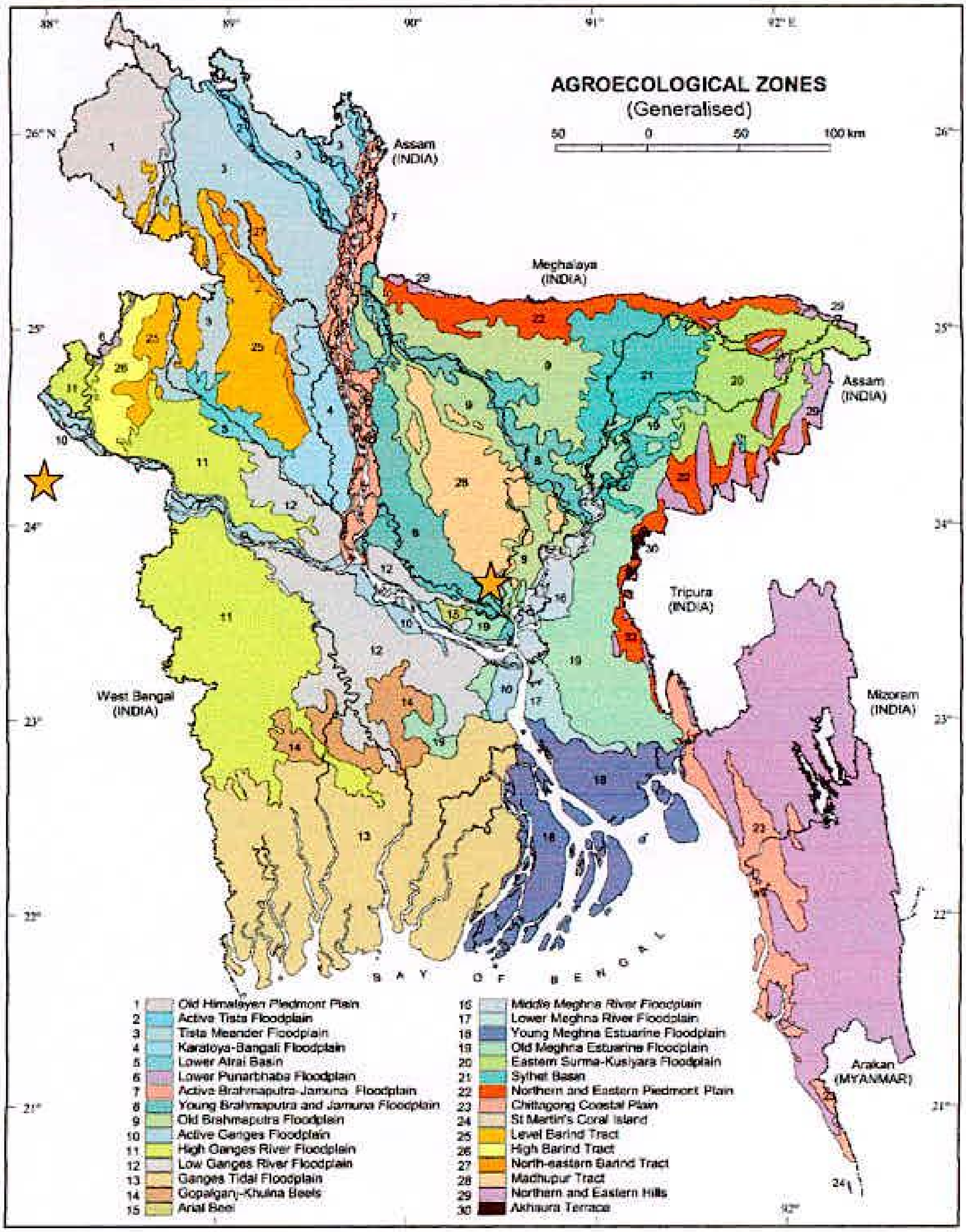

Figure 2: Location of the experimental field

3.4 Cross Combination

Table 1.List of F_1 hybrids for combining ability and heterosis estimaion

LINE / TESTER	NAP 9905	NAP BS-13	NAP 9908	NAP 205	NAP 9906	NAP 248	NAP 108
NAP 9904	9904X9905	9904X BS13	9904X9908	9904X205	9904X9906	9904X248	9904X108
NAP 2013	2013 X9905	2013X BS13	2013X9908	2013X205	2013X9906	2013X248	2013X108
NAP 9901	9901 X9905	9901XBS-13	9901X9908	9901X205	9901X9906	9901X248	9901X108
NAP 2022	2022 X9905	2022X BS13	2022X9908	2022X205	2022X9906	2022X248	2022X108
NAP 2001	2001 X9905	2001X BS13	2001X9908	2001X205	2001X9906	2001X248	2001X108
NAP 94006	94006X9905	94006XBS13	94006X9908	94006X205	94006X9906	94006X248	94006X108
NAP 2012	2012X9905	201X BS13	2012X9908	2012X205	2012X9906	2012X248	2012X108
NAP 206	206 X9905	206X BS13	206X9908	206X205	206X9906	206X248	206X108
NAP 0130	0130X9905	013X BS13	0130X9908	0130X205	0130X9906	0130X248	0130X108
NAP 2057	2057X9905	205X BS13	2057X9908	2057X205	2057X9906	2057X248	2057X108
NAP 2066	2066X9905	206X BS13	2066X9908	2066X205	2066X9906	2066X248	2066X108
NAP 179	179 X9905	179X BS13	179X9908	179X205	179X9906	179X248	179X108
NAP 2037	2037X9905	203X BS13	2037X9908	2037X205	2037X9906	2037X248	2037X108

3.5 Land Preparation and Fertilizer Application

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

3.6 Experimental Design and Layout

The seeds of ninety one F_1s and twenty parents were grown in Randomized Complete Block Design (RCBD) with two replications. Each plot consisted of single row of 3m length spaced 40cm apart and 10cm between plants. The seeds were sown in separate line in the experimental field on 15 November 2012 by hand uniformly. The seeds were sown at a soil depth of 2.5 to 3.5 cm. After sowing, the seeds were covered with soil carefully. Seed germination started after three days of sowing on 18 November 2012. Treatment was distributed in the experimental unit through randomization by using the random number.

3.7 Irrigation and Drainage

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

3.8 Intercultural Operation, Insect and Disease Control

Necessary intercultural operations were done during the crop period to ensure normal growth and development of the plants. Thinning and first weeding were done after fifteen days of sowing. Top-dressing, weeding and necessary thinning were done after 25 days of sowing. Malataf was sprayed two times one just before flowering and the other of the middle of flowering for protecting the crop from the attack of aphids and Rovral-50 WP was sprayed @

20-g/10L water first one at the time of siliqua setting of fruiting and second one after 15 days of 1st spraying to control *Alternaria* leaf spot. No remarkable disease attack was observed.

3.9 Harvesting of Sample Plants

When 80% of the plants showed symptoms of maturity i.e. straw color of siliquae, leaves, stem and desirable seed color in the matured siliquae, the crop was assessed to attain maturity. The sample plants were harvested by uprooting and then they were tagged properly.

3.10 Collection of Data

Data were recorded from 10 randomly selected plants per plot. Among the characters studied days to 50% flowering and plant height were recorded from the field and the remaining characters were recorded in the field laboratory after harvesting.

Data were collected for the following characters:

3.10.1 Days to 50% Flowering: Days to 50% flowering was counted when near about 50 percent plants had at least one open flower of each F_1s or parents. Flowering stage was shown in Plate 1 and Plater 2.

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

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

3.10.4 Number of Primary Branches per Plant: Mean Numbers of branches originated from the main stem from ten randomly selected plants from each F_1s and parents at maturity.

3.10.5 Number of Secondary Branches per Plant: Number of branches originated from the primary branch from ten randomly selected plants from each F_1s and parents at maturity.

3.10.6 Number of Siliquae per Plant: Mean number of siliquae obtained from ten randomly selected plants from each F_1s and parents at maturity.

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

Plate 2: Field view at flowering stage (side view)

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

3.10.9 Thousand-seed Weight (g): Weight in gram of 1000-seed was recorded from ten randomly selected plants of each F_1s and parents.

3.10.10 Seed Yield per Plant (g): Mean seed weight in grams of ten randomly selected plants from each F_1s and parents after harvest.

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

3.11.1 Analysis of Variance: The combined data were statistically analyzed, where the data were subjected to ANOVA using MSTATC computer software Version 1.2 individually for all the traits, to asses' statistical differences among F_1 progeny and their parents.

3.9.1 Estimation of Heterosis:

The amount of heterosis in the F_1s was analyzed using the following formulae:

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

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.

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

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.

3.9.2 Combining ability in relation to Line-tester cross

All quantitative data were subjected to combining ability analysis according to Kempthorne (1957) and determine the performance of the parents and their relative contribution to F_1s as determined by the general combing ability (GCA) and specific combining ability (SCA). GCA represents additive variance, whereas SCA represents non additive effects. Calculation was done using MS-EXCEL.

Analysis of variance for combining ability was as follows:

Source of variation	Df	MS	F-test	Expected Mean squares
Replication	r-1	-		
Treatments	T-1	-		
Parents	P-1	-		
Parents V Crosses	1	-		
Crosses	h-1	-		
Lines (Females)	l-1	Ml	$\frac{Ml}{Me}$	VE+Vlt+rtVl
Testers (Males)	t-1	Mt	$\frac{Mt}{Me}$	VE+rVlt+rlVt
Lines x Testers	(l-1)(t-1)	Ml x t	$\frac{Ml \times t}{Me}$	VE+Vlt
Error	(r-1)(lt-1)	Me		VE
Total	rlt-1			

The mathematical model used for GCA analysis was as follows:

a. Lines

$$Gi = \frac{xi}{tr} + \frac{x}{ltr}$$

Where

l=no.of lines r=no.of replication

t=no.of testers

b. Testers:

$$gi = \frac{Xi}{tr} + \frac{X}{ltr}$$

The mathematical model used for SCA analysis was as follows:

$$S_{ij} = \frac{xij}{r} - \frac{xi}{tr} - \frac{x.j}{lr} - \frac{x\ ...}{ltr}$$

Where,

Xij.=Individual cross value

Xi..=Line total

x.j. =Tester total

x...=Grand total

r=Replication

l=Line number

t=Tester number

Estimations of standard errors for combining ability effects

SE (gca for line) = $\sqrt{\frac{Me}{r}} \times t$ $\quad Where, Me = Error\ mean\ sum\ square$

SE (gca for tester) = $\sqrt{\frac{Me}{r}} \times l$ gi-gj=diffirence of GCA for any line or tester pair

SE (gi-gj) = $\sqrt{\frac{2Me}{r}} \times t$

SE (gi-gj) = $\sqrt{\frac{2Me}{r}} \times r$

SE (gij-gkl) = $\sqrt{\frac{2Me}{r}}$

Estmation of genetic component of variation

Variance of GCA and SCA were calculated by following formula;

CovH.S. (line) = $\frac{MiM(lr)}{(rxt)}$

CovH.S. (tester) = $\frac{MiM(lxt)}{(rxt)}$

CovH.S. (Average) = $\frac{1}{r(2lt-l-t)}\{\int \frac{(l-1)(Mi)+(t-1)(Mi)}{(l-t)-2} - M(l \times t)\}$

Chapter 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 MEAN PERFORMANCE

Mean performance of ten agronomic and yield related traits of parents and hybrid combinations are presented in Table 2.

4.1. 1 Days to 50% Flowering

In case of days to 50% flowering for lines, it was ranged from 38 to 49 days. However, the testers flowered within 39 and 44 days. On the other hand, the cross combination NAP-9905 × NAP-9904, NAP-9905 × NAP-2013, BS-13 × NAP-9901, BS-13 × NAP-130, NAP-205 × NAP-9904, NAP-9906 × NAP-94006, NAP-248 × NAP-2012 and NAP-248 × NAP-130 produced flower with the lowest growth duration 39days, which was about at least a day earlier than its both parents (Table 2).

4.1.2 Days to 50% Maturity

Considering earliness, the line NAP-9908 showed the lowest duration for maturation 96 days but the lines NAP-205, NAP-248 and NAP-108 had taken the maximum duration 99 days. Among the testers, NAP-9904 showed the lowest duration for maturation 67 days. On the other hand, no cross combinations matured earlier than its both parents (Table 2).

4.1.3 Plant Height

For line, the lowest plant height was observed in NAP-9905 (87.4) cm; for tester NAP-2022 (84.4) cm and for F_1 NAP-248 × NAP-2012 (92.6) cm, whereas the line NAP-108 had the highest (115.8) cm plant height. The highest plant height was found from the cross combination NAP-205 × NAP-9901 (124.5) cm. The hybrids were taller in terms of height than lines and testers (Table 2). **Plate 3 showing different plant height of line, tester and their hybrid.**

Table 2: Mean performance for 10 different characters in 20 parents and their 91 F_1s of *Brassica napus* L.

Genotypes	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branches	No. of Secondary Branches	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield/Plant (g)
Lines										
NAP-9905	45	98	87.4	2.1	0.7	88.8	8.53	25.64	3.9	5.89
BS-13	40	97	95.8	3.6	2.1	93.6	8.39	22.18	3.3	5.63
NAP-9908	38	96	93.1	4.25	3.35	104.1	6.78	21.4	2.4	5.95
NAP-205	45	99	109.3	3	1.25	100.1	8.04	17.94	3.75	4.03
NAP-9906	43	98	97.2	2.9	1.3	88.4	9.32	21.58	4.15	5.15
NAP-248	44	99	101.25	3.05	5.1	108	8.88	23.3	4.25	10.27
NAP-108	45	99	115.8	3.2	2.2	156.3	9.53	22.14	4.1	5.3
Maximum	45	99	115.8	4.25	5.1	156.3	9.53	25.64	4.25	10.27
Minimum	38	96	87.4	2.1	0.7	88.4	6.78	17.94	2.4	4.03
Tester										
NAP-9904	40	67	95.5	2.9	2.1	89.3	8.49	23.96	4.25	6.34
NAP-9901	43	98	89.4	3.3	2.15	101.75	7.32	25.4	2.75	4.72
NAP-2013	44	99	102.2	3	2.85	101.35	9.16	21.8	3.55	4.96
NAP-2022	39	98	84.4	1.9	1.2	71	8.17	21.9	3.75	6.69
NAP-2001	39	98	85.95	4.7	2.9	54.56	6.21	26.25	3.3	7.28
NAP-94006	43	98	97.2	2.9	1.3	88.4	9.32	21.58	4.15	5.15
NAP-2012	39	98	87.5	2.4	2.6	87.5	7.97	26.36	3.4	6.11
NAP-206	42	96	89.75	4.1	2.85	99.8	10.2	27	3.3	9.74
NAP-130	40	99	93.45	3.3	1.3	91.5	8.02	28.01	4.25	6.9
NAP-2057	44	98	99.4	3.15	3.4	100.3	9.75	25	4.1	8.91
NAP-2066	39	98	84.9	2.5	2.7	109.4	8.6	23.6	3.4	6.78
NAP-179	45	99	99.4	3.2	1.9	99.8	8.87	21.26	3.15	7.9
NAP-2037	39	98	95.55	3.75	4	105.4	8.09	28.3	2.6	8.72

Maximum	45	99	102.2	4.7	3.4	105.4	10.2	28.01	4.25	8.91
Minimum	39	67	84.4	1.9	1.2	54.56	6.21	21.26	2.6	5.15
Hybrids										
NAP-9905 x NAP-9904	39	98	102.9	3.6	4.9	134	9.26	27.28	3.6	10.18
NAP-9905 x NAP-9901	45	98	110.7	2.3	2.4	95	9.01	24.38	4.05	7.9
NAP-9905 x NAP-2013	39	98	117.9	2.4	1.8	104	9.7	26.6	4	9.33
NAP-9905 x NAP-2022	44	98	99.8	2.6	2.1	113.8	9.36	25.02	5	9.66
NAP-9905 x NAP-2001	44	98	101.1	2.5	2.3	93	9.62	24.78	4.25	6
NAP-9905 x NAP-94006	44	98	102	3.5	4.3	165.3	10.12	26.73	4.35	7.12
NAP-9905 x NAP-2012	39	99	96.8	3.2	2.2	121.6	8.4	23.02	4.05	8.82
NAP-9905 x NAP-206	45	98	106.8	2.7	2.4	104.3	9.78	23.5	4.8	8.88
NAP-9905 x NAP-130	47	98	102.8	2.7	1.3	90.3	9.05	22.54	2.55	5.14
NAP-9905 x NAP-2057	45	98	96.7	2.8	1.6	90.3	9.14	26.52	4.1	8.35
NAP-9905 x NAP-2066	45	98	109.6	1.9	1.4	87.8	9.2	23.36	4.4	7.11
NAP-9905 x NAP-179	45	98	110.9	2.7	2.7	126	10.15	27.32	3.3	7.31
NAP-9905 x NAP-2037	43	99	101.7	3.5	2.8	109.6	8.46	22.92	2.85	7.87
BS-13 x NAP-9904	45	98	112.7	2.2	1.6	94.5	8.93	24.1	4.55	6.84
BS-13 x NAP-9901	39	98	98.6	2.6	2.2	104.3	8.89	23.2	4.7	7.9
BS-13 x NAP-2013	48	98	108.9	2.2	1.7	89.9	9.08	25.1	3.35	6.95
BS-13 x NAP-2022	49	99	101.7	1.9	1.5	80.1	8.57	21.04	4.25	5.14
BS-13 x NAP-2001	47	98	117.3	2.6	1.3	85.4	9.5	26.68	4.05	7.91
BS-13 x NAP-94006	42	99	99.2	2.2	2.2	87.2	8.76	21.52	4.05	6.6
BS-13 x NAP-2012	43	99	109	2.8	2.7	129.3	9.1	22.56	3.95	7.49
BS-13 x NAP-206	42	99	103.1	2.8	1.3	106.9	8.86	23.82	3.25	7.07

Table 2: (Continued)

Genotypes	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branches	No. of Secondary Branches	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield/Plant (g)
BS-13 x NAP-130	39	99	102.7	2.9	1.6	123.8	9.01	25.46	4.35	7.53
BS-13 x NAP-2057	45	99	109.5	2.7	1.5	100.9	8.95	23.82	2.5	7.5
BS-13 x NAP-2066	44	100	111.4	2.5	1.9	112.6	8.75	25.32	3.65	12.8
BS-13 x NAP-179	46	99	105.2	2.4	3.7	154.3	9.81	22.44	5	11.31
BS-13 x NAP-2037	48	100	109.1	2.7	2.9	119.3	9.14	20.6	4.05	6.98
NAP-9908 x NAP-9904	39	98	102.4	2.7	3.1	104.4	9.26	20.92	3.8	5.85
NAP-9908 x NAP-9901	45	99	90.8	3.3	1.5	74	7.43	21.5	3.85	8.73
NAP-9908 x NAP-2013	41	98	109.6	2.7	2.9	138.7	8.83	25.46	4.5	6.32
NAP-9908 x NAP-2022	44	99	102.2	2.9	1.2	102.4	9.71	25.7	4.6	6.76
NAP-9908 x NAP-2001	46	98	109.9	2.5	1.9	96	9.09	22.3	3.9	9.25
NAP-9908 x NAP-94006	43	98	99.4	2.6	2.6	114.7	9.84	25.5	4.45	8.66
NAP-9908 x NAP-2012	44	98	90.9	2.7	1.6	93.5	9.02	25.06	3	8.86
NAP-9908 x NAP-206	46	98	102.2	2.5	1.3	86.3	9.44	21.86	4.05	5.49
NAP-9908 x NAP-130	44	99	113	3.1	3.1	157.1	9.73	23.46	5.8	7.83
NAP-9908 x NAP-2057	43	99	103.6	3	3	131.7	8.7	25.29	4.55	11.03
NAP-9908 x NAP-2066	44	99	113.9	2.9	3.8	143.7	8.45	22.06	4.25	11.57
NAP-9908 x NAP-179	46	99	110	3	2.5	125.4	9.47	24.36	1.7	7.36
NAP-9908 x NAP-2037	45	100	91.5	2.3	0.9	68.1	8.55	23.4	3.6	6.99
NAP-205 x NAP-9904	39	98	108.3	3.3	2.9	131.9	8.89	23.38	1.5	9.54
NAP-205 x NAP-9901	44	98	124.5	2.9	2.1	127.7	8.91	23.58	4.3	9.97
NAP-205 x NAP-2013	46	98	97.5	2.2	1.1	106.3	8.35	23.78	3.05	9
NAP-205 x NAP-2022	45	98	111.2	2.5	2.4	118.9	9.22	24.24	3.85	8.68
NAP-205 x NAP-2001	41	98	103.4	2.6	2.6	111.3	8.74	21.86	3.93	7.91

Table 2: (Continued)

Genotypes	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branches	No. of Secondary Branches	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield/Plant (g)
NAP-205 x NAP-94006	45	99	101.3	2.7	2.3	90.1	9.06	11.86	4	5.8
NAP-205 x NAP-2012	45	99	106.6	2.7	3	135.9	9.36	26.42	3.8	8.14
NAP-205 x NAP-206	49	100	119.9	3.3	2.4	141	8.67	24.22	4.25	8.32
NAP-205 x NAP-130	44	99	98.7	3.3	1.7	103.7	9.23	22.5	2.8	7.56
NAP-205 x NAP-2057	44	99	106.2	2.7	1.7	113.2	8.31	21.68	4.6	7.2
NAP-205 x NAP-2066	44	99	101.7	2.6	1.6	94.7	8.83	21.46	4.25	6.59
NAP-205 x NAP-179	47	99	109	2.3	2.6	109.7	9.1	23.02	3.8	7.81
NAP-205 x NAP-2037	43	99	104.5	2.7	2.2	90	9.42	25.02	3.85	8.22
NAP-9906 x NAP-9904	43	98	101.1	2.5	1.2	79	9.22	24.86	3.85	7.21
NAP-9906 x NAP-9901	46	99	116.2	2.6	3.1	132.4	8.99	24.73	4.2	8.62
NAP-9906 x NAP-2013	46	99	109.8	2.6	3.5	112.5	9.55	22.22	4.25	6.87
NAP-9906 x NAP-2022	39	98	98.3	2.2	2.9	89.6	10.03	21.88	4.35	5.2
NAP-9906 x NAP-2001	46	98	102.5	2.8	2.3	111.1	8.45	22.58	3.95	9.73
NAP-9906 x NAP-94006	39	98	113	2.9	2.7	111.1	9.62	25.16	3.8	6.82
NAP-9906 x NAP-2012	43	98	104.9	2.8	1.5	88.8	9.06	21.1	4.65	7.88
NAP-9906 x NAP-206	46	98	100.1	3	2.6	113	9.2	23	3.6	6.83
NAP-9906 x NAP-0130	46	99	95.3	3.4	1.5	95.4	8.85	22.74	2.45	7.81
NAP-9906 x NAP-2057	44	99	105.7	2.9	2.5	105.3	9.5	21.54	4.1	6.75
NAP-9906 x NAP-2066	44	99	104.9	2.7	2.9	128.4	8.95	24.44	4.25	12.05
NAP-9906 x NAP-179	46	99	97.5	2.9	3.5	135.3	9.75	23.38	4.8	6.53
NAP-9906 x NAP-2037	44	98	107.1	2.7	3.4	104.9	9.29	21.4	4.4	6.95
NAP-248 x NAP-9904	42	99	106.2	2.3	1.8	82.9	9.35	24.2	4.05	12.63
NAP-248 x NAP-9901	41	98	99.7	2.4	2.8	101.9	8.8	22.68	4.75	10.94

Table 2: (Continued)

Genotypes	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield/Plant (g)
NAP-248 x NAP-2013	41	98	98.8	2.7	1.6	116.8	8.69	23.04	3.3	5.15
NAP-248 x NAP-2022	43	99	105	3.1	2	98.9	9.54	25.54	4.35	6.73
NAP-248 x NAP-2001	42	98	104.4	3.5	2.7	97.9	9.29	24.18	4.35	7.45
NAP-248 x NAP-94006	45	98	105.3	2.6	2.3	107.8	9.51	24.02	4.7	10.34
NAP-248 x NAP-2012	39	98	88.5	2.2	2.3	79.7	8.71	23.34	5.05	10.78
NAP-248 x NAP-206	43	98	106.9	3	1.9	104.8	9.21	22.56	4.8	11.88
NAP-248 x NAP-130	39	98	110.6	2.7	2.3	130	9.45	26.86	4.65	10.88
NAP-248 x NAP-2057	43	99	108.8	2.5	2.9	122.8	9.18	22.65	4.5	7.81
NAP-248 x NAP-2066	44	98	98.9	2.7	2	97.5	9.08	23.36	2.7	7.77
NAP-248 x NAP-179	44	99	107.3	2.7	1.4	99.9	8.45	24.36	3.3	4.36
NAP-248 x NAP-2037	44	99	117.3	3.2	1.7	110.5	9.96	27.82	4.2	12.82
NAP-108 x NAP-9904	43	98	111.3	3.3	2.9	130.6	9.51	23.74	4.05	10.03
NAP-108 x NAP-9901	44	98	106	3.1	2.5	106	9.56	26.22	4.35	11.96
NAP-108 x NAP-2013	45	98	121.2	3.1	2.5	133.9	9.28	25.62	3.1	8.8
NAP-108 x NAP-2022	39	98	115.7	3.3	3.3	138.5	9.57	26.98	4.5	11.22
NAP-108 x NAP-2001	42	98	106.4	2.5	1.3	92.8	8.97	25.82	3.4	7.83
NAP-108 x NAP-94006	44	98	105.8	2.4	1.8	118	8.75	24.34	3.4	8.15
NAP-108 x NAP-2012	45	98	109.1	2	1.8	100.5	9.28	25.54	3.95	9.47
NAP-108 x NAP-206	48	99	116.9	2.7	2.9	103.8	8.93	25.08	4.1	6.37
NAP-108 x NAP-130	44	98	111.4	2.4	1.5	123.8	9.28	25.86	4.35	9.03
NAP-108 x NAP-2057	43	99	113.5	3.2	3.1	124.9	8.99	24.7	4.25	9.71
NAP-108 x NAP-2066	44	99	115.5	2.4	1.6	135.4	9.16	26.24	4.45	7.43
NAP-108 x NAP-179	45	99	114.9	3.2	4.7	172.6	9.16	26.66	4.15	11.38

Table 2: (Continued)

Genotypes	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primay Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield/Plant (g)
NAP-108 x NAP-2037	45	98	103.9	2.2	1.8	105.9	9.4	24.96	3.95	8.91
Maximum	49	100	124.5	3.6	4.9	172.6	10.15	27.82	12.63	5.8
Minimum	31	98	92.6	1.9	1.1	11.86	7.43	11.86	5.14	1.5
CV%	1.74	3.90	7.14	17.53	37.31	24.16	6.31	9.13	13.43	10.08

Plate 3: Photograph showing Nap 9905 (Line), Nap 9904 (Tester) and their hybrid (F1)

Plate 4: Photograph showing Nap 9905 (Line), Nap 9904 (Tester) and their hybrid (F1)

4.1.4 Number of Primary Branches per Plant

For the character, number of primary branches per plant, lines showed at a range from 2.1 to 4.25. But in the hybrids, the highest value (3.6) provided by the cross combination NAP-9905 x NAP-9904 (3.6) which was higher than the value of the line (2.1) and tester (2.9) (Table 2). Plate 4 showing different number of primary branches among line , tester and their hybrid.

Plate 4: Photograph showing Nap 9905 (Line), Nap 9904 (Tester) and their hybrid (F1)

4.1.5 Number of Secondary Branches per Plant

For the number of secondary branches per plant, lines showed at a range from 0.7 to 5.1. But in the hybrids, the highest value (4.9) for number of secondary branches per plant provided by the cross combination NAP-9905 x NAP-9904 (4.9) which was much higher than the value of the line (0.7) and tester (2.1) (Table 2).

4.1.6 Number of Siliquae per Plant

Number of siliquae per plant was varied from 88.4 to 156.3 where the line NAP-108 produced the highest (156.3) and NAP-9906 the lowest number of siliquae per plant (88.4). Considering hybrid performance, cross combination NAP-108 x NAP-179 (172.6) gave +- the highest number which was much higher than it's either parent (Table 2).

4.1.7 Siliqua Length (cm)

Siliqua length of lines was ranged from 6.78 to 9.53 cm and siliqua length of tester was 6.21 to 10.2 cm. The line, 108 produced the longest siliqua while the line NAP-9908 produced smallest siliqua. The tester, NAP-206 produced the longest siliqua while the tester NAP-2001 produced smallest siliqua. On the other hand, the values varied from 7.43 to 10.15 for hybrids. The cross combination NAP-9905 x NAP-179 exhibited the highest length of siliqua while the cross combination NAP-9908 x NAP-9901 exhibited the lowest siliqua length (Table 2).**Plate 5 shoswing different pod lenth between line, tester and their hybrid.**

Plate 5: Photograph showing Siliqua of Nap 248 (Line), Nap 9904 (Tester) and their hybrid (F_1)

4.1.8 Seeds per Siliqua

Seed per siliqua also varied from 17.94 to 25.64 in lines, from 21.26 to 28.3 in testers and from 11.86 to 27.82 in hybrids. The hybrid NAP-248 x NAP-2037 produced an excellent number of seeds per siliqua (27.82) which was higher than the parent used as line in this program (Table 2).

4.1.9 Seed Yield per Plant (g)

Seed yield per plant in *B. napus* varied from 4.03 to 10.27 g in lines, from 4.72 to 8.91 in testers but from 5.14 to 12.63 g in hybrids. However, the highest yield was produced by the line NAP-248 (10.27 g), the tester NAP-2057 (8.91 g) and the cross combination NAP-248 x NAP-9937(12.63 g). This hybrid produced the higher seed yield than it's both parents (Table 2).

4.1.10 1000- seed Weight (g)

Thousand seed weight of the genotypes varied from 2.4 to 4.25 g in lines, 2.6 to 4.25 tester and 1.5 to 5.8 g in hybrids. The heaviest seed of the lines was found in NAP-248 whereas lightest in NAP-9908. The heaviest seed of the testers was found in NAP-9904 and NAP-130 whereas lightest in NAP-2037. Similarly, the heaviest seed was observed in the cross combination NAP-9908 x NAP-130 which was higher than it's both of the parents (Table 2).

4.2 HETEROSIS

Ten yield contributing characters of *Brassica napus* were studied in seven lines and thirteen tester parental genotypes and their 91 F_1 hybrids obtained from 7x13 line-tester crosses. Percent heterosis for 10 different characters of the F_1 hybrids over their respective mid and better parental values is shown in Table 3. These results on heterosis of 91 F_1s are described by character wise below:

4.2.1 Days to 50% Flowering

Significant and negative heterosis over parent was desirable for selection of hybrid with short duration. Cross combination NAP-9905 x NAP-2013 showed highly significant and negative heterotic values (-12.36) for mid parent heterosis and better parent heterosis (-13.33). 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 3).

4.2.2 Days to 50% Maturity

For Days to 50% maturity, negative heterosis is usually useful to obtain early hybrid. Out of 91 crosses no hybrids had negative non-significant heterosis over mid parent and better parent. Kumar *et al.* (2002), Mahak *et al.* (2003a) and Das *et al.* (2004) found significant heterosis values for days to maturity over mid parent and better parent which were of disagreement with the majority of the findings of the parent crossed (Table 3).

4.2.3 Plant Height

Out of 91 crosses no hybrids had significant negative heterosis over mid parent and better parent for plant height (Table 3) which was desirable. 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. Yadav *et al.* (2004) observed the magnitude of heterosis was the highest for plant height in Trachystoma × SK 93-1 (27.7%) over BP and (25.8%) over CV both. For example, the hybrid Nap179 x Nap2001 is showing positive significance (46.02% and 37.63% over mid and better parent, respectively) in plant height .

4.2.4 Number of Primary Branches per Plant

Twenty five hybrids showed significant mid-parent ranged from -37.35 to 44.00.But positive significant heterosis is desirable .Heighest value belongs to combination NAP 9905X NAP9904. Thirty seven hybrids showed negative and significant better parent heterosis for number of primary branches per plant but positive significant value is desirable.In case of better parent theres no positive value.(Table 3) .Thakur and Segwall (1997) found a heterosis value ranging from -26.0 to 193.6% over better parent for the character of primary branches in rapeseed (*Brassica napus* L.). Yadav *et al.* (2004) observed the number of primary branches per plant, Trachystome × PR 905 showed 106.5% and 100.0% heterosis over BP and SV, respectively.

4.2.5 Number of Secondary Branches per Plant

Sixteen hybrids showed significant mid-parent heterosis and twenty seven showed significant better parent heterosis for number of secondary branches per plant. Positive significant value is desirable.Heighest value (330) belongs to combination NAP9905XNAP94006 in case of mid parent heterosis.Heighest value(230.77) belongs to combination NAP9905XNAP94006 in case of better parent heterosis (Table 3). 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.

4.2.6 Number of Siliquae per Plant

No cross combinations showed significant heterosis over mid parent for number of siliquae per plant. On the other hand, for better parent heterosis there was a total of six combinations showed significant heterosis which ranged from -40.63% to 86.15%. In this case, the hybrid NAP-9905 x NAP-94006 produced the highest heterotic value (86.15%) which is desirable (Table 3). Zheng and Fu (1991) found positive heterosis of 51.47% over mid parent in the hybrids in *Brassica nigra* for number of siliquae per plant. Thakur and Segwal (1997) estimated positive heterosis over better parent ranging from 21.9 to 162.6% in rape seed for siliquae per plant. Qi *et al.* (2003) observed the forty-seven crosses gave on average 28.02% (0.93-97.87%) more siliquae per plant.

4.2.7 Siliqua Length (cm)

Positive significant heterotic value is desired for siliqua length. Twenty eight hybrids showed significant mid-parent heterosis and nine showed better parent heterosis for siliqua length. NAP-9908 x NAP-2001 showed highest significant and positive heterosis (39.96) over mid parent and better parent (34.10) (Table 3). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea*.

4.2.8 Seeds per Siliqua

Positive and significant heterotic value is desired for seeds per siliqua. The results showed that nine crosses had positive significant heterotic value over mid parent and two had over better parent. NAP-108 x NAP-179 had highest positive and highly significant heterotic value (22.86) over mid parent and NAP-108 x NAP-2022 had highest positive and highly significant heterotic value (21.86) over better parent (Table 3). Kumar *et al.* (1990) reported positive heterosis for number of seeds per siliqua in *Brassica juncea*. Yadav *et al.* (2004) observed the Siifolia × SM-1 showed 54.1% heterosis over BP, negative heterosis (-9.2%) over SV for seeds per siliqua. Qi *et al.* (2003) observed the crossed showed 11.67% more seeds per siliqua.

4.2.9 1000- seed Weight (g)

Twenty two hybrid showed significant positive heterosis values over mid parent and five hybrids showed significant positive heterosis values over better parent (Table 3). 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 better parent heterosis (3.57 to 20.48%) in thousand seed weight.

Table 3: Heterosis (%) over mid parent and better parent for different characters in *Brassica napus* L.

Cross combination	Days of 50% Flowering		Days of 50% Maturity		Plant Height(cm)		NO. of Primary Branch		NO. of Secondary Branch	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-9905 x NAP-9904	-8.77 **	-13.33 **	18.43 **	0.00 ns	12.52 ns	7.75 ns	44.00 **	24.14 ns	250.0 **	133.33 **
NAP-9905 x NAP-9901	1.69 ns	0.00 ns	0.00 ns	0.00 ns	25.23 **	23.83 **	-14.81 ns	-30.3 *	68.42 ns	11.63 ns
NAP-9905 x NAP-2013	-12.36 **	-13.33 **	-0.51 ns	-1.01 ns	24.37 **	15.36 *	-5.88 ns	-20.0 ns	1.41 ns	-36.84 ns
NAP-9905 x NAP-2022	4.76 **	-2.22 ns	0.00 ns	0.00 ns	16.18 *	14.19 ns	30.00 ns	23.81 ns	121.05 ns	75.00 ns
NAP-9905 x NAP-2001	4.76 **	-2.22 ns	-0.25 ns	-0.51 ns	16.64 *	15.68 ns	-26.47 *	-46.81 **	27.78 ns	-20.69 ns
NAP-9905 x NAP-94006	0.00 ns	-2.22 ns	0.00 ns	0.00 ns	10.51 ns	4.94 ns	40.00 *	20.69 ns	330.0 **	230.77 **
NAP-9905 x NAP-2012	-7.69 **	-13.33 **	1.02 ns	1.02 ns	10.69 ns	10.63 ns	42.22 *	33.33 ns	33.33 ns	-15.38 ns
NAP-9905 x NAP-206	3.45 *	0.00 ns	0.77 ns	0.00 ns	20.58 **	19.0 *	-12.9 ns	-34.15 **	35.21 ns	-15.79 ns
NAP-9905 x NAP-130	10.59 **	4.44 **	-0.51 ns	-1.01 ns	13.69 ns	10.01 ns	0.00 ns	-18.18 ns	30.00 ns	0.00 ns
NAP-9905 x NAP-2057	1.12 ns	0.00 ns	-0.25 ns	-0.51 ns	3.53 ns	-2.72 ns	6.67 ns	-11.11 ns	-21.95 ns	-52.94 *
NAP-9905 x NAP-2066	7.14 **	0.00 ns	0.00 ns	0.00 ns	27.22 **	25.4 **	-17.39 ns	-24.0 ns	-17.65 ns	-48.15 ns
NAP-9905 x NAP-179	0.00 ns	0.00 ns	-0.51 ns	-1.01 ns	18.74 **	11.57 ns	1.89 ns	-15.62 ns	107.69 ns	42.11 ns
NAP-9905 x NAP-2037	2.38 ns	-4.44 **	1.02 ns	1.02 ns	11.18 ns	6.44 ns	19.66 ns	-6.67 ns	19.15 ns	-30.00 ns
BS-13 x NAP-9904	11.11 **	11.11 **	19.15 **	1.03 ns	17.83 **	17.64 *	-32.31 *	-38.89 **	-23.81 ns	-23.81 ns
BS-13 x NAP-9901	-7.14 **	-10.34 **	0.51 ns	0.00 ns	6.48 ns	2.92 ns	-24.64 *	-27.78 *	3.53 ns	2.33 ns
BS-13 x NAP-2013	13.61 **	9.09 **	0.00 ns	-1.01 ns	10.00 ns	6.56 ns	-33.33 **	-38.89 **	-31.31 ns	-40.35 ns
BS-13 x NAP-2022	23.27 **	20.99 **	1.54 ns	1.02 ns	12.87 ns	6.16 ns	-30.91 *	-47.22 **	-9.09 ns	-28.57 ns
BS-13 x NAP-2001	18.24 **	16.05 **	0.26 ns	-0.51 ns	29.08 **	22.44 **	-37.35 **	-44.68 **	-48.00 ns	-55.17 ns
BS-13 x NAP-94006	0.6 ns	-2.33 ns	1.54 ns	1.02 ns	2.8 ns	2.06 ns	-32.31 *	-38.89 **	29.41 ns	4.76 ns
BS-13 x NAP-2012	7.5 **	6.17 **	1.54 ns	1.02 ns	18.93 **	13.78 ns	-6.67 ns	-22.22 ns	14.89 ns	3.85 ns
BS-13 x NAP-206	1.82 ns	0.00 ns	2.33 ns	2.06 ns	11.13 ns	7.62 ns	-27.27 *	-31.71 **	-47.47 ns	-54.39 ns
BS-13 x NAP-0130	-3.11 ns	-3.7 *	1.02 ns	0.00 ns	8.53 ns	7.2 ns	-15.94 ns	-19.44 ns	-5.88 ns	-23.81 ns
BS-13 x NAP-2057	6.51 **	2.27 ns	1.28 ns	0.51 ns	12.19 ns	10.16 ns	-20.00 ns	-25.0 ns	-45.45 ns	-55.88 *
BS-13 x NAP-2066	10.69 **	8.64 **	2.56 ns	2.04 ns	23.3 **	16.28 *	-18.03 ns	-30.56 *	-20.83 ns	-29.63 ns

**$p<0.01$, *$p<0.05$

Table 3: (Continued)

Cross combination	Days of 50% Flowering		Days of 50% Maturity		Plant Height(cm)		NO. of Primary Branch		NO. of Secondary Branch	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
BS-13 x NAP-179	7.6 **	2.22 ns	1.02 ns	0.00 ns	7.79 ns	5.84 ns	-29.41 *	-33.33 *	85.00 *	76.19 ns
BS-13 x NAP-2037	20.75 **	18.52 **	2.56 ns	2.04 ns	14.03 *	13.88 ns	-26.53 *	-28.0 *	-4.92 ns	-27.5 ns
NAP-9908 x NAP-9904	-0.64 ns	-3.7 *	19.88 **	2.08 ns	8.59 ns	7.23 ns	-24.48 *	-36.47 **	13.76 ns	-7.46 ns
NAP-9908 x NAP-9901	10.43 **	3.45 *	2.06 ns	1.02 ns	-0.49 ns	-2.47 ns	-12.58 ns	-22.35 ns	-45.45 ns	-55.22 *
NAP-9908 x NAP-2013	0.00 ns	-6.82 **	0.51 ns	-1.01 ns	12.24 ns	7.24 ns	-25.52 *	-36.47 **	-6.45 ns	-13.43 ns
NAP-9908 x NAP-2022	14.29 **	12.82 **	2.06 ns	1.02 ns	15.15 *	9.77 ns	-5.69 ns	-31.76 **	-47.25 ns	-64.18 *
NAP-9908 x NAP-2001	19.48 **	17.95 **	0.77 ns	-0.51 ns	22.76 **	18.05 *	-44.13 **	-46.81 **	-39.2 ns	-43.28 ns
NAP-9908 x NAP-94006	6.17 **	0.00 ns	1.03 ns	0.00 ns	4.47 ns	2.26 ns	-27.27 *	-38.82 **	11.83 ns	-22.39 ns
NAP-9908 x NAP-2012	13.55 **	11.39 **	1.03 ns	0.00 ns	0.66 ns	-2.36 ns	-18.8 ns	-36.47 **	-46.22 ns	-52.24 *
NAP-9908 x NAP-206	15.00 **	9.52 **	1.82 ns	1.55 ns	11.79 ns	9.77 ns	-40.12 **	-41.18 **	-58.06 *	-61.19 *
NAP-9908 x NAP-130	12.82 **	10.00 **	1.54 ns	0.00 ns	21.15 **	20.92 **	-17.88 ns	-27.06 *	33.33 ns	-7.46 ns
NAP-9908 x NAP-2057	4.88 **	-2.27 ns	1.8 ns	0.51 ns	7.64 ns	4.23 ns	-18.92 ns	-29.41 *	-11.11 ns	-11.76 ns
NAP-9908 x NAP-2066	14.29 **	12.82 **	2.06 ns	1.02 ns	27.98 **	22.34 **	-14.07 ns	-31.76 **	25.62 ns	13.43 ns
NAP-9908 x NAP-179	10.84 **	2.22 ns	1.54 ns	0.00 ns	14.29 *	10.66 ns	-19.46 ns	-29.41 *	-4.76 ns	-25.37 ns
NAP-9908 x NAP-2037	16.88 **	15.38 **	3.09 ns	2.04 ns	-2.99 ns	-4.24 ns	-42.5 **	-45.88 **	-75.51 **	-77.5 **
NAP-205 x NAP-9904	-8.77 **	-13.33 **	17.72 **	-1.01 ns	5.76 ns	-0.91 ns	11.86 ns	10.0 ns	73.13 ns	38.1 ns
NAP-205 x NAP-9901	-0.56 ns	-2.22 ns	-0.51 ns	-1.01 ns	25.31 **	13.91 *	-7.94 ns	-12.12 ns	23.53 ns	-2.33 ns
NAP-205 x NAP-2013	3.37 *	2.22 ns	-1.01 ns	-1.01 ns	-7.8 ns	-10.8 ns	-26.67 ns	-26.67 ns	-46.34 ns	-61.4 *
NAP-205 x NAP-2022	7.14 **	0.00 ns	-0.51 ns	-1.01 ns	14.82 *	1.74 ns	2.04 ns	-16.67 ns	95.92 ns	92.00 ns
NAP-205 x NAP-2001	-2.38 ns	-8.89 **	-0.76 ns	-1.01 ns	5.92 ns	-5.4 ns	-32.47 **	-44.68 **	25.3 ns	-10.34 ns
NAP-205 x NAP-94006	2.27 ns	0.00 ns	0.51 ns	0.00 ns	-1.89 ns	-7.32 ns	-8.47 ns	-10.0 ns	80.39 ns	76.92 ns
NAP-205 x NAP-2012	6.51 **	0.00 ns	0.51 ns	0.00 ns	8.33 ns	-2.47 ns	0.00 ns	-10.0 ns	55.84 ns	15.38 ns
NAP-205 x NAP-206	12.64 **	8.89 **	2.3 ns	1.01 ns	20.47 **	9.7 ns	-7.04 ns	-19.51 ns	17.07 ns	-15.79 ns
NAP-205 x NAP-130	3.53 *	-2.22 ns	0.00 ns	0.00 ns	-2.64 ns	-9.7 ns	4.76 ns	0.00 ns	33.33 ns	30.77 ns

**p<0.01,*p<0.05

Table 3: (Continued)

Cross combination	Days of 50% Flowering		Days of 50% Maturity		Plant Height(cm)		NO. of Primary Branch		NO. of Secondary Branch	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-205 x NAP-2057	-1.12 ns	-2.22 ns	0.25 ns	0.00 ns	1.77 ns	-2.84 ns	-12.2 ns	-14.29 ns	-26.88 ns	-50.0 *
NAP-205 x NAP-2066	4.76 **	-2.22 ns	0.51 ns	0.00 ns	4.74 ns	-6.95 ns	-5.45 ns	-13.33 ns	-18.99 ns	-40.74 ns
NAP-205 x NAP-179	4.44 **	4.44 **	0 .00 ns	0.00 ns	4.46 ns	-0.27 ns	-25.81 ns	-28.13 ns	65.08 ns	36.84 ns
NAP-205 x NAP-2037	2.38 ns	-4.44 **	0.51 ns	0.00 ns	2.03 ns	-4.39 ns	-20.00 ns	-28.0 *	-16.19 ns	-45.00 *
NAP-9906 x NAP-9904	2.99 ns	0.00 ns	18.43 **	0.00 ns	4.93 ns	4.01 ns	-13.79 ns	-13.79 ns	-29.41 ns	-42.86 ns
NAP-9906 x NAP-9901	6.36 **	5.75 **	1.02 ns	1.02 ns	24.54 **	19.55 *	-16.13 ns	-21.21 ns	79.71 ns	44.19 ns
NAP-9906 x NAP-2013	5.75 **	4.55 **	0.51 ns	0.00 ns	10.13 ns	7.44 ns	-11.86 ns	-13.33 ns	68.67 ns	22.81 ns
NAP-9906 x NAP-2022	-4.88 **	-9.3 **	0.00 ns	0.00 ns	8.26 ns	1.13 ns	-8.33 ns	-24.14 ns	132.0 *	123.08 ns
NAP-9906 x NAP-2001	12.2 **	6.98 **	-0.25 ns	-0.51 ns	11.93 ns	5.45 ns	-26.32 *	-40.43 **	9.52 ns	-20.69 ns
NAP-9906 x NAP-94006	-9.3 **	-9.3 **	0.00 ns	0.00 ns	16.26 *	16.26 *	0.00 ns	0.00 ns	107.69 ns	107.69 ns
NAP-9906 x NAP-2012	4.24 **	0.00 ns	0.00 ns	0.00 ns	13.59 ns	7.92 ns	5.66 ns	-3.45 ns	-23.08 ns	-42.31 ns
NAP-9906 x NAP-206	8.24 **	6.98 **	0.77 ns	0.00 ns	7.09 ns	2.98 ns	-14.29 ns	-26.83 *	25.3 ns	-8.77 ns
NAP-9906 x NAP-0130	10.84 **	6.98 **	0.51 ns	0.00 ns	-0.03 ns	-1.95 ns	9.68 ns	3.03 ns	15.38 ns	15.38 ns
NAP-9906 x NAP-2057	1.15 ns	0.00 ns	0.76 ns	0.51 ns	7.53 ns	6.34 ns	-4.13 ns	-7.94 ns	6.38 ns	-26.47 ns
NAP-9906 x NAP-2066	7.32 **	2.33 ns	1.02 ns	1.02 ns	15.21 *	7.92 ns	0.00 ns	-6.9 ns	45.00 ns	7.41 ns
NAP-9906 x NAP-179	4.55 **	2.22 ns	0.51 ns	0.00 ns	-0.81 ns	-1.91 ns	-4.92 ns	-9.38 ns	118.75 *	84.21 ns
NAP-9906 x NAP-2037	7.32 **	2.33 ns	0.00 ns	0.00 ns	11.13 ns	10.19 ns	-18.8 ns	-28.0 *	28.3 ns	-15.00 ns
NAP-248 x NAP-9904	-0.59 ns	-4.55 **	18.92 **	0.00 ns	7.95 ns	4.89 ns	-22.69 ns	-24.59 ns	-50.00 *	-64.71 **
NAP-248 x NAP-9901	-6.29 **	-6.82 **	-0.51 ns	-1.01 ns	4.59 ns	-1.53 ns	-24.41 ns	-27.27 ns	-22.76 ns	-45.10 **
NAP-248 x NAP-2013	-6.82 **	-6.82 **	-1.01 ns	-1.01 ns	-2.88 ns	-3.33 ns	-10.74 ns	-11.48 ns	-59.75 **	-68.63 **
NAP-248 x NAP-2022	3.61 *	-2.27 ns	0.51 ns	0.00 ns	13.12 ns	3.7 ns	25.25 ns	1.64 ns	-36.51 ns	-60.78 **
NAP-248 x NAP-2001	1.20 ns	-4.55 **	-0.76 ns	-1.01 ns	11.54 ns	3.11 ns	-9.68 ns	-25.53 *	-32.5 ns	-47.06 **
NAP-248 x NAP-94006	3.45 *	2.27 ns	-0.51 ns	-1.01 ns	6.12 ns	4.00 ns	-12.61 ns	-14.75 ns	-28.13 ns	-54.9 **
NAP-248 x NAP-2012	-6.59 **	-11.36 **	-0.51 ns	-1.01 ns	-6.23 ns	-12.59 ns	-19.27 ns	-27.87 ns	-40.26 *	-54.9 **

$^{**}p<0.01$, $^{*}p<0.05$

Table 3: (Continued)

Cross combination	Days of 50% Flowering		Days of 50% Maturity		Plant Height(cm)		NO. of Primary Branch		NO. of Secondary Branch	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-248 x NAP-206	0.00 ns	-2.27 ns	0.26 ns	-1.01 ns	11.94 ns	5.58 ns	-16.08 ns	-26.83 *	-52.2 **	-62.75 **
NAP-248 x NAP-130	-7.14 **	-11.36 **	-1.01 ns	-1.01 ns	13.61 *	9.23 ns	-14.96 ns	-18.18 ns	-28.13 ns	-54.9 **
NAP-248 x NAP-2057	-2.27 ns	-2.27 ns	0.25 ns	0.00 ns	8.45 ns	7.46 ns	-19.35 ns	-20.63 ns	-31.76 ns	-43.14 *
NAP-248 x NAP-2066	6.02 **	0.00 ns	-0.51 ns	-1.01 ns	6.26 ns	-2.32 ns	-2.7 ns	-11.48 ns	-48.72 *	-60.78 **
NAP-248 x NAP-179	-1.12 ns	-2.22 ns	0.00 ns	0.00 ns	6.95 ns	5.98 ns	-13.6 ns	-15.62 ns	-60.00 **	-72.55 **
NAP-248 x NAP-2037	6.02 **	0.00 ns	0.51 ns	0.00 ns	19.21 **	15.85 *	-5.88 ns	-14.67 ns	-62.64 **	-66.67 **
NAP-108 x NAP-9904	0.58 ns	-4.44 **	17.72 **	-1.01 ns	5.35 ns	-3.89 ns	8.2 ns	3.13 ns	34.88 ns	31.82 ns
NAP-108 x NAP-9901	-0.56 ns	-2.22 ns	-0.51 ns	-1.01 ns	3.31 ns	-8.46 ns	-4.62 ns	-6.06 ns	14.94 ns	13.64 ns
NAP-108 x NAP-2013	1.12 ns	0.00 ns	-1.01 ns	-1.01 ns	11.19 ns	4.66 ns	0.00 ns	-3.13 ns	-0.99 ns	-12.28 ns
NAP-108 x NAP-2022	-7.14 **	-13.33 **	-0.51 ns	-1.01 ns	15.58 *	-0.09 ns	29.41 ns	3.13 ns	94.12 *	50.0 ns
NAP-108 x NAP-2001	0.00 ns	-6.67 **	-0.76 ns	-1.01 ns	5.48 ns	-8.12 ns	-36.71 **	-46.81 **	-49.02 ns	-55.17 ns
NAP-108 x NAP-94006	0.00 ns	-2.22 ns	-0.51 ns	-1.01 ns	-0.66 ns	-8.64 ns	-21.31 ns	-25.0 ns	2.86 ns	-18.18 ns
NAP-108 x NAP-2012	6.51 **	0.00 ns	-0.51 ns	1.01 ns	7.33 ns	-5.79 ns	-25.00 ns	-34.38 *	-25.00 ns	-30.77 ns
NAP-108 x NAP-206	10.34 **	6.67 **	1.28 ns	0.00 ns	13.74 *	0.95 ns	-26.03 *	-34.15 **	14.85 ns	1.75 ns
NAP-108 x NAP-130	4.71 **	-1.11 ns	-0.51 ns	-0.51 ns	6.48 ns	-3.80 ns	-26.15 *	-27.27 ns	-14.29 ns	-31.82 ns
NAP-108 x NAP-2057	-3.37 *	-4.44 **	0.25 ns	0.00 ns	5.48 ns	-1.99 ns	0.79 ns	0.00 ns	10.71 ns	-8.82 ns
NAP-108 x NAP-2066	4.76 **	-2.22 ns	0.51 ns	0.00 ns	15.1 *	-0.26 ns	-15.79 ns	-25.0 ns	-34.69 ns	-40.74 ns
NAP-108 x NAP-179	0.00 ns	0.00 ns	0.00 ns	0.00 ns	6.78 ns	-0.78 ns	0.00 ns	0.00 ns	129.27 **	113.64 **
NAP-108 x NAP-2037	7.14 **	0.00 ns	-0.51 ns	-1.01 ns	-1.68 ns	-10.28 ns	-36.69 **	-41.33 **	-41.94 ns	-55.0 *

**$p<0.01$, *$p<0.05$

Table 3: (Continued)

Cross combination	Silique/Plant		No. of. Seed/Silique		Silique Length(cm)		1000 Seed weight(g)		Yield/ Plant (g)	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-9905 x NAP-9904	50.48 ns	50.06 ns	10 ns	6.4 ns	8.8 ns	8.53 ns	-11.66 ns	-15.29 ns	66.4 **	60.5 **
NAP-9905 x NAP-9901	0.34 ns	-6.04 ns	-4.47 ns	-4.91 ns	13.71 *	5.65 ns	21.8 ns	3.85 ns	48.9 **	34.09 *
NAP-9905 x NAP-2013	9.81 ns	3.01 ns	12.14 ns	3.74 ns	9.65 ns	5.88 ns	7.38 ns	2.56 ns	71.84 **	58.26 **
NAP-9905 x NAP-2022	42.43 ns	28.15 ns	5.26 ns	-2.42 ns	12.1 *	9.73 ns	30.72 **	28.21 *	53.64 **	44.53 **
NAP-9905 x NAP-2001	29.74 ns	4.73 ns	-4.49 ns	-5.60 ns	30.48 **	12.75 ns	18.06 ns	8.97 ns	-8.93 ns	-17.6 ns
NAP-9905 x NAP-94006	86.5 ns	86.15 **	13.21 ns	4.25 ns	13.38 *	8.59 ns	8.07 ns	4.82 ns	28.82 *	20.72 ns
NAP-9905 x NAP-2012	37.95 ns	36.94 ns	-11.46 ns	-12.67 ns	1.82 ns	-1.52 ns	10.96 ns	3.85 ns	46.85 **	44.21 **
NAP-9905 x NAP-206	10.6 ns	4.51 ns	-10.71 ns	-12.96 ns	4.43 ns	-4.12 ns	33.33 **	23.08 ns	13.57 ns	-8.85 ns
NAP-9905 x NAP-130	0.17 ns	-1.31 ns	-15.97 *	-19.53 *	9.39 ns	6.14 ns	-37.42 **	-40.00 **	-19.73 ns	-25.60 ns
NAP-9905 x NAP-2057	-4.49 ns	-9.97 ns	4.74 ns	3.43 ns	-0.04 ns	-6.30 ns	2.5 ns	0.00 ns	12.77 ns	-6.32 ns
NAP-9905 x NAP-2066	-11.4 ns	-19.74 ns	-5.12 ns	-8.89 ns	7.44 ns	7.00 ns	20.55 ns	12.82 ns	12.21 ns	4.87 ns
NAP-9905 x NAP-179	33.62 ns	26.25 ns	16.50 *	6.55 ns	16.68 **	14.46 *	-6.38 ns	-15.38 ns	5.94 ns	-7.5 ns
NAP-9905 x NAP-2037	12.87 ns	3.98 ns	-15.02 *	-19.01 *	1.78 ns	-0.82 ns	-12.31 ns	-26.92 *	7.69 ns	-9.76 ns
BS-13 x NAP-9904	3.34 ns	0.96 ns	4.46 ns	0.58 ns	5.75 ns	5.16 ns	20.53 ns	7.06 ns	14.23 ns	7.79 ns
BS-13 x NAP-9901	6.78 ns	2.51 ns	-2.48 ns	-8.66 ns	13.19 ns	5.96 ns	55.37 **	42.42 **	52.69 **	40.39 **
BS-13 x NAP-2013	-7.77 ns	-11.3 ns	14.14 ns	13.17 ns	3.48 ns	-0.84 ns	-2.19 ns	-5.63 ns	31.19 *	23.44 ns
BS-13 x NAP-2022	-2.67 ns	-14.42 ns	-4.54 ns	-5.14 ns	3.53 ns	2.14 ns	20.57 ns	13.33 ns	-16.59 ns	-23.19 ns
BS-13 x NAP-2001	15.28 ns	-8.76 ns	10.18 ns	1.64 ns	30.06 **	13.15 ns	22.73 ns	22.73 ns	22.53 *	8.63 ns
BS-13 x NAP-94006	-4.18 ns	-6.84 ns	-1.65 ns	-2.98 ns	-1.08 ns	-5.99 ns	8.72 ns	-2.41 ns	22.52 ns	17.34 ns
BS-13 x NAP-2012	42.79 ns	38.14 ns	-7.05 ns	-14.42 ns	11.27 ns	8.46 ns	17.91 ns	16.18 ns	27.64 *	22.57 ns
BS-13 x NAP-206	10.55 ns	7.11 ns	-3.13 ns	-11.78 ns	-4.72 ns	-13.16 *	-1.52 ns	-1.52 ns	-8.00 ns	-27.42 **
BS-13 x NAP-0130	33.77 ns	32.26 ns	1.45 ns	-9.1 ns	9.71 ns	7.29 ns	15.23 ns	2.35 ns	20.11 ns	9.01 ns
BS-13 x NAP-2057	4.07 ns	0.6 ns	0.97 ns	-4.72 ns	-1.32 ns	-8.18 ns	-32.43 **	-39.02 **	3.23 ns	-15.78 ns
BS-13 x NAP-2066	10.94 ns	2.93 ns	10.62 ns	7.29 ns	2.98 ns	1.74 ns	8.96 ns	7.35 ns	106.33 **	88.79 **

**p<0.01,*p<0.05

Table 3: (Continued)

Cross combination	Silique/Plant		No. of. Seed/Silique		Silique Length(cm)		1000 Seed weight(g)		Yield/ Plant (g)	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
BS-13 x NAP-179	59.57 ns	54.61 *	3.31 ns	1.17 ns	13.71 *	10.67 ns	55.04 **	51.52 **	67.19 **	43.17 **
BS-13 x NAP-2037	19.9 ns	13.19 ns	-18.38 *	-27.21 **	10.87 ns	8.89 ns	37.29 *	22.73 ns	-2.66 ns	-19.92 *
NAP-9908 x NAP-9904	7.96 ns	0.29 ns	-7.76 ns	-12.69 ns	21.33 **	9.12 ns	14.29 ns	-10.59 ns	-4.88 ns	-7.85 ns
NAP-9908 x NAP-9901	-28.1 ns	-28.91 ns	-8.12 ns	-15.35 ns	5.35 ns	1.46 ns	49.51 **	40.00 *	63.63 **	46.76 **
NAP-9908 x NAP-2013	35.02 ns	33.24 ns	17.87 *	16.79 ns	10.8 ns	-3.59 ns	51.26 **	26.76 ns	15.85 ns	6.25 ns
NAP-9908 x NAP-2022	16.96 ns	-1.63 ns	18.71 *	17.35 ns	29.93 **	18.87 **	49.59 **	22.67 ns	6.96 ns	1.05 ns
NAP-9908 x NAP-2001	21.01 ns	-7.78 ns	-6.4 ns	-15.05 ns	39.96 **	34.10 **	36.84 *	18.18 ns	39.89 **	27.09 *
NAP-9908 x NAP-94006	19.17 ns	10.18 ns	18.66 *	18.16 ns	22.23 **	5.58 ns	35.88 **	7.23 ns	55.98 **	45.54 **
NAP-9908 x NAP-2012	-2.4 ns	-10.18 ns	4.94 ns	-4.93 ns	22.25 **	13.12 ns	3.45 ns	-11.76 ns	46.97 **	44.98 **
NAP-9908 x NAP-206	-15.35 ns	-17.1 ns	-9.67 ns	-19.04 *	11.19 ns	-7.45 ns	42.11 **	22.73 ns	-29.97 **	-43.6 **
NAP-9908 x NAP-130	60.63 ns	50.91 *	-5.04 ns	-16.24 *	31.51 **	21.31 **	74.44 **	36.47 **	21.84 *	13.4 ns
NAP-9908 x NAP-2057	28.86 ns	26.51 ns	9.01 ns	1.16 ns	5.24 ns	-10.79 ns	40.00 **	10.98 ns	48.4 **	23.74 **
NAP-9908 x NAP-2066	34.61 ns	31.35 ns	-1.96 ns	-6.53 ns	9.91 ns	-1.72 ns	46.55 **	25.00 ns	81.78 **	70.62 **
NAP-9908 x NAP-179	23.00 ns	20.46 ns	14.21 ns	13.83 ns	21.09 **	6.83 ns	-38.74 *	-46.03 **	6.29 ns	-6.83 ns
NAP-9908 x NAP-2037	-34.99 ns	-35.39 ns	-6.48 ns	-17.88 *	15.02 *	5.68 ns	44.00 *	38.46 ns	-4.65 ns	-19.81 ns
NAP-205 x NAP-9904	39.28 ns	31.77 ns	11.6 ns	-2.42 ns	7.56 ns	4.71 ns	-62.5 **	-64.71 **	83.81 **	50.33 **
NAP-205 x NAP-9901	26.53 ns	25.5 ns	8.81 ns	-7.17 ns	15.97 *	10.79 ns	32.31 *	14.67 ns	127.69 **	111.1 **
NAP-205 x NAP-2013	5.53 ns	4.88 ns	19.68 *	9.08 ns	-2.94 ns	-8.88 ns	-16.44 ns	-18.67 ns	100.14 **	81.4 **
NAP-205 x NAP-2022	38.98 ns	18.78 ns	21.69 *	10.64 ns	13.82 *	12.9 ns	2.67 ns	2.67 ns	62.03 **	29.88 *
NAP-205 x NAP-2001	43.93 ns	11.19 ns	-1.06 ns	-16.72 *	22.69 **	8.75 ns	11.49 ns	4.8 ns	39.79 **	8.62 ns
NAP-205 x NAP-94006	-4.4 ns	-9.99 ns	-39.98 **	-45.04 **	4.42 ns	-2.75 ns	1.27 ns	-3.61 ns	26.29 ns	12.58 ns
NAP-205 x NAP-2012	44.88 ns	35.76 ns	19.28 *	0.23 ns	16.89 **	16.39 *	6.29 ns	1.33 ns	60.5 **	33.19 *
NAP-205 x NAP-206	41.07 ns	40.86 ns	7.79 ns	-10.3 ns	-4.88 ns	-14.96 **	20.57 ns	13.33 ns	20.8 *	-14.59 ns
NAP-205 x NAP-130	8.25 ns	3.60 ns	-2.07 ns	-19.67 *	14.95 *	14.85 *	-30.00 **	-34.12 **	38.31 **	9.54 ns
NAP-205 x NAP-2057	12.97 ns	12.86 ns	0.98 ns	-13.28 ns	-6.61 ns	-14.81 *	17.2 ns	12.2 ns	11.26 ns	-19.19 *

**$p<0.01$, *$p<0.05$

Table 3:(Continued)

Cross combination	Silique/Plant		No. of. Seed/Silique		Silique Length(cm)		1000 Seed weight(g)		Yield/ Plant (g)	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-205 x NAP-2066	-9.59 ns	-13.44 ns	3.32 ns	-9.07 ns	6.14 ns	2.67 ns	18.88 ns	13.33 ns	21.92 ns	-2.78 ns
NAP-205 x NAP-179	9.75 ns	9.59 ns	17.45 ns	8.28 ns	7.65 ns	2.62 ns	10.14 ns	1.33 ns	30.88 **	-1.14 ns
NAP-205 x NAP-2037	-12.41 ns	-14.61 ns	8.22 ns	-11.59 ns	16.73 **	16.33 *	21.26 ns	2.67 ns	28.85 **	-5.78 ns
NAP-9906 x NAP-9904	-11.09 ns	-11.53 ns	9.18 ns	3.76 ns	3.56 ns	-1.05 ns	-8.33 ns	-9.41 ns	25.37 *	13.59 ns
NAP-9906 x NAP-9901	39.26 ns	30.12 ns	5.28 ns	-2.64 ns	8.06 ns	-3.52 ns	21.74 ns	1.2 ns	74.62 **	67.31 **
NAP-9906 x NAP-2013	18.58 ns	11.00 ns	2.44 ns	1.93 ns	3.33 ns	2.45 ns	10.39 ns	2.41 ns	35.84 **	33.35 *
NAP-9906 x NAP-2022	12.42 ns	1.36 ns	0.64 ns	-0.09 ns	14.68 **	7.62 ns	10.13 ns	4.82 ns	-12.21 ns	-22.28 ns
NAP-9906 x NAP-2001	55.43 ns	25.68 ns	-5.58 ns	-13.98 ns	8.8 ns	-9.34 ns	6.04 ns	-4.82 ns	56.45 **	33.59 **
NAP-9906 x NAP-94006	25.68 ns	25.68 ns	16.59 ns	16.59 ns	3.24 ns	3.24 ns	-8.43 ns	-8.43 ns	32.32 *	32.32 *
NAP-9906 x NAP-2012	0.97 ns	0.45 ns	-11.97 ns	-19.95 *	4.86 ns	-2.73 ns	23.18 ns	12.05 ns	39.91 **	28.9 *
NAP-9906 x NAP-206	20.09 ns	13.23 ns	-5.31 ns	-14.81 ns	-5.69 ns	-9.76 ns	-3.36 ns	-13.25 ns	-8.27 ns	-29.88 **
NAP-9906 x NAP-0130	6.06 ns	4.26 ns	-8.29 ns	-18.81 *	2.09 ns	-5.00 ns	-41.67 **	-42.35 **	29.6 *	13.15 ns
NAP-9906 x NAP-2057	11.61 ns	4.99 ns	-7.51 ns	-13.84 ns	-0.4 ns	-2.61 ns	-0.61 ns	-1.20 ns	-3.94 ns	-24.20 **
NAP-9906 x NAP-2066	29.83 ns	17.37 ns	8.19 ns	3.56 ns	-0.06 ns	-3.91 ns	12.58 ns	2.41 ns	101.94 **	77.69 **
NAP-9906 x NAP-179	43.78 ns	35.57 ns	9.15 ns	8.34 ns	7.27 ns	4.68 ns	31.51 *	15.66 ns	0.07 ns	-17.32 ns
NAP-9906 x NAP-2037	8.26 ns	-0.47 ns	-14.19 ns	-24.38 **	6.75 ns	-0.26 ns	30.37 *	6.02 ns	0.13 ns	-20.36 *
NAP-248 x NAP-9904	-15.97 ns	-23.24 ns	2.41 ns	1.00 ns	7.65 ns	5.27 ns	-4.71 **	-4.71 ns	52.08 **	23.01 **
NAP-248 x NAP-9901	-2.84 ns	-5.65 ns	-6.86 ns	-10.71 ns	8.68 ns	-0.86 ns	35.71 **	11.76 ns	45.94 **	6.51 ns
NAP-248 x NAP-2013	11.58 ns	8.15 ns	2.17 ns	-1.12 ns	-3.65 ns	-5.12 ns	-15.38 ns	-22.35 ns	-32.38 **	-49.85 **
NAP-248 x NAP-2022	10.5 ns	-8.43 ns	1.01 ns	9.61 ns	11.93 *	7.45 ns	8.75 ns	2.35 ns	-20.66 *	-34.5 **
NAP-248 x NAP-2001	20.45 ns	-9.35 ns	-2.4 ns	-7.89 ns	23.14 **	4.64 ns	15.23 ns	2.35 ns	-26.55 **	-37.24 **
NAP-248 x NAP-94006	9.78 ns	-0.19 ns	7.04 ns	3.09 ns	4.56 ns	2.10 ns	11.9 ns	10.59 ns	34.06 **	0.65 ns
NAP-248 x NAP-2012	-18.47 ns	-26.2 ns	-6.00ns	-11.46 ns	3.41 ns	-1.89 ns	32.03 **	18.82 ns	31.59 **	4.97 ns
NAP-248 x NAP-206	0.87 ns	-2.96 ns	-10.3 ns	-16.44 *	-3.48 ns	-9.73 ns	27.15 *	12.94 ns	18.78 **	15.72 *
NAP-248 x NAP-130	30.33 ns	20.37 ns	4.7 ns	-4.11 ns	11.81 *	6.42 ns	9.41 ns	9.41 ns	26.71 **	5.95 ns

**p<0.01,*p<0.05

Table 3:(Continued)

Cross combination	Silique/Plant		No. of. Seed/Silique		Silique Length(cm)		1000 Seed weight(g)		Yield/ Plant (g)	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
NAP-248 x NAP-2057	17.91 ns	13.7 ns	-6.21 ns	-9.4 ns	-1.48 ns	-5.88 ns	7.78 ns	5.88 ns	-18.51 *	-23.9 **
NAP-248 x NAP-2066	-10.3 ns	-10.88 ns	-0.38 ns	-1.02 ns	3.94 ns	2.3 ns	-29.41 *	-36.47 **	-8.87 ns	-24.35 **
NAP-248 x NAP-179	-3.85 ns	-7.50 ns	9.34 ns	4.55 ns	-4.76 ns	-4.82 ns	-10.81 ns	-22.35 ns	-52.02 **	-57.57 **
NAP-248 x NAP-2037	3.56 ns	2.31 ns	7.83 ns	-1.7 ns	17.38 **	12.18 ns	22.63 ns	-1.18 ns	35.00 **	24.82 **
NAP-108 x NAP-9904	6.35 ns	-16.44 ns	2.99 ns	-0.92 ns	5.53 ns	-0.25 ns	-2.99 ns	-4.71 ns	72.37 **	58.15 **
NAP-108 x NAP-9901	-17.85 ns	-32.18 ns	10.31 ns	3.23 ns	13.4 *	0.25 ns	27.01 *	6.10 ns	138.8 **	125.8 **
NAP-108 x NAP-2013	3.94 ns	-14.33 ns	16.61 ns	15.72 ns	-0.68 ns	-2.62 ns	-18.95 ns	-24.39 ns	71.5 **	66.08 **
NAP-108 x NAP-2022	21.87 ns	-11.39 ns	22.52 **	21.86 *	8.17 ns	0.44 ns	14.65 ns	9.76 ns	87.31 **	67.85 **
NAP-108 x NAP-2001	-11.98 ns	-40.63 *	6.72 ns	-1.64 ns	13.92 *	-5.92 ns	-8.11 ns	-17.07 ns	24.44 *	7.5 ns
NAP-108 x NAP-94006	-3.56 ns	-24.5 ns	11.34 ns	9.94 ns	-7.18 ns	-8.22 ns	-17.58 ns	-18.07 ns	55.91 **	53.77 **
NAP-108 x NAP-2012	-17.56 ns	-35.7 *	5.32 ns	-3.11 ns	6.02 ns	-2.66 ns	5.2 ns	-3.78 ns	65.9 **	54.82 **
NAP-108 x NAP-206	-18.94 ns	-33.59 *	2.08 ns	-7.11 ns	-9.49 ns	-12.45 *	10.81 ns	0.00 ns	-15.27 ns	-34.59 **
NAP-108 x NAP-130	-0.08 ns	-20.79 ns	3.13 ns	-7.68 ns	5.7 ns	-2.66 ns	4.07 ns	2.24 ns	47.94 **	30.72 **
NAP-108 x NAP-2057	-2.65 ns	-20.09 ns	4.79 ns	-1.2 ns	-6.71 ns	-7.75 ns	3.66 ns	3.66 ns	36.66 **	8.96 ns
NAP-108 x NAP-2066	1.92 ns	-13.37 ns	14.74 ns	11.19 ns	-0.99 ns	-3.94 ns	18.67 ns	8.54 ns	23.12 *	9.65 ns
NAP-108 x NAP-179	34.79 ns	10.43 ns	22.86 **	20.42 *	-0.43 ns	-3.9 ns	14.48 ns	1.22 ns	72.51 **	44.12 **
NAP-108 x NAP-2037	-19.07 ns	-32.25 ns	-1.03 ns	-11.8 ns	6.62 ns	-1.43 ns	17.91 ns	-3.66 ns	27.18 **	2.22 ns

**p<0.01,*p<0.05

4.2.10 Seed Yield per Plant (g)

In case of yield per plant, fifty five combinations represented positive heterosis which was ranged from 18.87% to 138.8%. The combination NAP-108 x NAP-9901 (138.8%) produced the highest heterosis over mid parent heterosis. On the other hand, thirty six combinations had significant positive heterosis over better parent. The hybrid NAP-108 x NAP-9901 (125.80%) showed the highest significant and positive heterosis (Table 3). However, all the mentioned combinations which having significant positive value could be selected for reevaluation for yield performance. Tyagi *et al.* (2001) found the highest standard heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant in the cross BIO 772 ×Rohini. Adefris *et al.* (2005) observed seed yield showed the highest relative mid parent heterosis that varied from 25 to 145% with a mean of 67% and relative high parent heterosis varied from 16 to 124% with a mean of 53%. The presence of high levels of mid and high parent heterosis indicated a considerable potential to embark on breeding hybrid or synthetic cultivars in mustard. Shen *et al.* (2005) observed mid parent heterosis and high parent heterosis of seed yield per plant ranged from 5.50 to 64.11% and from -2.81 to 46.02%, respectively. Wang *et al.*(1999) analysed heterosis and combining abilities of 20 reciprocal cross combinations of five double low rape (*Brassica napus*) cultivars (lines) showing high seed yield .

4.3 COMBINING ABILITY

The analysis of variance for the genotypes, combining ability variances, estimates of general and specific combining ability effects are presented in Tables 4 to Table 8. The analysis of variance carried out for ten characters are presented in Table 4 which indicated that the genotypes are differed significantly for all the characters studied. Parents and crosses showed highly significant variances for all the characters analyzed (Table 4).

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 5) revealed highly significant variation among the parents and hybrids indicating the presence of variability in the material. Variance due to genotypes was significant for all the traits. Combining ability analysis of seven lines, thirteen testers and ninety one F_1s line-tester mating were of 10 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 all the traits 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 all the characters studied indicating that the non-additive gene actions were predominant for the expression of these characters. 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 Tamber *et al.* (1991) in Indian mustard.

4.3.1 General Combining Ability (GCA) Effects

The additive nature and magnitude of gene action for a trait could be measured by estimation of GCA effects. A parent with higher significant GCA effects is considered as a good general combiner. A parent showing high GCA and SCA variances is a better parent for creating high yielding specific combination. Parents with significant high GCA effect could be used in conventional breeding program and crosses with significant high SCA effect could be used in hybrid development. The estimates of GCA effects are presented in Table(6 and7). The magnitude and direction of the significant GCA effects for twenty parents (Seven lines and thirteen testers) provide meaningful comparisons and would give a clue to design the future breeding program. The results of GCA effects of different characters are presented as follows:

4.3.1.1 Days to 50% Flowering

For the trait days to 50% flowering, a significant positive GCA effect is useful for shorter growth duration. Out of seven parents there were three parents showing significant and positive GCA effects. The line BS-13 (0.64) was the best general combiner followed by NAP-205 (0.57) and NAP-9906 (0.26) showed positive and significant GCA effects that were desirable general combiners to promote the earliness in *Brassica napus* (Table 6 and 7). The highest negative significant GCA effect (-1.43) was provided by Nap-248. The other parent which represented negative and significant GCA was NAP-9905 (-0.36). On the other hand, the parents NAP-9908 (0.1) and NAP-108 (0.22) showed insignificant and 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 compestris/rapa.* Verma (2000) observed earliness in RC 832 in *Brassica junecea* L. .(Table 6 and 7)

4.3.1.2 Days to 50% Maturity

The parent BS-13 provided (0.35) highest significant positive GCA effects for days to maturity which was desirable general combiner to promote the earliness in *Brassica napus* L. **(Table 6 and 7)** followed by NAP-205 (0.19) and NAP-9908 (0.12). Rest of the parents showed significant and negative gca effect. Chowdhury *et al.* (2004) observed in Din-2 in *Brassica rapa* L. Singh *et al.* (2000) found earliness in YSC-68 in *Brassica campestris* L.

4.3.1.3 Plant Height

Out of seven parental (lines) GCA, there was no parents showed significant and negative GCA effect. The parent NAP-108 showed positive and significant GCA effects (5.66) were desirable general combiners to promote the plant height in *Brassica napus* when tall type is desirable. But out of thirteen tester one tester NAP 2012(-5.11) showed negative significant effect which is desirable when dwarf type is desirable (Table 6 and 7) .Chowdhury *et al.* (2004) obtained dwarfness in YSK-8501 in *Brassica campestris* L. Singh *et al.* (1996) observed dwarfness in glossy mutant in *Brassica juncea* L.

.4.3.1.4 Number of Primary Branches per Plant

No parents provided significant and positive GCA effects which indicated that the parents were good general combiner for promising primary branches. So no parent was considered as good for using in the breeding program for more primary branches (Table 6 and 7). Only one parent (line) BS-13 showed significant negative effect (-0.23) and rest of the parents (lines) showed insignificant positive effects. Chowdhury *et al.* (2004) obtained more primary branches on sampan in *Brassica rapa* L. Singh *et al.* (2000) observed the maximum number of primary branches on YSP-842 in *Brassica campestris* L.

4.3.1.5 Number of Secondary Branches per Plant

For number of secondary branches per plant all the parents (lines) demonstrated insignificant GCA effects.Only parent (tester) NAP 179 showed positive significant effect (0.71) .The genotype with positive GCA effect considered as a good general combiner (Table 6 and 7). Singh *et al.* (1996) obtained the highest secondary branches in BJ-1235 in *Brassica juncea* L. Chowdhury *et al.* (2004a) observed more secondary branches in Din-2 in *Brassica rapa* L.

4.3.1.6 Number of Siliquae per Plant

All the parents showed insignificant positive and negative GCA effects except parent (tester NAP 2022).NAP 2022 showed positive significant effect (38.78).Genotype with positive GCA effect considered as a good general combiner. Chowdhury *et al.* (2004) found the highest number of silliquae in Din-2 in *Brassica rapa.* Singh and Murty (1980) obtained maximum number of siliquae per plant in SS-1 in *Brassica campestris* L. (Table 6 and 7).

4.3.1.7 Siliqua Length

All the parents showed insignificant positive and negative GCA effects except parent (tester) NAP9901 showed negative significant effect (-0.34) and genotype NAP2022 showed positive significant effect (0.29) (Table 6 and 7) .Genotype with positive GCA effect considered as a good combiner on the other hand genotype with negative GCA effect considerd as a poor combiner. Sheikh and Singh (1998) obtained maximum siliquae length in glossy mutant.

4.3.1.8 Number of Seeds per Siliqua

In this case of number of seeds per siliqua, the parent NAP-108 produced the highest significant and positive GCA effect (1.62) followed by NAP-9905 (1.02) (Table 6 and 7). Thus these parents was found as the best general combiner to increase the number of seeds per siliqua. Chowdhury *et al.* (2004) found the maximum seeds per siliqua in Dhali in *Brassica rapa* L. Singh and Murty (1980) obtained more seeds per siliqua in YPS-842 in *Brassica campestris* L.

Table 4: Analysis of variances (MS values) for seed yield per plant and its component characters in *Brassica napus* L.

Source	df	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
Replication ®	1	0.04	16.76	1.64	0.26	2.49 **	591.99	0.63 *	10.12 **	0.44	0.18
Hybrids ©	90	12.18 **	0.68	97.31 *	0.28	1.27 *	837.32	0.41	9.21 *	0.99 **	7.84 **
Lines	6	13.19 **	1.42	216.61 **	0.28	1.11	880.53	0.54	28.85 **	0.62 **	7.33 **
Testers	12	17.69 **	1.48	66.64	0.19	1.25 *	995.2	0.53	3.27	0.81	10.61 **
Line x Tester	72	11.18 **	0.48	92.48	0.3	1.29	807.41	0.37 *	8.57	1.05 **	5.93 **
Parent (p)	19	12.51 **	95.24 **	131.77 **	0.95	2.35 **	723.53	1.91	14.5 **	0.66 **	7.29 **
Females	6	14.74 **	2.67	189.84 **	0.87	4.55 **	1110.28 *	1.69 **	10.67 *	0.85 **	5.93 **
Males	12	10.53 **	145.95 **	73.11	1.07	1.44	456.27	2.18 **	12.41 **	0.59 *	4.85 **
Parent x Hybrid	1	22.79 **	42.22 **	487.21	0.01	0.13	1610.18 **	0.01	62.56 **	0.23	7.5 **
(LxT)	1	111.24 **	118.38 **	3809.03**	6.07	0.13	6244.19 **	14.19 **	0.93	5.04 **	89.8 **
Error	110	0.57	14.67	55.26	0.24	0.73	684.62	0.32	4.75	0.28	0.65

**p<0.01,*p<0.05

Table 5: Proportional contribution of lines, testers and their interactions to total variance in *Brassica napus* L.

Source	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
Due to lines	7.22	14.00	14.84	6.59	5.85	7.01	8.86	20.87	4.16	9.66
Due to testers	19.36	29.04	9.13	9.21	13.17	15.85	17.47	4.73	10.85	10.79
Due to Line x Tester	73.43	56.96	76.03	84.20	80.98	77.14	73.67	74.40	85.00	79.56

Table 6: Estimates of parental (lines) general combining ability effects for various traits

Parents	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
Lines										
NAP-9905	-0.36 **	-0.35 **	-1.41 ns	0.07 ns	0.18 ns	21.45 ns	0.19 ns	1.02 *	-0.04 ns	-0.3 ns
BS-13	0.64 **	0.35 **	0.8 ns	-0.23 *	-0.29 ns	-7.59 ns	-0.11 ns	-0.39 ns	-0.01 ns	-0.43 *
NAP-9908	0.1 ns	0.12 **	-2.97 ns	0.05 ns	-0.04 ns	-3.93 ns	-0.1 ns	-0.31 ns	0.02 ns	-0.22 ns
NAP-205	0.57 **	0.19 **	1.14 ns	0.02 ns	-0.1 ns	-0.98 ns	-0.21 ns	-1.36 **	-0.29 **	-0.22 ns
NAP-9906	0.26 *	-0.04 **	-1.66 ns	0.04 ns	0.28 ns	-6.18 ns	0.13 ns	-0.9 *	0.07 ns	-0.64 **
NAP-248	-1.43 **	-0.12 **	-1.56 ns	0.01 ns	-0.17 ns	-10.44 ns	0.03 ns	0.3 ns	0.23 *	0.84 **
NAP-108	0.22 ns	-0.15 **	5.66**	0.03 ns	0.14 ns	7.66 ns	0.08 ns	1.62 **	0.02 ns	0.98 **
SE (gi)	0.13	0.01	1.57	0.10	0.17	5.37	0.11	0.45	0.10	0.16
SE (gi-gj)	0.18	0.02	2.22	0.14	0.25	7.59	0.15	0.64	0.15	0.23

Table 7: Estimates of parental (tester) general combining ability effects for various traits

Parents	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
Testers										
NAP-9904	-2.31 **	-0.36 **	0.41ns	0.11 ns	0.33 ns	-6.21 ns	0.06 ns	0.17 ns	-0.35 *	0.62 **
NAP-9901	-0.31 ns	-0.21 **	0.64 ns	0.01 ns	0.07 ns	-8.41 ns	-0.34 *	-0.14 ns	0.33 *	1.15 **
NAP-2013	-0.03 ns	-0.36 **	3.10 ns	-0.17 ns	-0.14 ns	0.25 ns	-0.07 ns	0.65 ns	-0.33 *	-0.79 **
NAP-2022	-0.46 *	-0.07 **	-1.16 ns	-0.09 ns	-0.1 ns	38.78 *	0.29 *	0.44 ns	0.43 **	-0.65 **
NAP-2001	0.26 ns	-0.5 **	0.43 ns	-0.02 ns	-0.24 ns	-16.18ns	-0.05 ns	0.13 ns	-0.01 ns	-0.41 ns
NAP-94006	-0.6 **	-0.21 **	-2.29 ns	-0.03 ns	0.3 ns	-0.94 ns	0.24 ns	-1.17 ns	0.13 ns	-0.64 **
NAP-2012	-1.17 **	-0.07 **	-5.17 *	-0.09 ns	-0.14 ns	-7.35 ns	-0.15 ns	-0.04 ns	0.08 ns	0.5 *
NAP-206	1.83 **	0.07 **	1.99 ns	0.13 ns	-0.19 ns	-5.81 ns	0.02 ns	-0.46 ns	0.14 ns	-0.44 ns
NAP-130	-0.38 *	0.14 **	-1.07 ns	0.2 ns	-0.44 ns	3.34 ns	0.09 ns	0.3 ns	-0.13 ns	-0.31 ns
NAP-2057	0.12 ns	0.36 **	0.29 ns	0.1 ns	0.03 ns	-1.66 ns	-0.17 ns	-0.16 ns	0.1 ns	0.06 ns
NAP-2066	0.4 *	0.36 **	1.99 ns	-0.2 ns	-0.13 ns	-0.09 ns	-0.22 ns	-0.15 ns	0.01 ns	1.06 **
NAP-179	1.83 **	0.36 **	1.83 ns	0.01 ns	0.71 **	17.49 ns	0.27 ns	0.61 ns	-0.26 ns	-0.27 ns
NAP-2037	0.83 **	0.5 **	-0.99 ns	0.03 ns	-0.06 ns	-13.21ns	0.03 ns	-0.19 ns	-0.14 ns	0.12 ns
SE (gi)	0.18	0.02	2.13	0.14	0.24	7.32	0.15	0.61	0.14	0.22
SE (gi-gj)	0.25	0.03	3.02	0.51	0.33	10.39	0.21	0.87	0.20	0.32

**$p<0.01$, *$p<0.05$.

4.3.1.9 1000- seed Weight

Only parent (line) NAP-248 had positive significant GCA effect (0.23) for 1000-seed weight could be considered as the best general combiner for this trait. Among the other parents, NAP-205 had negative significant GCA effect (-0.29) (Table 6 and 7). Chowdhury *et al.* (2004a) found the highest seed weight in Dhali in *Braasica rapa* L.

4.3.1.10 Seed yield per plant

The highest significant and positive GCA effects was observed in NAP-108 (0.98) followed by NAP-248 (0.84) (Table 6 and 7). These parents having significant and positive GCA effects might be selected as promising general combiner for high yield potential in this regard. Rest of the parents produced either significant or insignificant and negative GCA effects indicated that these parents were not fit for increase seed yield. Chowdhury *et al.* (2004a) found the highest seed yield per plant in Pt-303 in *Brassica rapa* L.

4.3.2 Specific Combining Ability (SCA) Effects

The specific combining ability effects signify the role of non-additive i.e. dominance and or epistatic gene action in the expression of the characters. It denotes the highly specific combining ability leading to the 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 on 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 program. The specific combining ability effects of twenty one crosses for the different characters studied are presented in Table 8. The magnitude and direction of the significant effects for the eight parents provide meaningful comparisons and would give a clue to the future breeding program. The results of SCA effects for different characters are given below:

4.3.2.1 Days to 50% Flowering

BS-13 x NAP-2022 produced highest significant positive (5.07) value for days to 50% flowering (Table 8). This cross combination provides opportunity for earliness in mustard (*Brassica napus* L.). 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.

4.3.2.2 Days to 50%Maturity

Similar like days to 50% flowering, positive and significant SCA effects were also desirable for days to maturity. However, the highest positive SCA value was found in the combination NAP-205 x NAP-206 (1.24). So, the cross NAP-94006×NAP-248 was the best specific combiner among the hybrids (Table 8). Chowdhury *et al.* (2004) observed earliness in M-27 × Din-2 in *Brassica rapa* L. Singh *et al.* (2000) obtained earliness in SS-3 × SS-1 in *Brassica campestris* L.

4.3.2.3 Plant Height

All the F_1s showed highly significant SCA effect which ranged from -12.87 to 16.72 for plant height (Table 8). The combination NAP-9908 x NAP-9901 showed the lowest value (-12.87). NAP-205 x NAP-9901 showed the highest positive (16.72) SCA effect. Thus the cross NAP-205 x NAP-9901 was the best specific combiner for plant height. Chowdhury *et al.* (2004) observed dwarfness in PT-303 × Tori-7 in *Brassica rapa* L. Nair *et al.* (2005) observed significant variance for this trait in *Brassica juncea* L.

4.3.2.4 Number of Primary Branches per Plants

The highest significant and positive SCA effect was exhibited by the combination NAP-248 x NAP-2001 (0.78) considered as the best specific combiner for the trait which indicated that the combination would be effective for higher number of primary branches per plant as well as higher yield per plant (Table 8). 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 the best positive effect in Pusa × Barani in *Brassica juncea* L.

4.3.2.5 Number of Secondary Branches per Plant

Eight out of 91 hybrid combinations were found with significant SCA effect which ranged from -1.71 to 2.09. The combination NAP-9905 x NAP-9904 possessed the highest positive and significant SCA effect (2.09) which could be selected as the best specific combiner for number of secondary branches per plant and might be used in further hybridization program for good hybrid combination (Table 8). Chowdhury *et al.* (2004a) found maximum secondary branches in Sampad Din-2 in Brassica rapa L. Singh and Murty (1980) observed more secondary branches per plant in YSC-68 SS-2 in Brassica campestris L.

4.3.2.6 Number of Siliquae per Plant

The combination NAP-9905 x NAP-94006 produced the highest positive SCA effect (52.15) and considered as the best specific combiner for the trait concerned (Table 8) . Chowdhury *et al.* (2004) found the maximum siliquae in Sampad Din-2 in *Brassica rapa* L. Singh and Marty (1980) observed more siliquae per plant in YSP-842 SS-3 in *Brassica campestris* L .

4.3.2.7 Siliqua Length

No cross combinations were found with positive and significant SCA effects (Table 8). Huq (2006) showed BINAsar-6 × Tori 7 was not good for improving the trait in *Brassica rapa* L. Sheikh and Singh (1998) observed the maximum siliqua length in Pusa Barani × Glossy mutant and BM 20-12-3 × Pusha Bahar respectively in *Brassica juncea*.

4.3.2.8 Number of Seeds per Siliqua

The cross combination NAP-205 x NAP-2012 (3.92) produced the highest SCA effects indicated that the combination was the best specific combiner for the trait concerned and might be selected for higher seeds per siliqua (Table 8). Huq (2006) obtained BAR1sar-6 × BINA sar-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 the highest seeds per siliqua in Dhali × Sampad in *Brassica rapa* L. Singh *et al.* (2000) obtained more seeds per siliqua in YSP-842 × YSK-8501 in *Brassica campestris* L.

4.3.2.9 1000-Seed Weight

Among the cross combinations, seventeen of them were observed with significant effects in which seven with positive values. The combination NAP-9908 x NAP-130 produced the highest SCA effect (1.93) and considered as the best specific combiner for the trait (Table 8). Huq (2006) obtained all insignificant combination range-0.0534 to 0.0363 in *Brassica rapa* L. Singh *et al.* (2000) observed more seed weight per plant in YSC-68 × SS-2 in *Brassica campestris* L. Chowdhury *et al.* (2004a) obtained the highest seed weight in Dhali × Sampad in *Brassica rapa* L .

4.3.2.10 Seed Yield per Plant

In case of seed yield per plant there were forty two hybrid combinations showed significant and higher SCA effects which ranged from -4.49 to 3.90 (Table 8). The cross combinations BS-13 x NAP-2066 produced the highest SCA effect (3.90) which might be selected as the best specific combiner for the trait. Huq (2006) obtained the highest seed yield in Agroni × Tori 7, Agroni × BARIsar-6 and Shafal × BARIsar-6 in *Brassica rapa* L. Chowdhury *et al.* (2004) obtained the highest seed yield in M-27 × Din-2 in *Brassica rapa* L. Singh *et al.* (2000) observed more seed yield per plant in YSP-842 × YSK-8501 in *Brassica campestris* L.

Table 8: Estimates of specific combining ability effects of different crosses for various traits

Crosses	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
NAP-9905 x NAP-9904	-2.07 **	0.2 **	-2.11 ns	0.69 ns	2.09 **	26. 12 ns	-0.13 ns	2.19 ns	0.01 ns	1.59 **
NAP-9905 x NAP-9901	1.93 **	0.06 ns	5.46 ns	-0.51 ns	-0.15 ns	-10.08 ns	0.03 ns	-0.4 ns	-0.23 ns	-1.23 *
NAP-9905 x NAP-2013	-4.36 **	0.2 **	10.21 ns	-0.23 ns	-0.53 ns	-9.94 ns	0.44 ns	1.03 ns	0.39 ns	2.14 **
NAP-9905 x NAP-2022	1.07 *	-0.08 ns	-3.64 ns	-0.11 ns	-0.28 ns	8.08 ns	-0.26 ns	-0.35 ns	0.62 ns	2.34 **
NAP-9905 x NAP-2001	0.36 ns	0.35 **	-3.92 ns	-0.28 ns	0.07 ns	-4.91 ns	0.34 ns	-0.27 ns	0.31 ns	-1.56 **
NAP-9905 x NAP-94006	1.21 *	0.06 ns	-0.31 ns	0.73 *	1.52 *	52.15 **	0.55 ns	2.97 ns	0.28 ns	-0.22 ns
NAP-9905 x NAP-2012	-3.21 **	0.92 **	-2.62 ns	0.49 ns	-0.13 ns	14.86 ns	-0.78 *	-1.87 ns	0.02 ns	0.34 ns
NAP-9905 x NAP-206	-0.21 ns	-0.23 **	0.22 ns	-0.23 ns	0.11 ns	-3.98 ns	0.44 ns	-0.96 ns	0.71 ns	1.35 *
NAP-9905 x NAP-130	4.0 **	-0.3 **	-0.72 ns	-0.3 ns	-0.73 ns	-27.12 ns	-0.36 ns	-2.69 ns	-1.26 **	-2.53 **
NAP-9905 x NAP-2057	1.5 **	-0.51 **	-8.18 ns	-0.1 ns	-0.91 ns	-22.12 ns	-0.02 ns	1.75 ns	0.05 ns	0.31 ns
NAP-9905 x NAP-2066	1.21 *	-0.51 **	3.02 ns	-0.7 ns	-0.95 ns	-26.19 ns	0.1 ns	-1.41 ns	0.44 ns	-1.92 **
NAP-9905 x NAP-179	-0.21 ns	-0.51 **	4.48 ns	-0.11 ns	-0.49 ns	-5.58 ns	0.55 ns	1.79 ns	-0.39 ns	-0.40 ns
NAP-9905 x NAP-2037	-1.21 *	0.35 **	-1.91 ns	0.67 ns	0.38 ns	8.72 ns	-0.9 *	-1.81 ns	-0.96 *	-0.22 ns
BS-13 x NAP-9904	2.93 **	-0.49 **	5.49 ns	-0.41 ns	-0.74 ns	-9.73 ns	-0.16 ns	0.42 ns	0.93 *	-1.63 **
BS-13 x NAP-9901	-5.07 **	-0.63 **	-8.84 ns	0.09 ns	0.12 ns	2.27 ns	0.21 ns	-0.17 ns	0.39 ns	-1.10 ns
BS-13 x NAP-2013	3.64 **	-0.49 **	-1.0 ns	-0.13 ns	-0.16 ns	-20.78 ns	0.13 ns	0.94 ns	-0.29 ns	-0.11 ns
BS-13 x NAP-2022	5.07 **	0.23 **	-3.94 ns	-0.51 ns	-0.41 ns	-21.97 ns	-0.74 ns	-2.92 ns	-0.16 ns	-2.06 **
BS-13 x NAP-2001	2.36 **	-0.35 **	10.07 ns	0.12 ns	-0.46 ns	-8.85 ns	0.52 ns	3.04 ns	0.08 ns	0.47 ns
BS-13 x NAP-94006	-1.79 **	0.37 **	-5.31 ns	-0.27 ns	-0.11 ns	-22.3 ns	-0.51 ns	-0.83 ns	-0.05 ns	-0.61 ns
BS-13 x NAP-2012	-0.21 ns	0.23 **	7.37 ns	0.39 ns	0.84 ns	26.22 ns	0.23 ns	-0.92 ns	-0.11 ns	-0.85 ns
BS-13 x NAP-206	-4.21 **	0.08 ns	-5.69 ns	0.17 ns	-0.52 ns	2.27 ns	-0.19 ns	0.77 ns	-0.87 *	-0.34 ns
BS-13 x NAP-0130	-5.0 **	0.01 ns	-3.03 ns	0.2 ns	0.04 ns	10.03 ns	-0.11 ns	1.64 ns	0.51 ns	-0.01 ns
BS-13 x NAP-2057	0.5 ns	-0.2 **	2.41 ns	0.1 ns	-0.54 ns	-7.87 ns	0.1 ns	0.46 ns	-1.58 **	-0.40 ns
BS-13 x NAP-2066	-0.79 ns	0.8 **	2.61 ns	0.2 ns	0.02 ns	2.26 ns	-0.06 ns	1.96 ns	-0.34 ns	3.90 **

**p<0.01,*p<0.05

Table 8: (Continued)

Crosses	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
BS-13 x NAP-179	-0.21 ns	-0.2 **	-3.43 ns	-0.11 ns	0.98 ns	26.37 ns	0.51 ns	-1.68 ns	1.28 **	3.73 **
BS-13 x NAP-2037	2.79 **	0.65 **	3.29 ns	0.17 ns	0.95 ns	22.07 ns	0.08 ns	-2.72 ns	0.21 ns	-0.98 ns
NAP-9908 x NAP-9904	-2.53 **	-0.26 **	-1.05 ns	-0.2 ns	0.51 ns	-3.48 ns	0.16 ns	-2.84 ns	0.15 ns	-2.83 **
NAP-9908 x NAP-9901	1.47 **	0.6 **	-12.87 *	0.5 ns	-0.83 ns	-31.68 ns	-1.27 **	-1.95 ns	-0.49 ns	-0.48 ns
NAP-9908 x NAP-2013	-2.82 **	-0.26 **	3.47 ns	0.09 ns	0.78 ns	24.36 ns	-0.14 ns	1.22 ns	0.83 *	-0.94 ns
NAP-9908 x NAP-2022	0.61 ns	0.46 **	0.33 ns	0.2 ns	-0.96 ns	-3.32 ns	0.38 ns	1.66 ns	0.16 ns	-0.65 ns
NAP-9908 x NAP-2001	1.9 **	-0.12 *	6.44 ns	-0.27 ns	-0.12 ns	-1.91 ns	0.1 ns	-1.42 ns	-0.1 ns	1.61 **
NAP-9908 x NAP-94006	-0.25 ns	-0.4 **	-1.35 ns	-0.15 ns	0.04 ns	1.55 ns	0.56 ns	3.07 ns	0.32 ns	1.24 *
NAP-9908 x NAP-2012	1.32 **	-0.54 **	-6.96 ns	0.00 ns	-0.52 ns	-13.24 ns	0.13 ns	1.5 ns	-1.09 **	0.31 ns
NAP-9908 x NAP-206	0.32 ns	-0.69 **	-2.82 ns	-0.41 ns	-0.78 ns	-21.98 ns	0.38 ns	-1.27 ns	-0.09 ns	-2.12 **
NAP-9908 x NAP-130	0.54 ns	0.24 **	11.04 ns	0.12 ns	1.28 *	39.68 *	0.6 ns	-0.44 ns	1.93 **	0.08 ns
NAP-9908 x NAP-2057	-0.96 *	0.03 ns	0.28 ns	0.12 ns	0.71 ns	19.28 ns	-0.17 ns	1.85 ns	0.44 ns	2.91 **
NAP-9908 x NAP-2066	-0.25 ns	0.0 3 ns	8.88 ns	0.32 ns	1.67 **	29.71 ns	-0.37 ns	-1.38 ns	0.24 ns	2.46 **
NAP-9908 x NAP-179	0.32 ns	0.03 ns	5.14 ns	0.2 ns	-0.48 ns	-6.18 ns	0.16 ns	0.16 ns	-2.04 **	-0.43 ns
NAP-9908 x NAP-2037	0.32 ns	0.88 **	-10.55 ns	-0.51 ns	-1.3 *	-32.78 ns	-0.52 ns	-0.16 ns	-0.26 ns	-1.17 *
NAP-205 x NAP-9904	-2.99 **	-0.34 **	0.75 ns	0.43 ns	0.37 ns	21.07 ns	-0.1 ns	0.67 ns	-1.84 **	0.86 ns
NAP-205 x NAP-9901	0.01 ns	-0.48 **	16.72 **	0.13 ns	-0.17 ns	19.07 ns	0.32 ns	1.18 ns	0.28 ns	0.75 ns
NAP-205 x NAP-2013	1.72 **	-0.34 **	-12.74 *	-0.38 ns	-0.96 ns	-10.99 ns	-0.51 ns	0.59 ns	-0.31 ns	1.73 **
NAP-205 x NAP-2022	1.15 *	-0.62 **	5.22 ns	-0.17 ns	0.3 ns	10.22 ns	0.0 ns	1.26 ns	-0.27 ns	1.28 *
NAP-205 x NAP-2001	-3.57 **	-0.19 **	-4.17 ns	-0.14 ns	0.64 ns	10.44 ns	-0.14 ns	-0.81 ns	0.25 ns	0.26 ns
NAP-205 x NAP-94006	1.29 **	0.52 **	-3.55 ns	-0.02 ns	-0.2 ns	-26.01ns	-0.11 ns	-9.51 **	0.18 ns	-1.62 **
NAP-205 x NAP-2012	1.86 **	0.38 **	4.63 ns	0.03 ns	0.94 ns	26.21 ns	0.58 ns	3.92 *	0.03 ns	-0.42 ns
NAP-205 x NAP-206	2.86 **	1.24 **	10.78 ns	0.42 ns	0.39 ns	29.77 ns	-0.27 ns	2.14 ns	0.42 ns	0.70 ns
NAP-205 x NAP-130	0.08 ns	0.16 **	-7.37 ns	0.35 ns	-0.06 ns	-16.68 ns	0.21 ns	-0.34 ns	-0.76 *	-0.18 ns

**p<0.01,*p<0.05

Table 8: (Continued)

Crosses	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
NAP-205 x NAP-2057	-0.42 ns	-0.05 ns	-1.22 ns	-0.15 ns	-0.53 ns	-2.18 ns	-0.45 ns	-0.7 ns	0.81 *	-0.92 ns
NAP-205 x NAP-2066	-0.71 ns	-0.05 ns	-7.42 ns	0.05 ns	-0.47 ns	-22.25 ns	0.12 ns	-0.93 ns	0.55 ns	-2.52 **
NAP-205 x NAP-179	0.86 ns	-0.05 ns	0.03 ns	-0.47 ns	-0.31 ns	-24.83 ns	-0.1 ns	-0.13 ns	0.37 ns	0.02 ns
NAP-205 x NAP-2037	-2.14 **	-0.19 **	-1.65 ns	-0.08 ns	0.06 ns	-13.83 ns	0.45 ns	2.67 ns	0.3 ns	0.04 ns
NAP-9906 x NAP-9904	1.31 **	-0.1 *	-3.65 ns	-0.38 ns	-1.71 **	-26.63 ns	-0.11 ns	1.69 ns	0.15 ns	-1.05 ns
NAP-9906 x NAP-9901	2.31 **	0.75 **	1.22 *	-0.18 ns	0.44 ns	28.97 ns	0.06 ns	1.87 ns	-0.18 ns	-0.17 ns
NAP-9906 x NAP-2013	2.03 **	0.9 **	2.36 ns	0.0 ns	1.06 ns	0.41 ns	0.35 ns	-1.43 ns	0.53 ns	0.03 ns
NAP-9906 x NAP-2022	-4.54 **	-0.39 **	-4.88 ns	-0.48 ns	0.42 ns	-13.88 ns	0.47 ns	-1.57 ns	-0.13 ns	-1.79 **
NAP-9906 x NAP-2001	1.74 **	0.04 ns	-2.27 ns	0.05 ns	-0.04 ns	15.44 ns	-0.77 *	-0.55 ns	-0.09 ns	2.50 **
NAP-9906 x NAP-94006	-4.40 **	-0.25 **	10.95 ns	0.16 ns	-0.18 ns	0.19 ns	0.11 ns	3.32 *	-0.38 ns	-0.18 ns
NAP-9906 x NAP-2012	0.17 ns	-0.39 **	5.73 ns	0.12 ns	-0.94 ns	-15.69 ns	-0.05 ns	-1.87 ns	0.52 ns	-0.25 ns
NAP-9906 x NAP-206	0.17 ns	-0.53 **	-6.22 ns	0.1 ns	0.2 ns	6.97 ns	-0.08 ns	0.46 ns	-0.59 ns	-0.36 ns
NAP-9906 x NAP-0130	2.38 **	0.4 **	-7.97 ns	0.43 ns	-0.64 ns	-19.78 ns	-0.5 ns	-0.57 ns	-1.47 **	0.49 ns
NAP-9906 x NAP-2057	-0.12 ns	0.18 **	1.08 ns	0.03 ns	-0.11 ns	-4.88 ns	0.4 ns	-1.31 ns	-0.05 ns	-0.94 ns
NAP-9906 x NAP-2066	-0.4 ns	0.18 **	-1.42 ns	0.13 ns	0.44 ns	16.65 ns	-0.09 ns	1.59 ns	0.19 ns	3.36 **
NAP-9906 x NAP-179	0.17 ns	0.18 **	-8.67 ns	0.12 ns	0.2 ns	5.97 ns	0.21 ns	-0.23 ns	1.01 **	-0.83 ns
NAP-9906 x NAP-2037	-0.83 ns	-0.96 **	3.75 ns	-0.1 ns	0.87 ns	6.27 ns	-0.01 ns	-1.41 ns	0.94 ns	-0.80 ns
NAP-248 x NAP-9904	2.01 **	0.97 **	1.35 ns	-0.55 ns	-0.66 ns	-18.47 ns	0.11 ns	-0.17 ns	0.2 ns	2.89 **
NAP-248 x NAP-9901	-0.99 *	-0.17 **	-5.38 ns	-0.35 ns	0.6 ns	2.73 ns	-0.03 ns	-1.38 ns	0.21 ns	0.67 ns
NAP-248 x NAP-2013	-1.28 **	-0.03 ns	-8.74 ns	0.13 ns	-0.39 ns	8.97 ns	-0.47 ns	-1.81 ns	-0.58 ns	-3.18 **
NAP-248 x NAP-2022	1.15 *	0.69 **	1.72 ns	0.45 ns	-0.03 ns	-0.32 ns	0.08 ns	0.89 ns	-0.29 ns	-1.74 **
NAP-248 x NAP-2001	-0.57 ns	0.12 *	-0.47 ns	0.78 *	0.81 ns	6.5 ns	0.17 ns	-0.15 ns	0.15 ns	-2.26 **
NAP-248 x NAP-94006	3.29 **	-0.17 **	3.15 ns	-0.11 ns	-0.13 ns	1.16 ns	0.1 ns	0.98 ns	0.37 ns	1.86 **
NAP-248 x NAP-2012	-2.14 **	-0.31 **	-10.77 ns	-0.45 ns	0.31 ns	-20.53 ns	-0.31 ns	-0.83 ns	0.76 *	1.16 ns

**p<0.01,*p<0.05

Table 8: (Continued)

Crosses	Days to 50% Flowering	Days to 50% Maturity	Plant Height (cm)	No. of Primary Branch	No. of Secondary Branch	No. of Siliqua per Plant	Siliqua length (cm)	No. of Seed per Siliqua	1000 Seed Weight (g)	Seed Yield per plant (g)
NAP-248 x NAP-206	-1.14 *	-0.46 **	0.48 ns	0.13 ns	-0.05 ns	3.03ns	0.02 ns	-1.18 ns	0.45 ns	3.21 **
NAP-248 x NAP-130	-2.92 **	-0.53 **	7.23 ns	-0.24 ns	0.61 ns	19.08 ns	0.19 ns	2.35 ns	0.58 ns	2.07 **
NAP-248 x NAP-2057	0.58 ns	0.26 **	4.08 ns	-0.34 ns	0.74 ns	16.88 ns	0.18 ns	-1.4 ns	0.19 ns	-1.36 *
NAP-248 x NAP-2066	1.29 **	-0.74 **	-7.52 ns	0.16 ns	0.0 ns	-9.99 ns	0.13 ns	-0.69 ns	-1.52 **	-2.40 **
NAP-248 x NAP-179	-0.14 ns	0.26 **	1.03 ns	-0.05 ns	-1.45 *	-25.17 ns	-0.99 *	-0.45 ns	-0.65 ns	-4.49 **
NAP-248 x NAP-2037	0.86 ns	0.12 *	13.85 *	0.43 ns	-0.37 ns	16.13 ns	0.76 ns	3.81 *	0.13 ns	3.59 **
NAP-108 x NAP-9904	1.35 **	0.01 ns	-0.78 ns	0.43 ns	0.13 ns	11.13 ns	0.23 ns	-1.95 ns	0.4 ns	0.16 ns
NAP-108 x NAP-9901	0.35 ns	-0.13 *	-6.3 ns	0.33 ns	-0.01 ns	-11.27 ns	0.68 ns	0.84 ns	0.02 ns	1.55 *
NAP-108 x NAP-2013	1.07 **	0.01 ns	6.44 ns	0.51 ns	0.2 ns	7.97 ns	0.14 ns	-0.55 ns	-0.57 ns	0.33 ns
NAP-108 x NAP-2022	-4.51 **	-0.27 **	5.2 ns	0.63 ns	0.96 ns	21.18 ns	0.07 ns	1.02 ns	0.07 ns	2.62 **
NAP-108 x NAP-2001	-2.22 **	0.15 **	-5.69 ns	-0.25 ns	-0.9 ns	-16.7 ns	-0.2 ns	0.17 ns	-0.59 ns	-1.02 ns
NAP-108 x NAP-94006	0.64 ns	-0.13 *	-3.58 ns	-0.33 ns	-0.94 ns	-6.74 ns	-0.71 ns	-0.01 ns	-0.72 ns	-0.47 ns
NAP-108 x NAP-2012	2.21 **	-0.27 **	2.61 ns	-0.57 ns	-0.5 ns	-17.83 ns	0.21 ns	0.06 ns	-0.14 ns	-0.29 ns
NAP-108 x NAP-206	2.21 **	0.58 **	3.25 ns	-0.19 ns	0.65 ns	-16.07 ns	-0.3 ns	0.02 ns	-0.04 ns	-2.44 **
NAP-108 x NAP-130	0.92 *	0.01 ns	0.81 ns	-0.56 ns	-0.5 ns	-5.22 ns	-0.03 ns	0.04 ns	0.48 ns	0.08 ns
NAP-108 x NAP-2057	-1.08 *	0.3 **	1.55 ns	0.34 ns	0.63 ns	0.88 ns	-0.05 ns	-0.66 ns	0.15 ns	0.40 ns
NAP-108 x NAP-2066	-0.36 ns	0.3 **	1.85 ns	-0.16 ns	-0.71 ns	9.81 ns	0.16 ns	0.87 ns	0.44 ns	-2.87 **
NAP-108 x NAP-179	-0.79 ns	0.3 **	1.41 ns	0.43 ns	1.55 *	29.43 ns	-0.33 ns	0.53 ns	0.41 ns	2.40 **
NAP-108 x NAP-2037	0.21 ns	-0.85 **	-6.78 ns	-0.59 ns	-0.58 ns	-6.57 ns	0.14 ns	-0.37 ns	0.09 ns	-0.45 ns
SE (SCA effects)	0.46	0.05	5.65	0.36	0.63	19.36	0.39	1.62	0.37	0.59
SE (sij-skl)	0.65	0.07	7.99	0.51	0.88	27.38	0.54	2.29	0.52	0.83

**p<0.01,*p<0.

Chapter 5

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Seven *Brassica* genotypes namely NAP-9905, BS-13, NAP-9908, NAP-205, NAP-9906, NAP-248 and NAP-108 were used as lines and thirteen Brassica genotypes namely NAP-9904, NAP-9901, NAP-2013, NAP-2022, NAP-2001, NAP-94006, NAP-2012, NAP-206, NAP-130, NAP-2057, NAP-2066, NAP-179 and NAP-2037 as tester for line-tester cross and ninety one hybrids were evaluated for estimating the magnitude of heterosis over mid parent and better parent and combining ability effects.

It was observed that all the hybrids obtained did not perform 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 ninety one crosses, no cross combination showed desirable negative heterosis for the characters of shorter plant height. NAP-9905 x NAP-2013 showed desirable negative heterosis for early flowering but no crosses showed early maturity. NAP-9905 x NAP-9904 showed desirable positive heterosis for number of primary branches per plant, NAP-9905 x NAP-94006 for number of secondary branches per plant and number of siliqua per plant. The hybrids NAP-9908 x NAP-2001 were found to be the best heterosis for siliquae length but NAP-108 x NAP-179 and NAP-108 x NAP-2022 found to be best for seeds per siliqua. For thousand seed weight the hybrids NAP-9908 x NAP-2013 was best. For seed yield per plant the crosses NAP-108 x NAP-9901 was found to be the best.

Analysis of combining ability following Kempthorne showed significant GCA and SCA varianes for all the characters studied, indicating the role of both additive and non-additive components in the genetic system controlling these characters. Estimates of GCA effects for different characters sugested that parent Nap-248 was the best general combiner for early flowering. The parent NAP-108 is best for desirable plant height, seeds per siliqua and yield per plant. The parent BS-13 was the best general combiner for early maturity while the parent Nap-248 was the best general combiner for 1000 seed weight.

The SCA estimates of various characters revealed that cross NAP-9905 x NAP-9904 was good specific combiner for number of secondary branches and NAP-9905 x NAP-94006 for number of siliquae per plant. The cross NAP-205 x NAP-9901 was the best specific combiner for plant height. The combination BS-13 x NAP-2022 was the best specific combiner for early flowering and BS-13 x NAP-2066 for seed yield per plant while NAP-94006×NAP-248 was the best for early maturity. The hybrid NAP-248 x NAP-2001 was the best for number of primary branches per plant. The cross NAP-205 x NAP-2012 was the best for the number of seeds per siliqua and NAP-9908 x NAP-130 was best for 1000-seed weight. Among the genotypes, the parents had high GCA effects and hybrids had high heterotic value and SCA effect.

From the findings of the present study , the following recommendation could be made:

1. The crosses NAP 9905X NAP94006 , NAP205 X NAP9901, BS-13 X NAP 2066 , NAP 205 X NAP 2012 and NAP 9908 X NAP 0130 could be used for development of hybrid variety in mustard.

Chapter 6

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Chapter 7
APPENDICES

APPENDICES

Appendix I. Morphological, physical and chemical characteristics of initial soil (0-15 cm depth) of the experimental site

A. Physical composition of the soil

Soil separates	**%**	**Methods employed**
Sand	36.90	Hydrometer method (Day,1915)
Silt	26.40	Do
Clay	36.66	Do
Texture class	Clay loam	Do

B. Chemical composition of the soil

Sl. No.	**Soil characteristics**	**Analytical data**	**Methods employed**
1	Organic carbon (%)	0.82	Walkley and Black, 1947
2	Total N (kg/ha)	1790.00	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (kg/ha)	69.00	Olsen and Dean, 1965
7	Exchangeable K (kg/ha)	89.50	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	pH (1 : 2.5 soil to water)	5.55	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Source: Central library, Sher-e-Bangla Agricultural University, Dhaka

Appendix II. Monthly average Temperature, Relative Humidity and Total Rainfall of the experimental site during the period from October, 2012 to March, 2013

Month	Air temperature (°c)		Relative humidity (%)	Rainfall (mm) (total)	Sunshine (hr)
	Maximum	Minimum			
October, 2012	34.8	18.0	77	227	5
November, 2012	32.3	16.3	69	0	7
December, 2012	29.0	13.0	79	0	3
January, 2013	28.1	11.1	72	1	5
February, 2013	33.9	12.2	55	1	8
March, 2013	34.6	16.5	67	45	7
April, 2013	35.8	20.3	65	88	8

Source: Bangladesh Metrological Department (Climate division), Agargaon, Dhaka-1212.