HETEROSIS AND COMBINING ABILITY FROM 7X7 DIALLEL ANALYSIS IN *Brassica napus* L.

BY

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CERTIFICATE

This is to certify that thesis entitled, "Heterosis and Combining Ability from 7x7 Diallel 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 Farzana Sultana Registration No. 06-01946 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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TO

MY BELOVED PARENTS

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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 1^{st} generation of a cross between two dissimilar homozygous parents	F_1
The 2^{nd} 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	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

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ABSTRACT

An experiment on oleiferous *Brassica napus* L. was conducted to evaluate the heterosis and combining ability for ten different characters. Out of 21 of F_1's, the hybrids Nap2022 × Nap2001 and Nap2022 × Nap248 showed desirable negative heterosis for the characters of shorter plant height, early flowering and early maturity. The hybrid Nap248 × Nap2012 was the best for early flowering. The cross Nap248 × Nap179 was the best for number of primary branches/plant. The hybrid Nap2013 × Nap94006 was found to be the high heterotic for number of secondary branches and number of siliquae/plant. The cross Nap2001× Nap94006 was the best for siliqua length and number of seeds/siliqua, respectively. For 1000 seed weight the hybrids Nap179 × Nap2001 and Nap2012 × Nap94006 and for seed yield/plant the crosses Nap2012 × Nap94006 was found to be the best heterotic. The parent Nap-248 was the best general combiner for early flowering, early maturity, plant height. The parent Nap-2012 was the best for 1000 seed weight. For seed yield the parent Nap-179 and Nap-94006 and for number of siliquae/plant the parent, Nap-2022 was suitable general combiner.The parent Nap-94006 is best for high no of primary branches and no of secondary branches. On the basis of average score and rank position, the hybrid Nap2022 x Nap2001 was the best specific combiner for early flowering. The combination Nap2001 × Nap94006 was the best specific combiner for number of secondary branches/plant. The cross Nap2022 x Nap94006 and Nap179 x Nap94006 were the best for the number of primary branches and number of siliquae/plant respectively. For siliqua length Nap179 x Nap94006 was the best specific combiner. The cross Nap2013 x Nap2001 was the best specific combiner for seed yield/plant and 1000 seed weight. The mean sum of square due to GCA was significant for all traits indicating that the additive gene actions were predominant for the expression of these characters. The significant mean sum of square due to SCA was also observed for all the traits indicating that the non additive gene actions were predominant. The higher magnitude of SCA variance was observed than that of GCA variance for plant height, days to maturity, number of primary branches, number of secondary branches, number of seeds/siliqua, seed yield/plant and 1000 seed weight.

Chapter 1

Introduction

INTRODUCTION

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

The oleiferous *Brassica* is important source of vegetable fat and are mainly represented by rape, turnip rape and mustard. This is the fourth most important source of vegetative oil in the world after soybean, palm, and sunflower. The component of mustard group includes *B. Juncea* Czern and Cross (2x=36), *B. nigra* Koch, *B. carinata* Braun (2x=34) while rapeseed includes *B. rapa* L. (turnip rape, 2x=20) and B. napus L. (rape, 4x=38). All these species have many cultivated varieties suited to different agroclimatic conditions. In this sub-continent three species of *Brassica* are cultivated for oil purposes, viz, *B. campestris, B.juncea* and *B. napus.*

In Bangladesh, total oil seed crops cover 3.02 lakh ha of land. However, rapeseed and mustard cover 2.17 lakh ha of land produce about 5.95 lakh Mt of oil seeds. This crop covers about 74.5& area of the total edible oil crops cultivated in Bangladesh. Oilseed crop covers about 4.04% area of the total cultivable land in Bangladesh (BBS, 20006a).

The climate and edaphic factors of Bangladesh are quite favorable for the cultivation of rapeseed and mustard. 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. 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. The above scenario dictates the major quantitative and agronomic modification of this crop. The shortage of edible oil has become a chronic problem for the nation. Bangladesh requires 0.29 million tons of oil equivalent to 0.8 million tons of oilseeds for nourishing her people. But, the oilseed production is about 0.254 million tons, which covers only 40% of the domestic need (FAO, 2001). As a result, more than 60% of the requirement of oil and oil seed has been imported every year by spending huge amount of foreign currency involving over 317 cores taka (BBS, 2006c).

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

There is plenty of scope to increase yield per unit of area through breeding superior varieties. The production potential of rapeseed and mustard may be well exploited if the varieties can be identified with early maturity, rapid response to high fertility, has large seed size and high oil content. The oil content of mustard in Bangladesh varied from 30 to 40 percent depending on the variety, climate and production condition. 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 are also scope to increase yield per unit of area through cultivation of short duration high yielding varieties. The production potential of rapeseed and mustard may 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 varied from 30 to 40 percent depending on the variety, climate and production condition.

In cross pollinated crops like rapeseed *(Brassica napus)* these studies are useful in assessing the nicking ability of the parents which, when crossed, would give more desirable segregates. This, in turn, helps in choosing the parents for hybridization. There fore, the present work was undertaken with the following objectives:

- To estimate heterosis for different yield contributing characters of rapeseed,
- To estimate the nature and extent of gene action involving in controlling the traits and
- To identify the potential parents and promising cross combinations to develop 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 HETEROSIS

The term hetrosis 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.

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*.

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.

Huq (2006) conducted an experiment on *Brassica rapa* involving7×7 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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).

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.

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.

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%.

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.

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.

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.

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.

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).

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.

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

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.

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.

2.2 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.

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.

Goffman 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 ($5S_3$ and $4S_4$), 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 T996 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 × BICI702) in which reciprocal effects acted in a favorable direction for all traits. This allowed the selection of a maternal parent, which was capable of enhancing beneficial non-additive effects in a specific cross. The parents of this cross also showed high GCA for most of the traits, allowing the exploitation also of beneficial additive effects.

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

Yadav *et al.* (1992) evaluated 45 F_1 hybrids of Indian mustard together with ten parents for combining ability with respect to seed yield and its component characters. Veruna, Kranti, RIC1359 and RLCI357 were identified as good combiners for seed yield, earliness, siliqua length, number of seeds/siliqua and 1000 seed weight. The following varieties or parents ECI26743, ECI26745 and ECI26746-1 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 F_1 and 15 F_2 populations. They evaluated 11 quantitative and qualitative characters. GCA and SCA variance were significant for all characters. RLM198 showed good general combining ability for plant height, number of siliqua/plant, and 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 B3U 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

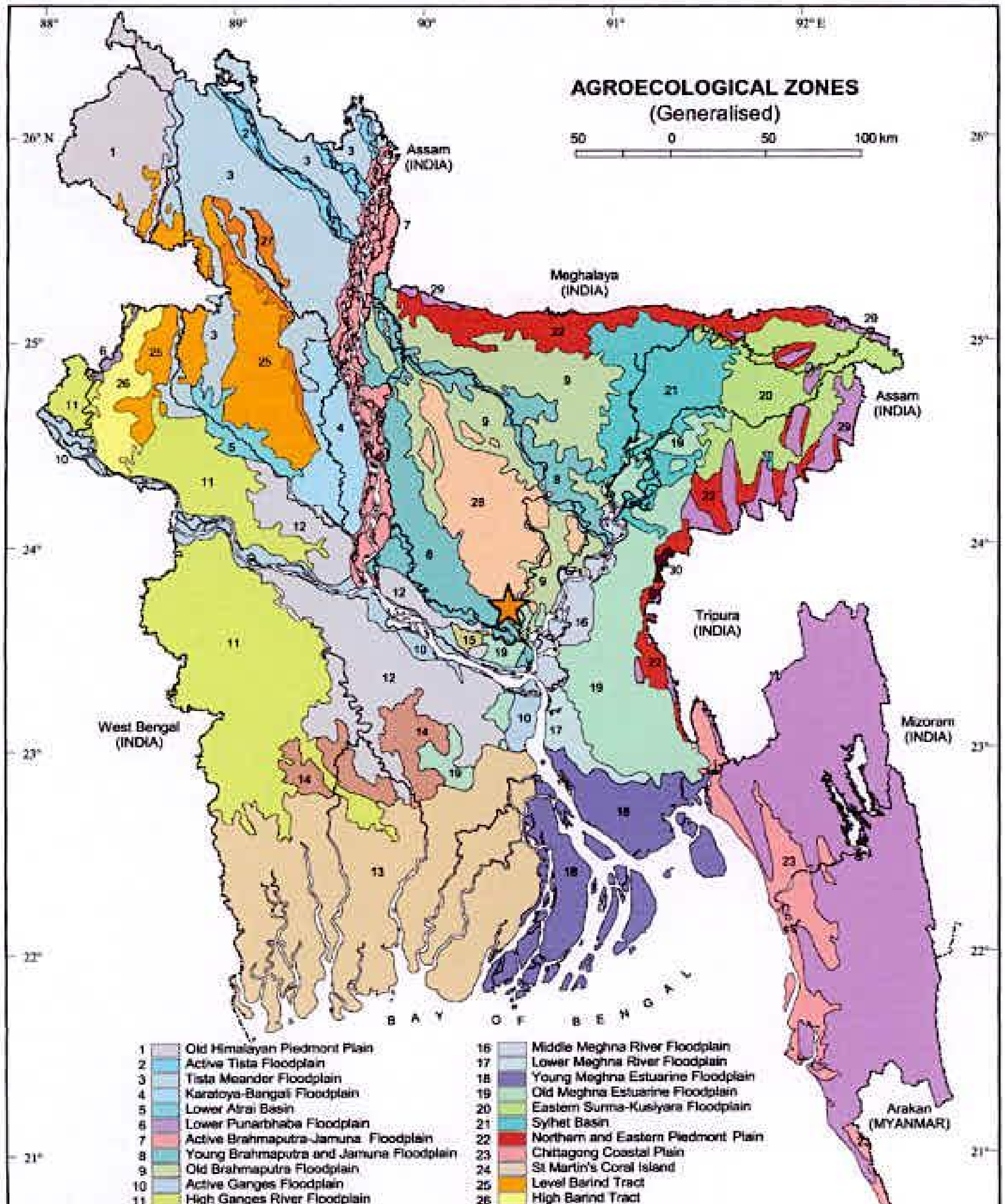
To conduct the experiment seven selected cultivars were used as parents and these were Nap-2022, Nap-2013, Nap-248, Nap-179, Nap-2012, Nap-2001, and Nap-94006. Twenty one crosses were done among parents in Rabi season 2011-2012. In 2011-2012 Rabi season, the parents and F_1's were grown in the experimental farm.

3.1 Experimental site and duration

The research work was conducted at the experimental farm of Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh, during the period from November 2011 to march 2012. The soil of the experimental plots were clay loam, land was medium high with medium fertility level. The site was situated in the subtropical climatic zone, wet summer and dry winter is the general climatic feature of this region (Figure 1). During the rabi season the rainfall generally is scant and temperature moderate with short day length. Meterogical data on rainfall, temperature, relative humidity from November 2011 to April 2012 were obtained from the Department of Metrological Centre, Dhaka-1207, Bangladesh.

3.2 Plant Materials used

Seven parental genotypes and their twenty-one intervarietal hybrids were used in the experiment. The present status, source of the materials and characteristics of the parents used in the intra-specific crosses and the attempted cross combinations are presented in Table 1. The parents were crossed in half diallel to produce 21 F_1's during winter 2011 at the experimental farm of SAU, Dhaka, Bangladesh.



★ The experimental site under study

Figure 1: Location of the experimental field

Table 1: Cross combinations in half diallel system of seven varieties in *Brassica napus* L.

Parents / Parents	**Nap- 2022 (P1)**	**Nap-2013 (P2)**	**Nap- 248 (P3)**	**Nap-179 (P4)**	**Nap- 2012 (P5)**	**Nap-2001 (P6)**	**Nap-94006 (P7)**	
Nap- 2022	**Nap-2022**	Nap2022x Nap2013 (C1)	Nap2022 x Nap248 (C2)	Nap2022 x Nap179 (C3)	Nap2022 x Nap2012 (C4)	Nap2022 x Nap2001 (C5)	Nap2022 x Nap94006 (C6)	
Nap-2013		**Nap-2013**	Nap2013x Nap248 (C8)	Nap2013 x Nap179 (C9)	Nap2013 x Nap2012 (C10)	Nap2013x Nap2001 (C11)	Nap2013 x Nap94006 (C12)	
Nap- 248			**Nap-248**	Nap248 x Nap179 (C14)	Nap248 x Nap2012 (C15)	Nap248 x Nap2001 (C16)	Nap248 x Nap94006 (C17)	
Nap-179				**Nap-179**	Nap179 x Nap2012 (C19)	Nap179 x Nap2001 (C20)	Nap179x Nap94006 (C21)	
Nap- 2012					**Nap-2012**	Nap2012 x Nap2001 (C23)	Nap2012 x Nap94006 (C24)	
Nap-2001						**Nap-2001**	Nap2001 x Nap94006 (C26)	
Nap-94006							**Nap-94006**	

3.3 Land preparation and fertilizer application

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

3.4 Experimental design and layout

The seeds of twenty one F_1's and seven parents were grown in Randomized Complete Block Design (RCBD) with three replications. Each plot consisted of single row of 3m length spaced 40cm apart and 10cm between plants. The seeds were sown in separate line in the experimental field on 15 November 2011 by hand uniformly. The seeds were sown at a soil depth of 2.5 to 3.5 cm. After sowing the seeds were covered with soil carefully so that no clods were on the seeds. Seed germination started after three days of sowing on 18 November 2011. Treatment was distributed in the experimental unit through randomization by using the random number.

3.5 Irrigation and drainage

One post sowing irrigation was given by sprinkler after sowing of seeds to bring proper moisture condition of 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.

3.6 Intercultural operation, Insect and disease control

Necessary intercultural operations were done during the crop period to ensure normal growth and development of the plants. Thinning and first weeding were done after 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.

3.7 Harvesting of sample plants

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

3.8 Data recorded

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

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

3.8.3 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.

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

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

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

Side view

Close view

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

3.8.7 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.

3.8.8 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.

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

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

3.9 Statistical analysis

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

3.9.1 Estimation of heterosis:

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

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

Here, $\overline{F1}$ =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, $\overline{F1}$ =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.

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

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 diallel cross

Griffing (1956) proposed four methods of analysis depending on the materials involved. Griffing has also considered Eisenhart's model 1 (fixed effect) and model 11 (random effect) situation in the analysis. In the present research work combining ability analysis were done following method 2 (excluding reciprocals) and model-1.

The mathematical model for the analysis was:

$$Y_{ij} = m + g_i + g_j + S_{ij} + 1/bc \sum_{kl}\sum e_{ijkl}$$

Where,

$i, j = 1, 2, ..., p$

$K = 1, 2, ..., b$

$L = 1, 2, ..., c$

P = Number of parents

B = Number of blocks or replications

c = Number of observation in each plot

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

m = The population mean.

g_i = The general combining ability (GCA) effect to ith parent

g_j = The GCA of jth parent

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

$1/bc \sum_{kl}\sum e_{ijkl}$ = The mean error effect

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

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

Item	d.f.	Sum of squares	MSS	Expected MSS
GCA	P-1	S_g	M_g	$\sigma_e^2 + (P+2)\frac{1}{(P-1)}\Sigma g_i^2$
SCA	P(P-1)/2	S_s	M_s	$\sigma_e^2 + \frac{2}{P(P-1)}\Sigma_i\Sigma_j S_{ij}^2$
Error	(b-1)(e-1)	S_e	M_e'	σ_e^2

Where,

GCA = general combining ability

SCA = specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

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

Y_{ii} = Mean value lof the ith parent

Y. = Grand total of the ½ p(p-1) crosses and parental lines

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

S_e = Sum of square due to error

$$S_g = \frac{1}{(P+2)}\left[\sum_i (Y_{i.} + Y_{ii})^2 - \frac{4}{P}Y..^2\right]$$

$$S_s = \sum_i\sum_j Y_{ij}^2 - \frac{1}{(P+2)}\sum(Y_{i.} + Y_{ii})^2 + \frac{2}{(P+1)(P+2)}Y..^2$$

The GCA and SCA effects of each character were calculated as follows;

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

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

The variance of GCA and SCA were,

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

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

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

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

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

Chapter 4

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 Plant height

For parent, the lowest plant height was observed in Nap-2012 (91.867) and for hybrid Nap2022 x Nap2001 (81.843) followed by Nap2022 x Nap2012 (95.133). Where as the parent Nap-248 had the highest (118.97) plant height. The highest plant height (156.6) was found from the hybrid Nap248 x Nap94006. The hybrids were approximately 5-7 cm higher than the other parents.

4.1. 2 Days to 50% Flowering

In case of days to 50% flowering for parent, it was ranged from 33.0 to 39.00 days. However, the parent Nap-2022 (33.) flowered with the lowest time but the parent Nap-248 (39) took the highest duration. On the other hand, the hybrid combination Nap248 x Nap2012 (33.00) produced with the lowest growth duration, which was about one week least earlier than its both parents.

4.1.3 Days to 50% Maturity

Considering earliness, the parent Nap-94006 (84.00) showed the lowest duration for maturation but the parent Nap-248 (89.333) had taken the maximum duration. On the other hand, the hybrid combination Nap2022 x Nap179 (82.00) matured with lowest growth duration, which was about one week earlier than its both parents.

4.1.4 Number of primary branches per plant

For the character, number of primary branches per plant, parents showed at a range from 2.6333 to 3.6667. But in the hybrid, the highest value provided by the combination Nap2001179 x Nap94006 (4.7533) followed by Nap2001 x Nap94006 (4.7533) which were almost doubled than the either parent.

Table 2: Mean performance for 10 different characters in 7 parents and their 21 F_1's of *Brassica napus* L.

Treatments	Plant height (cm)	Days to 50% flowering	Days to 80% maturity	No. of primary branch/plant	No. of secondary branch/plant
nap2022	120.46	35.57	85.52	3.20	3.21
nap2013	118.38	35.67	86.57	3.24	2.95
nap248	116.68	36.33	87.52	2.97	2.84
nap179	116.55	35.71	86.19	3.40	3.90
nap2012	111.67	35.86	85.57	3.08	3.05
nap2001	107.71	36.05	85.86	3.15	2.80
nap94006	107.28	35.57	85.29	3.91	4.42
nap2022xnap2013	106.38	35.67	88.00	3.40	2.20
nap2022xnap248	120.44	35.33	83.67	3.47	2.83
nap2022xnap179	105.31	38.67	87.67	3.31	3.48
nap2022xnap2012	125.57	35.33	**82.33**	3.00	4.56
nap2022xnap2001	95.13	**33.33**	83.33	2.77	2.07
nap2022xnap94006	**81.84**	37.00	86.33	2.30	**0.80**
nap2013xnap248	116.28	34.33	87.33	4.16	**6.51**
nap2013xnap179	111.60	36.67	86.00	3.17	2.93
nap2013xnap2012	119.52	38.67	**89.67**	3.40	3.02
nap2013xnap2001	114.47	35.00	88.67	2.80	3.47
nap2013xnap94006	113.10	33.67	86.67	2.63	1.93
nap248xnap179	137.60	35.33	85.33	2.83	2.20
nap248xnap2012	111.92	34.67	86.00	**4.37**	4.25
nap248xnap2001	118.97	38.33	89.33	3.10	3.50
nap248xnap94006	111.60	37.67	89.00	2.64	2.17
nap179xnap2012	100.70	33.67	86.67	**1.99**	1.21
nap179xnap2001	130.48	34.33	84.67	3.01	2.63
nap179xnap94006	**156.60**	37.67	85.67	3.34	3.87
nap2012xnap2001	112.57	**38.67**	88.67	3.03	2.90
nap2012xnap94006	130.78	**33.33**	83.67	4.17	4.30
nap2001xnap94006	110.38	37.33	85.67	3.37	3.60
Grand mean	113.147	35.726	86.202	3.258	3.409
CV%	12.857	5.309	2.282	20.886	46.344
SE	2.749	0.358	0.372	0.129	0.299

Table 2. (Continued)

Treatments	No. of siliquae/ plant	siliqua length (cm)	Seeds/ siliqua	Seed yield/ Plant (gm)	1000 seed Weight (gm)
nap2022	104.00	7.32	21.68	11.30	3.53
nap2013	139.80	7.45	22.26	11.52	3.38
nap248	124.77	7.69	22.37	10.68	3.40
nap179	133.93	8.66	23.40	12.11	2.91
nap2012	116.30	7.58	22.31	11.01	3.66
nap2001	133.78	7.73	23.11	11.38	3.59
nap94006	163.27	8.79	23.68	10.71	3.39
nap2022xnap2013	106.57	7.65	20.40	11.57	2.87
nap2022xnap248	105.31	7.07	22.65	13.00	3.07
nap2022xnap179	104.08	7.30	20.03	8.67	4.10
nap2022xnap2012	107.54	7.39	21.43	13.93	3.43
nap2022xnap2001	79.67	7.52	20.75	8.90	4.20
nap2022xnap94006	45.72	7.06	23.46	11.87	3.07
nap2013xnap248	179.14	7.29	23.03	11.17	4.03
nap2013xnap179	134.77	7.86	23.59	12.47	2.97
nap2013xnap2012	145.61	7.32	20.36	9.03	3.97
nap2013xnap2001	138.64	8.37	23.95	11.80	3.40
nap2013xnap94006	109.14	7.02	19.88	5.90	4.23
nap248xnap179	148.67	7.06	20.88	16.57	2.33
nap248xnap2012	196.47	7.46	24.50	11.90	4.07
nap248xnap2001	124.07	8.31	24.19	8.63	4.10
nap248xnap94006	84.39	7.53	23.57	11.38	2.20
nap179xnap2012	64.70	7.07	22.46	12.57	2.80
nap179xnap2001	167.67	8.12	22.68	12.33	2.17
nap179xnap94006	182.87	8.19	23.28	12.17	2.80
nap2012xnap2001	112.03	8.25	24.59	12.38	3.20
nap2012xnap94006	168.87	7.33	23.71	13.35	4.17
nap2001xnap94006	141.32	7.68	23.00	9.71	3.97
Grand mean	129.235	7.883	22.693	11.201	3.386
CV%	30.100	16.547	6.615	21.012	20.415
SE	7.351	0.247	0.284	0.445	0.131

4.1.5 Number of secondary branches per plant

For the number of secondary branches per plant, parents showed at a range from 2.80 to 4.42. But in the hybrid, the highest value of number of secondary branches per plant provided by the combination Nap2013 x Nap248 (6.51) which was almost doubled than the average value of the parents.

4.1.6 Number of siliquae per plant

Number of siliquae per plant were varied from 104.00 to 163.27 where the parent Nap-94006 produced the highest and Nap-2022 the lowest number of siliquae per plant. Considering hybrid performance, it was ranged from 45.72 to 196.47 The hybrid combination Nap248 x Nap2012 (383.00) provided the highest number which was much higher than its either parent.

4.1.7 Siliqua length (cm)

Siliqua length of parent was ranged from 7.32 to 8.158.79 cm. The parent, Nap-94006 produced the longest siliqua while the parent Nap-2022. On the other hand, for hybrid the values varied from 7.02 to 8.37. In this regard, the hybrid combination Nap2013 x Nap2001 exhibited the highest length of siliqua .

4.1.8 Seeds per siliqua

Seed per siliqua also varied from 21.68 to 23.68 in parents and from 19.88 to 24.59 in hybrids. The hybrid Nap2012x2001 produced an excellent number of seeds per siliqua which was much higher than any one parent in this programme (Table 2).

4.1.9 Seed yield per plant (gm)

Seed yield per plant was found at diversely in different genotypes including parents and hybrids. Seed yield of the genotypes varied from 10.68 to 12.11gm in parents and from 5.90 to 13.93gm in hybrids. The highest seed yield of the parent was found in Nap-179(12.11) where as lowest in Nap-248 (10.68). Similarly, the seed yield was also observed in the hybrid Nap2022 x Nap2012 which was almost higher than it's both parents.

4.1.10 Thousand seed weight (gm)

Thousand seed weight in *B. napus* varied with some extent i.e. from 2.91 to 3.66 gm in parent and that of from 2.17 to 4.23 gm in hybrid. However, the heaviest seeds were produced by the parent Nap-2012 (3.66 gm) and also by the hybrid combination Nap2013 x Nap94006 (4.23 gm). The hybrid provided the highest weighted seeds were higher than it's both parents (Table 2).

4.2 Heterosis

Ten yield contributing characters of *Brassica napus* were studied in sevent parental genotypes and their 21 hybrids obtained from 7x7 half diallel crosses. Percent heterosis for 10 different characters of the F_1 hybrids over there respective mid and better parental values are shown in Table 3. These results on heterosis of 21 F_1's are described by character wise below.

4.2.1 Plant height

Out of 21 crosses twelve hybrids had significant heterosis over mid parent and that of nine over better parent for is characters (Table 3). The significant heterosis over mid-parent ranged from -22.2% to 46.02% which were represented by the Nap2022 x Nap2001 (-22.2%) and Nap179 x Nap2001 (46.02%). On the other hand, the significant value of better parent heterosis were ranged from -24.54% to 37.63%. The highest better parent heterosis was obtained from Nap179 x Nap2001 (37.63%). Conversely, the lowest better parent heterosis was produced by Nap2022 x Nap2001 (-24.54%). 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 (Plate-2).

99.53 cm **122.76 cm** **109.80 cm**

Plate 2: Hybrid Nap179 x Nap2001 and its parent showing different plant height

Table 3. Percent heterosis over mid-parent and better parent for 10 different characters in intervarietal hybrids of oleiferous *Brassica napus* L.

Cross combination	Plant height		Days to 50% flowering		Days to 80% maturity	
	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)
nap2022xnap2013	11.45***	8.84**	1.00 ns	0.00 ns	-3.33**	-4.33**
nap2022xnap248	-7.37**	-13.66 ns	-0.83 ns	-3.33**	-1.00**	-1.67**
nap2022xnap179	16.1**	13**	5.00**	5.00**	-6.00**	-6.33**
nap2022xnap2012	-3.99**	-11.25 ns	0.17 ns	-1.33 ns	-4.17**	-4.67**
nap2022xnap2001	-22.2**	-24.54**	-2.17**	-4.00**	-1.00**	-1.67**
nap2022xnap94006	11.99**	9.9**	3.00**	2.67**	1.33**	-0.67**
nap2013xnap248	8.8 ns	5.28 ns	-2.83**	-4.33**	2.00**	0.33 ns
nap2013xnap179	4.24 ns	0.56 ns	2.00**	1.00**	1.33**	0.00 ns
nap2013xnap2012	2.38 ns	1.9 ns	2.50**	2.00**	0.17**	-0.33**
nap2013xnap2001	11.37 ns	1.5 ns	-1.50 ns	-2.33**	-1.00**	-1.33**
nap2013xnap94006	30.95 ns	26 ns	-1.33**	-2.00**	1.00**	0.00 ns
nap248xnap179	5.02**	0.32**	-0.83 ns	-3.33**	0.00**	-0.33**
nap248xnap2012	-2.56 ns	-1.03 ns	-3.00**	-4.00**	-1.50 ns	-2.67**
nap248xnap2001	-4.17**	-7.37 ns	0.33**	-0.33**	-3.33**	-4.67**
nap248xnap94006	-4.71 ns	-18.26 ns	1.17**	-1.00**	-1.00**	-3.67**
nap179xnap2012	20.15**	11.52**	-1.50**	-3.00**	-4.17 ns	-5.00 ns
nap179xnap2001	46.02**	37.63**	-1.17**	-3.00**	-2.00**	-3.00**
nap179xnap94006	30.25**	25.55**	3.67**	3.33**	-1.00**	-3.33**
nap2012xnap2001	28.56 ns	18.21 ns	1.67**	1.33**	0.83 ns	0.67**
nap2012xnap94006	3.25**	-2.18**	-2.17**	-3.33**	-1.50	-3.00**
nap2001xnap94006	3.08 ns	-2.11 ns	-0.50**	-2.00**	-0.67	-2.00 ns
Maximum	46.02	37.63	5.00	5.00	2.00	0.67
Minimum	-22.2	-24.54	-3.00	-4.23	-6.00	-6.33

***p<0.001, **p<0.01,*p<0.0

Table 3. Continued

Cross combination	No. of primary branch/ plant		No. of secondary branch/plant		No of siliquae/plant	
	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)
nap2022xnap2013	0.18^{ns}	0.07^{ns}	0.27**	-0.10**	-15.36^{ns}	-29.46**
nap2022xnap248	0.06**	-0.09^{ns}	0.63^{ns}	-0.02^{ns}	-11.24^{ns}	-19.99**
nap2022xnap179	-0.22^{ns}	-0.40^{ns}	2.01^{ns}	1.66^{ns}	-1.76^{ns}	-4.49**
nap2022xnap2012	-0.77^{ns}	-0.90^{ns}	-1.50**	-2.87**	-44.42^{ns}	-61.93^{ns}
nap2022xnap2001	-0.72**	-1.10**	-1.37**	-1.40**	-59.98**	-60.85**
nap2022xnap94006	1.06**	0.76**	3.98**	3.64**	74.67**	72.57**
nap2013xnap248	1.77**	0.99**	-0.19**	-0.48**	16.20**	10.85**
nap2013xnap179	0.27^{ns}	0.24^{ns}	0.55^{ns}	0.53**	15.24^{ns}	3.87^{ns}
nap2013xnap2012	-0.30^{ns}	-0.37^{ns}	-2.00^{ns}	-3.00^{ns}	-29.04^{ns}	-32.46^{ns}
nap2013xnap2001	-0.78**	-1.03**	-0.33^{ns}	-0.73**	28.87^{ns}	13.90^{ns}
nap2013xnap94006	-0.07**	-0.33**	1.35**	1.32**	77.90**	61.70**
nap248xnap179	1.38**	1.20**	-1.03**	-1.33**	-33.66**	-39.68^{ns}
nap248xnap2012	1.18**	1.05**	-3.01**	-3.72**	-68.14**	-76.90**
nap248xnap2001	-0.42^{ns}	-0.46^{ns}	-0.18^{ns}	-0.87**	53.22^{ns}	43.60^{ns}
nap248xnap94006	-1.40**	-1.68**	0.69**	0.37**	69.65**	58.80**
nap179xnap2012	0.14**	-0.09**	0.38**	-0.63**	42.05**	27.27**
nap179xnap2001	0.39^{ns}	0.24^{ns}	1.08^{ns}	0.70**	32.88**	29.28**
nap179xnap94006	0.25^{ns}	0.05^{ns}	3.44^{ns}	3.42**	77.50**	72.67**
nap2012xnap2001	0.82^{ns}	0.50^{ns}	0.48^{ns}	-0.92**	17.30^{ns}	-1.08**
nap2012xnap94006	0.53**	0.33**	-1.00^{ns}	-2.03^{ns}	-12.39**	-32.01^{ns}
nap2001xnap94006	1.87^{ns}	1.76**	1.74^{ns}	1.38**	84.16^{ns}	82.92**
Maximum	1.38	1.76	3.98	3.64	77.90	82.92
Minimum	-1.40	-1.68	-3.01	-3.72	-68.14	-76.90

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

Table 3. Continued

Cross Combination	Siliqua length		Seeds/ Siliqua	
	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)
nap2022xnap2013	-0.69 ns	-0.79 ns	0.65**	-0.95**
nap2022xnap248	-0.69 ns	-1.01**	-2.26 ns	-4.15 ns
nap2022xnap179	-0.57**	-0.86**	-1.07**	-3.16**
nap2022xnap2012	-0.19 ns	-0.26 ns	-0.31 ns	-0.97**
nap2022xnap2001	-0.55 ns	-0.60 ns	2.05**	1.04**
nap2022xnap94006	-0.26**	-0.36**	1.72**	0.82 ns
nap2013xnap248	-0.77 ns	-0.99 ns	-3.53**	-3.82**
nap2013xnap179	0.31**	0.12**	-0.14**	-0.64 ns
nap2013xnap2012	-0.80 ns	-0.84 ns	-2.78**	-3.72**
nap2013xnap2001	-0.65**	-0.79**	-2.12**	-2.71 ns
nap2013xnap94006	-0.19**	-0.40**	1.60**	0.91**
nap248xnap179	-0.75**	-0.78**	-0.82**	-1.02**
nap248xnap2012	-0.98 ns	-1.24 ns	-0.49**	-1.72**
nap248xnap2001	0.18**	-0.19**	-0.63**	-1.51 ns
nap248xnap94006	0.31**	-0.12**	0.08 ns	-0.91 ns
nap179xnap2012	-0.68**	-0.92**	0.55 ns	-0.89**
nap179xnap2001	-0.23 ns	-0.57 ns	-0.50**	-1.59**
nap179xnap94006	6.24 ns	5.84**	0.14 ns	-1.05 ns
nap2012xnap2001	0.32**	0.21**	1.81**	1.46**
nap2012xnap94006	0.75**	0.59**	1.82**	1.57**
Nap2001xnap94006	1.16**	1.10**	3.11	3.00**
Maximum	6.24	5.84	3.11	3.00
Minimum	-0.75	-0.92	-3.53	-3.82

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

Table 3. Continued

Cross Combination	Seed yield/plant		1000 seed weight	
	Heterosis over mid-parent (%)	Heterosis over better parent (%)	Heterosis over mid-parent (%)	Heterosis over better parent (%)
nap2022xnap2013	0.98 ^{ns}	0.53 ^{ns}	-0.22**	-1.13**
nap2022xnap248	-1.43**	-2.90**	-0.93**	-0.93 ^{ns}
nap2022xnap179	1.96**	1.56**	0.48**	0.10**
nap2022xnap2012	-3.08**	-3.50**	-0.55 ^{ns}	-0.57 ^{ns}
nap2022xnap2001	0.22**	0.13**	0.17**	0.13**
nap2022xnap94006	1.85 ^{ns}	-0.40 ^{ns}	-0.57**	-0.93**
nap2013xnap248	-1.52 ^{ns}	-3.43 ^{ns}	0.95**	0.03**
nap2013xnap179	-0.62 ^{ns}	-0.67**	0.27**	-0.27**
nap2013xnap2012	-6.53**	-6.57 ^{ns}	0.90**	0.00 ^{ns}
nap2013xnap2001	4.47 ^{ns}	4.11**	0.28 ^{ns}	-0.67 ^{ns}
nap2013xnap94006	2.13**	-0.57 ^{ns}	1.52**	0.97**
nap248xnap179	0.87**	-1.00**	-1.28**	-1.67**
nap248xnap2012	2.05 ^{ns}	0.17**	0.08**	0.07**
nap248xnap2001	2.15**	0.60 ^{ns}	0.07**	0.03**
nap248xnap94006	4.32 ^{ns}	3.53**	-1.43**	-1.80**
nap179xnap2012	0.96 ^{ns}	0.95 ^{ns}	-0.80**	-1.17**
nap179xnap2001	-2.35 ^{ns}	-2.67 ^{ns}	-1.48**	-1.90**
nap179xnap94006	2.52 ^{ns}	-0.14 ^{ns}	-0.45**	-0.47**
nap2012xnap2001	-1.60**	-1.93 ^{ns}	-0.82**	-0.87 ^{ns}
nap2012xnap94006	3.74**	1.07**	0.55**	0.20**
nap2001xnap94006	-2.43**	-4.77**	0.3**	-0.1 ^{ns}
Maximum	4.47	4.11	1.52	0.97
Minimum	-6.53	-6.57	-1.48	-1.90

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

4.2.2Days to 50% flowering

Significant and negative heterosis over parent is desirable for selection of hybrid with short duration. Here a total of sixteen combinations showed significant heterotic values of which thirteen were negative. The combination Nap248 x Nap2012 (-3%) produced the highest negative heterosis followed by Nap2022 x Nap2001 (-2.17%), Nap2012 x Nap94006 (-2.17%) and Nap108 x Nap0130 (-16.02%) over mid parent. Conversely, in case of better parent heterosis, there were nineteen combinations provided significant heterosis in which thirteen showed negative heterosis over better parent ranged from -0.33 to -4.33%. Regarding better parent heterosis, the combination Nap2013 x Nap248 (-4.33%) represented the highest negative values followed by Nap2022 x Nap248 (-3.33%), Nap2012 x Nap94006 (-3.33%) and Nap248 x Nap179 (-3.33%). However, the combinations presented significant and negative heterosis over both mid parent and better parent, might be useful for development of early *Brassica* variety. Kumar *et al.* (2002) and Mahak *et al.* (2003b) found significant heterotic values for days to first flowering over mid-parent and better parent. For example, the hybrid Nap108 x Nap9901 is showing early flowering than its parent (Plate-3).

4.2.3 Days to 80% maturity

Seventeen out of 21 cross combinations were found significant heterosis over mid parent including both positive and negative values. For the character negative heterosis is usually useful to obtain early hybrid. In this regard, there were ten combinations observed with negative heterosis ranged from -1.00% to -6.00%. The hybrid Nap2022 x Nap179 (-6.00) represented the highest negative heterosis followed by Nap2022 x Nap2012 (-4.17%), Nap179 x Nap2012 (-4.17%) and Nap2022 x Nap2013 (-3.33%), Nap 248 x Nap 2001 (-3.33%) over mid parent. In addition, for better parent heterosis, sixteen hybrids showed significant heterosis. Among the significant heterosis fifteen of them found with negative values. The combination Nap2022 x Nap179 (-6.33%) possessed the highest negative heterosis followed by the hybrid Nap2022 x Nap2012 (-4.67%) and Nap248 x Nap2001(-4.67%). However, the combinations presented significant and negative heterosis over both mid parent and better parent, might be useful for development of early *Brassica* variety. 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.

Nap94006 x Nap179

Plate 3: Field view of Nap94006 x Nap179 and its parents height after 30 days.

4.2.4 Number of primary branches per plant.

Only seven hybrids showed significant and positive mid-parent heterosis which ranged from 0.14% to 1.38% for number of primary branches per plant. The hybrid Nap248 x Nap179 showed the highest (1.38%) significant positive heterosis where as the lowest (0.14%) value was found from Nap179 x Nap2012. In case of better parent heterosis the significant values ranged from -1.68 to 1.76%. The combination Nap2001 x Nap94006 showed the highest positive value followed by Nap248 x Nap179 (1.20%). For example the hybrid Nap248 x nap179 is showing higher branches than its parent **(Plate-4).** The other combinations Nap2022 x Nap94006, and Nap2012 x Nap94006 were also found under significant positive values. However, the hybrids could be considered as the best performer for number of primary branches per plant. The three (Nap2022 x Nap94006 ,Nap248 x Nap 179 , and Nap2012 x Nap94006) hybrids were observed with significant heterosis for both mid parent and better parent heterosis. Thakur and Segwall (1997) found a heterosis value ranging from -26.0 to 193.6% over better parent for the character primary branches in rapeseed (*Brassica napus* L.). Yadav *et al.* (2004) observed the number of primary branches per plant, Trachystome × PR 905 showed 106.5% and 100.0% heterisis over BP and SV, respectively.

4.2.5 Number of secondary branches plant

There were ten hybrids showed significant mid parent heterosis, in which five of them with positive values ranged from 0.27% to 3.98%. The highest significant and positive mid-parent heterosis was produced by the combination Nap2022 x Nap94006 (3.98%) . For example the hybrid Nap248 x Nap179 is showing higher branches than its parent (Plate-4). These hybrids could be considered for further evaluation to development of heterotic *Brassica* hybrid. On the other hand, there six hybrid combinations were found with significant and positive better parent heterosis which ranged from 0.37% to 3.64%. Among the positive heterosis, the combination Nap2022 x Nap94006 (3.64%) exhibited the highest value followed by Nap179 x Nap94006 (3.42%) might be selected for number of secondary branches per plant. 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.

Nap 248 **Nap248 x Nap179 (F_1)** **Nap179**

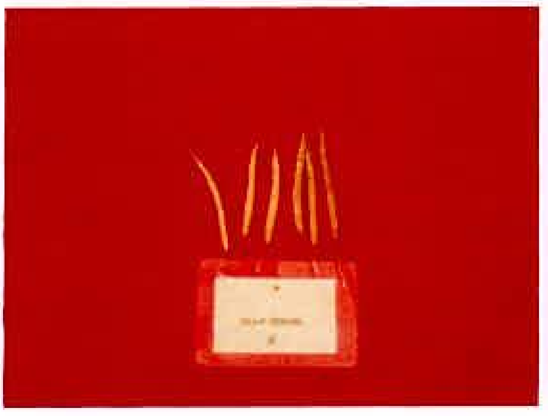
Plate 4: Hybrid Nap248 x Nap179 and its parent showing different branching status

4.2.6 Number of siliquae per plant

The highly significant and positive mid-parent heterosis for siliquae per plant was found in seven hybrids ranged from 16.20% to 77.90%. The hybrid combination Nap2013 x Nap94006 represented the highest heterosis over mid-parent (77.90%), where as the lowest was in Nap2013 x Nap248 (16.20%). On the other hand, for better parent heterosis there was a total of eight combinations showed significant and positive heterosis which ranged from 10.85% to 82.92%. In this case, the hybrid Nap2001 x Nap94006 produced the highest heterotic value (82.92%) followed by Nap179 x 94006 (72.67%)and Nap2022 X Nap 94006 (72.57%). There was very much interesting facts that at least seven combinations were found heterotic over both mid and better parent. However, all the hybrids having significant and positive heterosis produced more siliquae per plant than any parent and could be selected for further evaluation. 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

There were twelve combinations were found to significant heterosis over mid parent but only of them positive significant heterosis were Nap2013 x Nap179 (0.31%), Nap248 x Nap2001 (0.18%), Nap248 x Nap94006 (0.31), Nap2012 x Nap2001(0.32%), Nap2012 x Nap94006(0.75%),and Nap2001 x Nap94006(1.16%) . In case of better parent heterosis the significant and positive heterosis were Nap2013 x Nap179 (0.12%), Nap2012 x Nap2001 (0.21%), Nap2012 x Nap94006(0.59%),and Nap2001 x Nap94006(1.10%) . Others nine hybrids produced significant but negative heterotic value. For example, hybrid Nap248 x Nap2022 is showing higher siliqua length than its parent in Plate-5. Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea*.



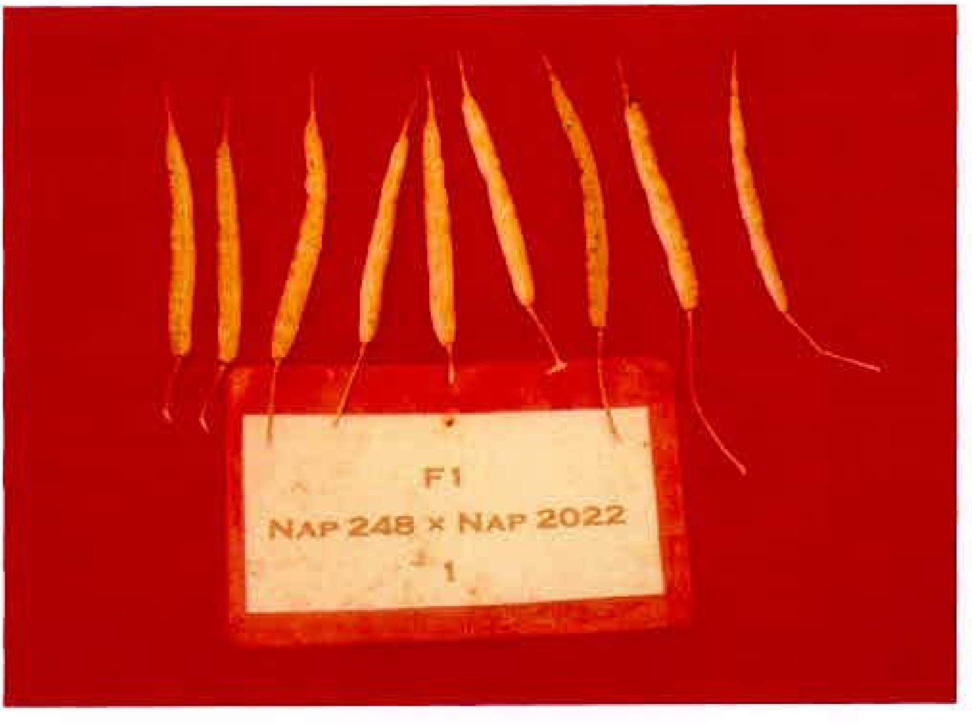


Plate 5: Hybrid Nap248 x Nap2022 and its parent showing different siliqua length

4.2.8 Number of seeds per siliqua

Most of the hybrids showed significant negatively heterosis over mid parent except Nap2022 x Nap2013 (0.65%), Nap2022 x Nap2001 (2.05%) , Nap2022 x Nap94006 (1.72%) Nap2013 x Nap 94006 (1.60%) ,Nap2012 x Nap 2001 (1.81%) Nap2001 x Nap 94006 (1.82%) and Nap 2001 x Nap 94006 (3.11%) . On the other hand, for better parent heterosis none of the combinations were positive heterosis except Nap2022 x Nap2001 (1.04%) and Nap2013 x Nap94006 (0.91%) Nap2012 x Nap2001 (1.46%), Nap2012 x Nap 94006 (1.57%) and Nap2001 x Nap94006 (3.00%) . However, both the mentioned two combinations (Nap2001 x Nap94006 and Nap2012 x Nap94006) having significant and positive heterosis over mid parent as well as better parent could be considered for further evaluation due to its higher heterosis. 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 Seed yield per plant

In case of yield per plant, there were six combinations, represented positive heterosis which was ranged from 0.22% to 3.74%. The combination Nap2012 x Nap94006 (3.74%) produced the highest heterosis, while Nap2022 x Nap2001 (0.22%) exhibited the lowest significant positive mid parent heterosis. On the other hand, for better parent heterosis, the six combination had significant positive heterosis. The hybrid Nap2013 x Nap2001 (4.11%) showed the highest significant and positive heterosis. The combinations like Nap248 x Nap94006 (3.53%), also demonstrated higher value of heterosis. 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 .

4.2.10 Thousand seed Weight

Out of 21 hybrid combinations nine were showed significant positive heterosis values. There were Nap2022 x Nap179 (0.48%), Nap2022 x Nap2001 (0.17%), Nap2013 x Nap248 (0.95%), Nap2013 x Nap179 (0.27) Nap2013 x Nap2012 (0,90), Nap 248 x 2012 (0.08%), Nap 248 x Nap 2001 (0.07%), Nap2012 x Nap 94006 (0.55%) and Nap2001 x Nap 94006 (0.3%) possessed significant and positive heterosis over mid parent. Similarly, for better parent heterosis, the combination Nap2012 x Nap94006 (0.20%) produced the highest significant and positive heterosis. The hybrids of Nap2022 x Nap179, Nap2022 x Nap2001, Nap2013 x Nap248 and Nap2013 x Nap94006, Nap248 x Nap 2012, Nap 248 x Nap x 2001 and Nap 2012 x Nap 94006 were positively significant over both of mid and better parent. 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.

4.3 COMBINING ABILITY

The analysis of variance for the genotypes, combining ability variances, ratio of GCA and SCA variances, sum of square, estimates of general and specific combining ability effects are presented in Tables 4 to Table 7. 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. Treatment mean sum of squares (mean of genotypes) were further partitioned into parents, crosses (hybrids) and parent vs crosses. Parents and crosses showed highly significant variances for all the characters analyzed (Table 4). Variances due to parent vs cross interaction was also observed significant for most of the traits except in days to 50% flowering.

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 4) revealed highly significant variation among the parents and hybrids indicating the presence of variability in the material. Variance due to genotypes were significant for all the traits. Combining ability analysis of eight parents and twenty eight F_1's in half diallel cross were of ten quantitative traits. The variances due to general and specific combining ability were estimated for assessing the contribution of the additive and non-additive type of gene action involved in the inheritance of different characters. The mean sum of square due to general combining ability (GCA) was significant for all the traits indicating that the additive gene action was predominant for the expression of these characters (Table 5). 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 (Table 5). 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.

The higher magnitude of SCA variance was observed than that of GCA variance for plant height, days to maturity, no. of primary branches, no. of secondary branches, no. of seeds/siliqua, seed yield/plant and 1000 seed weight. In an earlier study of Verma (2000), reported that SCA variance was higher than GCA variance (non-additive type) for seed yield per plant. Verma *et al.* (1980) reported non-additive type of gene action for siliquae per plant, seed yield per plant in yellow sarson.

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

Source of Variation	df	Plant height	Days to 50% flowering	Days to 80% maturity	No. of Primary branch/ plant	No. of secondary branch/ plant	No. of siliquae/ plant	Siliqua length	Seed/ siliqua	Seed yield/ plant	1000 seed weight
Replication	2	419.15	1.58	0.05	0.22	1.43	84.75	4.85	3.60	20.92	0.31
Cross	27	634.91**	10.13**	11.61**	1.39**	5.33**	4539.45**	5.11 ^{ns}	6.76*	16.62*	1.44**
Gca	6	638.52**	29.25*	88.18**	1.383**	37.13**	32819.37**	34.28 ^{ns}	67.24*	56.48*	1.48**
Sca	21	633.88**	244.37**	225.38**	1.39**	106.71**	89745.83**	103.56 ^{ns}	115.28 ^{ns}	392.19**	1.43**
Error	54	86.99	1.74	0.85	0.38	1.22	699.21	3.67	4.30	4.18	0.11
Total	110	2413.45	287.07	326.07	4.763	151.82	127888.61	151.47	197.18	490.39	4.77

Table 5. Analysis of variances (MS values) for GCA and SCA for seed yield and yield contributing components in *Brassica napus* L.

Source of Variation	df	Plant height	Days to 50% flowering	Days to 80% maturity	No of primary branch/ plant	No. of secondary branch/ plant	No. of siliquae/ plant	Siliqua length	Seed/ siliqua	Seed yield/ plant	1000 seed weight
GCA	6	0.17 ns	-0.25 ns	0.15 ns	0.00 ns	0.04 ns	44.31 ns	0.03 ns	0.21 ns	-0.34 ns	0 ns
SCA	21	182.3*	3.30*	3.29*	0.34 ns	1.29 ns	1191.47*	0.42 ns	0.40 ns	4.83 ns	0.44*
Error	54	86.99*	1.74	0.85	0.38	1.22	699.21	3.67	4.30	4.17	0.11
GCA:SCA	0.285	0.0009	0.075	0.045	0	0.031	0.037	0.071	0.525	0.070	0

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. Similarly, the magnitude and nature of non-additive ie. dominance and epistasis nature of gene actions could be measured by estimation of SCA 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 programme and crosses with significant high SCA effect could be used in hybrid development. The estimates of GCA effects are presented in Table 6. The magnitude and direction of the significant GCA effects for eight parents provide meaningful comparisons and would given a clue to design the future breeding programme. The results of GCA effects of different characters are presented as follows:

4.3.1.1 Plant height

Out of eight parental GCA there were three parents showed significant and negative GCA effect. The highest negative significant GCA effects (-6.6) was provided by Nap-2012. The other parents which represented negative and significant GCA were Nap-2022(-5.31), Nap-2001 (-2.42) . Those parents with positive and significant GCA effects were considered as good general combiner for the trait aimed to promot desirable plant height in their crosses (Table 6). The parent Nap-248(6.33) showed positive and significant GCA effects followed by Nap-2013 (3.9) and Nap-179(2.58) and Nap-94006(1.53). that were desirable general combiners to promote the plant height in *Brassica napus*. 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.

Table 6: General combining ability (GCA) effects for 7 parents in 7x7 Half diallel crosses of *Brassica napus* L.

Parents	Plant height	Days to 50% flowering	Days to 80% maturity	No of primary branch/ plant	No. of secondary branch/ plant	No. of siliquae/ plant	Siliqua length	Seeds/ siliqua	Seed yield/ plant	1000 seed weight
nap2022	-5.31**	-0.42 ns	-0.33*	-0.03 ns	-0.18 ns	-22.14***	-0.46 ns	-1.04**	0.12 ns	0.15*
nap2013	3.9*	-0.13 ns	0.26 ns	-0.02 ns	-0.30 ns	8.83 ns	-0.34 ns	-0.24 ns	0.39 ns	-0.18**
nap248	6.33***	0.72**	1.38***	-0.24*	-0.32 ns	-4.05 ns	-0.10 ns	-0.09 ns	-0.69 ns	0.05 ns
nap179	2.58 ns	-0.31 ns	0.26 ns	0.09 ns	0.44*	1.74 ns	0.65 ns	0.76*	0.84*	-0.42***
nap2012	-6.6***	0.13 ns	-0.40*	-0.10 ns	0.01 ns	-8.69 ns	-0.25 ns	-0.40 ns	-0.02 ns	0.24***
nap2001	-2.42 ns	0.35 ns	-0.22 ns	-0.15 ns	-0.50*	0.83 ns	-0.15 ns	0.29 ns	0.20 ns	0.2**
nap94006	1.53 ns	-0.35 ns	-0.96***	0.46***	0.84***	23.49**	0.66 ns	0.72 ns	-0.84*	-0.05 ns
SEgij	1.66	0.24	0.16	0.11	0.20	4.71	0.34	0.37	0.36	0.06
SE(gi-gj)	2.54	0.36	0.25	0.17	0.30	7.20	0.52	0.56	0.56	0.09

4.3.1.2 Days to fifty percent 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 parent Nap-248 (0.72) was the best general combiner followed by Nap-2001 (0.35) and Nap-2012 (0.13) showed positive and significant GCA effects that were desirable general combiners to promote the earliness in *Brassica napus* (Table 6). The highest negative significant GCA effects (-0.42) were provided by Nap-2022. The other parents which represented negative and significant GCA were Nap-2022(-0.42) and Nap-2013 (-0.13). On the other hand, the parents Nap-248(0.72) 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.

4.3.1.3 Days to 80% maturity:

The parent Nap-248 provided the highest (1.38) significant positive GCA effects for days to maturity followed by Nap-179 (0.26) and Nap-2013(0.26) and hence the parents were desirable general combiners to promote the earliness in *Brassica napus* L. **(Table 6).** Parent Nap-94006 showed the highest (-0.96) significant and negative gca effects followed by Nap-2022 (-0.33) and Nap-2012 (-0.40). 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.

4.3.1.4 Number of primary branches per plant:

There were only two parent out of seven viz. Nap-179 (0.09), Nap-94006 (0.46) and provided significant and positive GCA effects which indicated that the parents were good general combiners for promising primary branches. So these parents were considered as good for using in the breeding programme for more primary branches (Table 6). Other parents showed significant negative and insignificant positive and negative effects. Chowdhury *et al.* (2004) obtained more primary branches on sampan in *Brassica rapa* L. Singh *et al.* (2000) observed 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 the highly significant and positive GCA effects were observed in a number of parents such as Nap-94006 (0.84) provided the highest followed by Nap-179 (0.44) and Nap-2012(0.01) considered as the best general combiner for the trait. There were also fifty percent parents showed significant but negative GCA effects and other one demonstrated insignificant GCA effects. 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:

Only the two parents were found with significant GCA effects of which one is negative and the other is positive values. The parents Nap-94006 exhibited the highest (23.49) significant GCA effects and the next one was Nap-2013 (8.83) for the character. The two parents with higher positive and significant GCA were selected as the best general combiner and desirable to use in hybridization programme to improve the number of siliquae per plant in *Brassica napus* L. (**Table 6**). On the other hand the highest negative and significant GCA value provided by Nap-2022 (-22.14) . 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.

4.3.1.7 Siliqua length :

Out of all the seven parents only Nap-179(0.65) and Nap-94006(0.66) was exhibited significant and positive GCA effect . So the parent would be considered as a general combiner for the character and could be used for hybrid production with long siliqua development in breeding programme. Other two parents showed significant but negative GCA values. Rests of the parents were found to have under insignificant GCA effects. 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 there are similar trend of siliqua length was observed where the parent Nap-179 produced the highest significant and positive GCA effect (0.76). Thus this parent was found as the best general combiners to increase the number of seeds per siliqua. The four parents provided the significant and negative GCA for the trait were Nap-2022 (-1.04), Nap-2013(-0.24) Nap-248 (-0.09). 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.

4.3.1.9 Seed yield per plant:

The highest significant and positive GCA effects was observed in Nap-94006 (0.84) followed by Nap-2013 (0.39) and Nap-2001 (0.20) and Nap-20229(0.12). These parents having significant and positive GCA effects might be selected as promising general combiner for high yield potential in this regard. On the other side, Nap-179 (-0.84) and Nap-94006(-0.84) produced highly significant and negative GCA effects indicated parents were not fit for increase seed yield. Other two parents showed insignificant GCA effect for the character (Table 6) indicating the parents used in this experiment were not good general combiner for improving seed yield per plant. Chowdhury *et al.* (2004a) found the highest seed yield per plant in Pt-303 in *Brassica rapa* L.

4.3.1.10 Thousand seed weight

Most of the parents should significant GCA effects except Nap-248 and Nap-94006. Out of four significant positive parents three of them are viz. Nap-2022, Nap-248 and Nap-2012 Nap-2001. Here, Nap-2012 produced the highest GCA effect (0.24) and could be considered as the best general combiner for this trait. The parents Nap-2013 (-0.18), Nap-179 (-0.42) and Nap-94006(-0.05) produced significant but negative GCA effects. Chowdhury *et al.* (2004a) found the highest seed weight in Dhali in *Braasiea rapa* L.

4.3.2 Specific combining ability (SCA) effects

The specific combining ability effects signify the role of non-additive ie. 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 programme. The specific combining ability effects of twenty eight crosses for the different characters studied are presented in Table 7. The magnitude and direction of the significant effects for the eight parents provide meaningful comparisons and would give a clue to the future breeding programme. The results of SCA effects for different characters are given below:

Table 7. Specific combining ability (SCA) effects for 7 parents in 7x7 half diallel crosses of *Brassica napus* L.

Cross combination	Plant height	Days to 50% flowering	Days to 80% maturity	No. of primary branch/plant	No. of secondary branch/plant
nap2022xnap2013	8.71***	0.41^{ns}	-2.47***	0.26*	0.03^{ns}
nap2022xnap248	-8.85***	-0.78**	0.42**	0.32**	0.69**
nap2022xnap179	15.16***	3.59***	-3.81***	-0.32**	1.01***
nap2022xnap2012	-6.1***	-0.19^{ns}	-2.14***	-0.37**	-1.04***
nap2022xnap2001	-23.57***	-2.41***	0.68***	-0.78***	-1.80***
nap2022xnap94006	6.92***	1.96***	2.42***	0.48***	2.56***
nap2013xnap248	-3.85*	-2.07***	1.82***	0.41***	0.36^{ns}
nap2013xnap179	-5.16**	1.30***	1.94***	-0.52***	0.04^{ns}
nap2013xnap2012	2.65^{ns}	2.85***	0.60***	-0.50***	-1.06***
nap2013xnap2001	22.98***	-1.04***	-0.92***	-0.25*	-0.29^{ns}
nap2013xnap94006	-6.66***	-1.67***	0.49*	0.68***	0.42^{ns}
nap248xnap179	-10.46***	-0.89***	1.16***	-0.46***	-1.24***
nap248xnap2012	-12.18***	-2.00***	-0.51**	-0.93***	-1.76***
nap248xnap2001	13.43***	1.44***	-2.69***	0.15^{ns}	0.17^{ns}
nap248xnap94006	35.59***	1.48***	-0.95***	-0.13^{ns}	0.07^{ns}
nap179xnap2012	21.65***	-1.96***	-2.40***	0.92***	0.57**
nap179xnap2001	-2.92^{ns}	-1.52***	-0.58**	0.18^{ns}	0.38^{ns}
nap179xnap94006	-6.79***	2.52***	-0.18^{ns}	0.99***	1.76***
nap2012xnap2001	7.24***	2.37***	2.08***	0.15^{ns}	1.22***
nap2012xnap94006	2.91^{ns}	-2.26***	-0.84***	-0.47***	-1.23***
nap2001xnap94006	-3.97*	-0.48*	-0.36*	1.19***	0.03^{ns}
Max	35.59	3.59	2.42	1.19	2.56
Min	-23.57	0.36	0.25	0.17	0.3
SEgij	1.66	0.24	0.16	0.11	0.2
SE(gi-gj)	2.54	0.36	0.25	0.17	0.3

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

Table7. Continued

Cross combination	No. of siliquae/ plant	Siliqua length	Seeds/ siliqua	Seed yield/ plant	1000 seed weight
nap2022xnap2013	-10.61*	-0.02 ns	1.23**	1.29***	-0.53***
nap2022xnap248	1.03 ns	-0.02 ns	-1.53***	-1.96***	-0.55***
nap2022xnap179	-1.29 ns	-0.68 ns	-0.98**	1.78***	0.94***
nap2022xnap2012	-18.74***	0.35 ns	-0.49 ns	-2.40***	-0.38***
nap2022xnap2001	-62.20***	-0.21 ns	1.52***	0.35 ns	0.43***
nap2022xnap94006	48.56***	-0.79*	0.66 ns	0.69 ns	-0.46***
nap2013xnap248	11.59*	-0.12 ns	-2.01***	-1.87***	0.74***
nap2013xnap179	-1.17 ns	0.18 ns	0.73 ns	-0.63 ns	0.14*
nap2013xnap2012	-20.24***	-0.28 ns	-2.18***	-5.68***	0.48***
nap2013xnap2001	9.77 ns	-0.33 ns	-1.86***	4.78***	-0.05 ns
nap2013xnap94006	34.91***	-0.74*	1.33***	1.15**	1.03***
nap248xnap179	-42.54***	-0.90**	0.21 ns	0.03 ns	-0.72***
nap248xnap2012	-51.80***	-0.46 ns	0.26 ns	2.07***	0.35***
nap248xnap2001	41.66***	0.49 ns	-0.22 ns	1.62***	0.43***
nap248xnap94006	34.19***	-0.25 ns	-0.04 ns	2.49***	-1.22***
nap179xnap2012	46.58***	-0.95**	0.65 ns	1.33***	-0.45***
nap179xnap2001	9.52 ns	-0.70*	-0.74 ns	-2.53***	-1.04***
nap179xnap94006	30.24***	4.91***	-0.63 ns	1.04**	-0.16**
nap2012xnap2001	19.15***	0.50 ns	1.30***	-0.91 ns	-0.66***
nap2012xnap94006	-34.44***	0.07 ns	0.78*	3.13***	0.55***
nap2001xnap94006	34.21***	0.28 ns	1.72***	-3.59***	0.39***
Max	48.56	4.91	1.72	4.78	1.03
Min	-62.20	-0.95	-2.18	-5.68	-1.22
SEgij	4.71	0.34	0.37	0.36	0.06
SE(gi-gj)	7.2	0.52	0.56	0.56	0.09

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

4.3.2.1 Plant height

All the F_1s showed highly significant SCA effect which ranged from -23.57 to 35.59 for plant height (Table 7). The combination Nap2022 x Nap2001 showed the lowest value (-23.57) Nap248 x Nap94006 showed the highest positive (35.59) SCA effect. Thus the cross Nap248 x Nap94006 was the best specific combiner for plant height. Genotypes vs plant height was graphically represented in Figure 2. 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.

4.3.2.2 Days to 50% flowering

Most of the hybrids were observed with significant SCA values except Nap2022 x Nap2013 and Nap2022xNap2013. Nap2022x Nap2001 produced significant negative (-2.41) value. The highest positive SCA effect for days to 50 % flowering was observed in Nap2022 x Nap179 (3.59) and the lowest in Nap2022 x Nap2001 (-2.41). Thus, this cross combination Nap2022 x Nap179 provide opportunity for earliness in mustard (*Brassica napus* L.). Treatment VS days to 50% flowering was graphically represented in Figure 3. Singh *et al.* (2000) obtained earliness on YSK-S501 × SS-2 in *B. campestris/rapa*. Singh *et al.* (1996) observed earliness in PR-1108 × BJ-1235 in *Brassica juncea* L.

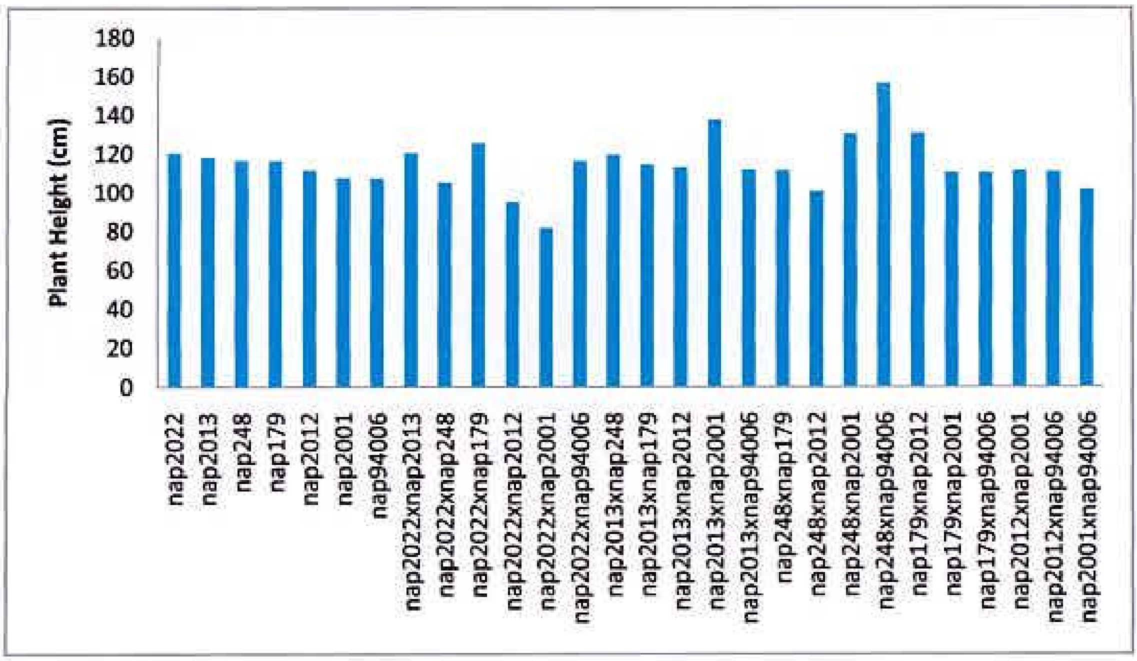


Fig 2: Graphical representation of plant height in 36 *B. napus* genotypes

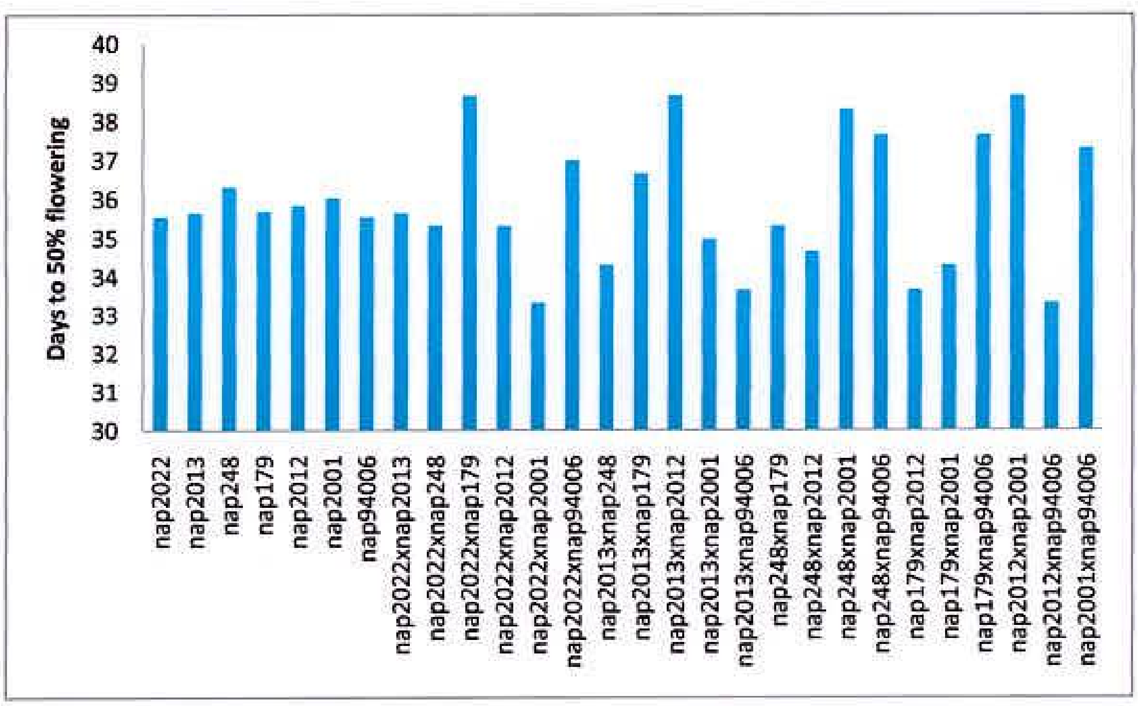


Fig 3: Graphical representation of days to 50% flowering in 36 *B. napus* genotypes

4.3.2.3 Days to maturity

Similar trends 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 Nap2022 x Nap94006 (2.42) and lowest in Nap2022 x Nap179 (-3.81). None of the combination was found under negative direction of SCA effect. So, the cross Nap2022 x Nap94006 was the best specific combiner in the hybrids. 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. Treatment VS days to maturity is graphically represented in Figure 4.

4.3.2.4 Number of primary branches per plants

seventeen out of 21 hybrid combinations were found with significant SCA effect which ranged from -0.93 to 1.19. The highest significant and positive SCA effect was exhibited by the combination Nap2001 x Nap94006 (1.19) 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. On the other hand, the combination Nap248 x Nap2012 showed the lowest and negative SCA effect (-0.93) which denoted as poor specific combiner for the character concerned. 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. Treatment VS number of primary branches per plant is graphically represented in Figure 5.

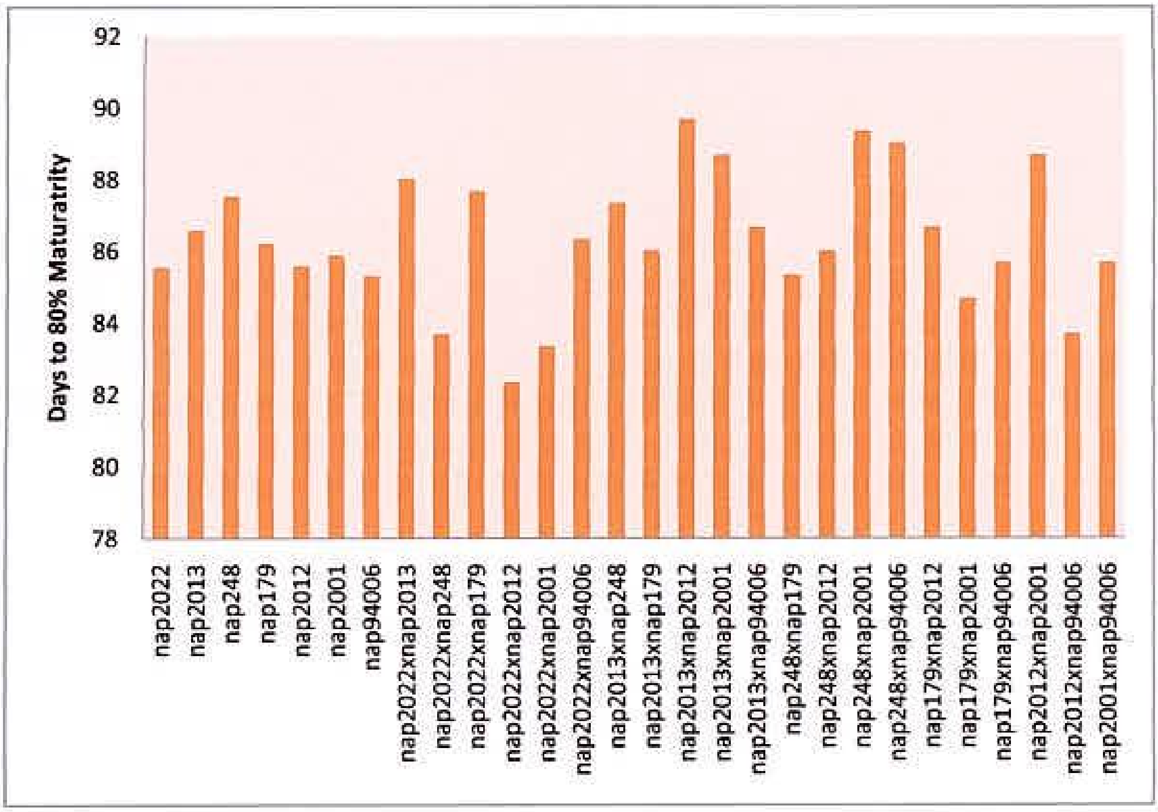


Fig 4: Graphical representation of days to 80% maturity in 36 genotypes of *B. napus* L.

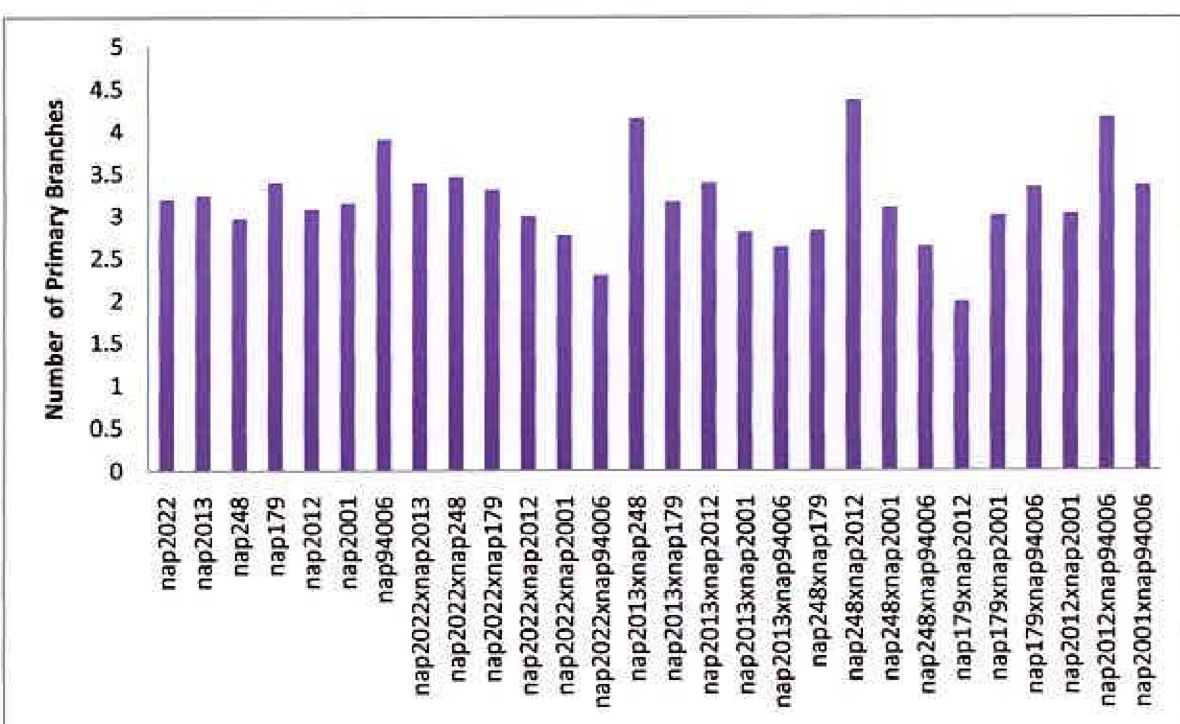


Fig 5: Graphical representation of number of primary branches per plant in 36 genotypes of *B. napus* L

4.3.2.5 Number of secondary branches per plant

Out of 21 combinations twelve of them produced significant SCA effects including six positive and six negative values ranged from -1.80 to 2.56. The combination Nap2022 x Nap94006 possessed the highest positive and significant SCA effect (2.56) followed by Nap179 x Nap94006 (1.76) which could be selected as the best specific combiner for number of secondary branches per plant and might be used in further hybridization programme for good hybrid combination. On the other hand, there were some combinations showed significant but negative SCA effects like Nap2022 x Nap2012 (-1.04), Nap2013 x Nap99052012 (-1.06) and Nap248 x Nap2012 (-1.76) indicated poor specific combiner for this character not suitable for hybrid production. 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. Treatment VS number of secondary branches per plant is graphically represented in Figure 6.

4.3.2.6 Number of Siliquae per plant

Out of 21 cross combinations, there were fifteen crosses found to have under highly significant SCA effects ranged from -62.20 to 48.56 in which nine with positive values. The combination Nap2022 x Nap94006 produced the highest effect (48.56). The other combinations which produced highly significant and positive SCA were Nap2013 x Nap248 (11.59), Nap2013 x Nap94006 (34.91), Nap248 x Nap2001 (41.56), Nap248 x Nap94006 (34.19), Nap179 x Nap2012 (46.58) and so on considered as the best specific combiner for the trait concerned. These combinations could be selected for the future breeding programme to obtain desirable hybrid with higher number of siliquae per plant. 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. Treatment vs siliquae per plant is graphically represented in Figure 7.

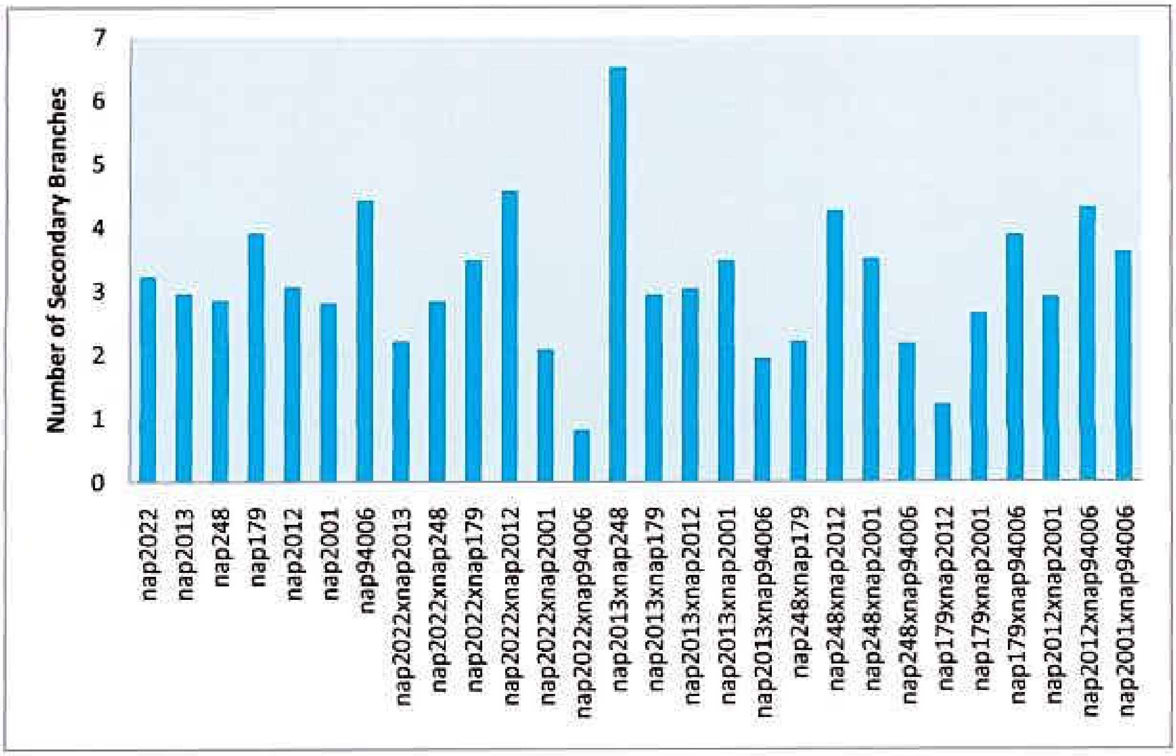


Fig 6: Graphical representation of number of secondary branches per plant in 36 Genotypes of *B. napus* L.

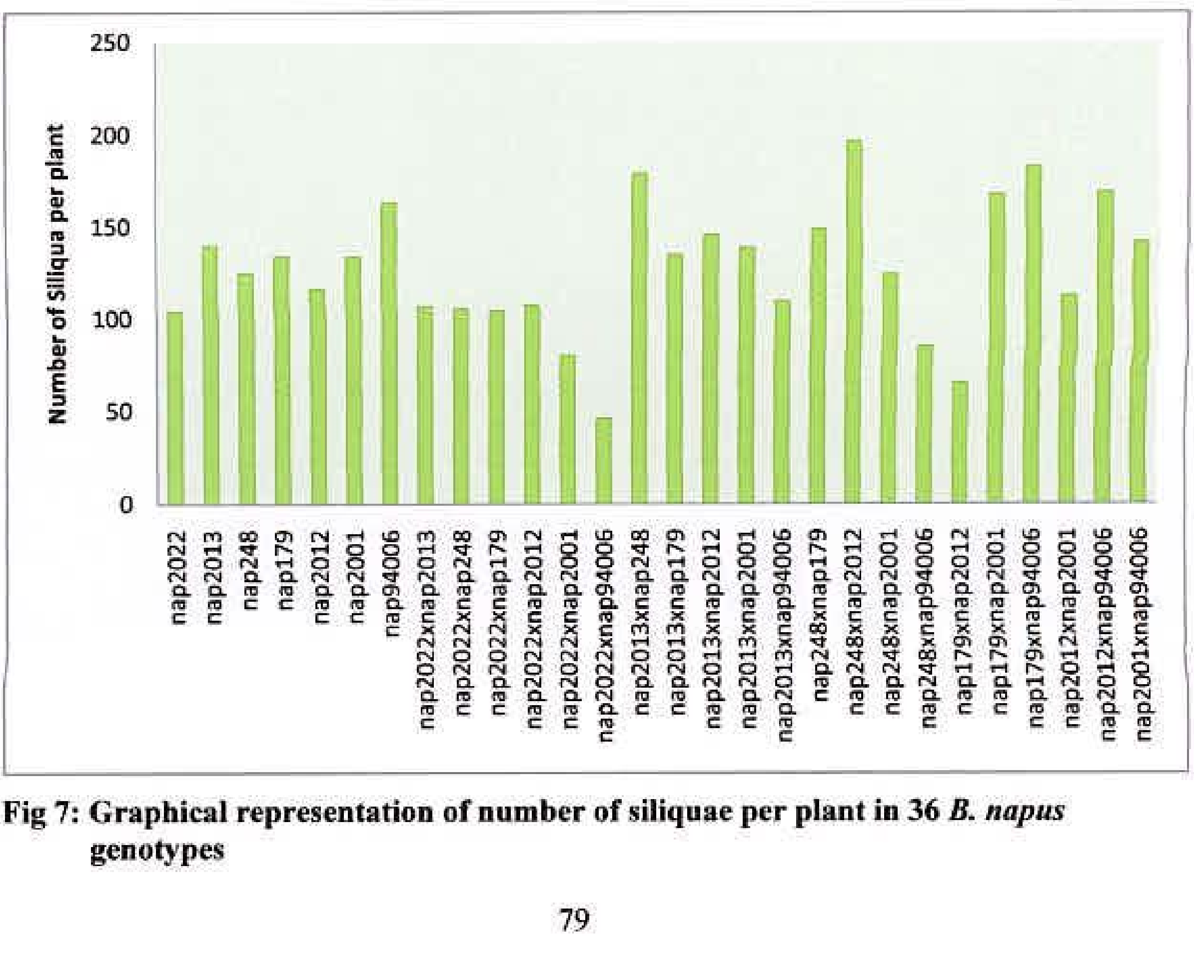


Fig 7: Graphical representation of number of siliquae per plant in 36 *B. napus* genotypes

4.3.2.7 Number of seeds per siliqua:

Only five, out of 21 combinations exhibited significant and positive SCA effects having the range between 1.23 and 1.72. The cross combination Nap2001 x Nap94006 (1.72) produced the highest followed by Nap2012 x Nap2001 (1.30) SCA effects indicated that the two combinations were the best specific combiner for this trait and might be selected for higher seeds per siliqua. 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. Treatment VS number of seeds per siliqua is graphically represented in Figure 8.

4.3.2.8 Siliqua length:

Only six cross combinations out of 21 crosses were found to under highly significant SCA effects ranged from -0.95 to 4.91. The combination Nap179 x Nap94006 produced the highest effect (4.91) which was considered as the best specific combiner for the trait concerned. These combinations could be selected for the future breeding program to obtained desirable hybrid with longer siliqua length (Table 7). 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*. Treatment VS length of siliqua is graphically represented in Figure 9.

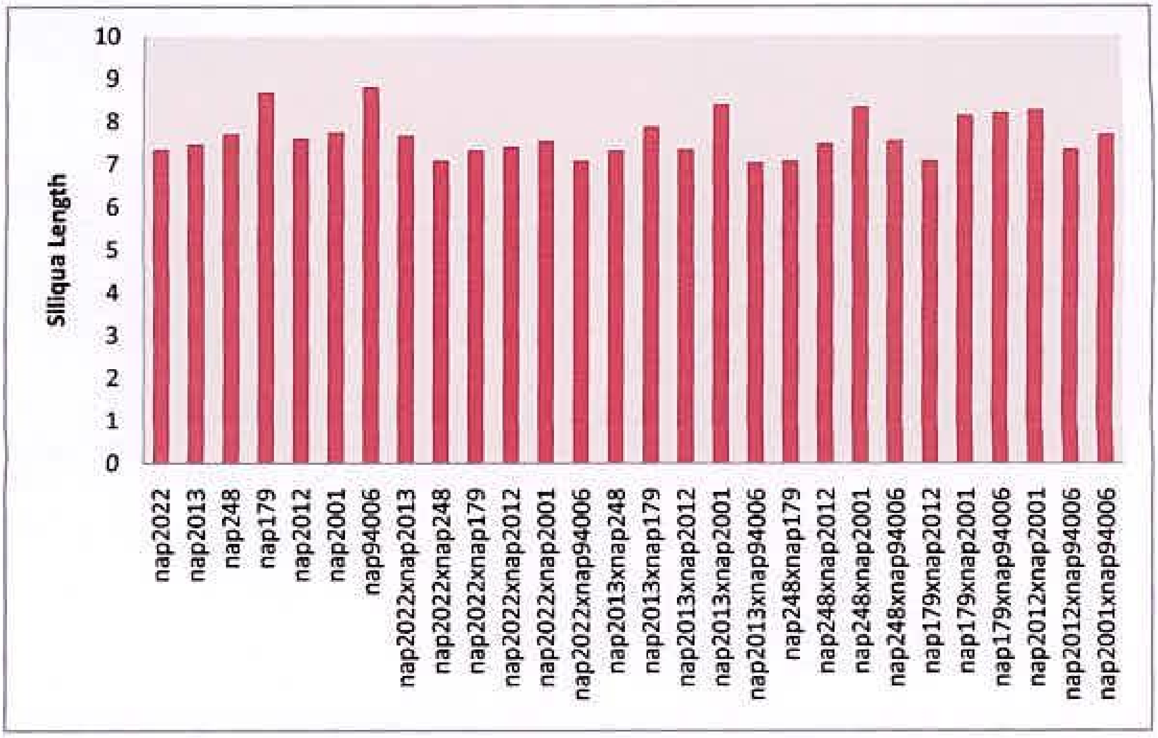


Fig 8: Graphical representation of number of seeds per siliqua in 36 *B. napus* genotypes

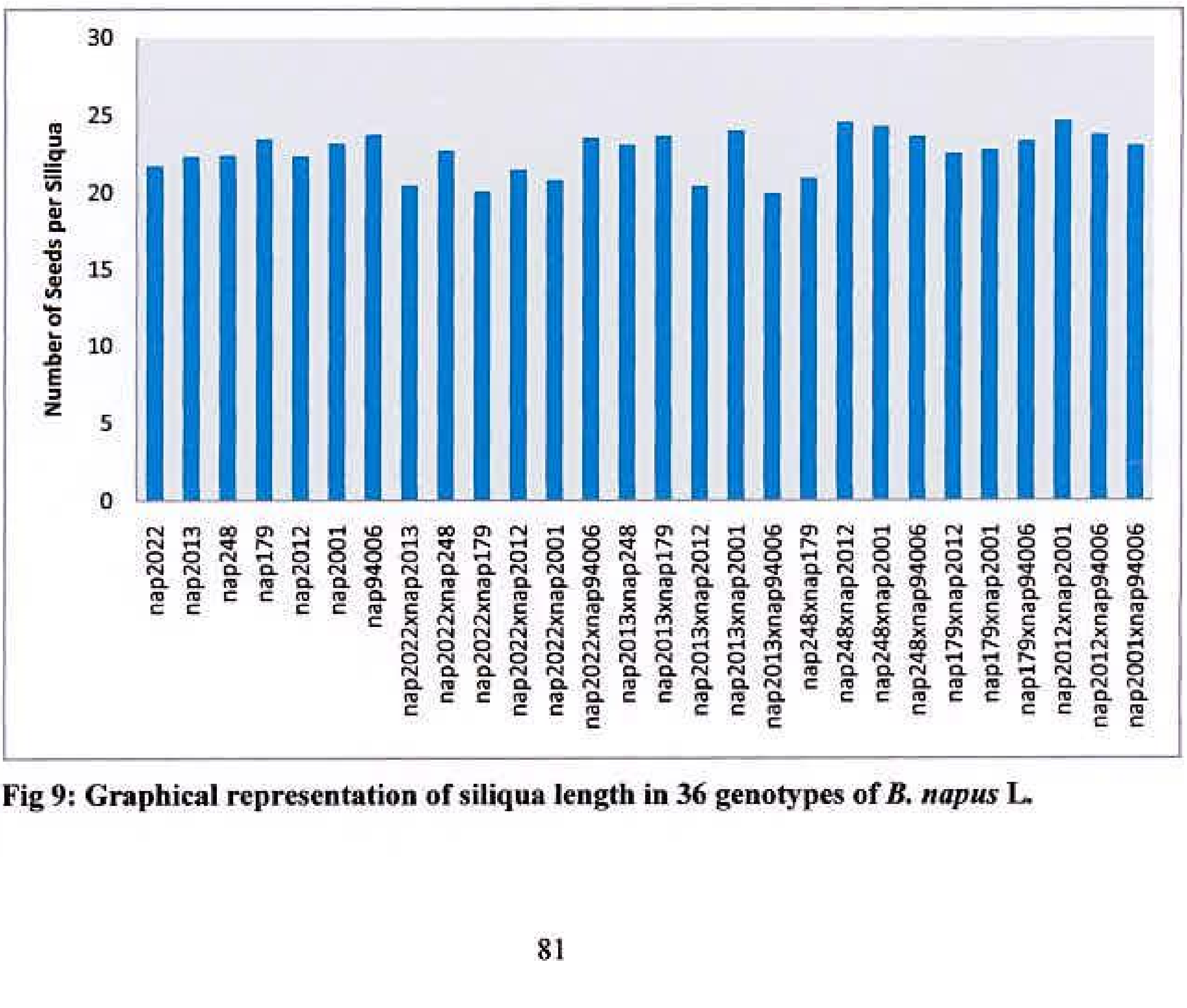


Fig 9: Graphical representation of siliqua length in 36 genotypes of *B. napus* L.

4.3.2.9 Thousands seed weight:

Among the cross combinations twenty of them were observed with significant effects in which ten with positive values. The combination Nap2013 x Nap94006 produced the highest SCA effect (1.03) and considered as the best specific combiner for the trait. The other crosses which were exhibited significant and positive SCA effect ranged from 0.14 to 1.03. However, these combinations could be selected for the development of hybrid with high seed weight. 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. Treatment VS thousand seed weight is graphically represented in Figure 10.

4.3.2.10 Seed yield per plant:

In case of seed yield per plant there were sixteen hybrid combinations showed significant and higher SCA effects which ranged from -5.68 to 4.78 (Table 7). The cross combinations Nap2013 x Nap2001 produced the highest SCA effect (4.78) followed by Nap2012 x Nap94006 (3.13) and Nap248 x Nap94006 (2.49) which might be selected as the best specific combiner for the trait. These three combinations could be selected for further evaluation to obtain heterotic hybrid combination in breeding program. There were also four combination showed significant but negative SCA effects. The other combinations showed the highest significant negative values were Nap2013 x Nap2012 (-5.68), followed by Nap2001 x Nap94006 (-3.59), Nap179 x Nap2001 (-2.53) and Nap2022 x Nap2012 (-2.40). 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. Treatment VS yield per plant is graphically represented in Figure 11.

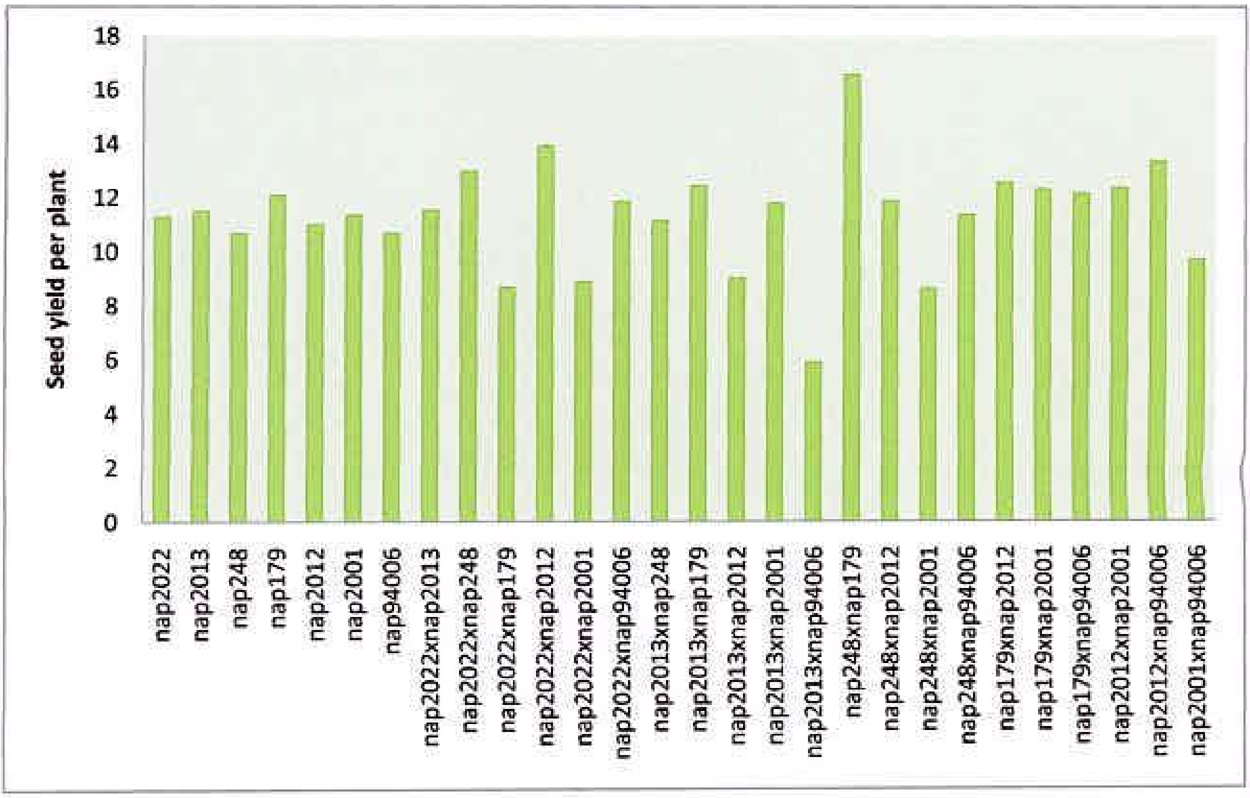


Fig 10: Graphical representation of 1000 seed weight in 36 *B. napus* genotypes

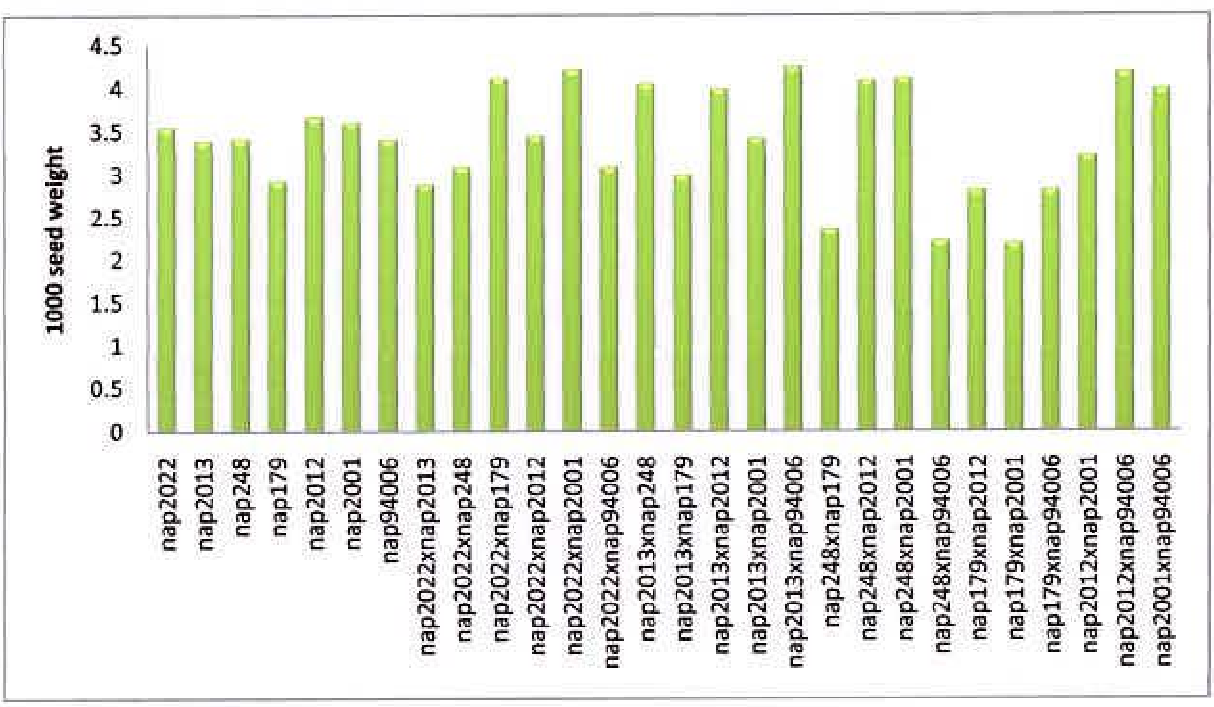


Fig 11: Graphical representation of seed yield per plant in 36 genotypes of *B. napus* L.

Chapter 5

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A seven parents (Nap-2022, Nap-2013, Nap-248, Nap-179, Nap-2012, Nap-2001, and Nap-94006) half diallel cross 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 twenty one crosses, the hybrids Nap2022 × Nap2001 and Nap2022 × Nap248 showed desirable negative heterosis for the characters of shorter plant height, early flowering and early maturity. The hybrid Nap248 × Nap2012 was the best for early flowering. The hybrids Nap248 × Nap179, Nap2022 × Nap94006, Nap2013 × Nap94006, were found to be the best heterosis for no. of primary branches per plant, no. of secondary branches per plant and no. of siliquae per plant. While the cross Nap2022 × Nap94006 produced the maximum no. of secondary branches and cross Nap2013x Nap94006 gave the maximum no of siliqua per plant. Most of all the crosses showed significant negative performance for length of siliqua and no. of seeds per siliqua. The cross Nap2001x Nap94006 was the best for siliqua length and for seeds per siliqua. For thousand seed weight the hybrids Nap179× Nap2001 and Nap2012 x Nap94006 were best. For seed yield per plant the crosses Nap2012 × Nap94006 was found to be the best two followed by crosses Nap248 × Nap2001, Nap2013 × Nap94006, Nap2022 × Nap179, and Nap2022 × Nap2001 . Thus selection out of these crosses in the subsequent generations might produce some suitable segregants.

Analysis of combining ability following Griffing approach showed significant GCA and SCA variance for 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 suggested that parent Nap-248 was the best general combiner for plant height,early flowering, early maturity, and parent Nap-94006 is best for high no of primary branches and no. of secondary branches. The parent Nap-2022 was the best general combiner for no of siliqua per plant. The parent Nap-179 was good general combiner for no. of seeds per siliqua and seed yield per plant. The parent Nap-2012 was the best for 1000 seed weight. For seed yield Nap-179, and Nap-94006 were suitable general combiner selected.

The higher magnitude of SCA variance was observed than that of GCA variance for plant height, days to maturity, no. of primary branches per plant, no. of secondary branches per plant, no. of seeds/siliqua, seed yield per plant and thousand seed weight which indicated the preponderance of non additive component in their expression.

The SCA estimates of various characters revealed that cross Nap2001 × Nap94006, Nap2022× Nap94006 Nap179 × Nap94006 Nap2013 x Nap2001 Nap2013 x Nap94006 were good specific combiner for no. of primary branches, no. of siliquae per plant, siliqua length, seed yield per plant and thousand seed weight. The combination Nap2022 × Nap2001 was the best specific combiner for early flowering. The hybrid Nap2022 × Nap94006 was the best for no. of secondary branches per plant. The cross Nap2001 x Nap94006 was the best for the no. of primary branches and Nap2022 x Nap 94006 was best for no of siliquae/plant. For siliqua length Nap179 x Nap94006 was the best specific combiner. The cross Nap2013 x Nap2001 was the best specific combiner for seed yield/plant and 1000 seed weight.

Among the genotypes, the parents had high GCA effects and hybrids had high heterotic value and SCA effect. So, in a breeding programme maximum emphasis should thus given on these traits. These genotypes could be effectively used in future for developing varieties of rape seed *Brassica napus* L.

Chapter 6
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Chapter 7
Appendics

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	21.75	Hydrometer method (Day,1915)
Silt	66.60	Do
Clay	11.65	Do
Texture class	silty 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: Soil Resource and Development Institute (SRDI), Dhaka

Appendix II. Monthly average Temperature, Relative Humidity and Total Rainfall of the experimental site during the period from November, 2011 to April, 2012

Month	Air temperature (°c)		Relative humidity (%)	Rainfall (mm) (total)	Sunshine (hr)
	Maximum	Minimum			
October, 2011	34.8	18.0	77	227	5.8
November, 2011	32.3	16.3	69	0	7.9
December, 2011	29.0	13.0	79	0	3.9
January, 2012	28.1	11.1	72	1	5.7
February, 2012	33.9	12.2	55	1	8.7
March, 2012	34.6	16.5	67	45	7.3
April, 2012	35.8	20.3	65	88	8.3

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