HETEROSIS AND COMBINING ABILITY IN RAPESEED (*Brassica rapa* L.)

BY

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CERTIFICATE

This is to certify that the thesis entitled, "**HETEROSIS AND COMBINING ABILITY IN RAPESEED (*Brassica rapa* L.)**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE in GENETICS AND PLANT BREEDING**, embodies the result of a piece of bona fide research work carried out by **KAZI MOHAMMAD ENAMUL HUQ**, Registration No. 27512/00695 under my supervision and my guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: December, 2007
Dhaka, Bangladesh

(Professor. Dr. Md. Shahidur Rashid Bhuiyan)
Supervisor

Dedicated to

My

Beloved Mother

&

Late Father

LIST OF SYMBOLS AND ABBREVIATIONS

FULL WORD	ABBREVIATION
Percentage	%
Critical Difference	CD
Specific Combining Ability	sca, SCA
General Combining Ability	gca, GCA
Exempli gratia (by way of example)	e.g.
and others (at ell)	*et al.*
Food and Agriculture Organization	FAO
Centimeter	cm
Bangladesh Agricultural Research Institute	BARI
Sher-e-Bangla Agricultural University	SAU
Journal	*J.*
Number	No.
Variety	var.
Namely	viz.
Degrees of freedom	df.
Mid parent	MP
The 1st generation of a cross between two dissimilar homozygous parents	F_1
The 2nd generation of a cross between two dissimilar homozygous parents	F_2
Better parent	BP
Triple Super Phosphate	TSP
Muriate of Potash	MoP
Emulsifiable concentrate	EC
At the rate of	@
Milliliter	ml
Randomized Complete Block Design	RCBD
Mean of F_1 individuals or Mean of reciprocal individuals	$\overline{F_1}$
Mean of the better parent values	$\overline{BP}$
Mean of the mid parent values	$\overline{MP}$
Gram	g
Bangladesh Bureau of Statistics	BBS
Analysis of variance	ANOVA
Sarisha	sar
Kilogram	kg
Sonali sarisha	SS
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

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ABSTRACT

Field experiment on rapeseed (*Brassica rapa* L.) involving 7 x 7 half diallel cross excluding reciprocal were conducted at the Sher-e-Bangla Agricultural University, Dhaka during the winter season of 2006 – 2007. Heterosis and Combining ability were estimated for seed yield and other related characters such as plant height, days to 50% flowering, days to maturity, no. of primary branches per plant, no. of siliquae per plant, no. of seeds per siliqua, length of siliqua and hundred seed weight per plant. Out of twenty one crosses, Agroni x BARIsar-6, Agroni x Tori 7, Shafal x BARIsar-6 and BARIsar-6 x Tori 7 showed highly significant heterosis over mid parent and better parent for seed yield per plant. The hybrid Shafal x BARIsar-9 showed desirable heterosis for the early flowering. Agroni x Tori 7 was found to be the best one for number of primary branches per plant. The cross Agroni x Tori 7 produced maximum heterosis for number of siliquae per plant. The crosses Shafal x Tori 7 and Agroni x BARIsar-9 showed maximum length of siliqua and number of seeds per siliqua respectively. Desirable significant negative heterosis was found in the cross Tori 7 x BARIsar-9 over mid parent and over better parent for plant height. Hybrid Agroni x Tori 7 was found to have the best heterotic effect for number of primary branches per plant and maximum number of siliquae per plant where Tori 7 x BARIsar-9 for dwarfness. The variance due to GCA and SCA were highly significant for all the characters studied except hundred seed weight and seed yield per plant indicating the importance of both additive and non-additive gene effects. Highly significant GCA effect was found in case of hundred seed weight while highly significant SCA effect was found for seed yield per plant. The parent BARIsar-9 (P_7) was an excellent general combiner for earliness and dwarfness where as Tori 7 for earliness, siliquae per plant and length of siliqua; BINAsar-6 (P_3) and Shafal (P_2) for primary branches per plant; BINAsar-6 for hundred seed weight and Agroni (P_1) for more seeds per siliqua. The SCA estimates indicated that the crosses Tori 7 × BARIsar-9 (C_{21}) was the best specific combiner for dwarfness where as Agroni × Tori 7 (C_5) for primary branches per plant, siliquae per plant and seed yield per plant; Shafal × BARIsar-6 (C_7) for early flowering, early maturity and seed yield per plant; Shafal × Tori 7 (C_{10}) for length of siliqua; BARIsar-6 × BINAsar-6 (C_{12}) for seeds per siliqua and SS 75 × Tori 7 (C_{19}) for earliness. The GCA and SCA ratio for all the characters except seed yield per plant were more than one indicating that these characters were predominantly under additive genetic control.

CHAPTER I

INTRODUCTION

INTRODUCTION

Rapeseed and mustard (*Brassica sp.*) are important oil crops of Bangladesh. *Brassica* is an important genus of plant kingdom consisting of over 3200 species with highly devise morphology. Among the oil seed crops rapeseed and mustard is the third highest source of edible oil in the world after soybean and palm (FAO 2000, Piazza and Foglia 2001, Walker and Booth, 2001). About 13.2% of the world edible oil supply comes from this crop (Downey and Robbelen, 1989).

The oleiferous *Brassica* is an important source of vegetable fat and are mainly represented by rape, turnip rape and mustard. The genus *Brassica* has generally divided into three groups, namely mustard, rapeseed and cole. The component of mustard group includes *B. juncea* Czern and Coss (4x =36), *B. nigra* (2x= 16) Koch, *B. carinata* Braun (2x =34) while rapeseed includes *B. rapa* L. (turnip rape, 2x =20) and *B. napus* L. (rape, 4x = 38) (Yarnell, 1965). All these species have many cultivated varieties suited to different agro-climatic conditions. In this sub-continent three species of *Brassica* are cultivated for oil purposes, viz, *B. campestris, B. juncea* and *B. napus.*

In Bangladesh, rapeseed and mustard is the top ranking oil seed crop. The crop occupied about 71.75 % of total oilseed area in 2005-06 cropping season (BBS, 2006b). The production of the crop was 183 thousand M. tons in crop year 2005-06 (BBS, 2006a). The average yield per hectare of this crop was only 960 Kg in Bangladesh in 2005-06.

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

Bangladesh is facing a huge shortage in edible oils. It requires 0.29 million tons of oil equivalent to 0.8 million tons of oil seeds for nourishing her people, but oil seed 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 crore taka (BBS 2006).

The climate and edaphic factors of Bangladesh are quite favorable for the cultivation of rapeseed and mustard (Haque *et al.*, 1987). 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 sown 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.

There is plenty of scope to increase yield per unit of area through cultivation of short duration high yielding varieties. The production potential of rapeseed and mustard may be well exploited if the varieties can be identified with early maturity, rapid response to high fertility, has large seed size and high oil content.

The oil content of mustard in Bangladesh varied from 30 to 40 percent depending on the variety, climate and production condition (Rahman *et al.*, 1993).

The seed yield is contributed by many morphological characters of the plant. Intra-species hybridization is a good way of improving the varieties of *Brassica rapa* 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 of heritability of materials in early generations, heterosis of different degrees is very useful for the purpose of selection from the hybrid populations.

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

Combining ability studies are reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits. Genetic information helps in the selection of suitable parents for hybridization and in isolating the promising early generation hybrids for further exploitation in breeding programs. Combining ability studies provide better estimates of general and specific combining abilities (GCA and SCA), which are useful in classifying parental lines in terms of their hybrid performance. In cross pollinated crops like rapeseed (*Brassica rapa* L.) these studies are useful in assessing the nicking ability of the parents which, when crossed, would give more desirable segregates.

Therefore, the present work was undertaken with the following objectives:

1. Estimation of heterosis for different yield contributing characters of rapeseed (*Brassica rapa* L.).
2. Identification of potential parent and promising cross combinations to develop HYV and hybrids.
3. To estimate the nature and extent of gene action involved in controlling the traits.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

In the field of *Brassica* breeding, many researchers has contributed research works on heterosis over mid parental values or better parental values and combining ability by their work. A large volume of literature is available on these issues. However, Attempt has been made to review some of the literatures relevant to the present study on rapeseed and presented in this chapter.

2.1. HETEROSIS

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

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

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 of 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.

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

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

Liersch *et al.* (2004) conducted a breeding approach known as CMS ogura system of oilseed rape hybrid cultivars in Poland to evaluate yield and yield component variability of F_1 hybrids and their parental lines, along with heterosis effect, and qualitative traits such as oil and glucosinolate content in seeds. They found that composite hybrid cultivars produced higher yield 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 crosses exhibited highly significant heterosis for most of the characters studied viz; 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.

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

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

An investigation was conducted by Pourdad *et al.* (2003) to study heterosis and inbreeding depression in rapeseed (*B. napus*, *[B. napus* var. *oleifera]*) and For this they planted 42 F_1s along with 7 parents over three environments. They reported that TERI(OE)R15 x TERI(OE)R983 showed high negative heterobeltiosis for days to 50% flowering and days to maturity, which indicates a suitable hybrid for the development of short duration cultivars. TERI(OE)R983 x HNS9801 exhibited high negative heterobeltiosis for plant height. By the result of this experiment they concluded that heterosis breeding was not suitable for development of dwarf cultivars. The highest positive heterobeltiosis for seed yield per plant over three environments was observed in GSC3A00 x HNS9801 with mean performance of 14.3 g. The mean of inbreeding depression was 45.63% in this hybrid. Results showed that heterosis breeding was a suitable method to increase seed yield. In most of the hybrids, oil content showed negative heterobeltiosis over three environments. The mean of inbreeding depression in this character was 2.39%. Selection for high oil content was more effective than hybrid production. The highest negative heterobeltiosis for glucosinolate concentration over three environments was observed in GSC3A00 x NPN02. The lowest glucosinolate concentration was observed in GSC3A00 x TERI(OE)R983, with mean performance of 80.6 micro mol/g. The highest negative heterobeltiosis for linolenic acid content was observed in HNS9802 x NPN01, with a mean performance of 10.7%. The highest negative heterobeltiosis for erucic acid content was observed in TERI(OE)R983 x GSC3A00, with a mean performance of 2.3%. Heterosis breeding was not suitable for developing single zero cultivar. Characters with low and high inbreeding depression could be basically controlled by additive and non-additive gene action, respectively.

Qi *et al.* (2003) carried an experiment out in 1997 where 66 crosses were made in a diallel design of 12 parental varieties of *Brassica napus* to study heterosis of seed and its components. Twenty-one crosses showed a significant heterosis in seed yield/plant. The average yield heterosis over their parents was 70.24% (30.70-218.10%). Eight crosses showed better parent heterosis (3.57-20.48%) in 1000-seed weight, while the parent of 7 crosses showed low 1000-seed weights. Forty-seven crosses gave on average 28.02% (0.93-97.87%) more silique/plant in parents, while 13 crosses showed 11.67% more seeds/silique in parents. By this experiment they concluded that there is large potential heterosis in seed yield with heterosis of silique number/plant making the biggest contribution.

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

Kumar *et al.* (2002) crossed three lines and twelve testers of Indian mustard and the resulting 36 F_1's and 15 parents were grown. Physiological data were determined from 5 plants per entry and the range of heterosis given for all crosses. The five hybrids with the highest heterosis for seed yield were RN-505 x RN-490, RN-505 x PCR-43, RN-393 x RN-481, RN-393 x RN-453 and RN-505 x RN-481, and these crosses offer the best possibilities of further exploitation for the development of high yielding varieties.

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

Zhang *et al.* (2002) crossed three double low cytoplasmically male sterile (CMS) and five double low restorer lines of *Brassica napus* and they analysed resulting 15 hybrids for 8 yield components. In this experiment they found that the CMS F1 had significant heterosis, particularly for yield, but that predicted for the F_2 was lower. They also suggested that the major yield components, total silique number/plant had the highest heterosis and would be of more value in a breeding programme than trying to increase seed number per silique or 1000-seed weight.

Lu *et al.* (2001) proposed that heterosis is proportional to genetic divergence between respective parents in many crops. They evaluate heterosis in interspecific hybrids between *Brassica napus* (AACC, 2n=38) and *Brassica rapa* [*B. campestris*] (AA, 2n=20) for ten agronomic characters 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 better-parent heterosis in the number of secondary branches and silique 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 hybrids was significantly lower than both parents' and varied with different combinations and Inter-specific hybrids showed higher vegetative heterosis than intra-specific hybrids.

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

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

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

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

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

Thakur *et al.* (1997) evaluated nine diverse inbreds and their 36 F1 hybrids from a diallel cross for yield and its components and for oil content. They observed that estimates of heterosis over better parent (BP) for the various traits were significant for seed yield (-14.8 to 82.8%), primary branches (-26.0 to 193.6%) and siliquae per plant (-21.9 to 162.6%). They also observed unidirectional dominance for most of the traits studied and the cross GSB7027 x HNS8803 gave highest positive heterosis for seed yield per plant.

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

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

Ali *et al.* (1995) investigated the association between genetic distance and mid-parent heterosis and they found that the correlation between genetic distance and heterosis was positive and highly significant for seed yield, silique/plant and seeds/silique. 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, siliqua/plant, seeds/silique and yield/plant). Two cultivars from each cluster were selected as parents and 15 partial-diallel inter- and intracluster crosses were made between the six selected parents and evaluated at two locations in Michigan, USA in 1990-91.

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

Information on heterosis has also been recorded by Rai and Singh (1994) from data on 6 yield component in 8 *Brassica campestris* varieties and their 28 F_1 hybrids. A number of hybrids expressed heterosis for seed yield and its component. The average heterosis over better parent for seed yield was 21.3%. The crosses showed significantly high positive heterosis for seed yield in all cases except had high negative heterosis for yield in DTS xYST151.

Ahmad (1993) worked with parents and F_1 hybrids from crosses between resynthesized lines and improved 00 varieties. FI were earlier maturing than resynthesized lines andheterosis was observed for spring regrowth and plant height. In trials, 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 8 genetic stocks with 28 hybrids being derived from crosses of the initial S_0 population and the rest from crosses of S_1 families from each of the parents. The use of S_1 families generally gave hybrids with a higher degree of commercial heterosis (over the best open pollinated commercial variety) than hybrids using S_0 materials, though the S_0 x S_0 crosses gave high commercial heterosis for yield in many cases.

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

Krzymanski et al. (1993) found significant heterosis for seed yield, oil content and some flowering traits in 10 parental strains and their 45 hybrids. The mean heterosis for seed yield over the mid parental mean was 24.71%. The highest heterosis for this trait was seen in the cross of PN2595/91x PN2870/91 (71.81%relative to the mid parental mean).

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

Srivastava and Rai (1993) tested heterosis for seed yield and 3 of its component in hybrids from a half diallel set of 15 crosses involving 3 Indian and 3 foreign varieties. The highly heterotic hybrids YST151 x Tobin, YSTI5I x Torch and PT303 x Torch, each had one Indian and one foreign parent and in general the Indian x foreign hybrids showed a higher degree of heterosis than the Indian x Indian and Foreign x Foreign.

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

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

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

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

Kumar *et al.* (1990) evaluated 16 parents and 39 F_1s for six traits. Crosses showing positive heterosis for seed yield, primary branches, secondary branches, siliqua length and number of seeds/siliqua. Highest positive heterosis were observed secondary branches, siliqua length and number of seeds/siliqua. Highest positive heterosis for seed yield was observed in the cross RLM198 x RH30 followed by the crosses RJLMSH x Varuna; RL18 x Varuna and RS64 x Varuna. The cross RLM198 x 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 x TS-72 showed highest heterosis over mid parent for seed yield/plant.

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

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

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

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

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

Schuster *et al.* (1978) reported heterosis of 203% for seed yield, 211% for number of seeds/siliqua and 187% for number of siliquae/plant in crosses between diverse lines in each generation of black mustard *(Brassica nigra* L). There was lower heterosis for 1000 seed weight.

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

2.2. COMBINING ABILITY

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

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

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

Heterosis for seedling, physiological and morphological traits in 3 rape crosses derived from 4 genotypes (Ester, Rainbow, Range and Shiralee) and grown under irrigated and non-irrigated conditions was determined in experiments conducted by Cheema *et al.* (2004) 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 x Ester under normal and drought conditions. Heterosis over the mid parent for chlorophyll was recorded in Range x Shiralee grown under normal and drought conditions. Range x Sheralee recorded high heterosis over the mid and better parent under drought conditions and high heterosis for yield over the mid parent under normal conditions.

Chowdhury *et al.* (2004) studied the nature and magnitude of combining ability of parents and crosses (F_1s) in a 7 x 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 x low, average x average and average x low gca parents.

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

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

Prasad *et al.* (2002) evaluated combining ability of 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 x low gca parents.

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

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

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

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

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

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

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

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

Sheikh and Singh (1998) analysed combining ability, in 10 x 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 x low gca parents.

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

Thakur *et al.* (1997) found that GSL8809, HPN1, GSL1501 and HNS8803 were good combiners for seed yield and some of its components and for oil content. They evaluated nine diverse inbreeds and their 36 F1 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 x 8 diallel analysis (excluding reciprocals), Yadav and Yadava (1996) reported that the presence of both additive and dominance genetic components for seed yield and yield components in Toria (*Brassica campestris* L. var. Toria). But the magnitude of dominance component was larger than the additive component for all the traits including seed yield. Heritability estimates were higher for days to maturity and 1000 seed weight.

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

Barua and Hazarika (1993) conducted a study during 1993 with 5 varieties representing 2 *Brassica napus* types and *Brassica campestris* var toria along with their hybrids from a half diallel set of crosses. According to them, heterosis mainly due to non-additive gene effect was important for dry matter and seed yield/plant. The important heterotic crosses were BSH_1 x M27, B9 x PT303 and PK x 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 x SL502.

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

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

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

Rawat (1992) studied the reciprocal differences in the inheritance of 8 yield triats in progeny from a diallel set of cross involving 12 lines of *Brassica juncea*. GCA effects predominated in the control of all the traits. Reciprocal effects were more pronounced than SCA effects, though the later were significant for all traits. The most promising parent lines on the basis of *per se* performance and of combining ability and F_1 performance were BICI624, BICI3S2, BICI439, BICI114 and BICI702. There was only one cross (BICI382 x 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 x 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 x BC2 and BCIDI x BC2 for using a pedigree selection programme.

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

EC126746-1 have emerged as good combiners for plant height, primary branch and secondary branch.

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

Chauhan *et al.* (1990), reported that a wide variation in yield and its component when 36 *Brassica juncea* crosses and their 15 parents were tested. Significant difference were observed among the genotypes for seed yield. NDRS602, Krishna, Pusa Bold and TM9 showed good general combining ability.

Siddique *et al.* (1990) studied a complete diallel cross involving four genotypes of *Brassica campestris* and their F_1s for nine characters including seed yield/plant. Both additive and non additive gene action was found in the inheritance of characters except days to flower, plant height and primary branches. Preponderance of additive gene action for days to maturity, number of secondary branches/plant number of siliqua/plant, number seeds/siliqua and non additive gene action for days to flowering, plant height, number of primary branches, siliqua length were found. Among the parents M-27 was the best general combiner for siliqua/plant and seed yield/plant. The hybrids YS-52 x 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 x 3 tester mating design of

Brassica napus. The varieties Midas, Regent 3-1 and DB054 were identified as good general combiners and DNA38 x DISNI and N20-1 x Regent as good specific cross combinations.

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

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

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

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

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

Badwal and Labana (1987) analysed data on seed yield/plant and 8 related traits from a 10 x 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/silique, plant height, primary branches, silique length; only non additive variance was significant for secondary branches.

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

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

Gupta *et al.* (1987a) worked with 8 x 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 x Varuna and RLM19SxRH30.

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

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

Rawat (1987) observed a line x tester analysis involving 12 females and 5 males of *Brassica juncea* of diverse origin. Variance components of GCA and SCA were significant for days to 50% flowering, Number of primary branch, plant height, seed height and seed yield/plant. For secondary branches GCA was important. Pusa Rai 34 and Pusa Rai 45 among the female parents and Pusa Rai 30 among the male parents performed well and were good general combiners. The cross RLM514 x RLM198, RW336 x Pusa Rai30, Pusa Rai45 xBR40 and RH7710 x 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 x 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 x RW75-80-1, additive genetic variance was estimated to be predominant for plant height and dominant for days to maturity, number of seeds/siliqua, 1000 seed weight, yield/plant.

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

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

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka-1207, during October, 2006 to Mid-February, 2007. The location of the experimental site was situated at $23^0 41'$ N latitude and $90^0 22'$ E longitude with an elevation of 8.6 meter from the sea level (Figure 1). The physical and chemical characteristics of the soil have been presented in Appendix I.

3.2 Climate and soil

The experimental site was situated in the subtropical zone. The soil of the experimental site lies in Agroecological region of "Madhupur Tract" (AEZ No. 28) of Norda soil series. The soil is sandy loam in texture and olive gray with common fine to medium distinct dark yellowish brown mottles. The pH is 5.47 to 5.63 and organic carbon content is 0.82% (Appendix I).The mean temperature during the research period was 24.21^0C with average maximum and minimum being 29.4^0C and 19.03^0C respectively. The record of air temperature, humidity and rainfall during the period of experiment were noted from the Bangladesh Meteorological Department, Agargaon, Dhaka (Appendix II).

3.3 Plant materials

A total number of 28 (twenty eight) genotypes were used in this experiment where 7 (seven) were parents and remaining 21 (twenty one) are F_1 (Hybrid). Out of the twenty eight genotypes twenty seven genotypes including six parents seed were collected from Department of Genetics and Pant Breeding, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh and rest one genotype (parent seed) was collected from Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh. (Table 1). The 21 F_1 (hybrid) seeds produced during the winter 2005-2006, which shown in the Table 2.

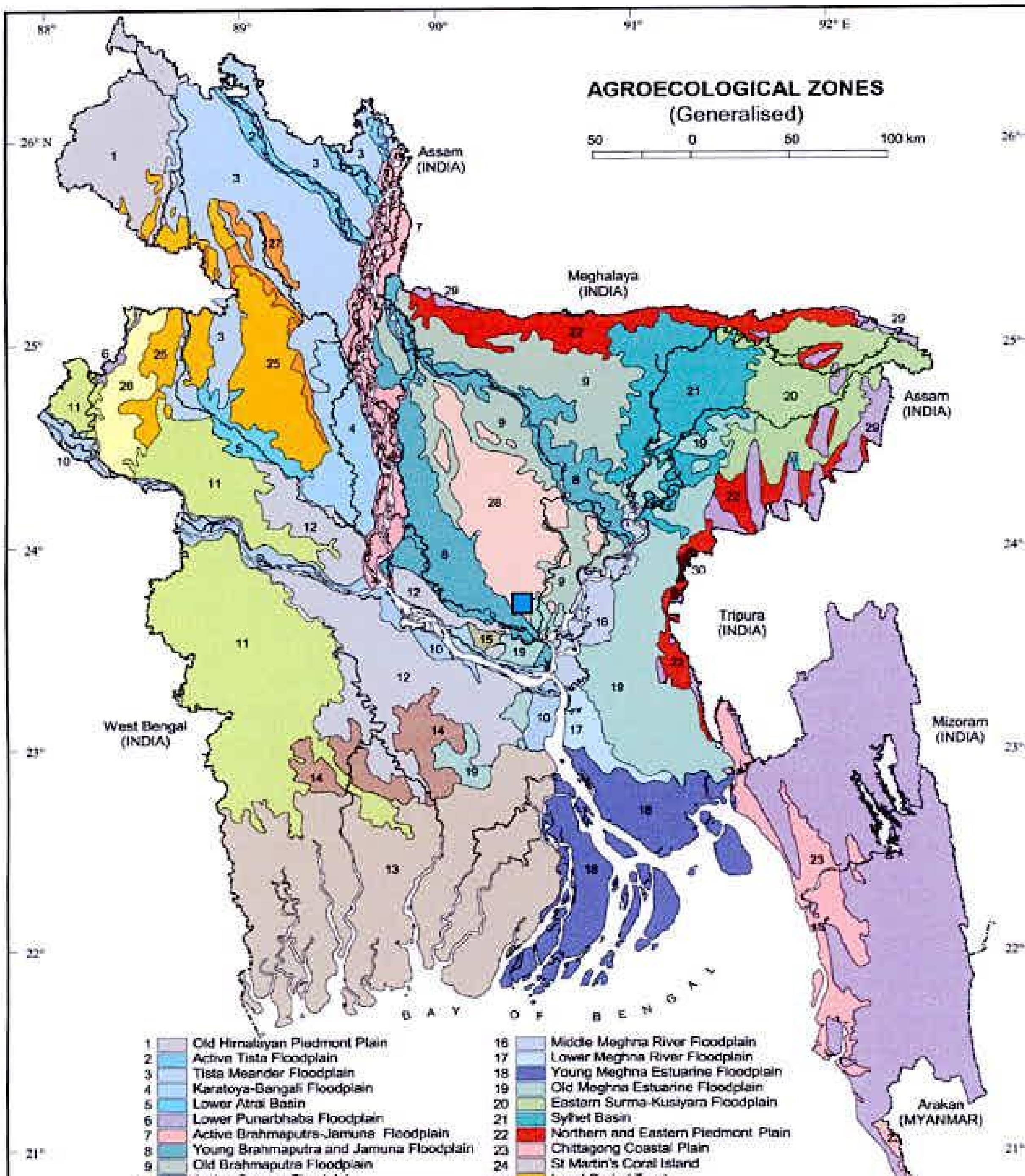

Figure 1. Location of the experimental field

Table 1. Materials used for the experiment

Sl. No.	Genotypes	Name of the Genotypes
01	P_1	Agroni
02	P_2	Shafal
03	P_3	BARI Sar-6
04	P_4	BINA Sar-6
05	P_5	SS75
06	P_6	Tori 7
07	P_7	BARI Sar-9
08	C_1	Agroni (P1) × Shafal (P2)
09	C_2	Agroni (P1) × BARIsar-6 (P3)
10	C_3	Agroni (P1) × BINAsar-6 (P4)
11	C_4	Agroni (P1) × SS 75 (P5)
12	C_5	Agroni (P1) × Tori 7 (P6)
13	C_6	Agroni (P1) × BARIsar-9 (P7)
14	C_7	Shafal (P2) × BARIsar-6 (P3)
15	C_8	Shafal (P2) × BINAsar-6 (P4)
16	C_9	Shafal (P2) × SS 75 (P5)
17	C_{10}	Shafal (P2) × Tori 7 (P6)
18	C_{11}	Shafal (P2) × BARIsar-9 (P7)
19	C_{12}	BARIsar-6 (P3) × BINAsar-6 (P4)
20	C_{13}	BARIsar-6 (P3) × SS 75 (P5)
21	C_{14}	BARIsar-6 (P3) × Tori 7 (P6)
22	C_{15}	BARIsar-6 (P3) × BARIsar-9 (P7)
23	C_{16}	BINAsar-6 (P4) × SS 75 (P5)
24	C_{17}	BINA sar-6 (P4) × Tori 7 (P6)
25	C_{18}	BINAsar-6 (P4) × BARIsar-9 (P7)
26	C_{19}	SS 75 (P5) × Tori 7 (P6)
27	C_{20}	SS 75 (P5) × BARIsar-9 (P7)
28	C_{21}	Tori 7 (P6) × BARIsar-9 (P7)

BARI – Bangladesh Agricultural Research Institute
BINA – Bangladesh Institute of Nuclear Agriculture
SS – Sonali Sarisha

Table 2. Cross combinations in half diallel system of seven varieties of *Brassica rapa*.

Parents \ Parents	Agroni	Shafal	BARI sar-6	BINA sar-6	SS 75	Tori 7	BARI sar-9
Agroni	Agroni x Agroni	Agroni x Shafal	Agroni x BARI sar-6	Agroni x BINA sar-6	Agroni x SS 75	Agroni x Tori 7	Agroni x BARI sar-9
Shafal		Shafal x Shafal	Shafal x BARI sar-6	Shafal x BINA sar-6	Shafal x SS 75	Shafal x Tori 7	Shafal x BARI sar-9
BARI sar-6			BARI sar-6 x BARI sar-6	BARI sar-6 x BINA sar-6	BARI sar-6 x SS 75	BARI sar-6 x Tori 7	BARI sar-6 x BARI sar-9
BINA sar-6				BINA sar-6 x BINA sar-6	BINA sar-6 x SS 75	BINA sar-6 x Tori 7	BINA sar-6 x BARI sar-9
SS 75					SS 75 x SS 75	SS 75 x Tori 7	SS 75 x BARI sar-9
Tori 7						Tori 7 x Tori 7	Tori 7 x BARI sar-9
BARI sar-9							BARI sar-9 x BARI sar-9

Note: The diagonal crosses are parents, above the diagonal crosses are the F_1s.

3.4 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The total area of the experiment was 26 m X 10 m = 260 m^2. The unit size was 24 m X 2 m, and the distance between two units was 1 m. The spacing between line to line was 40 cm and the total line in each block was 66.

3.5 Land preparation

The experimental plot was prepared by several ploughing and cross ploughing followed by laddering and harrowing with power tiller and country plough to bring about good tilth. Weeds and other stubbles were removed carefully from the experimental plot and leveled properly. The final land preparation was done on 08 November 2006.

3.6 Application of manure and fertilizer

The crop was fertilized at the rate of 10 tons of Cowdung, 250 kg Urea, 175 kg Triple Super Phosphate (TSP), 85 kg Muriate of Potash (MoP), 250 kg Gypsum, 3 kg Zinc oxide and Boron 1 kg per hectare. At this recommended rate 260 kg Cowdung, 6.5 kg Urea, 4.5 kg TSP, 2.25 kg MoP 3.9 kg Gypsum, 0.08 kg Zinc oxide and Boron 0.03 kg were applied into the experimental plots. The half amount of urea, total amount of TSP, MoP, Gypsum, Zinc Oxide and Boron was applied during final land preparation. The rest amount of urea was applied as top dressing after 26 days of sowing.

3.7 Seed sowing

Seeds of each genotype were sown in row on 10 November 2006 by hand uniformly where 40 cm row to row distance was maintained. After sowing the seeds were covered with soil carefully so that no clods were on the seeds.

3.8 Intercultural operations

Intercultural operations such as weeding, mulching, irrigation etc. were done when necessary for proper growth and development of the plants.

3.8.1 Thinning

Thinning was done twice. The first thinning was done on 18 November 2006 just after 10 days of seed sowing and the second one done on 28 November 2006, which was after 20 days of seed sowing.

3.8.2 Weeding

The first weeding was done after 20 days of seed sowing to keep the crop free from weeds. Weeding was also done in several times when it was needed.

3.8.3 Irrigation

In the early stage of seedling, irrigation was done thrice by water cane. In maximum flowering stage, flood irrigation was done to the field when it was necessary for the crop.

3.8.4 Pesticide application

Aphid infection was found in the crop during the siliqua development stage. To control aphids Malathion-57 EC @ 2ml/liter of water was applied. The insecticide was applied in the afternoon.

3.9 Crop harvesting

Harvesting was done from 15-28 February, 2007 depending upon the maturity of crop varieties and their F_1 s.

3.10 Data collection

The data were recorded on ten randomly selected plants for each genotype by avoiding the two boarder plants from each replication. Plant height, Number of primary branches per plant, Days to 50 % flowering, Days to maturity, Number of siliqua per plant, Number of seeds per siliqua, Lenth of siliqua and 100 seed weight and Seed yield per plant were recorded.

Plate 1a. Field view of the experimental site

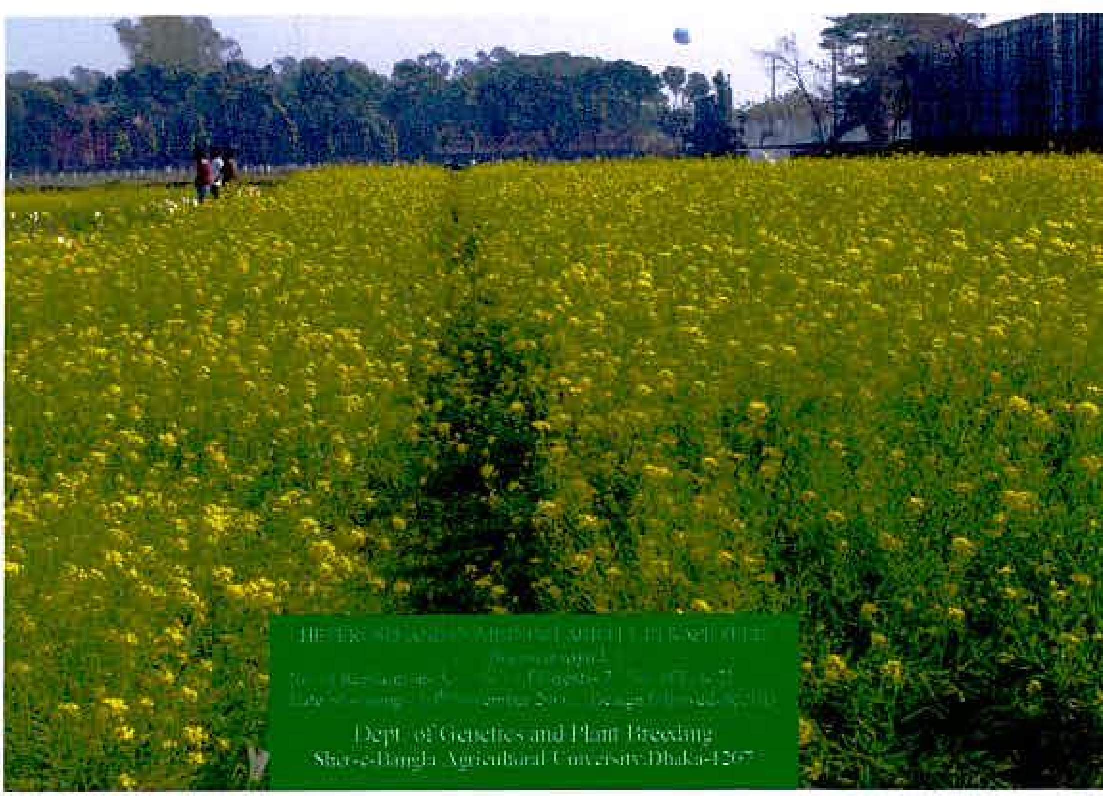

Plate 1b. Field view of the experiment

3.10.1 Plant height

Length of main stem from ground level to the longest tip of the stem was measured at ripening stage. The data were measured in centimeter (cm).

3.10.2 Days to 50 % flowering

Days to 50 % flowering were recorded from sowing date to the date of 50% flowering of every genotype.

3.10.3 Days to maturity

The data were recorded from the date of sowing to the date of 50 % fruit maturity of every single plant of every genotype.

3.10.4 Number of primary branches per plant

After harvesting the plant, number of primary branches of each plant under each genotype was recorded after harvesting the plant.

3.10.5 Number of siliquae/plant

The total number of siliquae of every plant was counted which was fertile or not.

3.10.6 Number of seeds/siliqua

Mean number of seeds counted from ten randomly selected siliquae.

3.10.7 Length of siliqua

One siliqua was selected at random from every selected plant to measure the length of siliqua. The measurement was in cm.

3.10.8 100-seed weight

Well dried one hundred harvested seeds were taken from ten plant and were weighted in gram.

3.10.9 Seed yield/plant

The weight of total seed from each selected plant in each replication of each genotype was recorded in gram.

3.11 Statistical analysis

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

To calculate the amount of heterosis in F_1s and, statistical analysis were done using the following formulae:

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

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

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

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

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

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

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

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

Here, EMS= Error Mean Sum of square

r = No. of replication

t = tabulated t value at error df.

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

Combining ability in relation to diallel cross

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

The mathematical model for the analysis was:

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

Where,

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

K= 1,2, ..., b

L = 1, 2, ..., c

P = Number of parents

b = Number of blocks or replications

c = Number of observation in each plot

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

m = The population mean

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

g_j = The gca of jth parent

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

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

The restriction imposed are $\sum_i g_i = 0$ and $\sum_j S_{ij} + S_{ii} = 0$ (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	Mean squares
GCA	P-1	$\frac{1}{(p+2)}[\sum_i (Y_{i.} + Y_{ii})^2 - \frac{4}{P} Y..^2]$	Mg
SCA	P(P-1)/2	$\sum_i \sum_j Y_{ij}^2 - \frac{1}{(p+2)} \Sigma(Y_{i.} + Y_{ii})^2 + \frac{2}{(p+1)(p+2)} Y..^2$	Ms
Error	(b-1) (e-1)	SSe	Me

Where,

gca = general combining ability

sca = specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

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

Y_{ii} = Mean value of the ith parent

$Y..$ = Grand total of the $\frac{1}{2}$ p(p-1) crosses and parental lines

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

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

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

$$g_i = \frac{1}{p+2}[\Sigma(Y_{i.}+Y_{ii}) - \frac{2}{p}Y..]$$

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

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

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

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

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

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 HETEROSIS

Nine yield contributing characters of *Brassica rapa* were studied in seven parental genotypes and their twenty one hybrids without reciprocals obtained from a half diallel cross. Percent heterosis and for different characters of the F_1 hybrids over their respective mid and better parental values are shown in Table 3. The mean performance for different characters of the parents and F_1 hybrids are presented in Table 4. The results on heterosis of 21 F_1s are described below character wise:

4.1.1 Plant height

Significant Negative heterosis over better parent (-11.41%) was showed by the hybrid Tori 7 x BARIsar-9 (C_{21}) for plant height followed by SS 75 x Tori 7(C_{19}= -8.87%) (Table 3). Thus these hybrids might produce suitable dwarf plant in the next generation. The cross Agroni × Tori 7 (C_5) showed highly significant positive heterotic effect over better parent (17.35%) followed by Agroni x SS 75 (C_4= 14.74%), SS 75 × BARIsar-9 (C_{20}= 14.46%) and Agroni × BARIsar-9 (C_6= 13.00%). Maximum of the crosses except Tori 7 x BARIsar-9 (C_{21}) showed highly significant heterosis over mid parent. Tori 7 x BARIsar-9 (C_{21}) showed the significant negative heterosis (-9.27%) over mid parent. Highly significant positive heterosis over mid parent was observed in Agroni × Tori 7 (C_5= 25.76%) followed by BINAsar-6 ×Tori 7 (C_{17}= 22.15%), SS 75 × BARIsar-9 (C_{20}= 20.91%), Agroni × BARIsar-9 (C_6= 18.8%), Agroni × SS 75 (C_4= 15.74%), BARISar-6 × Tori 7 (C_{14}= 15.53%), BINAsar-6 × BARIsar-9 (C_{18}= 13.22%) and Shafal × Tori 7 (C_{10}= 11.23%) which can be used for exploiting heterosis where tallness is desirable for that character. Sohoo *et al.* (1993) found 29.13% heterosis over better parent for plant height in the crosses of *Brassica juncea* cv. RLM240 with strain 3 of *Brassica napus*. Yadav *et al.* (2004) observed the magnitude of heterosis was highest for plant height in Trachystoma x SK 93-1 (27.7%) over BP and (25.8%) over CV both.

4.1.2 Days to 50% flowering

Highest significant negative heterosis (-14.96%) was provided by the hybrid Shafal x BARIsar-6 (C_7) for days to 50% flowering over better parent (Table 3). It was followed by the crosses Shafal x BARIsar-9 (C_{11}= -13.61%), SS 75 x Tori 7 (C_{19}= -12.69%), Shafal x Tori 7 (C_{10}= -11.57%), BARIsar-6 x BINAsar-6 (C_{12}= -10.88%), BINAsar-6 x Tori 7 (C_{17}= -10.20%), BINAsar-6 x BARIsar-9 (C_{18}= -9.53%), BARIsar-6 x BARIsar-9 (C_{15}= -7.93%), Shafal x SS 75 (C_9= -7.49%), Agroni x Shafal (C_1= -7.49%), BINAsar-6 x SS 75 (C_{16}= -7.14%), Shafal x BINAsar-6 (C_8= -2.96%) and Agroni x BINAsar-6 (C_3= -4.76%), The Agroni x BARIsar-6 (C_2= -2.96%) hybrid showed significant negative heterosis over better parent. The cross Agroni x SS 75 (C_4= 4.44%) showed highly positive significant heterotic effect.

On the other hand Shafal x BARIsar-6 (C_7= -8.42%) showed highest significant negative hrterosis over mid parental value followed by Shafal x BINAsar-6 (C_8= -5.45%), BARIsar-6 x BINAsar-6 (C_{12}= -4.02%), and Agroni x Shafal (C_1= -3.55%). Agroni x BARIsar-9 (C_6= 14.98%) showed highly positive significant heterosis over mid parent followed by Agroni x Tori 7 (C_5= 13.52%), BARIsar-6 × Tori 7 (C_{14}= 10.96%), SS 75 × BARIsar-9 (C_{20}= 9.77%) and Agroni × SS 75 (C_4= 8.05%).

Shafal x BARIsar-6 (C_7), Shafal × BINAsar-6 (C8) and BARIsar-6 × BINAsar-6 (C_{12}) showed highly significant negative heterosis over both better and mid parent. Thus they could be used for exploiting desirable heterosis for the trait. Low in magnitude but significant heterosis over better parent has been observed for days to 50% flowering in F_2 by Pathak *et al.* (2002).

4.1.3 Days to maturity

Tori 7 x BARIsar-9 (C_{21}) showed highest significant positive heterosis (11.95%) over better parent followed by SS 75 x Tori 7 (C_{19}= 11.45%) and BINAsar-6 × SS 75 (C_{16}= 7.64%) (Table 3). Highest significant negative heterosis over better parent was observed in Agroni × BARISar-6 (C_2=-7.24%). Highest significant positive heterosis over mid parent was observed in Tori 7 ×BARIsar-9 (C_{21}= 12.21%), followed by SS 75 × Tori 7

Shafal (P_2) **BARIsar-9 (P_7)**

Shafal x BARIsar-9 (C_{11})

Plate No. 2. Hybrid Shafal x BARIsar-9 and it's parents at flowering stage

Table 3. Percent heterosis over mid parent and better parent for 9 characters in 21 inter-varietal hybrids of *Brassica rapa*

Plant characters	Plant height (cm)		Days to 50% flowering		Days to maturity		No. of primary branches/plant	
Cross	HBP	HMP	HBP	HMP	HBP	HMP	HBP	HMP
Agroni × Shafal (C_1)	-4.06	0.48	-7.49**	-3.55*	-2.48	3.66	-25.58*	-2.93
Agroni × BARISar-6 (C_2)	1.93	6.00	-2.96*	0.39	-7.24**	-4.62*	55.78**	58.25**
Agroni × BINASar-6 (C_3)	1.14	7.48	-4.76**	-0.70	1.40	2.71	-22.46*	2.84
Agroni × SS 75 (C_4)	14.74**	15.74**	4.44**	8.05**	1.02	3.99*	39.87*	51.86**
Agroni × Tori 7 (C_5)	17.35**	25.76**	-0.73	13.52**	-1.63	4.22*	104.84**	114.92**
Agroni × BARIsar-9 (C_6)	13.00**	18.38**	-0.73	14.98**	-5.03*	0.73	85.00**	92.52**
Shafal × BARISar-6 (C_7)	-4.16	-3.46	-14.96**	-8.42**	3.21	8.38**	-19.42	6.26
Shafal × BINASar-6 (C_8)	-1.71	-0.19	-5.45**	-5.45**	0.94	2.50	-9.76	-7.56
Shafal × SS 75 (C_9)	2.68	6.63	-7.49**	-0.37	4.09*	5.81**	-17.50	1.02
Shafal × Tori 7 (C_{10})	-0.56	11.23**	-11.57**	4.79**	2.09	6.85**	-30.83**	-6.74
Shafal × BARIsar-9 (C_{11})	-6.87	1.94	-13.61**	3.62*	-3.21	1.40	-12.50	17.32
BARISar-6 × BINASar-6 (C_{12})	-2.57	-0.35	-10.88**	-4.02**	-0.58	2.86	-22.46*	3.94
BARISar-6 ×SS 75 (C_{13})	-6.56	-3.64	1.60	1.60	2.88	2.99	-10.13	-1.01
BARISar-6 × Tori 7 (C_{14})	3.96	15.53**	0.00	10.96**	0.14	3.26	44.03*	48.83*
BARISar-6 × BARIsar-9 (C_{15})	3.83	12.90**	-7.93**	3.53*	2.70	6.02**	39.19	42.64*
BINAsar-6 × SS 75 (C_{16})	-0.87	4.48	-6.12**	1.10	7.14**	10.74**	-31.11**	-14.06
BINAsar-6 ×Tori 7 (C_{17})	7.74*	22.15**	-10.20**	6.41**	-2.66	0.27	-10.32	22.83
BINAsar-6 ×BARIsar-9 (C_{18})	2.01	13.22**	-9.53**	8.52**	0.65	3.79	-24.05*	3.46
SS 75 × Tori 7 (C_{19})	-8.87*	-1.54	-12.69**	-3.12	11.45**	11.83**	6.84	21.19
SS 75 × BARIsar-9 (C_{20})	14.46**	20.91**	-2.38	9.77**	2.53	2.65	1.32	14.07
Tori 7 × BARIsar-9 (C_{21})	-11.41*	-9.27*	0.89	2.41	11.95**	12.21**	20.69	19.66
Mean	**1.68**	**7.83**	**-5.84**	**3.05**	**1.40**	**4.39**	**7.69**	**23.30**
Range: Min	**-11.41**	**-9.27**	**-14.96**	**-8.42**	**-7.24**	**-4.62**	**-31.11**	**-14.06**
Max	**17.35**	**25.76**	**4.44**	**14.98**	**11.95**	**12.21**	**104.84**	**114.92**

* and ** indicate significance at 5% and 1% level of probability, respectively
HBP= Heterosis over Beter Parent, HMP= Heterosis over Mid Parent

Table 3 (cont.)

Plant characters	No. of siliquae/plant		No. of seed/siliqua		Length of siliqua (cm)		Hundred seed weight/ plant (g)		Seed yield/plant (g)	
Cross	HBP	HMP	HBP	HMP	HBP	HMP	HBP	HMP	HBP	HMP
Agroni × Shafal (C_1)	-16.66	6.70	-6.26	-1.81	-9.50	-5.57	-10.00	-10.00	5.32	28.04
Agroni × BARISar-6 (C_2)	165.43**	222.48**	-31.85**	-19.81	-4.50	-4.50	-32.00*	-15.00	165.92**	192.81**
Agroni × BINASar-6 (C_3)	7.42	41.10	-13.91	-5.12	-7.17	-2.28	3.33	24.00	10.00	42.81
Agroni × SS 75 (C_4)	-16.72	12.52	-15.23	-1.44	1.83	7.19	23.33	23.33	27.27	58.49
Agroni × Tori 7 (C_5)	153.31**	260.12**	-39.09**	-26.55*	-4.17	-0.86	6.67	6.67	191.05**	242.06**
Agroni × BARIsar-9 (C_6)	28.76	89.54**	-48.44**	-39.76**	-19.83**	-17.07**	-3.33	-3.33	-12.80	17.21
Shafal × BARISar-6 (C_7)	102.38**	116.48**	-33.67**	-25.01*	-7.33	-3.30	-16.00	5.00	96.45**	119.46**
Shafal × BINASar-6 (C_8)	4.26	8.04	-17.15	-12.60	-2.00	-1.10	6.67	28.00	12.03	21.91
Shafal × SS 75 (C_9)	-12.61	-5.75	-16.24	-6.52	-0.55	0.37	23.33	23.33	6.82	10.16
Shafal × Tori 7 (C_{10})	25.84	45.99	-34.39**	-23.88*	25.18**	26.31**	6.67	6.67	27.90	33.28
Shafal × BARIsar-9 (C_{11})	50.84*	84.14**	-32.53**	-24.31*	-8.57	-7.75	10.00	10.00	-0.24	13.61
BARISar-6 × BINASar-6 (C_{12})	6.55	17.81	15.45	24.24*	3.67	9.12	-44.00**	-20.00	2.43	23.25
BARISar-6 ×SS 75 (C_{13})	16.08	33.18	-10.46	-9.16	-5.33	-0.35	-30.00*	-12.50	13.03	29.74
BARISar-6 × Tori 7 (C_{14})	80.98**	122.13**	-25.59*	-23.33	-9.17	-6.03	-36.00**	-20.00	88.25**	102.45**
BARISar-6 × BARIsar-9 (C_{15})	77.62**	128.43**	-39.42**	-38.89**	-15.33*	-12.41*	-30.00*	-12.50	30.85	63.82*
BINAsar-6 × SS 75 (C_{16})	25.96	31.28	-14.65	-9.38	0.74	0.74	6.67	28.00	5.68	11.71
BINAsar-6 ×Tori 7 (C_{17})	147.63**	178.49**	-38.89**	-32.40**	-12.14	-10.55	-10.00	8.00	32.30	49.47
BINAsar-6 ×BARIsar-9 (C_{18})	73.85**	106.18**	-43.08**	-39.25**	-7.68	-6.00	6.67	28.00	9.39	15.00
SS 75 × Tori 7 (C_{19})	33.90	44.98	-4.86	-0.60	9.46	11.45	-10.00	-10.00	26.21	35.45
SS 75 × BARIsar-9 (C_{20})	14.34	30.90	-39.60**	-39.25**	-4.11	-2.36	0.00	0.00	-24.63	-16.49
Tori 7 × BARIsar-9 (C_{21})	-6.23	-0.34	-14.57	-11.23	-5.54	-5.54	0.00	0.00	-26.46	-13.24
Mean	**45.85**	**74.97**	**-24.02**	**-17.43**	**-3.91**	**-1.45**	**-6.10**	**4.17**	**32.70**	**51.48**
Range: Min	**-16.72**	**-5.75**	**-48.44**	**-39.76**	**-19.83**	**-17.07**	**-44.00**	**-20.00**	**-26.46**	**-16.49**
Max	**165.43**	**260.12**	**15.45**	**24.24**	**25.18**	**26.31**	**23.33**	**28.00**	**191.05**	**242.06**

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

HBP= Heterosis over Beter Parent, HMP= Heterosis over Mid Parent

Table 4. Mean performance of 9 different characters of 7 parents and their 21 F_1s in *Brassica rapa*

Crosses/ parents	Characters								
	Plant height(cm)	Days to 50% flowering	Days to maturity	No. of primary branches/ plant	No. of siliqua/ plant	No. of seed/ siliquae	Length of siliqua (cm)	Hundred Seed wt/ plant(g)	Seed yield/ plant(g)
Agroni × Shafal (C_1)	125.40	45	96	8.93	106.17	22.78	5.43	0.27	6.53
Agroni × BARISar-6 (C_2)	131.29	44	92	9.97	294.10	16.56	5.73	0.34	13.03
Agroni × BINASar-6 (C_3)	136.33	47	99	9.77	147.17	20.92	5.57	0.31	8.14
Agroni × SS 75 (C_4)	138.83	47	99	10.63	124.17	20.60	6.11	0.37	8.40
Agroni × Tori 7 (C_5)	139.53	45	97	13.11	445.83	14.80	5.75	0.32	16.59
Agroni × BARIsar-9 (C_6)	134.36	45	97	11.84	257.01	12.53	4.81	0.29	7.15
Shafal × BARISar-6 (C_7)	125.27	42	91	9.67	257.83	14.66	5.56	0.42	12.18
Shafal × BINASar-6 (C_8)	132.50	46	99	11.37	142.83	18.31	5.39	0.32	8.29
Shafal × SS 75 (C_9)	134.20	45	99	9.90	130.30	18.51	5.47	0.37	7.05
Shafal × Tori 7 (C_{10})	129.97	43	96	8.30	221.47	14.50	7.01	0.32	7.93
Shafal × BARIsar-9 (C_{11})	121.72	42	93	10.50	301.07	14.91	5.12	0.33	8.18
BARISar-6 × BINASar-6 (C_{12})	131.33	44	96	9.77	145.97	22.86	6.22	0.28	7.58
BARISar-6 ×SS 75 (C_{13})	120.36	43	95	6.83	173.07	15.67	5.68	0.35	7.46
BARISar-6 × Tori 7 (C_{14})	133.90	42	93	8.93	318.53	12.65	5.45	0.32	10.73
BARISar-6 × BARIsar-9 (C_{15})	133.73	39	95	8.63	354.53	10.48	5.08	0.35	10.73
BINAsar-6 × SS 75 (C_{16})	133.63	46	99	8.68	187.80	16.90	5.44	0.32	7.82
BINAsar-6 ×Tori 7 (C_{17})	145.23	44	98	11.30	435.83	12.10	4.92	0.27	9.79
BINAsar-6 ×BARIsar-9 (C_{18})	137.50	44	92	9.57	347.00	11.27	5.17	0.32	8.97
SS 75 × Tori 7 (C_{19})	110.27	37	90	8.12	235.67	16.65	6.13	0.27	8.33
SS 75 × BARIsar-9 (C_{20})	138.50	41	93	7.70	228.23	10.57	5.37	0.30	6.18
Tori 7 × BARIsar-9 (C_{21})	95.77	34	89	7.00	187.17	14.78	5.29	0.30	6.03
Agroni (P_1)	118.90	45	86	6.40	71.60	24.30	6.00	0.30	4.00
Shafal (P_2)	130.70	49	98	12.00	127.40	22.10	5.50	0.30	6.20
BARIsar-6 (P_3)	128.80	42	93	6.20	110.80	17.00	6.00	0.50	4.90
BINAsar-6 (P_4)	134.80	49	96	12.60	137.00	19.80	5.40	0.20	7.40
SS75 (P_5)	121.00	42	92	7.60	149.10	17.50	5.40	0.30	6.60
Tori 7 (P_6)	103.00	34	87	5.80	176.00	16.00	5.60	0.30	5.70
BARIsar-9 (P_7)	108.10	33	87	5.90	199.60	17.30	5.60	0.30	8.20

(C19= 11.83%), BINAsar-6 × SS 75 (C16= 10.74%), Shafal × BARIsar-6 (C7= 8.38%), Shafal × Tori 7 (C10= 6.85%), BARIsar-6 × BARIsar-9 (C15= 6.02%), Shafal × SS 75 (C9= 5.81%). Agroni × BARIsar-6 (C2) showed significant negative heterosis over both better parent (-7.24%) and mid parent (-4.62%). Thus it can be used for producing varietiy with earliness. Kumar *et al.* (2002), Mahak *et al.* (2003) and Das *et al.* (2004) found significant heterosis values for days to maturity over mid parent and better parent.

4.1.4 Number of primary branches per plant

Heterosis values ranging from -31.11% to 104.84% and -14.06 to 114.92 over better parent and mid parent respectively were found for the character number of primary branches per plant. The hybrid Agroni x Tori 7 (C_5) (Plate no. 3) showed the highest significant positive heterosis over the mid parent (104.84%) as well as better parent (114.92%) followed by Agroni x BARIsar-9 (C_6= 85.00% and 92.52%) and Agroni × BINAsar-6 (C_3= 55.78% and 58.25%) for number of primary branches per plant. Crosses Shafal × Tori 7 (C_{10}= -30.83%) and BINAsar-6 × SS 75 (C_{16}= -31.11%) showed highly significant negative heterosis over better parent (Table 3). Thakur and Segwall (1997) found a heterosis value ranging from -26.0 to 193.6% over better parent for the character primary branches in rapeseed (*Brassica napus* L.). Yadav *et al.* (2004) observed the number of primary branches per plant, Trachystoma x PR 905 showed 106.5% and 100.0% heterosis over BP and SV, respectively.

4.1.5 Number of Siliquae per plant

Significant positive heterosis value ranged from 50.84% to 165.43% over better parent and 84.14% to 260.12% over mid parent and produced on an average 45.85% and 74.97% more siliquae per plant than better and mid parent respectively. Highest significant positive heterosis over better parent was found in Agroni x BARIsar-6 (C_5= 165.43%), BINAsar-6 x Tori 7 (C_5= 153.31%), BINAsar-6 x Tori 7 (C_{17}=147.63%), Shafal x BARIsar-6 (C_7=102.38%), BARIsar-6 x Tori 7 (C_{14}= 80.98%), BARIsar-6 x BARIsar-9 (C_{15}= 77.62%) and BINAsar-6 x BARIsar-9 (C_{18}= 73.85%) while no significant negative heterosis over better parent was observed for the traits. Highest significant positive heterosis over mid patent was found in Agroni x Tori 7 (C_5=

Agroni (P_1)

Tori 7 (P_6)

Agroni X Tori 7 (C_5)

Plate No. 3. Hybrid Agroni x Tori 7 and it's parents at mature stage

260.12%) followed by Agroni x BARIsar-6 (C_2=220.48%), BINAsar-6 x Tori 7 (C_{17}= 178.49%), BARIsar-6 x BARIsar-9 (C_{15}= 128.43%), BARIsar-6 x Tori 7 (C_{14}= 122.13%), Shafal x BARIsar-6 (C_7=116.48%), BINAsar-6 x BARIsar-9 (C_{18}= 106.18%), Agroni x BARIsar-9 (C_6= 89.54%) and Shafal x BARIsar-9 (C_{11}=84.14%) where as significant negative heterosis was not found. Negative heterosis was observed insignificant, Zheng and Fu (1991) found positive heterosis of 51.47% over mid parent in the F_1 hybrids in *Brassica nigra* for number of siliquae per plant. Thakur and Segwal (1997) estimated positive heterosis over better parent ranging from 21.9 to 162.60% 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.

4.1.6 Number of seeds per siliqua

Incase of number of seeds per siliqua was highly significant with negative heterosis over better parent (-48.44%) was observed in Agroni x BARIsar-9 (C_6) followed by BARIsar6 x BARIsar-9 (C_{18}= -43.08%), SS 75 x BARIsar-9 (C_{20}= -39.60%), BARIsar-6 x BARIsar-9 (C_{15}= -39.42%), Agroni x Tori 7 (C_5= -39.09%), BINAsar-6 x Tori 7 (C_{17}= -38.89%), Shafal x Tori 7 (C_{10}= -34.39%), Shafal x BARIsar-6 (C_7= -33.67%), Shafal x BARIsar-9 (C_{11}= -32.53%), Agroni x BARIsar-6 (C_2= -31.85%). Positive heterosis was not found incase of heterosis over better parent but significant positive heterosis over mid parent found only in BARIsar-6 x BINAsar-6 (C_{12}= 24.24%) (Table 3).

4.1.7 Length of siliqua

Highly Significant and positive heterosis was found in Shafal x Tori 7(C_{10}) both over better parent (25.18%) as well as mid parent (26.31%) values and the rest were observed either non-significant positive or significant negative heterosis (Table 3). Highly negative heterosis was found only on Agroni x BARIsar-9 over better parent (-19.83%) and mid parent (-17.07%). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea* in their study.

4.1.8 Hundred seed weight

Incase of hundred seed weight significant heterosis over better parent and mid parent ranged from -44.00% to 23.33% and -20.00% to 28.00% respectively and the mean value were -6.10% to 4.17% respectively. The significant positive heterosis was not found where the values ranged from 0% (zero) to 23.33% over better parent and 0% (zero) to 28.00% over mid parent (Table 3). Highest significant negative heterosis over better parent (-44.00%) were found in BARIsar-6 × BINAsar-6 (C_{12}) followed by BARIsar-6 x Tori 7 (C_{14}= -12.41%).

4.1.9 Seed yield per plant

The cross Agroni x Tori 7 (C_5) showed highly significant positive heterosis over better parent (191.05%) as well as over mid parent (242.06%) followed by Agroni x BARIsar-6 (C_2), Shafal x BARIsar-6 (C_7), BARIsar-6 x Tori 7 (C_{14}), BARIsar-6 x BARIsar-9 (C_{15}) and Agroni x SS 75 (C_4) (Table 3). Moreover, significant positive heterosis value ranged from 88.25% to 191.05% over better parent and 102.45% to 242.06% over mid parent and produced on an average 32.70% and 51.48% more seed yield per plant than better and mid parent, respectively. The presence of high levels of mid and better parent heterosis indicates a considerable potential to embark on breeding of hybrid or synthetic cultivars. In *Brassica juncea* Tyagi *et al.* (2001) found the highest standard heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant in the cross BIO 772 x Rohini. Adefris *et al.* (2005) observed seed yield showed the highest relative mid parent heterosis that varied from 25% to 145% with a mean of 67% and relative high parent heterosis varied from 16% to 124% with a mean of 53%.

Agroni (P_1)

BARIsar-6 (P_4)

Agroni x BARIsar-6 (C_2)

Plate No. 4. Hybrid Agroni x BARIsar-6 and it's parents at mature stage

4.2 COMBINING ABILITY

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 highly significant for all traits except seed yield per plant indicating that the additive gene actions 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 except hundred seed weight indicating that the non-additive gene actions was 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 Acharya and Swain (2004), Tamber *et al.* (1991) in Indian mustard and Labana *et al.* (1978) in Yellowsarson.

The higher magnitude of gca variance was observed than that of sca variance for all the characters except seed yield per plant. In an earlier study of Verma (2000), reported that sca variance was higher than gca variance (non-additive type) for seed yield per plant. Verma *et al.* (1989) and Labana *et al.* (1978) reported non-additive type of gene action for siliquae per plant, seed yield per plant in yellowsarson,

4.2.1 General combining ability (gca) effects

The gca effects represent the additive nature and magnitude of gene action. A parent with higher positive significant gca effects is considered as a good general combiner and higher significant sca effect considered as a good specific combiner. A parent showing high gca and sca variances is a better parent for creating high yielding specific combination.

The estimates of gca effects are presented in Table 6, The magnitude and direction of the significant gca effects for seven parents provide meaningful comparisons and would give clue to the future breeding programme. The results of gca effects of different characters are presented as follows:

Table 5. Analysis of variance for general and specific combining ability for seed yield and yield contributing components in *Brassica rapa* genotypes

Source of variation	df	Plant Height (cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of siliquae/ plant	No. of seeds/ siliqua	Length of siliqua (cm)	Hundred seed weight (g)	Seed yield/ plant (g)
gca	6	194.567**	64.402**	27.723**	7.517**	11253.95**	31.800**	0.22**	0.0064**	2.431
sca	21	120.990**	4.804**	11.890**	3.260**	9354.54**	9.657**	0.20**	0.0012	8.000**
Error	54	11.394	0.216	1.736	0.766	934.23	2.321	0.06	0.0019	1.313
gca:sca		1.61	13.41	2.33	2.31	1.20	3.29	1.08	5.17	0.30
σ^2g		8.18	6.62	1.76	0.47	211.05	2.46	0.00	0.00	-0.62
σ^2s		109.60	4.59	10.15	2.49	8420.31	7.34	0.14	0.00	6.69

*Significant at P = 0.05 ** Significant at P = 0.01

4.2.1.1 Plant height

The higher significant and negative effects (-6.745) for the parameter was found in Tori 7 (P_6) followed by BARIsar-9 (P_7 = -4.844). Thus, both Tori 7 (P_6) and BARIsar-9(P_7) are good general combiners for breeding dwarf plant type. The highest significant and positive gca effect (7.195) was observed in BINAsar-6 (P_4) (Table 6). Chowdhury *et al.* (2004) found dwarfness in Din-2 in *Brassica rapa* L. Singh *et al.* (2000) obtained dwarfness in YSK-8501 in *Brassica campestris* L. Singh *et al.* (1996) observed dwarf ness in glossy mutant in *Brassica juncea* L.

4.2.1.2 Days to fifty percent flowering

Highest negative significant gca effects (-3.529) was provided by BARIsar-9 (P_7) for Days to fifty percent flowering followed by Tori 7 (P_6= 3.334). Hence the parent BAKIsar-9 (P_7) and Tori 7 (P_6) were desired as general combiner in crosses aimed at promoting earliness in rapeseed (Table 6). Chowdhury *et al.* (2004) found earliness in Din-2 in *Brassica rapa L.* Singh *et al.* (2000) obtained earliness in YSK-8501 in *Brassica campestris/ rapa.* Verma (2000) observed earliness in RC 832 in *Brassica juncea* L.

4.2.1.3 Days to maturity

Parent BARIsar- 9 (P_7) showed highest significant and negative gca effects (-2.237) followed by Tori 7 (P_6 = -1.879) and hence these two cultivars BARIsar-9 (P_7) and Tori 7 (P_6) were the best general combiners for early maturity in rapeseed (*Brassica sp.* L.). The parent BINAsar-6 (P_4) provided highest significant positive gca effects for days to maturity (2.345) followed by Shafal (P_2 = 1.884), and hence these two parents were undesirable general combiners to promote the earliness in rapeseed (*Brassica sp.* L). (Table 6). Chowdhury *et al.* (2004) observed earliness in Din-2 in *Brassica rapa* L. Acharya and Swain (2004) obtained earliness in JC 26 in *Brassica juncea L.* Singh *et al.* (2000) found earliness in YSC-68 in *Brassica campestris* L.

4.2.1.4 Number of primary branches per plant

All the parents showed low values for this parameter. BINAsar-6 (P_4) provided significant and positive gca effects (1.356) followed by Shafal (P_2 = 1.025). The parents BARIsar-9 (P_7), SS75 (P_5) showed the significant but

Table 6. GCA effects and mean performance of 7 parents for 9 characters in a half diallel cross of *Brassica rapa* genotypes

Parents	Characters								
	Plant height (cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of siliquae/ plant	No. of seed/ siliqua	Length of siliqua (cm)	Hundred seed weight (g)	Seed yield/ plant (g)
Agroni	2.455 118.90	2.212** 45	-0.169 87	0.400 6.40	-22.278 71.60	2.597** 24.30	0.092 6.00	-0.012 0.30	0.240 4.00
Shafal	1.000 130.70	2.249** 49	1.844** 98	1.025** 12.00	-33.727* 127.40	1.601* 22.10	0.030 5.50	0.012 0.30	-0.358 6.20
BARIsar-6	1.337 128.80	-0.640** 42	-0.665 93	-0.797* 6.20	5.281 110.80	-0.733 17.00	0.130 6.00	0.049* 0.50	0.647 4.90
BINAsar-6	7.195** 134.80	2.989** 49	2.345** 96	1.356** 12.60	-4.164 137.00	0.954 19.80	-0.118 5.40	-0.032 0.20	-0.039 7.40
SS75	-0.398 121.00	0.063 42	0.761 92	-0.708* 7.60	-37.841** 149.10	0.058 17.50	0.047 5.40	0.005 0.30	-0.806 6.60
Tori 7	-6.745** 103.00	-3.344** 34	-1.879** 87	-0.564 5.80	53.158** 176.00	-1.782** 16.00	0.116 5.60	-0.022 0.30	0.555 5.70
BARIsar-9	-4.844** 108.10	-3.529** 33	-2.237** 87	-0.712* 5.90	39.571** 199.60	-2.696** 17.30	-0.296** 5.60	-0.001 0.30	-0.239 8.20
SE(gi)	**1.042**	**0.143**	**0.407**	**0.270**	**9.433**	**0.470**	**0.077**	**0.013**	**0.354**
SED(gi-gj)	**3.030**	**0.417**	**1.183**	**0.786**	**27.433**	**1.367**	**0.223**	**0.039**	**1.028**

*Significant at P = 0.05 ** Significant at P = 0.01

negative effects (-0.712 and -0.708 respectively). Thus, BARIsar-9 (P_7) and SS75 (P_5) were found good for using in the breeding programme for more primary branches (Table 6). Chowdhury *et al.* (2004) obtained more primary branches on sampad in *Brassica rapa* L. Sheikh and Sing (1998) found more primary branches in poorbijayr in *Brassica juncea* L. Singh *et al.* (2000) observed maximum number of primary branches on YSP-842 in *Brassica campestris* L.

4.2.1.5 Number of siliquae per plant

The higher significant and positive gca effects for the character was observed in Tori 7 (P_5= 53.158) followed by BARIsar-9 (P_6 = 39.571). SS75 (P_5) showed highest significant negative effect (-37.841). Thus, Tori 7 (P_6) and BARIsar-9 (P_7) were the best general combiner to use in hybridization programme to improve number of siliqiiae per plant in rapeseed (*Brassica sp.* L.) (Table 6). Chowdhury *et al.* (2004) found highest number of siliquae in Din-2 in *Brassica rapa* L. Acharya and Swain (2004) observed more siliquae in Pusa Bahar in *Brassica juncea* L. Singh and Murty (1980) obtained maximum number of siliquae per plant in SS-1 in *Brassica campestris* L.

4.2.1.6 Number of seeds per siliqua

Higher significant and positive gca effect was observed in Agroni (P_1 = 2.597). Thus this parent was found best general combiners to increase the number of seeds per silique in rapeseed (*Brassica sp.* L.) (Table 6). Chowdhury *et al.* (2004) found maximum seeds per siliqua in Dhali in *Brassica rapa* L. Acharya and Swain (2004) observed highest seeds per siliqua in Varuna in *Brassica juncea* L. Singh and Murty (1980) obtained more seeds per siliqua in YPS-842 in *Brassica campestris* L.

4.2.1.7 Length of siliqua

No significant positive gca effect was observed in the parents for the trait. Most of them showed insignificant effect except BARIsar-9 (P_7). It showed higher significant negative effect (P_1= -0.297) (Table 6). Thus there was no opportunity to improve the length of siliqua by using these parents due to their poor gca though Sheikh and Singh (1998); and Acharya and Swain (2004) obtained maximum siliqua length in glossy mutant and Pusa Bahar respectively in *Brassica juncea*.

4.2.1.8 Hundred seed weight

Significant and positive gca effects for hundred seed weight was observed in BARIsar-6 (P_3 = 0.049). The other parents showed insignificant effects for the trait. Hence BARIsar-6 (P_3) was the good general combiner to use in crossing for improved seed size (Table 6). Chowdhury *et al.*(2004a) found highest seed weight in Dhali in *Braasica rapa* L. Acharya and Swain (2004) obtained maximum seed weight in Pusa Bahar in *Brassica juncea L.* Singh *et al.* (2000) observed more seed weight in YSC-68 in *Brassica campestris L.*

4.2.1.9 Seed yield per plant

All parents showed insignificant gca effect for the character (Table 6) indicating the parents used in this experiment were not good general combiner for improved seed yield per plant in rape seed (*Brassica rapa.* L.).

4.2.2 Specific combining ability (sca) effects

The specific combining ability effects signify the role of non-additive gene action in the expression of the characters. It denotes the highly specific combining ability leading to highest performance of some specific cross combinations. For this reason it relates to a particular cross. The specific combining ability effects are also seen in relation to their size. High sca effects may arise not only in cross involving high x high combinations, but also in those involving low x high and also from low x low. Thus in practice, some of the low combiners should also be accommodated in hybridization programme. The specific combining ability effects of twenty one crosses for Nine different characters studied are presented in Table 7. The magnitude and direction of the significant effects for the seven parents provide meaningful comparisons and would give clue to the future breeding programme. The results of sca effects of different characters are given below:

4.2.2.1 Plant height

The F_1 of crosses, Tori 7 x BARIsar-9 (C_{21}) and SS75 x Tori 7(C17) showed higher significant and negative sca effects (-20.325 and -10.264, respectively) for plant height. The highest significant and positive sca effects was observed in the cross combination, BINAsar-6 x Tori 7 (C_{17} = 17.102) followed by Agroni x Tori 7 (C_5= 16.142), BARIsar-6 x Tori 7 (C_{14}=11.628), Agroni x SS75 (C_4= 9.095) and Agroni x BARIsar-9 (C_6= 9.068). Thus, the cross combinations BINAsar-6 x Tori 7 (C_{17}), Agroni x Tori 7 (C_5), BARIsar-6 x Tori 7 (C_{14}) and Agroni x SS75 (C_4) could be used for dwarfness of the crop (Table 7). Chowdhury *et al.* (2004) observed dwarfness in PT-303 x Tori-7 in *Brassica rapa* L. Acharya and Swain (2004) obtained dwarfness in Varuna x Pusa Bahar in *Brassica juncea* L.

4.2.2.2 Days to fifty percent flowering

Highest significant and negative value from the parameter was obtained from BARIsar-10 x BARIsar-11 (C_{19} = -2.815) followed by Shafal x BARIsar-6 (C_7= -2.704), Tori 7 x BARIsar-9 (C_{21}= -1.889), Shafal x BINAsar-6 (C_8= -1.667), BARIsar-6 x BINAsar-6 (C_{12}= -1.444) and Agroni x BINAsar-6 (C_3= -1.296) for days to fifty percent flower (Table 7). Significant and positive sca effects was observed in the cross combinations, Agroni x BARIsar-9 (C_6 = 3.222) and BARIsar-6 x Tori 7 (C_{14}=3.222) followed by Agroni x Tori 7 (C_5 = 3.037), BINAsar-6 x BARIsar-9 (C_{18}= 2.111), Agroni x SS75 (C_4= 1.963), SS75 x BARIsar-9 (C_{20}= 1.704), Shafal x Tori 7 (C_{10}= 1.687) and BINAsar-6 x Tori 7 (C_{17}= 1.593). Thus, the cross combinations, C_6, C_{14}, C_5, C_{18}, C_4, C_{20}, C_{10}, and C_{17} provide opportunity for earliness in rapeseed (*Brassica sp.* L) (Table 7). Singh *et al.* (2000) obtained earliness on YSK.-S501 x SS-2 in *B.campestris/rapa.* Singh *et al.* (1996) observed earliness in PR-1 108 x BJ-I235 in *Brassica juncea* L.

4.2.2.3 Days to maturity

The cross combination Shafal x BARIsar-6 (C_7) showed highest significant and negative sca effects (- 4.484) while significant and positive value form the parameter was obtained from Agroni x BARIsar-9 (C_6= 5.375), Agroni x Tori 7 (C_5= 4.799), Agroni x SS75 (C_4= 4.203), BARIsar-6 x BARIsar-9 (C_{15}= 3.797). Hence the cross combination Shafal x BARIsar-6 (C_7) provides opportunity for early maturity in *Brassica juncea* L. (Table 7). Chowdiiury et al. (2004) observed earliness in M-27 x Din-2 in *Bmsaica rapa* L. Acharya and Swain (2004) found early maturity in JC 26 x Jai Idsan in *Brassica juncea* L. Singh et al. (2000) obtained earliness in SS-3 x SS-1 in *Brassica campestris* L.

4.2.2.4 Number of primary branches per plant

The cross combinations Agoni x Tori 7 (C_5= 4.091) and Agroni x BARIsar-9 (C_6 = 2.968) were found to be the best specific combiner to improve plants with more number of primary branches as they showed significant positive sca effects for this trait (Table 7). Chowdhury et al. (2004) found more primary branches in Sampad x Tori-7 in *Brassica rapa* L. Singh et al. (2000) obtained maximum number of primary branches per plant in YSK-8501 x SS-1 in *Brassica campeslris* L. Sheikh and Singh (1998) observed best positive effect in Pusa x Barani in *Brassica juncea* L.

4.2.2.5 Siliquae per plant

Among the cross combinations, Agroni x Tori 7 (C_5= 200.194) showed highest significant and positive sca effects followed by BINAsar-6 x Tori 7 (C_{17}= 172.079), BINAsar-6 x BARIsar-9 (C_{18}= 96.834), Agroni x BARIsar-6 (C_2= 96.334), BARIsar-6 x BARIsar-9 (C_{15}= 94.923), Shafal x BARIsar-9 (C_{11}= 80.464), respectively. On the other hand, the cross Tori 7 x BARIsar-9 (C_{21}= -120.322) showed highest significant but negative sca effect for the trait (Table 7). Chowdhury *et al.* (2004) found maximum siliquae in Sampad x Din-2 in *Brassica rapa* L Acharya and Swain (2004) obtained highest siliquae per plant in Pusa Bahar x JC 26 in *Brassica juncea* L, Singh and Murty (1980) observed more siliquae per plant in YSP-842 x SS-3 in *Brassica campestris* L.

4.2.2.6 Number of seeds per siliqua

Among the cross combinations, BARIsar-6 x BINAsar-6 (C_{12}= 5.959) exhibited highest significant and positive sca effects for seeds per siliqua. The other cross combinations showed insignificant or negative sca effects. Hence BARIsar-6 x BINAsar-6 (C_{12}) was the best specific combiner to increase the number of seeds in the siliqua for yield improvement (Table 7). Chowdhury *et al.* (2004) found highest seeds per siliqua in Dhali x Sampad in *Brassica rapa* L. Acharya and Swain (2004) observed maximum seeds per siliqua in BM 20-12-3 x Pusa Bahar in *Brassica juncea* L. Singh *et al.* (2000) obtained more seeds per siliqua in YSP-842 x YSK-8501 in *Brassica campestris* L.

Table 7. SCA effects for 9 characters in half diallel cross of *Brassica rapa* genotypes

SCA effects	Characters								
	Plant height (cm)	Days to 50% flowering	Days to maturity	No. of primary branches	No. of siliquae/ plant	No. of seed/ siliqua	Length of siliqua (cm)	Hundred seed weight (g)	Seed yield/ plant (g)
Agroni × Shafal (C1)	-5.737	-1.889**	-0.313	-1.672*	-52.588	1.905	-0.270	-0.0534	-1.569
Agroni × BARIsar-6 (C2)	-0.188	-0.667	-1.315	1.184	96.334**	-1.985	-0.069	-0.0176	3.932**
Agroni × BINAsar-6 (C3)	-0.998	-1.296**	2.186	-1.170	-41.151	0.685	0.013	0.0324	-0.273
Agroni × SS 75 (C4)	9.095**	1.963**	4.203**	1.761*	-30.473	1.261	0.387	0.0565	0.752
Agroni × Tori 7 (C5)	16.142**	3.037**	4.799**	4.091**	200.194**	-2.696	-0.038	0.0363	7.576**
Agroni × BARIsar-9 (C6)	9.068**	3.222**	5.375**	2.968**	24.958	-4.048**	-0.572*	-0.0192	-1.067
Shafal × BARIsar-6 (C7)	-4.751	-2.704**	-4.484**	0.259	71.520*	-2.888*	-0.184	0.0371	3.673**
Shafal × BINAsar-6 (C8)	-3.376	-1.667**	0.973	-0.195	-34.036	-0.925	-0.098	0.0185	0.471
Shafal × SS 75 (C9)	5.917	0.259	2.190	0.403	-12.891	0.175	-0.189	0.0279	0.000
Shafal × Tori 7 (C10)	8.031*	1.667**	2.230	-1.341	-12.724	-1.998	1.288**	0.0041	-0.487
Shafal × BARIsar-9 (C11)	-2.120	0.852	-0.745	1.006	80.464**	-0.672	-0.193	0.0012	0.562
BARIsar-6 × BINAsar-6 (C12)	-4.879	-1.444**	0.515	0.028	-69.910*	5.959**	0.628*	-0.0613	-1.247
BARIsar-6 ×SS 75 (C13)	-8.263*	0.481	0.966	-0.842	-9.132	-0.338	-0.078	-0.0246	-0.599
BARIsar-6 × Tori 7 (C14)	11.628**	3.222**	1.072	1.115	45.335	-1.519	-0.376	-0.0297	1.310
BARIsar-6 × BARIsar-9 (C15)	9.560**	0.074	3.797**	0.962	94.923**	-2.775	-0.331	-0.0202	2.106
BINAsar-6 × SS 75 (C16)	-0.845	0.185	2.102	-1.148	15.049	-0.789	-0.072	0.0290	0.451
BINAsar-6 ×Tori 7 (C17)	17.102**	1.593**	2.828*	1.328	172.079**	-3.752*	-0.661**	0.0039	1.059
BINAsar-6 ×BARIsar-9 (C18)	7.472*	2.111**	-1.881	-0.258	96.834**	-3.669*	0.007	0.0275	1.033
SS 75 × Tori 7 (C19)	-10.264**	-2.815**	-3.144*	0.215	5.590	1.697	0.382	-0.0349	0.364
SS 75 × BARIsar-9 (C20)	16.062**	1.704**	0.271	-0.061	11.745	-3.473*	0.034	-0.0232	-0.993
Tori 7 ×BARIsar-9 (C21)	-20.325**	-1.889**	-0.889	-0.904	-120.32**	2.581	-0.110	0.0029	-2.504*
SE(sij)	**3.030**	**0.417**	**1.183**	**0.786**	**27.433**	**1.367**	**0.223**	**0.0390**	**1.028**
SED(sij-sik)	**4.501**	**0.620**	**1.757**	**1.167**	**40.754**	**2.031**	**0.331**	**0.0580**	**1.528**
SED(sij-skl)	**4.210**	**0.580**	**1.643**	**1.092**	**38.121**	**1.900**	**0.309**	**0.0540**	**1.429**

*Significant at P = 0.05 ** Significant at P = 0.01

4.2.2.7 Length of siliqua

Among the cross combinations, Shafal x Tori 7 (C_{10}= 1.288) showed highest significant and positive sca effects where BARIsar-6 x BINAsar-6 (C_{12}= 0.628) showed moderate significant and positive sca effect. On the other hand, the combination BINAsar-6 x Tori 7 (C_{17}= -0.661) showed highest significant but negative sca effect for the trait where Agroni x BARIsar-9 (C_6= -0.572) showed moderate significant and negative sca effect (Table 7). Sheikh and Singh (1998) and Acharya and Swain (2004) observed maximum siliqua length In Pusa Barani x Glossy mutant and BM 20-12-3 x Pusa Bahar respectively in *Brassica juncea* L.

4.2.2.8 Hundred seed weight

All crosses combinations showed insignificant sca effect for the character (Table 7). Highest sca effect was found in Agroni x SS 75 (C_4= 0.0565) followed by Agroni x Tori 7 (C_5= 0.0363) . Highest negative sca effect was found with BARIsar-6 x BINAsar-6 (C_{12}= -0.0613) cross followed by Agroni x Shafal (C_1= -0.0534).

4.2.2.9 Seed yield per plant

The cross combinations Agroni x Tori 7 (C_5) exhibited significant and positive sca effect (7.576) followed by Agroni x BARIsar-6 (C_2= 3.932), Shafal x BARIsar-6 (C_7= 3.673) for seed yield per plant. The other combinations showed either significant negative or insignificant sca effects. Thus, Agroni x Tori 7 (C_5), Agroni x BARIsar-6 (C_2), Shafal x BARIsar-6 (C_7) were the best specific combinations for the improvement of seed yield per plant in *Brassica rapa* L. (Table 7). Chowdhury *et al.* (2004) obtained highest seed yield in M-27 x Din-2 in *Brassica rapa* L. Acharya and Swain (2004) found maximum seed yield in Pusa Bold x Pusa Bahar in *Brassica juncea* L. Singh *et al.* (2000) observed more seed yield per plant in YSP-842 x YSK-8501 in *Brassica campeslris* L.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A 7x7 half-diallel cross analysis in rapeseed (*Brassica rapa* L.) was carried out during November, 2006 to March, 2007 with the aim to estimate magnitude of heterosis over mid parent and better parent and combining ability for seed yield and other important quantitative traits to identifying best parents and specific combiners of rapeseed.

The parental genotypes used in the study were Agroni, Shafal, BARIsar-6, BINAsar-6, SS 75, Tori 7 and BARIsar-9 which were chosen for their genetic divergence and diverse origin. The characters studied were plant height, days to 50% flowering, days to maturity, no. of primary branches per plant, no. of siliquae per plant, no. of seeds per siliqua, length of siliqua, hundred seed weight per plant and seed yield per plant.

Out of twenty one crosses, the hybrids Shafal x BARIsar-6, Shafal x BINAsar-6, and BARIsar-6 x BINAsar-6 showed desirable negative heterosis over both better and mid parent for the characters days to 50% flowering. The hybrid Agroni x Tori 7 found to be the best one for number of primary branches per plant followed by Agroni x BARIsar-9 and Agroni x BARIsar-9. The cross Agroni x Tori 7 produced maximum heterosis for number of siliquae per plant followed by Agroni x BARIsar-6, BINAsar-6 x Tori 7, Shafal x BARIsar-6, Agroni × BINAsar-6, BARIsar-6 x Tori 7 and BARIsar-6 x BARIsar-9. The crosses Shafal x Tori 7 and Agroni x BARIsar-9 showed maximum length of siliqua and number of seeds per siliqua respectively. The crosses Agroni x SS 75 and Shafal x SS 75 showed maximum heterosis for hundred seed weight. Most of the hybrids showed significant positive heterosis for plant height, however, the desirable significant negative heterosis was found in the cross Tori 7 x BARIsar-9 over mid parent and over better parent. For seed yield per plant the cross Agroni x Tori 7 was found to be the best one followed by cross Agroni x BARIsar-6, Shafal x BARIsar-6 and BARIsar-6 x Tori 7. Selection out of these crosses in the subsequent generations might produce some suitable segregants.

Analysis of combining ability following Griffing's approach showed significant gca and sca variances ($P < 0.05$-0.01) for all the characters studied, indicating the role of both additive and non-additive components in the genetic system controlling these characters. The higher magnitude of gca variance was observed than that of sca variance for all the characters except seed yield per plant, which indicated the preponderance of additive component in their expression. Estimates of gca effects for different characters suggested that parent BARIsar-9 (P_7) is the best general combiner for dwarfness and earliness. Tori 7 (P_6) was also good general combiner for dwarfness and earliness along with more primary branches per plant, siliquae per plant and length of siliqua. BINAsar-6 (P_4) and Shafal (P_2) showed desirable gca for primary branch per plant. BARIsar-6 (P_3) and Agroni (P_1) showed desirable gca for hundred seed weight and seeds per siliqua respectively.

The sca estimates of various characters revealed that cross Tori 7 ×BARIsar-9 (C_{21}) was the best specific combiner for dwarfness followed by SS 75 x Tori 7 (C_{19}) and which was also reflected the mean perfomance (Table- 4). The best specific combiners were Agroni × Tori 7 (C_5) for primary branches per plant, secondary branches per plant, siliquae per plant and seed yield per plant; Shafal × BARIsar-6 (C_7) for early flowering, early maturity and seed yield per plant; Shafal × Tori 7 (C_{10}) for length of siliqua; BARIsar-6 × BINAsar-6 (C_{12}) for seeds per siliqua and SS 75 × Tori 7 (C_{19}) for earliness.

Considering the estimated genetic parameters as well as heterotic effects, Shafal x BARIsar-9 seemed to be best one followed by Tori 7 x BARIsar-9, Agroni x Tori 7, Shafal x Tori 7, Agroni x BARIsar-9, Tori 7 x BARIsar-9 and Shafal x BARIsar-6 for different characters. The parent BARIsar-9 was found good general combiner and for earliness and dwarfness based on the gca effects and per se performance. This parent could be effectively used in future hybridization programme for developing high yielding and short duration varieties of rapeseed (*Brassica rapa* L.) The F_1s Agroni x BARIsar-6 and Agroni x Tori 7 found best specific combiners for seed yield per plant, number of seeds per siliqua, days to maturity and number of primary branches per plant which might be used to produced high yielding hybrid varieties if suitable pollination control mechanisms would become available.

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APPENDICES

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

I.A. Physical Composition of the Soil

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

I.B. Chemical Composition of the Soil

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

Appendix II. Monthly average temperature, number of rainy days, relative humidity and total rainfall of the experiment site during the period from October, 2006 to April, 2007

Year	Months	*Air Temperature (^{0}C)			Number of Rainy Days**	Relative Humidity (%)	**Rainfall (mm)
		Max.	Min.	Mean			
2006	October	32.3	24.7	28.50	07	72	88
	November	29.7	20.1	24.90	04	65	05
	December	26.9	15.8	21.35	00	68	00
2007	January	24.6	12.5	18.55	00	66	00
	February	27.1	16.8	21.95	00	64	00
	March	31.5	19.6	25.55	10	47	160
	April	33.7	23.7	28.70	12	65	87
Total		205.80	133.2	169.50	33	--	--

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