HETEROSIS AND COMBINING ABILITY ANALYSIS IN *Brassica rapa* L.

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CERTIFICATE

This is to certify that the thesis entitled **"HETEROSIS AND COMBINING ABILITY ANALYSIS IN Brassica rapa L."** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING,** embodies the result of a piece of bonafide research work carried out by **Jubaida Ferdous, Registration No. 17-08260**, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

I further certify that any help or sources of information as has been availed of during the course of this work has been duly acknowledged & style of the thesis have been approved and recommended for submission.

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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 elI)	*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
Heterosis Over Mid Parent	HMP
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
Heterosis Over Better Parent	HBP
Triple Super Phosphate	TSP
Muriate of Potash	MoP
Emulsifiable concentrate	EC
Randomized Complete Block Design	RCBD
Mean of F1 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
North	N
East	E

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ABSTRACT

Field experiment on rapeseed (*Brassica rapa* L.) involving 7 x 7 full diallel cross including reciprocal were conducted at the Sher-e-Bangla Agricultural University, Dhaka during the winter season of 2018-2019. 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 siliqua per plant, no. of seeds per siliqua, length of siliqua and hundred seed weight per plant. Out of forty-one crosses, the hybrid SAU proposed 4 ×BARI Sar-15 was found to be the best for number of primary branches per plant. While the cross BARI Sar-6 × Local Tori-7 produced maximum number of secondary branches per plant. The cross BARI Sar-6 × Local Tori-7 produced maximum number of siliqua per plant. maximum length of siliqua was found in SAU proposed 4 × BARI Sar-6 whereas BARI Sar-17×BARI Sar-14 produced the highest number of seeds per siliqua. The highest seed yield was also observed in the hybrid Local Tori-7×Yellow Special. Highly significant positive heterosis was found in the cross SAU proposed 4 × BARI Sar-17 over better parent and in SAU proposed 4 ×BARI Sar-15 over mid parent for plant height. The hybrid SAU proposed 4 ×Yellow Special was found to have the best heterotic effect for number of primary branches per plant. Highest significant positive heterosis for number of secondary branches per plant and for number of silique per plant over better parent as well as mid parent was found in BARI Sar-6 × Local Tori-7. Significant negative heterosis over mid parent and better parent was found in SAU proposed 4 and thus these can be used for producing variety with earliness. Highly significant and positive value for both mid parent and better parent was represented by Local Tori-7 × Yellow Special. The variance due to GCA and SCA were highly significant for all the characters studied. The parent BARI Sar-17 was an excellent general combiner for dwarfness. For number of secondary branches, Seed yield per plant and the number of siliqua highly significant and positive GCA effects were observed in Local Tori-7. BARI Sar-17 exhibited the highest significant and positive GCA effects for seed per silique and can be considered as a good general combiner. Yellow Special × SAU proposed 4 was the best specific combiner for dwarfness where as Local Tori-7 × BARI Sar-17 for primary branches per plant and Local Tori-7 × BARI Sar-15 siliqua per plant. Yellow Special × BARI Sar-14 was the best specific combiner for seed yield per plant and SAU proposed 4 ×Local Tori-7 for seeds per siliqua.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

Rapeseed is a major oilseed crop contributing a major share to the total edible oil production in Bangladesh. *Brassica rapa* belongs to the family Brassicaceae. It is commonly known as field mustard, turnip mustard or yellow sarson. Mustard seeds contain 42% oil and 25% protein (Khaleque, 1985). It is the second most important oil crop providing about 13% of the world's edible oil after soybean. Total area of mustard and rapeseed in the world is 34.33 million hectares (FAO, 2013). In 2017-2018, the edible oil production from major oilseed crops in the world is 578.67 million tons where rapeseed contributes 71.52 million tons. (www.statistica.com).

Rapeseed (Brassica rapa) is a cross pollinated oil crop. It belongs to the family Brassiceae. Brassica is an important genus of plant kingdom consisting of over 3200 species which has a highly devise morphology. The genus *Brassica* has generally divided into three main 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). On the otherhand, rapeseed includes *B. rapa* L. (turnip rape, 2x =20) and *B. napus* L. (rape, 4x = 38) (Yarnell, 1965). In addition, it is one of the diploid progenitor parental species which contributed A genome to the important oilseed crops, *Brassica juncea* ($2n$ = 36, AABB) and *Brassica napus* ($2n$ = 38, AACC).

Rapeseed and mustard occupy the first position in oil crops in Bangladesh covering cultivated area 9,75,000 acres which produced 9,27000 metric tons oil seed during 2017-2018 (BBS, 2018). *Brassica rapa* is the most popular and major oil seed crop in Bangladesh and covers about 71% of the total oil crops acreage of Bangladesh. Still there is a lacking of edible oil in Bangladesh. Therefore, we need to import oil and oilseeds to meet up the deficit.

Our internal production can meet only about 21% of our consumption and the rest 79% is needed to import (Begum et al., 2012). To fulfill this lacking the country imports 0.246 million tons of mustard oil that costs 301.847 million Tk. (BBS, 2018).

Oil is used for healthy balanced diet, hair dressing, body massing, to prepare different types of pickles as well as industrial purposes. It is a high energy food along with a carrier of fat soluble vitamins like A, D, E and K. For human health, 20-25% of calories should come from fats and oils.

Although oilseed crops play a vital role in human diet the consumption rate of oil in our country, it is far below than that of balanced diet (6 g oil per day per capita but the optimum requirement is 35 g per head per day). There is plenty of scope to increase yield through breeding superior varieties. If the varieties of rapeseed and mustard can be identified with early maturity, rapid response to high fertility, has large seed size and high oil content, their production potential may be well exploited.

The oil content of mustard in Bangladesh varied from 30 to 40 percent depending on the variety, climate and production condition (Rahman *et al.,* 1993). Intra-specific hybridization is a possible way of improving the varieties of rapeseed by combining and selecting for the desirable character(s). For doing this, the most important aspects are the choice of parents for hybridization and selection of best lines from hybrid progenies. Information on heritability of materials in early generations, gene actions involved and heterosis of different degrees is very useful for the purpose of selection among the hybrid populations.

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

Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions that is involved in the expression of quantitative traits. Genetic information about the combining ability helps not only to select suitable parents for hybridization but also to isolate the promising early generation hybrids for further exploitation in breeding programs. Combining ability studies provide better estimates of general and specific combining abilities (GCA, SCA). This studies are useful in classifying parental lines in terms of their hybrid performance. In cross pollinated crops like rapeseed (*Brassica rapa*) these studies are useful in assessing the exact ability of the parents which, when crossed, would give more desirable segregates. This helps in choosing the parents for hybridization. Therefore, the present work was undertaken with the following objectives.

1. To identify potential parents and promising cross combinations to develop HYV and hybrid varieties.
2. To study the nature and extent of gene action involved in controlling the traits.
3. To estimate heterosis for different yield contributing characters of *Brassica rapa* L.

CHAPTER II
REVIEW OF LITERATURE

In the field of Brassica breeding, many researchers have 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. Therefore, relevant information available in the literature pertaining to the combining ability, heterosis and associations of characters of rapeseed and mustard are reviewed in this section.

2.1. HETEROSIS

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

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

Adefris and Heiko (2005) conducted an experiment to generate information on heterosis. Nine inbred parents and their 36 F_1 s, were evaluated for 12 traits at three locations in Ethiopia. Analysis of variance showed the presence of significant heterosis for all 12 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, 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. The 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*. Among the crosses, 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, YS151 x Pusa gold (dwarf), and MYSL-203 x EC-333596 showed highest heterosis up to 150.33 percent over best parent and 43.38 percent over commercial variety. 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.

Satyendra *et al.* (2004) evaluated twenty-one Indian mustard hybrids and their parents for eight quantitative traits such as 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. All these hybrids showed high heterosis over the best cultivar.

Liersch *et al.* (2004) performed a breeding approach known as CMS ogura system of oilseed rape hybrid cultivars in Poland to evaluate yield and yield component variability of F1 hybrids and their parental lines along with heterosis effect and qualitative traits: oil and glucosinolate content in seeds. They found that composite hybrid cultivars resulted 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) conducted an experiment on Indian mustard strains/cultivars Varuna, Shekhar, Vardan, Laha 101, Pusa Bold, RH-30, Pusa Basant, NDR-8501 and Kranti. They were crossed in a diallel mating design excluding reciprocals. The crosses exhibited highly significant heterosis for most of the characters viz; plant height, branches per plant, siliqua on main raceme, seed yield per plant, thousand seed weight, seed oil content, de-fatted seed content and protein content.

Mahak *et al* (2003) studied heterosis for 11 different characters such as 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%).

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

Swarnkar *et al.* (2001) conducted heterosis analyses using 36 F_1 hybrids, 36 F_2 generations and parents obtained from 9 x 9 diallel mating design for eleven quantitative traits, viz. days to flowering, plant height (cm), number of primary branches, number of secondary branches, length of main raceme (cm), number of siliqua 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 found to be present in four crosses, KR-5610 x PR-is (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.

An experiment was carried out 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 is the indicator of 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 stated 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 GSC3AOO 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 GSC3AOO x NPN02. The lowest glucosinolate concentration was observed in GSC3AOO x TERI(OE)R983, with mean performance of 80.6 micro mol/g. The highest negative heterobeltiosis for linolenic acid content was observed in HN59802 x NPNO1, with a mean performance of 10.7%. The highest negative heterobeltiosis for erucic acid content was observed in TERI(OE)R983 x GSC3AOO, 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) conducted an experiment 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 heterosis over 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 per plant in parents, while 13 crosses showed 11.67% more seeds per 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.

Qi *et al.* (2000) investigated heterosis in hybrids of 6 cultivars of *Brassica carnpestris*. 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%.

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. 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_1's and 28 reciprocal F_1's (R F_1's). 24 F_1 s and 21 RF_1's showed significant positive heterosis for seed yield over mid parent (MP) and 16 F_1's and 21 RF_1's over the better parent (BP).

Zhang *et al.* (2002) crossed three double low cytoplasmic male sterile (CMS) and five double low restorer lines of *Brassica napus* and they analysed resulting 15 hybrids for 8 yield components. In this experiment they found that the CMS F_1 had significant heterosis, particularly for yield, but that predicted for the F_2 was lower. They also stated that the major yield components, total silique number/plant had the highest heterosis and would be of more value in a breeding program than trying to increase seed number per silique or 1000-seed weight.

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.

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.

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 F1 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.

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 BlO 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 Xianyou 91S, and the combining ability of 40 test cross lines. The results of identification test showed that among 47 combinations yielding over the control Xianyou 15, seventeen ones with 402S and three ones with Xianyou 91S over yielded more than 20%, reaching the significant level of 1%; and among 51 combinations yielding over their corresponding higher yield parents, 18 ones with 402S and nine ones with Xianyou 91S over yielded at 5 or 1% significant level.

Thakur *et al.* (1997) evaluated nine diverse inbreeds and their 36 F_1 hybrids from a diallel cross for yield and yield 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 examined unidirectional dominance for most of the traits studied and the cross G587027 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 showed 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 analyzed thirty cultivars from various sources and clustered into three distinct clusters based upon five morphological characteristics and yield components such as 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, silique 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 program.

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. F_1 were earlier maturing than resynthesized lines and heterosis 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 families from each of the parents. The use of S_1 families generally produced 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, number 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 F1 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 stated that characters such as no. of primary and secondary branches, number of siliqua per 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, YST151 x Torch and PT303 x Torch, each had one Indian and one foreign parent. 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/viariation between genotypes is not always positively associated with heterosis.

Zheng and Fu (1991) worked with 8 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.

Engqvist and Becker (1991) analyzed Heterosis and epistasis in spring oil seed rape (*Brassica napus*) by comparing generation means for 10 agronomic traits. Parents, F_2, F_3 and F_5 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 at (1991). The seedling stage of F_1 hybrids showed fairly strong heterosis; there was also heterosis in seed yield. The F_1 hybrids yielded 19.2-34.8% more than CV. Kunming -Gaoke.

Kumar *et al.* (1990) evaluated 16 parents and 39 F1s 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 R864 x Varuna. The cross RLM198 x RH30 also recorded highest heterobeltiosis for secondary branches.

In a similar experiment 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.

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

Badwal and Labana (1987) studied *Brassica juncea* for seed yield/plant and other eight related characters. In F_1, they found positive and significant heterosis for almost all traits. In a study for heterosis and cytoplasmic-genetic male sterility in oil seed rape (Brassica napus L) through diallel cross of six Canadian and European cultivars. Grants (1985) found heterosis for seed yield up to 72% over better parents.

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

Lefort (1982) studied 140 F_1 hybrids of winter oil seed rape (*Brassica napus* L.) and reported that for seed yield average hybrid vigor was 23.5% on the basis of the mid parent. In a few cross combinations the value reached up to 50% in relation to the best parent value. This 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 silique/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 on the other hand, the specific combining ability is expressed through average performance of the parent in a specific 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 which indicates the presence of heterosis in the crosses through conducted an experiment during the rabi seasons of 1998-2000 to study the nature of combining ability for seed yield and other yield-attributing characters through line x tester analysis in rape (*Brassica napus* var. *oleifera*). They derived forty-five F_1 s from the crosses of two cytoplasmic male sterile lines (Ogura, ISN706a) 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, GSL6067, 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.

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 (p) 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.

Cheema *et al.* (2004) conducted an experiment during 1999-2002 and determined 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. 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) observed and studied the nature and magnitude of combining ability of parents and crosses (F_1 s) 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.

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

Prasad *et al.* (2002) examined 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) analyzed combining ability using 36 F1 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.

Pietka *et al.* (2001) carried 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.

Matho and Haider (2001) worked with the magnitude of specific combining ability (sca) effects which 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.

Huang *et al.* (2000) studied three rapeseeds (*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 at.* (1999) studied the combining ability in *Brassica campestris* L. Comparison between 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

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.

Sheikh and Singh (1998) analyzed 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.

Yadav and Yadava (1996) conducted a study of 8 x 8 diallel analysis (excluding reciprocals), 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.

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

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 et al. (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 F1 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 T!039 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.

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

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 juricea. 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, B1C1439, 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, CARS 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 program.

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 F_1 and parents and F_2 and parents were sown in 1988-89 and 1989-90, respectively. Data were recorded on number of days to first flowering and maturity. Analysis of variance of combining ability in both generations revealed that GCA variance due to lines and testers were significant for all characters except for maturity in the F_1 and additive effects in the F_2 were greater than in the F_1. Among the lines, RSK11 was the best general combining parent and was seen to be a suitable parent for evolving lines having short period of maturity. Among the testers, Varuna was a good general combiner in the F2 generation and an average general combiner in the F_1 generation.

Chauhan *et al.* (1990), stated that a wide variation in yield and its component when 36 *Brassica juncea* crosses and their 15 parents were tested. Significant difference was 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_1 s for nine characters including seed yield/plant. Both additive and non-additive gene action was found in the inheritance of characters except days to flower, plant height and primary branches. Preponderance of additive gene action for days to maturity, number of secondary branches/plant number of silique/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 siliqua4lant and seed yield/plant. The hybrids YS-52 x M-27 exhibited highest significant SCA effect for seed yield/plant.

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 siliqua4lant, 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.

Wani and Srivasiava (1989) gave information on combining ability derived from data on seven characters in 23 lines of *Brassica juncea* and their F_1 and F_2 hybrids indicating 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.

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.

Chaudhury *et al.* (1988) examined 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.

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 the 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.

Badwal and Labana (1987) analyzed 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.

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 RLM 198. The best crosses for further selection were RLM822 xVaruna and RLM19S X RH3O.

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 Ri 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, RLM24 x RH30 and RLM82 X Varuana showed desirable significant SCA effect for seed yield and plant height.

Prakash *et al.* (1987) analyzed 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 D1R146 and RCL1 017 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 RH771 0 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_1 s. 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 nonadditive 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.

CHAPTER III

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, 2018 to Mid-February, 2019. The location of the experimental site was situated at $23^0 41'$ N latitude and $90^0 35'$ 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 Soil and Climate

The experimental site was situated in the subtropical zone. The soil of the experimental site is in Agro ecological region of "Madhupur Tract" (AEZ No. 28). The soil was clay loam in texture and olive gray with common fine to medium distinct dark yellowish brown mottles. The pH was 5.47 to 5.63 and organic carbon content was 0.82% (Appendix II). The records of air temperature, humidity and rainfall during the period of experiment were noted from the Bangladesh Meteorological Department, Agargaon, Dhaka (Appendix III).

3.3 Plant materials

A total number of 48 (forty-eighty) genotypes were used in this experiment where 7 (seven) were parents and remaining 42 (forty-two) were F_1 (Hybrid). Forty-eight genotypes were collected from Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh (Table 1).

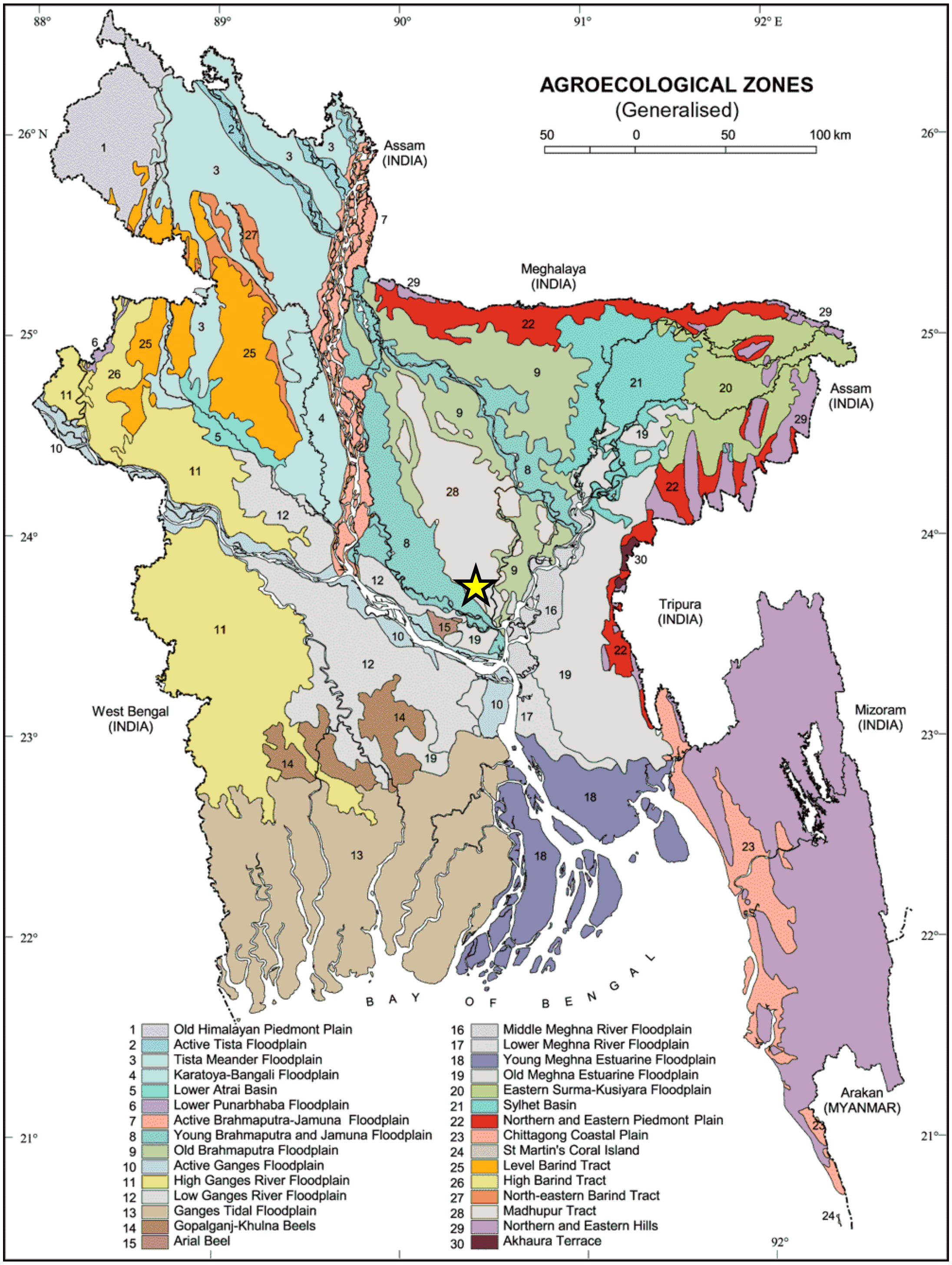
3.4 Experimental design and layout

Forty-one F_1 s along with their seven parents were grown on October 29, 2018. The seeds were sown continuously in a randomized block design with 3 replications. The total area of the experiment was $25m \times 20m = 500m^2$. Each F_1 line and their parents comprised of single rows of 6 m long with a spacing of 1m between rows and line sowing method was used during seed sowing. The genotypes were randomly distributed to each row within the blocks in each replication. The seedling emerged three to four days after sowing. Plant spacing within the rows was maintained by thinning after 15 days of seedling emergence.

Plate 1. Photograph showing the experimental field at SAU

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 ensure good tillage. Weeds and other stubbles were removed carefully from the experimental plot and leveled properly. The final land preparation was done on 26 October, 2018.



★ **The experimental site under study**

Figure 1: Location of the experimental field

Table 1. Materials used for the experiment

Sl. No.	Name of parents	Sl. No.	Name of parents	Sl. No.	Name of parents
1.	BARI Sar-14	4.	Local Tori-7	7.	BARI Sar-6
2.	SAU proposed 4	5.	BARI Sar-17		
3.	Yellow Special	6.	BARI Sar-15		
Sl. No.	**F_1 Hybrids**	**SL. No.**	**F_1 Hybrids**		
1.	BARI Sar-14 × SAU proposed 4	22.	Local Tori-7 × BARI Sar-17		
2.	BARI Sar-14 × Yellow Special	23.	Local Tori-7 × BARI Sar-15		
3.	BARI Sar-14 × Local Tori-7	24.	Local Tori-7 × BARI Sar-6		
4.	BARI Sar-14 × BARI Sar-17	25.	BARI Sar-17 × BARI Sar-14		
5.	BARI Sar-14 × BARI Sar-15	26.	BARI Sar-17 × SAU proposed 4		
6.	BARI Sar-14 × BARI Sar-6	27.	BARI Sar-17 × Yellow Special		
7.	SAU proposed 4 × BARI Sar-14	28.	BARI Sar-17 × Local Tori-7		
8.	SAU proposed 4 × Yellow Special	29.	BARI Sar-17 × BARI Sar-15		
9.	SAU proposed 4 × Local Tori-7	30.	BARI Sar-17 × BARI Sar-6		
10.	SAU proposed 4 × BARI Sar-17	31.	BARI Sar-15 × BARI Sar-14		
11.	SAU proposed 4 × BARI Sar-15	32.	BARI Sar-15 × SAU proposed 4		
12.	SAU proposed 4 × BARI Sar-6	33.	BARI Sar-15 × Yellow Special		
13.	Yellow Special × BARI Sar-14	34.	BARI Sar-15 × Local Tori-7		
14.	Yellow Special × SAU proposed 4	35.	BARI Sar-15 × BARI Sar-17		
15.	Yellow Special × Local Tori-7	36.	BARI Sar-15 × BARI Sar-6		
16.	Yellow Special × BARI Sar-17	37.	BARI Sar-6 × BARI Sar-14		
17.	Yellow Special × BARI Sar-15	38.	BARI Sar-6 × SAU proposed 4		
18.	Yellow Special × BARI Sar-6	39.	BARI Sar-6 × Yellow Special		
19.	Local Tori-7 × BARI Sar-14	40.	BARI Sar-6 × Local Tori-7		
20.	Local Tori-7 × SAU proposed 4	41.	BARI Sar-6 × BARI Sar-17		
21.	Local Tori-7 × Yellow Special	42.	BARI Sar-6 × BARI Sar-15		

Note: BARI-Bangladesh Agricultural Research Institute, BINA - Bangladesh Institute of Nuclear Agriculture

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

Parents / Parents	BARI Sar-14	SAU proposed 4	Yellow Special	Local Tori-7	BARI Sar-17	BARI Sar-15	BARI Sar-6
BARI Sar-14	-	BARI Sar-14 × SAU proposed 4	BARI Sar-14 × Yellow Special	BARI Sar-14 × Local Tori-7	BARI Sar-14 × BARI Sar-17	BARI Sar-14 × BARI Sar-15	BARI Sar-14 × BARI Sar-6
SAU proposed 4	SAU proposed 4 × BARI Sar-14	-	SAU proposed 4× Yellow Special	SAU proposed 4× Local Tori-7	SAU proposed 4× BARI Sar-17	SAU proposed 4× BARI Sar-15	SAU proposed 4× BARI Sar-6
Yellow Special	Yellow Special × BARI Sar-14	Yellow Special × SAU proposed 4	-	Yellow Special × Local Tori-7	Yellow Special × BARI Sar-17	Yellow Special × BARI Sar-15	Yellow Special × BARI Sar-6
Local Tori-7	Local Tori-7 × BARI Sar-14	Local Tori-7 × SAU proposed 4	Local Tori-7 × Yellow Special	-	Local Tori-7 × BARI Sar-17	Local Tori-7 × BARI Sar-15	Local Tori-7 × BARI Sar-6
BARI Sar-17	BARI Sar-17 × BARI Sar-14	BARI Sar-17 × SAU proposed 4	BARI Sar-17 × Yellow Special	BARI Sar-17 × Local Tori-7	-	BARI Sar-17 × BARI Sar-15	BARI Sar-17 × BARI Sar-6
BARI Sar-15	BARI Sar-15 × BARI Sar-14	BARI Sar-15 × SAU proposed 4	BARI Sar-15 × Yellow Special	BARI Sar-15 × Local Tori-7	BARI Sar-15 × BARI Sar-17	-	BARI Sar-15 × BARI Sar-6
BARI Sar-6	BARI Sar-6 × BARI Sar-14	BARI Sar-6 × SAU proposed 4	BARI Sar-6 × Yellow Special	BARI Sar-6 × Local Tori-7	BARI Sar-6 × BARI Sar-17	BARI Sar-6 × BARI Sar-15	-

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), 86 kg Muriate of Potash (MoP), 250 kg Gypsum, 3 kg Zinc oxide and Boron 1 kg per hectare. At this recommended rate 270 kg Cowdung, 6.5 kg Urea. 4.5 kg TSP, 2.25 kg MoP 3.9 kg Gypsum, 0.09 kg Zinc oxide and Boron 0.03 kg were applied into the experimental plots. 50% urea were applied as basal dose. The rest amount of urea was applied as top dressing after 25 days of sowing and total amount of TSP, MoP, Gypsum, Zinc Oxide and Boron was applied during final land preparation.

3.7 Irrigation and drainage:

In the early stage of seedling, irrigation was done thrice. One post sowing flood irrigation was given after the seeds were sown to bring proper moisture condition of the soil and to ensure uniform germination of the seeds. A good drainage system was maintained for immediate release of rainwater from the experimental field during the growing period.

3.8 Seed sowing

Seeds of each genotype were sown in row on October 29, 2018 by hand uniformly where 1 m row to row distance was maintained. After sowing the seeds, they were covered with soil carefully so that no clods were on the seeds.

3.9 Intercultural operation, insect and disease control

Necessary intercultural operations were done during the crop period for normal growth and development of the plants. Thinning of seedlings was done during first weeding after 12 days of germination. The second weeding was done before flowering. Top dressing of urea was done after the second weeding. Aphid infestations were found in the crop during the siliquae development stage. To control aphid, diazinon 60 EC at the rate of l ml per liter was applied. No remarkable disease attack was observed during the growing season.

3.10 Crop harvesting

Harvesting was done from 30th January to 16th February, 2019, depending upon the maturity of crop varieties and their F_1 s.

3.11 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, Number of secondary branches, Days to 50 % flowering, Days to maturity. Number of siliqua per plant, Number of seeds per siliqua, Length of siliqua , 1000 seed weight and Seed yield per plant were recorded.

3.11.1 Days to 50% flowering

Days to 50% flowering was counted when about 50 percent plants had at least one open flower of each F_1 s or parents. Flowering stage was shown in plate 2.

3.11.2 Days to maturity

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

3.11.3 Plant height

During harvesting the plant height was measured in cm from the ground level of the plant to the top of the plant.

3.11.4 Number of primary branches per plant

Mean numbers of branches originated from the main stem from randomly selected plants from each F_1 s and parents at maturity.

3.11.5 Number of secondary branches per plant

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

3.11.6 Number of siliqua per plant

Mean number of siliqua obtained from ten randomly selected plants from each Fi's and parents at maturity.

Plate 2. Field view at flowering stage

Plate 3. Field view at maturity stage

3.11.7 Length of silique

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

3.11.8 Number of seeds per silique

All siliqua from the sample plants was collected and 3 siliqua was randomly selected from each plant. Seeds obtained front them, were counted and average numbers of seeds per siliqua was recorded.

3.11.9 Thousand-seed weight (g)

Weight in grams of 1000-seed was recorded from ten randomly selected plants of each F_1's and parents.

3.11.10 Seed yield per plant (g)

Mean seed weight in grams of ten randomly selected plants from each F_1's and parents after harvest.

3.12 Statistical analysis

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

3.12.1 Estimation of heterosis: The amount of heterosis in the F1 s was calculated using the following formula:

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

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.

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

Here, EMS= Error Mean Sum of square

r = No. of replication

t = Tabulated t value at error df

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

3.12.2 Combining ability in relation to diallel cross

Giriffing (1956) proposed four methods of analysis depending on the materials involved. Grffling has also considered Eisenhart's model I (fixed effect) and model II (random effect) situation in the analysis. In the present research work combining ability analysis were done following method 1 (including reciprocals) and Model-I. The mathematical model for the analysis was: $Y_{ij} = m + g_i + g_j + S_{ij} + 1/bc \sum\sum_{kl} e_{ijkl}$

Where,

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

K=l, 2, ..., b

L=1, 2, ..., c

P = Number of parents

B = Number of blocks or replications

c = Number of observation in each plot

Y_i = The mean of i x jth genotype over K and I.

m = The population mean.

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

g_j = The GCA of jth parent

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

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

The restriction imposed are : $\sum g_i = 0$ and $\sum S_{ij} + S_{ii} = 0$

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 Square	MSS	Expected MSS
GCA	p-1	S_g	M_g	$\sigma_e^2 + (P+2)\frac{1}{(P-1)}\sum g_i^2$
SCA	p(p-l)/2	S_s	M_s	$\sigma_e^2 + \frac{2}{P(P-1)}\sum_i \sum_j S_{ij}^2$
Error	(b-1)(e-1)	S_e	M_e	σ_e^2

Where,

GCA = general combining ability

SCA = specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

Yi = Array total of the ith parent

Yjj = Mean value of the ith parent

Yg = Grand total of the P(P-l)/2 crosses and parental lines

Yij= Progeny mean values in the diallel table

S_e = Sum of square due to error

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

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

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

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

$$S_{ij} = Y_{ij} - \frac{1}{(P+2)} \sum_i (y_i + y_{ii} + y_j + y_{ji}) + \frac{2}{(p+1)(p+2)} y..$$

The variance of GCA and SCA were,

$$Var(g_i) = \frac{(P-1)}{P(P+2)} \sigma_e^2$$

$$Var(S_{ij}) = \frac{2(P-1)}{(P+1)(P+2)} \sigma_e^2 (i \neq j)$$

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

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

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

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Mean performance

Mean performance of ten agronomic and yield related traits of parents and hybrid combinations are showed in Table 3.

4.1.1 Plant height

For parent, plant height ranged from 99 cm to 115.43 cm. The lowest plant height was observed in SAU proposed 4 and the parent BARI Sar-6 (115.43 cm) exhibited the highest plant height. For hybrid, plant height ranged from 105.13 cm to 150 cm. Yellow Special × BARI Sar-17 showed lowest plant height followed by SAU proposed 4 × BARI Sar-14 (111.50 cm). They can be used as a variety for getting dwarf plants. Whereas, the highest plant height was found from the hybrid SAU proposed 4×BARI Sar-15 followed by BARI Sar-6 × SAU proposed 4. The hybrids were approximately 15-17 cm higher than the parents.

4.1.2 Number of primary branches per plant

Number of primary branches per plant is a very important trait as it directly contributes to the yield. For the parents, number of primary branches per plant ranged from 3.57 to 6.33. BARI Sar-14 showed the lowest number and BARI Sar-15 showed the highest value. In the hybrids, SAU proposed 4 × BARI Sar-15 showed the highest number (14) among the hybrids and parents.

4.1.3 Number of secondary branches per plant

Number of secondary branches per plant is an important yield contributing trait. Number of secondary branches per plant was highest in parent SAU proposed 4 (4.45). In the hybrid, number of secondary branches per plant was above 10 (12.33-21.07) in four combinations and among them three were reciprocal crosses. The highest number was provided by the reciprocal combination BARI Sar-6 × Local Tori-7 (21.07) followed by BARI Sar-15 × Local Tori-7 (18.07). The cross combination Local Tori-7 × BARI Sar-15 also provided a high number of secondar

Table 3 Mean performance for 10 different characters in 7 parents and their 42 F_1's of *Brassica rapa* L.

Sl. No.	Plant characters	Plant height (cm)	No. of primary branches/ plant	No. of secondary branches/ plant	Siliqua per plant	Siliqua length (cm)	Seed per siliqua	1000 seed wt. (gm)	Days to 50% flowering	Days to 80% maturity	Seed yield per plant
	Parent										
1.	BARI Sar-14	100.10	3.47	1.00	84.28	3.83	19.08	4.06	31	87	7.07
2.	SAU proposed 4	99.00	5.63	4.45	126.93	4.61	14.72	3.50	30	89	6.59
3.	Yellow Special	104.77	4.40	0.53	68.00	4.12	14.15	4.59	35	86	4.16
4.	Local Tori-7	106.40	5.67	2.73	143.33	4.37	13.06	4.07	29	87	6.89
5.	BARI Sar-17	101.13	4.27	0.00	54.87	4.22	26.20	3.52	32	92	4.65
6.	BARI Sar-15	110.67	6.33	0.00	82.67	4.45	18.43	5.53	36	88	5.12
7.	BARI Sar-6	115.43	5.50	0.42	129.33	5.07	17.03	5.27	39	99	5.59
	Cross										
1.	BARI Sar-14 × SAU proposed 4	134.83	10.67	2.57	317.74	4.43	10.55	4.25	31	90	12.65
2.	BARI Sar-14 × Yellow Special	121.55	8.88	4.28	228.37	4.69	17.43	3.92	34	85	15.18
3.	BARI Sar-14 × Local Tori-7	122.00	10.43	3.50	303.47	3.84	9.04	4.12	33	86	8.96
4.	BARI Sar-14 × BARI Sar-17	127.35	6.50	1.22	90.45	3.00	7.80	3.50	35	90	7.33
5.	BARI Sar-14 × BARI Sar-15	134.40	9.30	0.17	181.27	4.43	15.14	4.30	33	84	8.73
6.	BARI Sar-14 × BARI Sar-6	117.40	6.50	0.70	143.40	4.38	13.33	4.39	34	88	8.79
7.	SAU proposed 4 × Yellow Special	111.50	13.70	4.43	344.43	3.94	16.53	4.24	35	87	11.26
8.	SAU proposed 4 × Local Tori-7	113.13	9.07	6.53	314.43	4.02	10.23	2.92	31	86	7.77
9.	SAU proposed 4 × BARI Sar-17	139.00	7.00	3.57	192.33	3.36	10.45	3.74	35	93	9.07
10.	SAU proposed 4 × BARI Sar-15	150.00	14.00	9.18	532.00	3.45	8.27	4.02	34	90	13.45
11.	SAU proposed 4 × BARI Sar-6	117.47	7.93	0.60	193.20	4.86	12.69	5.04	34	88	9.13
12.	Yellow Special × Local Tori-7	119.71	7.40	1.26	183.46	3.91	10.76	3.45	35	88	7.79

Table 3 (Cont.)

Sl. No	Plant characters	Plant height (cm)	No. of primary branches/ plant	No. of secondary branches/ plant	Siliqua per plant	Siliqua length (cm)	Seed per siliqua	1000 seed wt. (gm)	Days to 50% flowering	Days to 80% maturity	Seed yield per plant
	Cross										
13.	Yellow Special × BARI Sar-17	105.13	4.53	0.00	73.60	4.69	19.87	4.72	34	93	7.01
14.	Yellow Special × BARI Sar-15	117.60	8.67	2.47	230.67	4.45	14.11	4.15	35	89	13.61
15.	Yellow Special × BARI Sar-6	119.11	7.83	2.00	236.96	4.63	13.23	3.21	34	90	8.06
16.	Local Tori-7 × BARI Sar-17	118.71	11.38	6.50	421.50	4.06	10.00	4.40	34	93	11.81
17.	Local Tori-7 × BARI Sar-15	132.53	11.85	14.60	573.73	3.13	5.01	2.81	36	94	12.03
18.	Local Tori-7 × BARI Sar-6	118.93	8.60	6.13	301.00	4.42	9.25	4.15	34	92	11.92
19.	BARI Sar-17 × BARI Sar-15	121.33	8.30	0.08	144.40	4.34	12.76	3.19	34	84	7.54
20.	BARI Sar-17 × BARI Sar-6	124.00	6.60	0.18	193.14	4.31	11.07	3.71	35	89	8.08
21.	BARI Sar-15 × BARI Sar-6	132.00	10.53	1.18	306.18	4.15	11.19	5.41	36	95	12.24
	Reciprocal										
22.	SAU proposed 4 × BARI Sar-14	137.40	9.00	4.45	305.43	3.97	7.56	3.09	34	90	10.41
23.	Yellow Special × BARI Sar-14	112.13	4.80	0.13	81.20	4.39	18.96	5.20	33	82	5.51
24.	Yellow Special × SAU proposed 4	140.17	7.30	1.97	173.50	4.67	13.20	4.16	36	86	5.58
25.	Local Tori-7 × BARI Sar-14	130.70	11.75	3.50	330.73	4.24	11.28	4.02	35	93	14.23
26.	Local Tori-7 × SAU proposed 4	127.13	11.93	8.87	438.67	4.72	12.50	4.37	32	90	11.47
27.	Local Tori-7 × Yellow Special	132.67	11.90	12.33	472.90	4.20	10.98	5.42	35	95	20.09
28.	BARI Sar-17 × BARI Sar-14	105.69	7.67	0.00	100.13	4.24	25.41	4.37	33	82	9.14
29.	BARI Sar-17 × SAU proposed 4	123.28	8.42	3.47	260.73	4.05	10.82	3.60	33	82	8.58
30.	BARI Sar-17 × Yellow Special	119.00	7.20	0.14	138.03	4.68	18.43	3.01	36	87	6.65

Table 3 (Cont.)

Sl. No	Plant characters	Plant height (cm)	No. of primary branches/ plant	No. of secondary branches/ plant	Siliqua per plant	Siliqua length (cm)	Seed per siliqua	1000 seed wt. (gm)	Days to 50% flowering	Days to 80% maturity	Seed yield per plant
	Reciprocals										
31.	BARI Sar-17 × Local Tori-7	139.13	13.40	9.80	471.80	3.91	10.34	5.38	34	93	18.94
32.	BARI Sar-15 × BARI Sar-14	117.87	6.77	0.37	118.47	4.27	12.71	3.53	33	85	6.02
33.	BARI Sar-15 × SAU proposed 4	119.90	9.35	0.92	227.42	3.60	5.81	5.58	35	88	6.01
34.	BARI Sar-15 × Yellow Special	126.15	7.50	0.00	114.30	4.03	13.26	3.10	35	85	5.67
35.	BARI Sar-15 × Local Tori-7	136.18	13.17	18.07	569.07	3.58	7.30	3.01	35	92	17.69
36.	BARI Sar-15 × BARI Sar-17	124.48	6.73	0.25	109.63	4.27	13.63	1.82	33	86	4.88
37.	BARI Sar-6 × BARI Sar-14	135.90	7.33	0.00	130.40	4.51	16.16	2.44	36	91	7.49
38.	BARI Sar-6 × SAU proposed 4	144.87	8.30	1.90	224.50	4.85	11.58	4.42	34	92	9.11
39.	BARI Sar-6 × Yellow Special	130.58	7.00	0.00	110.23	4.72	20.44	2.10	37	90	5.51
40.	BARI Sar-6 × Local Tori-7	141.07	11.73	21.07	756.33	4.50	9.96	3.11	35	92	14.73
41.	BARI Sar-6 × BARI Sar-17	126.15	7.27	0.14	116.88	4.83	17.72	5.69	35	86	8.73
42.	BARI Sar-6 × BARI Sar-15	135.63	7.50	0.00	152.90	3.82	9.28	3.28	37	88	8.24

branches (14.60). The avenge value of the hybrids were almost two times higher than the parental average.

4.1.4 Siliqua per plant

Siliqua per plant is an important yield contributing trait. Usually, the combination producing higher number of siliqua provide more yield. in parent, number of siliqua per plant varied from 54.87 to 143.33 where the parent Local Tori-7 produced the highest and BARI Sar-17 produced the lowest number of siliqua per plant. Considering hybrid performance, the cross combinations, BARI Sar-14 × Yellow Special, BARI Sar-14 × Local Tori-7, SAU proposed 4 × Yellow Special, SAU proposed 4 × Local Tori-7, Yellow Special × BARI Sar-15, Yellow Special × BARI Sar-6, Local Tori-7 × BARI Sar-6, BARI Sar-15 × BARI Sar-6 and the reciprocals, SAU proposed 4×BARI Sar-14, Local Tori-7 × BARI Sar-14, BARI Sar-17 × SAU proposed 4, BARI Sar-6 × SAU proposed 4 provided siliqua per plant ranging from 200-350. The hybrid combination SAU proposed 4 × BARI Sar-15, Local Tori-7 × BARI Sar-17, Local Tori-7 × BARI Sar-15 and the reciprocals Local Tori-7×SAU proposed 4, Local Tori-7 × Yellow Special, BARI Sar-17 × Local Tori-7, BARI Sar-15×Local Tori-7, BARI Sar-6×Local Tori-7 provided siliqua per plant ranging from 400-760. BARI Sar-6 × Local Tori-7 (756.33) provided the highest number which was much higher than its parent. BARI Sar-6 × Local Tori-7 also had the heist number of secondary branches per plant (Table 3).

4.1.5 Siliqua length

Siliqua length of parent ranged from 3.83 cm to 5.07 cm. The parent BARI Sar-6 produced the longest silique (5.07 cm) while the parent BARI Sar-14 produced the shortest silique (3.83cm). On the other hand, the length varied from 3.13 cm to 4.86 cm for hybrids. In this regard, the hybrid combination SAU proposed 4 × BARI Sar-6 (4.86 cm) exhibited the highest length of siliqua and that was a little bit higher than that of it's either parent (Table 3).

4.1.6 Seeds per siliqua

Seeds per siliqua varied from 13.06 to 26.20 in parents. The parent BARI Sar-17 produced the highest (26.20) while the parent Local Tori-7 produced the lowest number of seeds per siliqua (13.06). In the hybrids, seeds per siliqua also varied from

5.01 to 25.41. The combination BARI Sar-17 × BARI Sar-14 produced the highest seeds per siliqua but it was lower than any of the parents and Local Tori-7 × BARI Sar-15 (5.01) produced the lowest number of seeds per siliqua (Table 3).

4.1.7 Thousand seed weight

Thousand seed weight in parents varied from 3.50 gm to 5.53 gm. However, the heaviest seeds were produced by the parent BARI Sar-15. The hybrid combination BARI Sar-6 × BARI Sar-17 (5.69 gm) followed by BARI Sar-15 × SAU proposed 4 (5.58 gm) provided the highest weighted seeds which were higher than it's both parents (Table 3).

4.1.8 Days to 50% flowering

In case of days to 50% flowering, it ranged from 29 to 39 days for parent. However, the parent Local Tori-7 flowered within the lowest time but the parent BARI Sar-6 (39 Days) took the highest duration. On the other hand, the hybrid combination BARI Sar-14 × SAU proposed 4 and SAU proposed 4 × Local Tori-7 (31 Days) produced fifty percent flower with the lowest growth duration.

4.1.9 Days to 80% maturity

Considering earliness, the parent Yellow Special (86 Days) showed the lowest duration for maturation but the parent BARI Sar-6 (99 Days) had taken the highest duration. On the other hand, the hybrid combination Yellow Special × BARI Sar-14, BARI Sar-17 × BARI Sar-14, BARI Sar-17 × SAU proposed 4 (82 Days) matured with the lowest growth duration, which earlier than either of the parents.

4.1.10 Seed yield per plant

Siliqua per plant is an important yield contributing trait. Usually, the traits responsible for high seed yield per plant are- number of primary branch, number of secondary branch, siliqua per plant and thousand seed weight. Seed yield of the genotypes varied from 4.16 to 7.07 gm in parents and from 4.88 to 20.09 gm in hybrids. The highest seed yield of the parent was found in BARI Sar-14 (7.07 gm). Similarly, in the hybrids, the highest seed yield was observed in the reciprocal Local Tori-7 × Yellow special. Hybrid Local Tori-7 × Yellow special also had higher number of primary branches, number of secondary branches, siliqua per plant and 1000 seed weight. Nine crosses BARI Sar-14 × SAU proposed 4, BARI Sar-14×Yellow Special, SAU proposed 4×Yellow Special, SAU proposed 4×BARI Sar-15, Yellow Special × BARI Sar-15, Local Tori-7 × BARI Sar-17, Local Tori-7 × BARI Sar-15, Local Tori-7 × BARI Sar-6 and BARI Sar-15 × BARI Sar-6 showed seed yield above 10 gm. Whereas, only four reciprocals Local Tori-7×Yellow Special, BARI Sar-17×Local Tori-7, BARI Sar-15×Local Tori-7, BARI Sar-6×Local Tori-7 showed seed yield above 10 gm.

4.2 Heterosis

Ten yield contributing characters of *Brassica rapa* were studied in seven parental genotypes and their 42 hybrids obtained from 7×7 full diallel crosses. Percent heterosis for 10 different characters of the F_1 hybrids over their respective mid and better parental values is shown in Table 4. These results on heterosis of 42 F_1 's are described by character wise below.

4.2.1 Plant height

The cross SAU proposed 4 × BARI Sar-17 showed highly significant positive heterotic effect over better parent (37.44%) followed by BARI-9 × BARI-6) × BARI Sar-14 (37.26%) and BARI Sar-14 ×SAU proposed 4 (34.70%). Maximum crosses showed highly significant heterosis over mid parent. Highly significant positive heterosis over mid parent was observed in SAU proposed 4 × BARI Sar-15 (43.08%) followed by SAU proposed 4 × BARI Sar-17 (38.91%), SAU proposed 4 × BARI Sar-14 (38.02%), BARI Sar-14 × SAU proposed 4 (35.44%), Yellow Special × SAU proposed 4 (37.57%), BARI Sar-17 × Local Tori-7 (34.08%) and BARI Sar-6 × SAU proposed 4 (35.12%) which can be used for exploiting heterosis where tallness is desirable for that character. Lefort *et al.* (1987) while studying *Brassica napus* of Asian and European parental lines and their hybrids, reported that plant height and seed yield showed positive heterosis in the hybrids. Yadav *et al.* (2004) observed the magnitude of heterosis was the highest for plant height in Trachystoma x SK 93-1(27.7%) over LW and (25.8%) over CV both.

4.2.2 Number of primary branches per plant

Heterosis values ranging from -3.91 to 143.20 and 4.61 to 173.09 over better parent and mid parent respectively were found for the character number of primary branches per plant. The hybrid SAU proposed 4 × Yellow Special showed the highest significant positive heterosis over the mid parent (173.09%) as well as better parent (143. 20%). The highest significant positive heterosis (above 100%) over both better and mid parent for number of primary branches per plant were found in the crosses SAU proposed 4×Yellow Special, SAU proposed 4 × BARI Sar-15 and Local Tori-7 × BARI Sar-17. The reciprocals having the highest significant positive heterosis (above 100%) Local Tori-7 × BARI Sar-14, Local Tori-7 × SAU proposed 4, Local Tori-7 × Yellow Special, BARI Sar-17 × Local Tori-7, BARI Sar-15 × Local Tori-7 and BARI Sar-6 × Local Tori-7. 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 at (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.

4.2.3 Number of secondary branches plant

Forty hybrids of 42 crosses showed highly significant mid parent heterosis, in which twenty-eight hybrids showed positive values ranging from 55.81% to 1237.57%. The highest significant and positive mid-parent heterosis was produced by the combination BARI Sar-6 × Local Tori-7 (1237.57%) followed by BARI Sar-15 × Local Tori-7(1221.97%) and Local Tori-7 × BARI Sar-15 (968.31%) The hybrid BARI Sar-6 × Local Tori-7 showed higher branches than its parent. These hybrids could be considered for further development of heterotic *Brassica* hybrid. On the other hand, eighteen cross combinations were found to be significant and positive for better parent heterosis which ranged from 24.05% to 670.74%. Among these eighteen hybrids, the combination BARI Sar-6 × Local Tori-7 (670.74%) exhibited the highest value followed by BARI Sar-15 × Local Tori-7 (560.98%) and Local Tori-7 × BARI Sar-15 (434.15%) and they might be selected for number of secondary branches per plant. Kumar *et al.* (1990) found positive heterosis for number of secondary branches per plant and they also recorded highest heterobeltiosis for number of secondary branches per plant. Yadav *et al.* (2004) observed maximum heterosis over BP in

Table 4. Percent heterosis over mid parent and better parent for 10 characters in 42 hybrids of *Brassica rapa* L.

Sl. No.	Plant characters	Plant height (cm)		No. of primary branches/plant		No. of secondary branches/ plant		Siliqua per plant	
	Cross	HBP	HMP	HBP	HMP	HBP	HMP	HBP	HMP
1.	BARI Sar-14 × SAU proposed 4	34.70**	35.44**	89.35**	150.32**	200.87**	-5.81**	150.32**	200.87**
2.	BARI Sar-14 × Yellow Special	16.02*	18.66*	101.89**	170.95**	199.92**	458.70**	170.95**	199.92**
3.	BARI Sar-14 × Local Tori-7	14.66*	18.16*	84**	111.72**	166.65**	87.50**	111.72**	166.65**
4.	BARI Sar-14 × BARI Sar-17	25.92**	26.22**	52.22**	67.96**	22.00**	22.00**	7.32	29.99
5.	BARI Sar-14 × BARI Sar-15	21.45**	27.53**	46.84**	115.07**	117.15**	-66.66**	115.07**	117.15**
6.	BARI Sar-14 × BARI Sar-6	1.70	8.94	18.18**	10.88	34.26	-1.64**	10.88	34.26
7.	SAU proposed 4 × Yellow Special	6.43	9.44	143.20**	173.09**	-0.38	77.93**	171.36**	253.39**
8.	SAU proposed 4 × Local Tori-7	6.33	10.16	60**	60.47**	46.82**	81.90**	119.37**	132.69**
9.	SAU proposed 4 × BARI Sar-17	37.44**	38.91**	24.26**	41.41**	-19.85**	60.30**	51.53	111.59**
10.	SAU proposed 4 × BARI Sar-15	35.54**	43.08**	121.05**	133.98**	106.22**	312.44**	319.13**	407.64**
11.	SAU proposed 4 × BARI Sar-6	1.76	9.56	40.83**	42.51**	-86.52**	-75.34**	49.38	50.78
12.	Yellow Special × Local Tori-7	12.51	13.38	30.59**	47.02**	-53.90**	-22.86**	27.99	73.62*
13.	Yellow Special × BARI Sar-17	0.35	2.12	3.03**	4.61**	-100**	-100**	8.24	19.8
14.	Yellow Special × BARI Sar-15	6.27	9.18	36.84**	61.49**	362.54**	825.07**	179.03**	206.19**
15.	Yellow Special × BARI Sar-6	3.19	8.18	42.42**	58.25**	275.02**	321.05**	83.21*	140.16**
16.	Local Tori-7 × BARI Sar-17	11.57	14.40*	100.73**	129.025**	137.81**	375.62**	194.07**	325.33**
17.	Local Tori-7 × BARI Sar-15	19.76**	22.11**	87.16**	97.56**	434.15**	968.31**	300.28**	407.73**
18.	Local Tori-7 × BARI Sar-6	3.03	7.23	51.76**	54.03**	124.39**	289.42**	110.00**	120.78**

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

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

Table 4 (Cont.)

Sl. No.	Plant characters	Plant height (cm)		No. of primary branches/plant		No. of secondary branches/ plant		Siliqua per plant	
	Cross	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
19.	BARI Sar-17 × BARI Sar-15	9.64	14.57*	31.05**	56.60**	0.00	0.00	74.68*	109.99**
20.	BARI Sar-17 × BARI Sar-6	7.42	14.51*	20**	35.15**	-56.01**	-12.02**	49.34	109.71**
21.	BARI Sar-15 × BARI Sar-6	14.35*	16.76*	66.32	78.03	183.97**	183.97**	136.74**	188.85**
	Reciprocal								
22.	SAU proposed 4 × BARI Sar-14	37.26**	38.02**	59.76**	97.80**	0.00	63.30**	140.63**	189.22**
23.	Yellow Special × BARI Sar-14	7.03	9.47	9.09**	22.03**	-86.67**	-82.61**	-3.66	6.64
24.	Yellow Special × SAU proposed 4	33.79**	37.57**	29.59*	45.52**	-55.80**	-21.07**	36.69	78.01*
25.	Local Tori-7 × BARI Sar-14	22.84**	26.59**	107.35**	157.30**	28.05**	87.50**	130.74**	190.61**
26.	Local Tori-7 × SAU proposed 4	19.49**	23.79**	110.59**	111.21**	99.25**	146.87**	206.05**	224.62**
27.	Local Tori-7 × Yellow Special	24.69**	25.65**	110**	136.42**	351.22**	655.12**	229.93**	347.54**
28.	BARI Sar-17 × BARI Sar-14	4.51	5.04	79.69**	98.28**	-100**	-100**	18.81	43.92
29.	BARI Sar-17 × SAU proposed 4	21.90**	23.20**	49.41**	70.03**	-22.10**	55.81**	105.42**	186.84**
30	BARI Sar-17 × Yellow Special	13.59	15.59*	63.64**	66.15**	-73.75**	-47.5**	102.99**	124.69**
31.	BARI Sar-17 × Local Tori-7	30.76**	34.08**	136.47**	169.80**	258.54**	617.08**	229.16**	376.08**
32.	BARI Sar-15 ×BARI Sar-14	6.51	11.85	6.84**	38.10**	-63.33**	-26.66**	40.56	41.92
33.	BARI Sar-15 × SAU proposed 4	8.34	14.37*	47.63**	56.27**	-79.40**	-58.80**	79.17*	117.00**
34.	BARI Sar-15 × Yellow Special	13.99	17.11*	18.42**	39.75**	-100**	-100**	38.27	51.73

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

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

Table 4 (Cont.)

Sl. No.	Plant characters	Plant height (cm)		No. of primary branches/plant		No. of secondary branches/ plant		Siliqua per plant	
	Reciprocal	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
35.	BARI Sar-15 × Local Tori-7	23.05**	25.47**	107.90**	119.45**	560.98**	1221.97**	297.02**	403.60**
36.	BARI Sar-15 × BARI Sar-17	12.48	17.55*	6.32**	27.04**	0.00	0.00	32.62	59.43
37.	BARI Sar-6 × BARI Sar-14	17.73*	26.11**	33.33**	63.57**	-100**	-100**	0.82	22.09
38.	BARI Sar-6 × SAU proposed 4	25.50**	35.12**	47.34**	49.10**	-57.30**	-21.92**	73.58*	75.21*
39.	BARI Sar-6 × Yellow Special	13.12	18.60*	27.27**	41.41**	-100**	-100**	-14.77	11.72
40.	BARI Sar-6 × Local Tori-7	22.21**	27.18**	107.06**	110.15**	670.74**	1237.57**	427.67**	454.77**
41.	BARI Sar-6 × BARI Sar-17	9.28	16.50*	32.12**	48.81**	-65.61**	-31.22**	-9.63	26.91
42.	BARI Sar-6 × BARI Sar-15	17.50*	19.98**	18.42**	26.76**	-100**	-100**	18.22	44.25
	Min	0.35	2.12	3.03	4.61	-100.00	-100.00	-14.77	6.64
	Max	37.44	43.80	143.20	173.09	670.74	1237.57	427.67	454.77

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

HBP= Heterosis over Better Parent,

HMP= Heterosis over Mid Parent

Table 4 (Cont.)

Sl. No.	Plant characters	Siliqua length (cm)		Seed per siliqua		1000 seed wt. (gm)	
	Cross	HBP	HMP	HBP	HMP	HBP	HMP
1.	BARI Sar-14 × SAU proposed 4	-3.83**	5.013**	-44.70**	-37.57**	4.51**	12.30**
2.	BARI Sar-14 × Yellow Special	13.74**	17.890**	-8.65**	4.90**	-14.53**	-9.32**
3.	BARI Sar-14 × Local Tori-7	-12.12**	-6.336**	-52.61**	-43.73**	1.23**	1.27**
4.	BARI Sar-14 × BARI Sar-17	-28.91**	-25.56**	-70.02**	-65.41**	-13.79**	-7.69**
5.	BARI Sar-14 × BARI Sar-15	-0.3	7.085**	-20.62**	-19.24**	-22.23**	-10.32**
6.	BARI Sar-14 × BARI Sar-6	-13.69**	-1.675**	-30.11**	-26.15**	-16.65**	-5.89**
7.	SAU proposed 4 × Yellow Special	-14.53**	-9.77**	12.32**	14.54**	-7.70**	4.74**
8.	SAU proposed 4 × Local Tori-7	-12.80**	-10.5**	-30.53**	-26.36**	-28.20**	-22.82**
9.	SAU proposed 4 × BARI Sar-17	-27.04**	-23.793**	-60.12**	-48.94**	6.44**	6.70**
10.	SAU proposed 4 × BARI Sar-15	-25.09**	-23.74**	-55.14**	-50.12**	-27.35**	-11.00**
11.	SAU proposed 4 × BARI Sar-6	-4.14**	0.447	-25.48**	-20.05**	-4.24**	15.06**
12.	Yellow Special × Local Tori-7	-10.67**	-8.041**	-23.98**	-20.93**	-24.91**	-20.37**
13.	Yellow Special × BARI Sar-17	11.15**	12.391**	-24.16**	-1.52	2.90**	16.53**
14.	Yellow Special × BARI Sar-15	0.15	3.928**	-23.44**	-13.39**	-25.00**	-18.01**
15.	Yellow Special × BARI Sar-6	-8.80**	0.618*	-22.33**	-15.15**	-39.11**	-34.93**
16.	Local Tori-7 × BARI Sar-17	-7.09**	-5.395**	-61.83**	-49.05**	8.28**	16.13**
17.	Local Tori-7 × BARI Sar-15	-29.61**	-29.025**	-72.83**	-68.19**	-49.16**	-41.39**
18.	Local Tori-7 × BARI Sar-6	-12.94**	-6.491**	-45.68**	-38.50**	-21.27**	-11.14**

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

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

Table 4 (Cont.)

Sl. No.	Plant characters	Siliqua length (cm)		Seed per siliqua		1000 seed wt. (gm)	
	Cross	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
19.	BARI Sar-17 × BARI Sar-15	-2.33**	0.268	-51.29**	-42.81**	-42.29**	-29.43**
20.	BARI Sar-17 × BARI Sar-6	-15.11**	-7.283**	-57.73**	-48.77**	-29.56**	-15.52**
21.	BARI Sar-15 × BARI Sar-6	-18.20**	-12.815**	-39.25**	-36.87**	-2.23**	0.19
	Reciprocal						
22.	SAU proposed 4 × BARI Sar-14	-3.83**	5.013**	-44.70**	-37.57**	-24.03**	-18.38**
23.	Yellow Special × BARI Sar-14	6.55**	10.432**	-0.61	14.13**	13.36**	20.26**
24.	Yellow Special × SAU proposed 4	1.23**	6.871**	-10.33**	-8.56**	-9.44**	2.76**
25.	Local Tori-7 × BARI Sar-14	-3.01**	3.373**	-40.85**	-29.77**	-1.15**	-1.11**
26.	Local Tori-7 × SAU proposed 4	2.46**	5.157**	-15.10**	-10.02**	7.54**	15.59**
27.	Local Tori-7 × Yellow Special	-3.89**	-1.059**	-22.40**	-19.28**	18.15**	25.30**
28.	BARI Sar-17 × BARI Sar-14	0.47	5.260**	-2.99**	12.27**	7.55**	15.30**
29.	BARI Sar-17 × SAU proposed 4	-12.08**	-8.158**	-58.68**	-47.10**	2.37**	2.61**
30	BARI Sar-17 × Yellow Special	10.91**	12.151**	-29.66**	-8.66**	-34.49**	-25.82**
31.	BARI Sar-17 × Local Tori-7	-10.59**	-8.964**	-60.53**	-47.32**	32.21**	41.80**
32.	BARI Sar-15 × BARI Sar-14	-4.05**	3.060**	-33.37**	-32.22**	-36.14**	-26.36**
33.	BARI Sar-15 × SAU proposed 4	-22.02**	-20.611**	-68.48**	-64.95**	0.84**	23.54**
34.	BARI Sar-15 × Yellow Special	-9.48**	-6.068**	-28.04**	-18.59**	-43.92**	-38.69**

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

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

Table 4 (Cont.)

Sl. No.	Plant characters	Siliqua length (cm)		Seed per siliqua		1000 seed wt. (gm)	
	Reciprocal	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
35.	BARI Sar-15 × Local Tori-7	-19.42**	-18.746**	-60.37**	-53.61**	-45.54**	-37.22**
36.	BARI Sar-15 × BARI Sar-17	-3.90**	-1.348**	-47.97**	-38.91**	-67.17**	-59.85**
37.	BARI Sar-6 × BARI Sar-14	-11.17**	1.199**	-15.29**	-10.50**	-53.67**	-47.70**
38.	BARI Sar-6 × SAU proposed 4	-4.47**	0.104	-32.02**	-27.06**	-16.08**	0.84**
39.	BARI Sar-6 ×Yellow Special	-6.90**	2.718**	19.98**	31.07**	-60.06**	-57.32**
40.	BARI Sar-6 × Local Tori-7	-11.30**	-4.728**	-41.53**	-33.80**	-41.01**	-33.43**
41.	BARI Sar-6 × BARI Sar-17	-4.73**	4.054**	-32.37**	-18.04**	8.10**	29.64**
42.	BARI Sar-6 × BARI Sar-15	-24.77**	-19.817**	-49.64**	-47.66**	-40.78**	-39.32**
	Min	-29.61	-29.025	-72.83	-68.19	-67.17	-59.85
	Max	13.74	17.89	19.98	31.07	32.21	41.8

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

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

Table 4 (Cont.)

Sl. No	Plant characters	Days to 50% flowering		Days to 80% maturity		Seed yield / plant (gm)	
	Cross	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
1.	BARI Sar-14 × SAU proposed 4	3.30**	2.17*	3.05	2.27	79.00**	85.25**
2.	BARI Sar-14 × Yellow Special	9.68**	3.03**	-0.78	-1.54	114.80**	170.53**
3.	BARI Sar-14 × Local Tori-7	13.79**	10.00**	-1.15	-1.34	26.80**	28.39**
4.	BARI Sar-14 × BARI Sar-17	12.09**	11.11**	3.44	0.56	3.68**	25.09**
5.	BARI Sar-14 × BARI Sar-15	6.45**	-1	-4.20*	-4.56*	23.44**	43.21**
6.	BARI Sar-14 × BARI Sar-6	9.68**	-3.32**	0.76	-5.38*	24.34**	38.89**
7.	SAU proposed 4 × Yellow Special	16.48**	8.16**	1.16	-0.38	70.78**	109.48**
8.	SAU proposed 4 × Local Tori-7	6.90**	4.49**	-0.77	-1.71	12.69**	15.21**
9.	SAU proposed 4 × BARI Sar-17	16.48**	13.37**	4.89*	2.76	37.55**	61.26**
10.	SAU proposed 4 × BARI Sar-15	10.99**	2.02*	1.89	1.51	104.10**	129.81**
11.	SAU proposed 4 × BARI Sar-6	13.19**	-1.44	-1.13	-6.41**	38.54**	49.97**
12.	Yellow Special × Local Tori-7	20.69**	9.38**	1.94	1.35	13.06**	41.07**
13.	Yellow Special × BARI Sar-17	8.33**	3.48**	8.53**	4.67*	50.65**	59.15**
14.	Yellow Special × BARI Sar-15	0.95	0	3.49	2.3	165.93**	193.48**
15.	Yellow Special × BARI Sar-6	-0.95	-6.73**	4.65**	-2.53	44.25**	65.44**
16.	Local Tori-7 × BARI Sar-17	17.24**	11.48**	7.28**	4.09	71.36**	104.60**
17.	Local Tori-7 × BARI Sar-15	25.29**	12.37**	7.66**	7.05**	74.50**	100.31**
18.	Local Tori-7 × BARI Sar-6	18.39**	0.49	5.36*	-1.26	72.92**	91.02**

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

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

Table 4 (Cont.)

Sl. No.	Plant characters	Days to 50% flowering		Days to 80% maturity		Seed yield / plant (gm)	
	Cross	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
19.	BARI Sar-17 × BARI Sar-15	7.29**	1.48	-4.55*	-6.84**	47.39**	54.38**
20.	BARI Sar-17 × BARI Sar-6	9.38**	-1.87*	-3.61	-6.81**	44.65**	57.83**
21.	BARI Sar-15 × BARI Sar-6	1.87*	-3.11**	8.33**	2.14	119.09**	128.71**
	Reciprocal						
22.	SAU proposed 4 × BARI Sar-14	12.09**	10.87**	2.67	1.89	47.30**	52.44**
23.	Yellow Special × BARI Sar-14	7.53**	1.01	-4.26*	-5.00*	-22.06**	-1.84**
24.	Yellow Special × SAU proposed 4	18.68**	10.20**	0	-1.53	-15.39**	3.78**
25.	Local Tori-7 × BARI Sar-14	21.84**	17.78**	6.51**	6.31**	101.26**	103.78**
26.	Local Tori-7 × SAU proposed 4	11.49**	8.99**	3.83	2.85	66.40**	70.12**
27.	Local Tori-7 × Yellow Special	19.54**	8.33**	10.08**	9.44**	191.49**	263.70**
28.	BARI Sar-17 × BARI Sar-14	5.38**	3.70**	-5.73**	-8.35**	29.34**	55.99**
29.	BARI Sar-17 × SAU proposed 4	9.89**	6.95**	-7.14**	-9.02**	30.16**	52.59**
30	BARI Sar-17 × Yellow Special	12.50**	7.46**	0.78	-2.8	42.84**	50.91**
31.	BARI Sar-17 × Local Tori-7	16.09**	10.38**	6.90**	3.72	174.72**	228.01**
32.	BARI Sar-15× BARI Sar-14	5.38**	-2.00*	-2.29	-2.66	-14.80**	-1.16
33.	BARI Sar-15 × SAU proposed 4	14.29**	5.05**	0	-0.38	-8.90**	2.58*
34.	BARI Sar-15 × Yellow Special	0	-0.94	-1.16	-2.3	10.72**	22.19**

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

HBP= Heterosis over Better Parent,

HMP= Heterosis over Mid Parent

Table 4 (Cont.)

Sl. No.	Plant characters	Days to 50% flowering		Days to 80% maturity		Seed yield / plant (gm)	
	Reciprocal	**HBP**	**HMP**	**HBP**	**HMP**	**HBP**	**HMP**
35.	BARI Sar-15× Local Tori-7	20.69**	8.25**	5.75**	5.14*	156.57**	194.52**
36.	BARI Sar-15×BARI Sar-17	2.08*	-3.45**	-2.27	-4.62*	-4.54**	-0.01
37.	BARI Sar-6×BARI Sar-14	16.13**	2.37**	4.58*	-1.79	6.03**	18.44**
38.	BARI Sar-6SAU proposed 4	13.19**	-1.44	3.76	-1.78	38.23**	49.63**
39.	BARI Sar-6×Yellow Special	7.62**	1.35	4.65*	-2.53	-1.45	13.02**
40.	BARI Sar-6×Local Tori-7	20.69**	2.44**	5.75**	-0.9	113.73**	136.11**
41.	BARI Sar-6×BARI Sar-17	10.42**	-0.93	-6.86**	-9.95**	56.19**	70.42**
42.	BARI Sar-6×BARI Sar-15	3.74**	-1.33	0	-5.71**	47.48**	53.96**
	Min	-0.95	-6.73	-7.14	-9.95	-22.06	-1.84
	Max	25.29	17.78	10.08	9.44	191.49	263.7

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

HBP= Heterosis over Better Parent,

HMP = Heterosis over Mid Parent

Trachystoma x PHR- I (125.1%) and over CV in Moricandia NRCM-79 (9.6%) for the number of secondary branches per plant.

4.2.4 Siliqua per plant

Significant positive heterosis value ranged from 73% to 427.67 % over better parent and 6.64% to 454.77% over mid parent was found. Highest significant positive heterosis over better parent was found in BARI Sar-6 × Local Tori-7 (427.67%) followed by SAU proposed 4 ×BARI Sar-15 (319.13%), Local Tori-7 × BARI Sar-15 (300.28%) and BARI Sar-15 × Local Tori-7 (297.02%) while no significant negative heterosis over better parent was observed for the traits. Highest significant positive heterosis over mid patent was found in BARI Sar-6 × Local Tori-7 (454.77%) followed by Local Tori-7 × BARI Sar-15 (407.73%), SAU proposed 4 ×BARI Sar-15 (407.64%), BARI Sar-15 × Local Tori-7 (403.60%) 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 siliqua per plant. Thakur and Segwal (1997) estimated positive heterosis over better parent ranging from 21.9 to 162.60% in rape seed for siliqua per plant. Qi *et al.* (2003) observed the forty-seven crosses gave on average 28.02% (0.93-97.87%) more siliqua per plant.

4.2.5 Siliqua length:

Out of 42 combinations, 38 combinations showed significant heterosis over mid parent but eighteen of them showed positive and significant heterosis. Highly Significant and positive heterosis was found in BARI Sar-14×Yellow Special both over better parent (13.74 %) as well as mid parent (17.890%) values and the rest were observed either non-significant positive or significant negative heterosis (Table 4). Highly negative heterosis was found on Local Tori-7 × BARI Sar-15 over better parent (-29.61%) and mid parent (-29.025%). Kumar *et al.* (1990) found positive heterosis for length of siliqua in *Brassica juncea* in their study.

4.2.6 Seeds per siliqua

All the hybrids showed significant and negative heterosis over mid parent except BARI Sar-6 × Yellow Special (31.07 %), SAU proposed 4 ×Yellow Special (14.54 %), Yellow Special × BARI Sar-14 (14.13 %) and BARI Sar-17 × BARI Sar-14

(12.27 %). On the other hand, no combinations were found to be significant and positive for better parent heterosis except BARI Sar-6 × Yellow Special (19.98 %) and SAU proposed 4 ×Yellow Special (12.32 %). However, the mentioned combinations showed highly significant and positive heterosis over mid parent as well as better parent and could be considered for further evaluation. Kumar *et al.* (1990) reported positive heterosis for number of seeds per siliqua in *Brassica juncea.* Yadav et al (2004) observed that the Siifolia x SM-I showed 54.1% heterosis over BP and 9.2% negative heterosis over SV for seeds per siliqua.

4.2.7 Thousand seed Weight

Out of 42 hybrids, only sixteen showed significant and positive heterosis over mid parent. Among them BARI Sar-17 × Local Tori-7 (41.80 %) gave the highest significance and positive heterosis over mid parent followed by Local Tori-7 × Yellow Special (25.30 %), BARI Sar-15 × SAU proposed 4 (23.54 %) and BARI Sar-6 × BARI Sar-17 (29.64 %). Similarly, for better parent heterosis, the combinations BARI Sar-17 × Local Tori-7 (32.21 %) showed the highest significant and positive heterosis followed by The Hybrids Local Tori-7 × Yellow Special (18.15 %), Yellow Special × BARI Sar-14 (13.36 %). Yadav *et al.* (2004) observed the highest heterosis for thousand seed weight in Moricandia x PHR-1 (48.80%) followed by Trachystoma NRCM 69 (20.6%) over BP and SV respectively. Qi *et al*. (2003) observed that eight crosses showed better parent heterosis (3.57 to 20.48%) in thousand seed weight.

4.2.8 Days to 50% flowering

Significant and negative heterosis over parent is desirable for selection of hybrid with short duration. Highest significant negative heterosis (-6.73%)was provided by the hybrid Yellow Special × BARI Sar-6 for days to 50% flowering over mid parent (Table 4). It was followed by the crosses BARI Sar-15 × BARI Sar-17(-3.45%), BARI Sar-14 ×BARI Sar-6(-3.32%), BARI Sar-15 × BARI Sar-6(-3.11%), BARI Sar-15 × BARI Sar-14(-2.00 %) and BARI Sar-17 × BARI Sar-6 (-1.87%). The cross Local Tori-7 × BARI Sar-14 (17.78%) showed highly positive significant heterotic effect over mid parent. Thus they could be used for exploiting desirable heterosis for the trait. On the other hand, no significant negative heterosis over better parental value was found. Local Tori-7 × BARI Sar-15 (25.29%) showed highly positive significant heterosis over better parent followed by Local Tori-7 × BARI Sar-14

(21.84%). Yellow Special × BARI Sar-6(-0.95%) negative heterosis but it was not significant. 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).

4.2.9 Days to 80% maturity

Local Tori-7 × Yellow Special showed the highest significant positive heterosis (10.08%) over better parent followed by Yellow Special × BARI Sar-17 (8.53%) and BARI Sar-15 × BARI Sar-6 (8.33%) (Table 4). Highest significant negative heterosis over better parent was observed in BARI Sar-17 × SAU proposed 4 (-7.14%) followed by BARI Sar-6 × BARI Sar-17 (-6.86%) and BARI Sar-17 × BARI Sar-14 (-5.73%). Highest significant positive heterosis over mid parent was observed in Local Tori-7 × Yellow Special (9.44%) followed by Local Tori-7 × BARI Sar-15 (7.05%) and Local Tori-7 × BARI Sar-14 (6.31%). Highest significant negative heterosis over mid parent was found in BARI Sar-6 × BARI Sar-17 (-9.95%) followed by BARI Sar-17 × SAU proposed 4 (-9.02%), BARI Sar-17 × BARI Sar-14 (-8.35%) and SAU proposed 4 × BARI Sar-6 (-6.41%). BARI Sar-17 × BARI Sar-14, BARI Sar-17 × SAU proposed 4, BARI Sar-6 × BARI Sar-17 showed significant negative heterosis over both better parent and mid parent. Thus these 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.

4.2.10 Seed yield per plant

Out of 42 hybrids, 35 hybrids showed highly significant positive heterosis in better parent and 39 hybrids showed highly significant positive heterosis in mid parent. Four crosses and 5 reciprocals showed highly significant positive heterosis for better parent. Whereas, 7 crosses and 4 reciprocals showed highly significant positive heterosis over mid parent. In case of yield per plant, reciprocal Local Tori-7 × Yellow Special represented highly significant and positive value for both mid parent (263.70%) and better parent (191.49 %) heterosis. Local Tori-7 × Yellow Special was followed by BARI Sar-17 × Local Tori-7 (HBP:174.72%, HMP: 228.01%) and BARI Sar-15 × Local Tori-7 (HBP:156.57%, HMP: 194.52%) showing highly significant positive heterosis. These combinations could be selected for improvement of yield performance. Tyagi *et al.* (2001) found the highest standard heterosis (206.14%) and heterobeltiosis (240.56%) for seed yield per plant in the cross BlO 772 x Rohini.

Adefris *et al.* (2005) observed that seed yield showed the highest relative mid parent heterosis that varied from 25 to 145% with a mean of 67% and relative high parent heterosis varied from 16 to 124% with a mean of 53%. The presence of high Levels of mid and high parent heterosis indicated a considerable potential to embark on breeding hybrid or synthetic cultivars in mustard. Shen *et al*. (2005) observed mid parent heterosis and high parent heterosis of seed yield per plant ranged from 5.50 to 64.11% and from -2.81 to 46.02% respectively. Wang *et al.* (1999) analyzed heterosis and combining abilities of 20 reciprocal cross combinations of five rape (*Brassica napus*) cultivars (lines) showing high seed yield.

4.3 Combining ability

The analysis of variance carried out for ten characters was presented in Table 5 which indicated that the genotypes differed significantly for all the characters studied. Highly significant variances for Plant height, no. of primary branches/ plant, no. of secondary branches/ plant, no. of siliqua / plant, siliqua length, seed/ siliqua days to 50% flowering, and seed yield/plant (Table 5). 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 which is involved in the inheritance of different characters. The mean sum of square due to general combining ability (GCA) was highly significant for all traits indicating that the additive gene actions was predominant for the expression of these characters (Table 6). The significant mean sum of square due to specific combining ability (SCA) was also observed for all the characters indicating that the non-additive gene actions was predominant for the expression of these characters (Table 6). The results showed the agreement with the findings of Malik *et al*. (1995); Thakur and Sagwal (1997) in rape seed. Similar findings were also reported by Acharya and Swain (2004), Tamber *et al.* (1991) in Indian mustard and Labana *et al* (1978) in yellow sarson. The higher magnitude of GCA variance was observed than that of SCA variance for 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. Verrna et al. (1989) and Labana *et al* (1978) reported non-additive type of gene action for siliquae per plant, seed yield per plant in yellow sarson,

Table 5: Analysis of variance for seed yield per plant and its component characters in *Brassica rapa* genotypes

Source of Variation	df	Plant Height (cm)	No of Primary Branches Plant	Number of Secondary Branches Per Plant	No. of Siliqua Per Plant	Siliqua Length (cm)	Seed Per siliqua	1000 seed weight (gm)	Days to 50% Flowering	Days to 80% Maturity	Seed yield Per plant (gm)
Replication	2	2982.17	6.3	4.60	9221.2	0.07	10.31	0.01	1.76	97.00	20.34
Genotype	48	465.33**	21.76**	69.32**	74026.4**	0.52**	70.69**	2.55**	11.00**	39.69**	42.82**
Error	96	78.43	1.22	0.96	1526.2	0.09	2.01	0.03	1.16	6.70	2.08

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

Table 6: Analysis of variance) for GCA and SCA for seed yield and yield contributing components in *Brassica rapa* genotypes

Source of Variation	df	Plant Height (cm)	Number of Primary Branches Per Plant	Number of Secondary Branches Per Plant	No. of Siliqua Per Plant	Siliqua Length (cm)	Seed Per siliqua	1000 seed weight (gm)	Days to 50% Flowering	Days to 80% Maturity	Seed yield Per plant (gm)
GCA	6	183.62**	18.57**	78.65**	80502.60**	0.46**	93.82**	0.08**	16.36**	29.93**	24.42**
SCA	21	176.92**	7.20**	18.82**	20836.59**	0.19**	23.15**	1.09**	2.70**	10.53**	11.87**
Reciprocal	21	125.15**	4.07**	11.52**	12563.73**	0.07**	3.91**	0.83**	1.00**	11.15**	13.78**
Error	96	26.15	0.41	0.32	508.73	0.03	0.67	0.01	0.39	2.23	0.69

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

4.3.1 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 7. The magnitude and direction of the significant GCA effects for seven parents provide meaningful comparisons and would give clue to the future breeding program. The results of GCA effects of different characters are presented as follows:

4.3.1.1 Plant height

Out of seven parental GCA there were two parents showed highly significant and negative GCA effect and one parent showed significant GCA effect. The highest negative significant GCA effects (-4.41) was provided by BARI Sar-17 followed by Yellow Special (-4.05). The other parent which represented negative and significant GCA was BARI Sar-14 (-2.85). Those parents with positive and significant GCA effects were considered as good general combiner for the trait aimed to promote desirable plant height in their crosses (Table 7). The parent BARI Sar-6 (3.74) showed positive and significant GCA effects followed by BARI Sar-15 (3.42) and SAU proposed 4 (2.51). that were desirable general combiners to promote the plant height in *Brassica rapa*. Chowdhury *et al* (2004) obtained dwarfness in YSK-8501 in *Brassica campestris* L. Singh et al. (1996) observed dwarfness in glossy mutant in *Brassica juncea* L.

4.3.1.3 Number of secondary branches per plant:

For number of secondary branches per plant the highly significant and positive GCA effects were observed in only Local Tori-7 (5.02) and thus it can be considered as the best general combiner for the trait. Other parents demonstrated insignificant GCA effects. Singh *et al.* (1996) obtained the highest secondary branches in BJ-1235 in

Table 7: General combining ability (GCA) effects for 7 parents in 7× 7 full diallel crosses of *Brassica rapa* L.

Parent	Plant height (cm)	No. of primary branches/ plant	Number of secondary branches/ plant	Number of siliqua per plant	Siliqua length (cm)	Seed per siliqua	1000 seed weight (gm)	Days to 50% Flowering	Days to 80% Maturity	Seed yield per plant
BARI Sar-14	-2.85*	-0.90	-1.89	-57.62**	-0.01	2.25	-0.03	-1.13	-1.65	-0.19
SAU proposed 4	2.51*	0.80	0.52	32.96**	-0.03	-2.22	0.05	-0.89	-0.42	-0.19
Yellow Special	-4.05**	-0.80	-1.23	-56.66**	0.12	1.77	0.01	0.92	-1.15	-0.73
Local Tori-7	1.65	1.94	5.02**	150.49**	-0.17	-3.42*	-0.03	-0.79	1.59	2.92*
BARI Sar-17	-4.41**	-1.11	-1.52	-63.14**	0.00	3.48*	-0.11	-0.44	-0.06	-1.01
BARI Sar-15	3.42*	0.69	0.00	7.75**	-0.23	-1.81	-0.03	0.61	-0.68	-0.29
BARI Sar-6	3.74**	-0.61	-0.90	-13.79**	0.32	-0.05	0.13	1.71	2.37	-0.51
SE(gi)	1.27	0.16	0.14	5.58	0.04	0.20	0.03	0.15	0.37	0.21

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

Brassica juncea L. Chowdhury *et al.* (2004a) observed more secondary branches in Din-2 in *Brassica rapa* L.

4.3.1.4 Number of siliquae per plant:

All the parents were found with significant GCA effects of which four are negative and the others are positive values. The parents Local Tori-7 exhibited the highest (150.49) significant and positive GCA effects followed by SAU proposed 4 (32.96) and BARI Sar-15 (7.75) for the character. These three parents with higher positive and significant GCA were selected as the best general combiner and desirable to use in hybridization program to improve the number of siliqua per plant in *Brassica rapa* L. (Table 7). On the other hand, the highest negative and significant GCA value provided by BARI Sar-17 (-63.14). Chowdhury *et al.* (2004) found the highest number of siliquae in Din-2 in *Brassica rapa*. Singh and Murty (1980) obtained maximum number of siliquae per plant in SS-1 in *Brassica campestris* L.

4.3.1.5 Siliqua length:

No significant positive GCA effect was observed in the parents for the trait. All of them showed insignificant effect. 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* L.

4.3.1.6 Seeds per siliqua

The parent BARI Sar-17 exhibited the highest ((3.48) significant and positive GCA effects for this character. This parent was selected as the best general combiner and desirable to use in hybridization program to improve the number of siliquae per plant in *Brassica rapa* L. (Table 7). On the other hand, the highest negative and significant GCA value were provided by Local Tori-7 (-3.42). Chowdhury *et al.* (2004) found the highest number of siliquae in Din-2 in *Brassica rapa*. Singh and Murty (1980) obtained maximum number of siliquae per plant in SS- 1 in *Brassica campestris* L.

4.3.1.7 Thousand seed weight

No significant positive GCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to improve the thousand seed weight by using these parents due to their poor GCA though Chowdhury *et al.* (2004a) found highest seed weight in Dhali in *Braasica rapa* L.

4.3.1.8 Days to 50% flowering

For the trait days to 50% flowering, a significant positive GCA effect is useful for shorter gowth duration. No significant positive GCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to shorten the duration by using these parents due to their poor GCA. Chowdhury *et al.* (2004) found earliness in Din-2 in *Brassica rapa* L. Singh *et al.* (2000) obtained earliness in YSK-8501 in Brassica *compestris/rapa*. Verma (2000) observed earliness in RC 832 in *Brassica Juncea* L.

4.3.1.9 Days to 80% maturity

No significant positive GCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to improve the trait by using these parents due to their poor GCA though Chowdhury *et al.* (2004) observed earliness in Din-2 in *Brassica rapa* L. Singh *et al.* (2000) found earliness in YSC-68 in *Brassica campestris* L.

4.3.1.10 Seed yield per plant

The highest significant and positive GCA effects was observed only in Local Tori-7 (2.92). This parent having significant and positive GCA effects might be selected as promising general combiner for high yield potential in this regard. On the other side, Other parents showed insignificant GCA effect for the character (Table 7) indicating the parents used in this experiment were not good general combiner for improving seed yield per plant. Chowdhury *et al*. (2004) found the highest seed yield per plant in Pt-303 in *Brassica rapa* L.

4.3.2 Specific combining ability (SCA) effects

The specific combining ability effects significant the role of non-additive i.e. dominance and or epistatic gene action in the expression of the characters. It denotes the highly specific combining ability leading to the highest performance of some specific cross combinations. For this reason, it relates to a particular cross. The specific combining ability effects are also seen in relation to their size. High SCA effects may arise not only on cross involving high 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 program. The specific combining ability effects of forty-two crosses for the 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 a clue to the future breeding program. The results of SCA effects for different characters are given below:

4.3.2.1 Plant height

Out of 42 crosses, twelve crosses showed significant and negative SCA effect. Yellow Special × SAU proposed 4 (-14.33) showed the highest significant and negative SCA effects for plant height followed by BARI Sar-6 × SAU proposed 4 (-13.70), BARI Sar-6 × Local Tori-7 (-11.07), BARI Sar-17 × Local Tori-7(-10.21) and BARI Sar-6 × BARI Sar-14(-9.25). These crosses could be considered as the best combination. Thus, the cross combinations could be used for dwarfness of this crop. The highest positive SCA effects were observed BARI Sar-15 × SAU proposed 4 (15.05). 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.

4.3.2.2 Number of primary branches per plants

The cross combination Local Tori-7 × BARI Sar-17 (3.22) was found to be the best to improve this crop with more number of primary branches as it showed the highest significant and positive SCA effects for this trait (Table 8). Chowdhury *et al.* (2004) found more primary branches in Sampad x Tori-7 in *Brassica rapa*. Singh *et al.* (2000) obtained maximum number of primary branches per plant in YSK-8501 x SS-I

Table 8. SCA effects for 10 characters in full diallel cross of *Brassica rapa* genotypes

Sl. No.	Cross	Plant height (cm)	No. of primary branches per plant	No.of secondary branches per plant	No. of siliqua per plant	Siliqua length (cm)	Seeds per siliqua	1000 seed wt. (gm)	Days to 50% flowering	Days to 80% maturity	Seed yield per plant
1.	BARI Sar-14 × SAU proposed 4	13.49**	1.60	0.10	99.33**	-0.02	-4.60**	-0.33	0.48	2.96**	2.60*
2.	BARI Sar-14 × Yellow Special	0.77	0.21	1.95	32.14**	0.17	0.55	0.60	-0.33	-2.30*	1.94
3.	BARI Sar-14 × Local Tori-7	4.58**	1.71	-3.01**	-12.69**	-0.04	-2.29*	0.15	1.89	0.46	-0.45
4.	BARI Sar-14 × BARI Sar-17	1.64	1.54	1.12	6.45**	-0.67	-5.32**	0.65	0.23	.58	1.25
5.	BARI Sar-14 × BARI Sar-15	2.60*	-0.09	-1.22	-37.18**	0.33	-0.13	0.00	-0.85	-2.11*	-1.47
6.	BARI Sar-14 × BARI Sar-6	2.79*	0.09	-0.24	-28.61**	-0.13	-1.07	-0.66	0.22	0.01	-0.47
7.	SAU proposed 4 × Yellow Special	4.41**	2.16*	0.54	45.75**	-0.04	1.69	0.15	1.44	-0.87	0.02
8.	SAU proposed 4 × Local Tori-7	-6.99**	-0.58	-1.22	-43.82**	0.31	3.38**	-0.36	-0.85	-1.78	-2.42*
9.	SAU proposed 4 × BARI Sar-17	10.08**	-0.32	1.14	19.80**	-0.52	-4.24**	-0.25	1.46	-0.80	0.71
10.	SAU proposed 4 × BARI Sar-15	6.06**	1.85	1.15	102.08**	-0.47	-2.55*	0.80	0.24	0.99	0.90
11.	SAU proposed 4 × BARI Sar-6	1.95	-0.41	-1.75	-47.24**	0.31	0.78	0.57	-0.68	-1.06	0.52
12.	Yellow Special × Local Tori-7	5.62**	0.17	-0.38	-2.58*	-0.15	-1.10	0.47	0.51	1.80	2.44*
13.	Yellow Special × BARI Sar-17	-2.44*	-0.56	-0.56	-11.31**	0.31	0.28	-0.02	0.65	2.27*	-0.75
14.	Yellow Special × BARI Sar-15	-0.46	-0.14	-0.91	-15.53**	0.09	0.10	-0.34	-0.56	-0.11	1.34
15.	Yellow Special × BARI Sar-6	2.18*	0.49	-0.25	7.12**	-0.02	1.49	-1.46	-0.66	-0.16	-1.29
16.	Local Tori-7 × BARI Sar-17	8.71**	3.22**	1.26	122.38**	-0.11	-3.50**	1.05	0.86	2.70*	4.15**
17.	Local Tori-7 × BARI Sar-15	6.32**	1.54	7.93**	176.24**	-0.51	-2.23*	-1.01	1.65	2.99**	2.92**
18.	Local Tori-7 × BARI Sar-6	1.64	0.50	6.10**	155.04**	0.05	-0.54	-0.45	-0.45	-1.06	1.61
19.	BARI Sar-17 × BARI Sar-15	0.93	-0.39	-1.69	-54.52**	0.28	-2.09*	-1.33	-0.87	-3.20**	-1.80
20.	BARI Sar-17 × BARI Sar-6	2.78*	0.32	-0.80	-4.98**	-0.01	-2.65*	0.71	-0.30	-3.75**	0.61
21.	BARI Sar-15 × BARI Sar-6	3.69**	0.61	-1.89	-1.34	-0.37	-1.52	0.27	0.15	1.03	1.73

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

Table 8 (Cont.)

Sl. No.	Reciprocal	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	No. of siliqua per plant	Siliqua length (cm)	Seeds per siliqua	1000 seed wt. (gm)	Days to 50% flowe-ring	Days to 80% maturity	Seed yield per plant
22.	SAU proposed 4 × BARI Sar-14	-1.28	0.83	0.47	6.15**	0.23	1.50	0.58	-1.33	0.17	1.12
23.	Yellow Special × BARI Sar-14	4.71**	2.04	2.08*	73.58**	0.15	-0.77	-0.64	0.33	1.50	4.84**
24.	Yellow Special ×SAU proposed 4	-14.33**	3.20**	1.23	85.47**	-0.36	1.67	0.04	-0.33	0.50	2.84**
25.	Local Tori-7 × BARI Sar-14	-4.35**	-0.66	0.00	-13.63**	-0.20	-1.12	0.05	-1.17	-3.33**	-2.63*
26.	Local Tori-7 × SAU proposed 4	7.00**	-1.43	-1.17	-62.12**	-0.35	-1.14	-0.73	-0.67	-2.00	-1.85
27.	Local Tori-7 × Yellow Special	-6.48**	-2.25*	-5.54**	-144.72**	-0.15	-0.11	-0.99	0.17	-3.50**	-6.15**
28.	BARI Sar-17 × BARI Sar-14	2.97**	-1.78	0.97	0.43	0.12	0.52	-0.45	-0.50	4.17**	-1.30
29.	BARI Sar-17 × SAU proposed 4	7.86**	-0.71	0.05	-34.20**	-0.35	-0.19	0.07	1.00	5.33**	0.24
30.	BARI Sar-17 ×Yellow Special	-6.93**	-1.33	-0.07	-32.22**	0.01	0.72	0.86	-0.67	3.33**	0.18
31.	BARI Sar-17 × Local Tori-7	-10.21**	-1.01	-1.65	-25.15**	0.08	-0.17	-0.49	0.17	0.17	-3.56**
32.	BARI Sar-15 × BARI Sar-14	8.27**	1.27	-0.10	31.40**	0.08	1.22	0.39	0.17	-0.83	1.35
33.	BARI Sar-1×SAU proposed 4	15.05**	2.33*	4.13**	152.29**	-0.07	1.23	-0.78	-0.50	0.83	3.72**
34.	BARI Sar-15 × Yellow Special	-4.28**	0.58	1.23	58.18**	0.21	0.42	0.52	0.17	2.00	3.97**
35.	BARI Sar-15 × Local Tori-7	-1.82	-0.66	-1.73	2.33**	-0.23	-1.15	-0.10	0.67	0.83	-2.83**

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

Table 8 (Cont.)

Sl. No.	Reciprocal	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Siliqua per plant	Siliqua length (cm)	Seeds per siliqua	1000 seed wt. (gm)	Days to 50% flowering	Days to 80% maturity	Seed yield per plant (gm)
36.	BARI Sar-15 ×BARI Sar-17	-1.58	0.78	-0.08	17.38**	0.04	-0.44	0.69	0.83	-1.00	1.33
37.	BARI Sar-6 × BARI Sar-14	-9.25**	-0.42	0.35	6.50**	-0.06	-1.41	0.98	-1.00	-1.67	0.65
38.	BARI Sar-6×SAU proposed 4	-13.70**	-0.18	-0.65	-15.65**	0.01	0.56	0.31	0.00	-2.17*	0.01
39.	BARI Sar-6 × Yellow Special	-5.73**	0.42	1.00	63.36**	-0.05	-3.60**	0.55	-1.50	0.00	1.28
40.	BARI Sar-6 × Local Tori-7	-11.07**	-1.57	-7.47**	-227.67**	-0.04	-0.35	0.52	-0.33	-0.17	-1.41
41.	BARI Sar-6 × BARI Sar-17	-1.08	-0.33	0.02	38.13**	-0.26	-3.32**	-0.99	-0.17	1.50	-0.32
42.	BARI Sar-6 × BARI Sar-15	-1.82	1.52	0.59	76.64**	0.17	0.96	1.07	-0.33	3.67**	2.00
	SE(sij)	**3.142**	**0.393**	**0.348**	**13.859**	**0.109**	**0.502**	**0.063**	**0.383**	**0.918**	**0.512**
	SED(sij-sik)	**4.734**	**0.592**	**0.524**	**20.882**	**0.164**	**0.757**	**0.095**	**0.577**	**1.384**	**0.771**
	SED(sij-skl)	**4.322**	**0.540**	**0.479**	**19.062**	**0.150**	**0.691**	**0.087**	**0.527**	**1.263**	**0.704**

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

in *Brassica rapa*. Sheikh and Sing (1998) observed best positive effect in Pusa x Barani in *Brassica juncea*.

4.3.2.3 Number of secondary branches per plant

Out of 42 combinations seven of them produced significant SCA effects including four positive and three negative values ranged from -7.47 to 7.93. The combination Local Tori-7 × BARI Sar-15 possessed the highest positive and significant SCA effect (7.93) followed by Local Tori-7 × BARI Sar-6 (6.10) which could be selected as the best specific combiner for number of secondary branches per plant and might be used in further hybridization program for good hybrid combination. On the other hand, there were some combinations showed significant but negative SCA effects like BARI Sar-6 × Local Tori-7 (-7.47), Local Tori-7 × Yellow Special (-5.54) and BARI Sar-14 × Local Tori-7(-3.01) indicated poor specific combiner for this character not suitable for hybrid production. Chowdhury *et al* (2004) found maximum secondary branches in Sampad x Din-2 in *Brassica rapa* L. Singh and Murty (1980) observed more secondary branches per plant in YSC-68 x 55-2 in *Brassica campestris* L.

4.3.2.4 Siliqua per plant

Out of 41 cross combinations, there were forty crosses found to have under significant SCA effects and thirty-eight under highly significant effects ranged from -227.67 to 176.24 in which twenty-one with positive values. The combination Local Tori-7 × BARI Sar-15 produced the highest effect (176.24). The other combinations which produced highly significant and positive SCA included Local Tori-7 × BARI Sar-6(155.04) and BARI Sar-15 × SAU proposed 4 (152.29) and soon considered as the best specific combiner for the trait concerned. These combinations could be selected for the future breeding program to obtain desirable hybrid with higher number of siliquae per plant. Chowdhury *et al.* (2004) found the maximum siliquae in Sampad x Din-2 in *Brassica rapa* L. Singh and Marty (1980) observed more siliquae per plant in YSP-842 x SS-3 in *Brassica campestris* L.

4.3.2.5 Siliqua length

No significant positive SCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to improve siliqua length by using these parents due to their poor SCA. Huq (2006) showed BINAsar-6 x Tori 7 was not good for improving the trait in *Brassica rapa* L. Sheikh and Singh (1998) observed the maximum siliqua length in Pusa Barani x Glossy mutant and BM 20-12-3 x Pusha Bahar respectively in *Brassica juncea*.

4.3.2.6 Seeds per siliqua

Only one, out of 42 combinations exhibited significant and positive SCA effects having 3.38. The other cross combinations showed insignificant or significant and negative SCA effects. The cross combination SAU proposed 4 ×Local Tori-7 (3.38) produced the highest SCA effects indicated that this combination was the best specific combiner for this trait and might be selected for higher seeds per siliqua. Huq (2006) obtained BARI sar-6 x BINA sar-6 (C 12) the best specific combiner to increase the number of seeds in the siliqua for yield improvement in *Brassica rapa* L. *Chowdhury et al.* (2004) found the highest seeds per siliqua in Dhali x Sampad in *Brassica rapa* L. Singh *et al.* (2000) obtained more seeds per siliqua in YSP-842 x YSK-8501 in *Brassica campestiris* L.

4.3.2.7 Thousand seed weight

No significant positive SCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to improve the thousand seed weight by using these parents due to their poor SCA. Huq (2006) obtained all insignificant combination range -0.0534 to 0.0363 in *Brassica rapa* L. Singh *et al.* (2000) observed more seed weight per plant in YSC-68 x SS-2 in *Brassica campestris* L. Chowdhury *et al.* (2004) obtained the highest seed weight in Dhali x Sampad in *Brassica rapa* L.

4.3.2.8 Days to 50% flowering

No significant positive SCA effect was observed in the parents for the trait. All of them showed insignificant effect. Thus there was no opportunity to improve the days to 50% flowering by using these parents due to their poor SCA though Singh *et al.*

(2000) obtained earliness on YSK-S501 x SS-2 in *Brassica campestris/rapa*. Singh *et al.* (1996) observed earliness in PR-I 108 x BJ-1235 in *Brassica juncea* L.

4.3.2.9 Days to 80% maturity

Similar trends like days to 50% flowering, positive and significant SCA effects were also desirable for days to maturity. However, the highest positive SCA value was found in the combination BARI Sar-17 × SAU proposed 4 (5.33) followed by BARI Sar-17 × BARI Sar-14 (4.17), BARI Sar-6 × BARI Sar-15 (3.67), BARI Sar-17 × Yellow Special (3.33) and Local Tori-7 × BARI Sar-15 (2.99). On the other hand, the lowest in BARI Sar-17 × BARI Sar-6 (-3.75). So, the cross BARI Sar-17 × SAU proposed 4 was the best specific combiner in the hybrids. Chowdhury c/al. (2004) observed earliness in M-27 x Din-2 in *Brassica rapa* L. Singh *et al.* (2000) obtained earliness in SS-3 x SS-1 in *Brassica campestris* L.

4.3.2.10 Seed yield per plant

In case of seed yield per plant there were thirteen hybrid combinations showed significant SCA effects which ranged from -6.15 to 4.84 (Table 8). Among them six cross combinations showed highly significant and positive SCA effect and two showed significant positive SCA effect. The cross combinations Yellow Special × BARI Sar-14 produced the highest SCA effect (4.84) followed by Local Tori-7 × BARI Sar-17 (4.15), BARI Sar-15 × Yellow Special (3.97), BARI Sar-15 × SAU proposed 4 (3.72), Local Tori-7 × BARI Sar-15 (2.92) and Yellow Special × SAU proposed 4 (2.84) which might be selected as the best specific combiner for the trait. These six combinations could be selected for further evaluation to obtain heterotic hybrid combination in breeding program. Huq (2006) obtained the highest seed yield in Agroni x Tori 7, Agroni x BARlsar-6 and Shafal x l3ARlsar-6 in *Brassica rapa* L. Chowdhury *et al.* (2004) obtained the highest seed yield in M-27 x Din-2 in *Brassica rapa* L. Singh *et al.* (2000) observed more seed yield per plant in YSP-842 x YSK-8501 in *Brassica campestris* L.

CHAPTER V
SUMMARY AND CONCLUTION

A 7x7 full diallel cross analysis in rapeseed (*Brassica rapa* L.) was carried out during October, 2018 to February, 2019 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 BARI Sar-14, SAU proposed 4, Yellow Special, Local Tori-7, BARI Sar-17, BARI Sar-15 and BARI Sar-6 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 siliqua per plant, no. of seeds per siliqua, length of siliqua, thousand seed weight per plant and seed yield per plant.

The hybrid SAU proposed 4 × BARI Sar-15 found to be the best one for number of primary branches per plant followed by BARI Sar-17 × Local Tori-7, BARI Sar-15 × Local Tori-7. BARI Sar-6 × Local Tori-7 produced maximum number of secondary branches followed by SAU proposed 4 × BARI Sar-15 and Local Tori-7×BARI Sar-15. Crosses SAU proposed 4 × BARI Sar-6 and BARI Sar-17 × BARI Sar-14 showed maximum length of siliqua and number of seeds per siliqua respectively. The hybrid combination BARI Sar-6 × BARI Sar-17 followed by BARI Sar-15 × SAU proposed 4, Local Tori-7 × Yellow Special provided the highest weighted seeds. For seed yield per plant the cross Local Tori-7 × Yellow showed the maximum production followed by BARI Sar-17 × Local Tori-7 and BARI Sar-15 × Local Tori-7. Special Selection out of these crosses in the subsequent generations might produce some suitable segregates. It was observed that all the hybrids obtained did not perform well for many of the important characters and to find out the desirable hybrids, the crosses were scored on the basis of desirable heterotic values. Out of forty-one crosses, significant but highest negative heterosis was provided by the hybrid Yellow Special × BARI Sar-6, BARI Sar-15 × BARI Sar-17, BARI Sar-14 ×BARI Sar-6, BARI Sar-15 × BARI Sar-6, BARI Sar-15 × BARI Sar-14 and BARI Sar-17 × BARI Sar-6 for days to 50% flowering. Significant negative heterosis for 80% maturity was found in BARI Sar-17 × SAU proposed 4 and BARI Sar-6 × BARI Sar-17. Thus these can be used for producing variety with earliness. For primary branches per plant maximum heterosis was found in SAU proposed 4 × Yellow Special, BARI Sar-17 × Local Tori-7 and Local Tori-7 × SAU proposed 4. The highest significant and positive heterosis for number of secondary branches was produced by the combination BARI Sar-6 × Local Tori-7, BARI Sar-15 × Local Tori-7 and Local Tori-7 × BARI Sar-15. The cross BARI Sar-6 × Local Tori-7 produced maximum heterosis for number of siliqua per plant followed by SAU proposed 4 × BARI Sar-15. The crosses BARI Sar-17 × Local Tori-7 showed maximum heterosis for hundred seed weight and the cross Local Tori-7 × Yellow Special showed maximum heterosis for seed yield per plant.

Analysis of combining ability following Griffing's approach showed significant GCA and SCA variance for all the characters studied, indicating the role of both additive and non-additive components in the genetic system controlling these characters. Estimates of GCA effects for different characters suggested that parent Local Tori-7 was the best general combiner for producing number of secondary branches, number of siliqua per plant and seed yield per plant. BARI sar-6 was the best for plant height and the parent BARI Sar-17 was the best for producing higher seeds per siliqua. For plant height, a good general combiner was BARI sar-6.

The SCA estimates of various characters revealed that Yellow Special × SAU proposed 4 was the best for plant height and could be used for dwarfness of this crop. The cross combination Local Tori-7 × BARI Sar-17 for number of primary branches per plants, the combination Local Tori-7 × BARI Sar-15 for number of secondary branches per plant and for siliqua per plant Local Tori-7 × BARI Sar-15 produced the highest effect. The cross combination SAU proposed 4 ×Local Tori-7 (3.38) produced the highest SCA effects for seeds per siliqua. the cross BARI Sar-17 × SAU proposed 4 was the best specific combiner in the hybrids for early maturity. The cross combinations Yellow Special × BARI Sar-14 produced the highest SCA effect for seed yield.

Among the genotypes, the parents had high GCA effects and wide genetic diversity and hybrids had high heterotic value and SCA effect should give maximum emphasis. These genotypes could be effectively used in future for developing varieties of *Brassica rapa* L.

RECOMMENDATIONS

Based on the summary and conclusions following recommendations can be made:

1. The hybrid BARI Sar-17 × SAU proposed 4 and BARI Sar-6 × BARI Sar-17 can be used for producing variety with earliness.

2. The hybrid Local Tori-7 × Yellow special can be used to get maximum yield.

3. The hybrid Yellow Special × SAU proposed 4 can be used for dwarfness of the crop.

REFERENCES

Acharya, N.N. and Swain, D. (2004). Combining ability analysis of seed yield and its components in Indian mustard (*Brassica juncea* L.). *Indian J. Agril. Res.* **38**(1): 40-44.

Adefris, T. and Heiko, C.B. (2005). Heterosis and Combining Ability in a Diallel Cross of Ethiopian Mustard Inbred Lines. *Crop Sc.* **45:** 2629-2635.

Ahmad, M.R. (1993). Study of agronomic value of resynthesized rapeseed lines and early generations of crosses "rsyn-lines x improved varieties. *lranian J. Agril. Sci*. **24** (3/4): 1-13.

Arva, A.S., Singli, D., Hari, S. and Singh. H. (1989). Unified selection procedure for simultaneous improvement of characters in rapeseed (*Brassica napus* L.) *Crop Res.-Hisar.* **2**(2): 137-141.

Ali, M. Copeland, L.O. Elias, S.C. and Kelly, J.D. (1995). Relationship between genetic distance and heterosis for yield and morphological traits in winter canola (*Brassica napus* L.). *Theor. Appl. Genet.* **91**(1): 118-121.

Badwal, S.S. and Labana, K.S. (1987). Diallel analysis for some metric traits in Indian mustard. Crop improvement **14**(2): 191-194.

Barua, P.K., Hazarika, M.H. (1993). Heterosis analysis in Indian mustard rapeseed. *In:* heterosis breeding in crop plant - theory and application: short communications: symposium Ludhiana, April 5-6, Ludhiana, India. pp. 4-5.

BBS, (2018). Statistical Yearbook of Bangladesh. Bangladesh Bureau of Statistics, Stat. Div., Ministry Planning, Govt. Peoples Rep. Bangladesh, Dhaka. p. 148-149.

Begum F., Hossain F. and Mondal M.R.I. (2012). Influence of Sulphur on morpho-physiological and yield parameters of rapeseed. *Bangladsh J. Agril. Res.* **37**(4): 645-652.

Chaudhury, B.D., Ashok, K., Singh, D.P. and Phool, S. (1988). Genetics of yield and its components in Indian mustard. Narendra Deva. *J Agril. Res.* **3**(1): 37-43.

Chaudhury, B.D., Kumar. A., Singh, D.P., Singh, P. and Kumar, A. (1987). Combining abilities and components of variation in *Brassica campestris*. *Res. Development Report.* **4**(2): 125-129.

Chauhan, Y.S. (1987). Genetic analysis for yield and its components in Indian mustard. *Indian J. Agril. Res.* **21**(2): 77-82.

Chauhan, Y.S., Kumar, K., Ram, B. and Singh, S.K. (1990). Breeding for increased yield. Research on rapeseed and mustard. Proceedings of an Indo Swedish Symposium, 4-6 September, UP Saha, Sweden [Ed. Ohlsson, I., Kumar. P.R.]: 109-121.

Cheema, K.L. and Sadaqat, H.A. (2004). Potential and genetic basis of drought tolerance in canola (*Brassica napus*): II. Heterosis manifestation in some morpho-physiological traits in canola. *Int. J. Agric. Biol.* **6**(1): 82-85.

Chowdhury, M.A.Z., Mian, M.A.K., Akbar, M.A. and Alanm, M.Z. (2004) Combining ability for seed yield and yield contributing characters in turnip rape (*Brassica rapa* L.). *Bangladesh J. Plant. Breed Genet.* **17**(1): 17-24.

Engqvist, G.M. and Becker, H.C. (1991). Heterosis and epistasis in rapeseed estimated from generation means. *Euphytica.* **58**(1): 1165-1170.

Ghosh, S.K., Gulati, S.C., Rajani, R. and Raman, R. (2002). Combining ability and heterosis for seed yield and its components in Indian mustard (*Brassica juncea* L. Czern & Coss). *Indian J. Genet. Plant. Breed.* **62**(1): 29-33.

Goswami, P.K., Thakral, N.K., Behl, R.K. and Kumar, R. (2004). Heterosis breeding in Indian mustard (*Brassica juncea* L.Czeni & Coss.). *Brassica*. **6**(1/2): 47-51.

Griffing, B. (1956). A generalized treatment of the use in diallel cross in quantitative inheritance. *Heredity*. **10:** 13-50.

Griffing, J.E. (1958). Application of sampling variance in the identification of methods which yields unbiased estimates of genotypic variances. *Aust. J. Biol. Sci.* **11**: 219-245.

Gupta, M.L., Banga, K.S. and Sandha, G.S. (1993). Commercially exploitable heterosis in *Brassica campestris* L. Oleiferous var. toria. In heterosis breeding in crop plant-theory and application: short communuication: symposium Ludhiana, 23-24 February 1993. Ludhiana. India; crop improvement society of india (1993) 18-19. [Plant Breeding Abstract. **64** (2): 264]

Gupta, M.L., Labana, KS., Badwal, S.S. (1987a). Combining ability analysis of seed yield and its components in Indian mustard. In 7th International rapeseed congress, Poznan, Poland, 11-14 May.

Gupta, M.L., Gupta. V.P., Labana, K.S. (1987b). Combining ability analysis of seed yield and its components in Indian mustard. *Crop Improvement* **14**(2): 160-164.

Habetinek, J. (1993). Heterosis and combining ability in a diallel cross of five varieties of winter swede rape (*Brassica napus* L.). *Roslinna Vyraba.* **55**: 151 -160.

Hari, S., Malik, V.S. and Singh, D. (1995). Heterosis in some intervarietal crosses of rapeseed (*Brassica napus*). *J. Oilseeds Res.* **12**(2): 180-183.

Huang, Y.J., Chen, J. and Li, Y.C. (2000). Genetic study of *Sclerotinia sclerotiorum* resistance in rapeseed (*Brassica napus* L.) I. Its inheritance and combining ability. *Chinese J. Oil Crop Sci.* **22**(4): 1-5.

Huq, K.M.E. (2006). Heterosis and combining ability in rapseed (*Brassica rapa* L.) derivatives. MS. Thesis, SAU, Dhaka.

Katiyar, R.K., Chamola, R., Singh, H.B. and Tickoo, S. (2004). Heterosis and combining ability analysis for seed yield in yellow sarson (*Brassica campestris*). *Brassica.* **6**(1/2): 23-28.

Khaleque, M. A. (1985). A Guide book on Production of Oil Crops in Bangladesh. DAE and FAO/UNDP Project BGD/79/034, " Strengthening the Agricultural Extension Service" Khamarbari, Farmgate. Dhaka.3.

Krishnapal, Ghose, S.K. (1992). Heterosis in relation to genetic divergence in rapeseed and mustard. J. *Oilseed Res.* **9**(1): 169-174.

Krzymanski, J., Pietka, T. and Krotka, K. (1993). Combining ability and heterosis in diallel crosses double zero winter swede rape. 1. F_1 generation, *Postepy Nomk rolnizych* **40/45**(5): 41-52. [Plant Breeding Abstract. **65**(6): 912]

Krzymanski, J., Pietka, T. and Krotka, K. (1994). Combining ability and heterosis in diallel crosses double zero winter swede rape. 2. F_1 and F_2 generations. *Rosling Oleistc.* **15**(1): 2 1-32.

Kudla, M. (1993). Comparative analysis of winter swede rape genotypes. *Biuletyn Instytutu Hodowi Roslin.* **90**: 99-107.

Kumar, C., Muralia, S., Deepak, C. and Gupta, D. (2002). Heterosis studies in Indian mustard (*Brassica juncea* L.). *Cruciferae Newsletter.* **24**: 59-60.

Kumar, P.R., Arora, R.K., Singh, N.P., Yadav, R.C. and Kumar. P. (1990). A study of heterosis in Indian mustard (*Brassica juncea* L. Cross and Czem). *Acta Agron. Hungarica.* **39**(1 -2): 137-143.

Labana, K.S., Jindal S.K. and Menon, O.K. (1978). Heterosis and combining ability in yellow sarson. *Crop Improvement* **2**: 46-51.

Lefort, B. M. (1982). Heterosis with summer rapeseed (*Brassica napus* L.) *Cruciferae Newsletter.* **7**: 16-17

Lefort, B. M. Guillot, L. B. and Dattee, V. (1987). Heterosis and genetic distance in rapeseed (*Brassica napus* L.); crosses between European and Asiatic selfed lines. Genome. **29**(3): 41 3-41 8.

Liersch, A., Bartkowiak, B.I. and Ogrodowczyk. M. (2004). Analysis of the variability of yield components and heterosis effect of CMS ogura hybrids of oilseed rape (*Brassica napus* L.). Rosliny Oleiste. **25**(2): 371-382.

Liu, XX., Dong, Z.S., Liu, C.S., Dong, J.G. and Li, H.B. (2001). Combining ability and heritability of the main agronomic characters of some fine hybrids of rapeseed (*Brassica napus* L.). *Chinese J. Oil Crop Sci*. **23**(3): 1-4.

Lu, CM., Shen F, S., Hu, K. and Hu, K. (2001). Heterosis in interspecific hybrids between *Brassica napus* and *B. rapa*. SABRAO *J. Breed. Genet.* **33**(2): 73-85.

Malik, V.S., Singh, H. and Singh, D. (1995). Gene action of seed yield and other desirable characters in rape seed (*Brassica napus* L.). *Annal Biol*. **11**: 97-7.

Mahak, S. and S. Lallu. (2004). Heterosis in relation to combining ability for seed yield and its contributing traits in Indian mustard, *Brassica juncea* (L) Czern and Coss. *J.oilseeds Res.* **21**(1): 140-142.

Mahak, S., S. Lallu, Swarnkar, G.B., Lalta ,P. and Dixit, R.K. (2003). Heterobeltiosis and inbreeding depression in India mustard [*Brassica juncea* L.) Czern and Coss]. *Crop Res. Hisar.* **26**(2): 318-325.

Mahak, S., Srivastava, R.L., Dixit, R.K. and Singh, M. (2003). Heterosis and inbreeding depression in relation to seed yield in Indian mustard [*Brassica juncea* (L) Czern and Coss.]. *Plant. Arch.* **3**(1): 71-72.

Matho, J.L. and Haider, Z.A. (2001). Assessing suitable combiners in *Brassica juncea* L. for high altitude acidic soils. *Cruciferae Newsletter*. **23**. pp. 47-48.

Nasim. M. (1990). Combining Ability and Heterosis in Cultivars of *Brassica campestris* L. M.Sc. (Ag) in Genetics and plant breeding. Dissertation, submitted to the Faculty of Agriculture, Bangladesh Agril. University, Mymensingh.

Pankaj, S., Pant, D.P., Singh, S.P., Chanchal, S., Ritesh, S., Sharma, P., Sah, C. and Sharma, R. (2002). Heterosis vis-a-vis GCA of parents in toria (*Brassica campestris* L.). *Cruciferae Newsletter.* **24**: 71-72.

Pathak, AD., Tripathi, R.M. and Tripathi, R. (2002). Residual heterosis in Indian mustard (*Brassica juncea* L. Czern & Coss). *New Botanist* **29** (1-4): 201-207.

Pietka, T. Krotka, K. and Krzymanski, J. (2001). Study on combining ability in respect to glucosinolate content in F_1 and F_2 generations of winter rapeseed hybrids (*Brassica napus* L.). *Rosliny Oleiste.* **22**(2): 303-314.

Pietka, T. Krotka, K. and Krzymanski, J. (2003). General combining ability and heritability of glucosinolate content of winter oilseed rape (*Brassica napus* L.) seeds. *Biulety instytutu Hodowli Aklimatyzacji Roslin.* (226/227): 405-414.

Pradhan, Ak. Sodhi, Y.S., Mukhopadhaya, A. and Pental, D. (1993). Heterosis breeding in Indian mustard (*Brassica juncea* L. Czern and coss): analysis of component characters contributing to heterosis for yield. *Euphytica.* **69**(3): 21 9-229.

Prakash, N., Chauhan, Y.S., Kumar, K. (1987). Combining ability and path coefficient analysis in F_2 generation in Indian mustard (*Brassica juncea* L. Czern and Coss.) In 7th International Rapeseed Congress, 11-54 May, Poznan, Poland, pp.110.

Prasad, L., Singh, M. and Dixit, R.K. (2002). Combining ability analysis in Indian mustard (*Brassica juncea* L. Czern & Coss.). *Advances in Plant Sci.* **15**(1): 307-314.

Pszczola, J. (1993). Estimation of combining ability for selected traits in winter swede rape in two sets of diallel crosses. Postepy Nauk Rolniczych **40/45**(5): 33-40.

Qi, C.K., Gao, G.J. and Zhang, J.F. (2000). Analysis of heterosis among varieties or inbred lines in *Brassica campestris*. *Jiangsu J. Agril. Sci.* **11**(3): 30-32.

Qi, C.K., Pu, H. M., Zhang, J. F. and Fu, S. Z. (2003). Analysis of heterosis of seed yield and its components of intervarietal cross in *Brassica napus* L. *Jiangsu J. Agril. Sci*. **19**(3): 145-150.

Rahman, L., Quddus, M. A. and Rahman, M.A. (1993). Recent advances in advances in oilseeds breeding in Bangladesh Advances in Crop Science Proc. of the 1st Biennial conference of the Crop Science Society of Bangladesh, 18-20 January 1992.

Rai, B. and Singh, P.K. (1994). Expression of yield heterosis in some inter varietal crosses in Indian rapeseed (*Brassica campestris* L.). *Indian J. Genet. Pl. Breed.* **54**(3): 310-314.

Rawat, D.S. (1987). Line x tester analysis and rank index in mustard. *Ann. Agril. Res.* **8**(2): 173-182.

Rawat, D.S. (1992). Analysis of reciprocal differences in Indian mustard. *Acta Agron. Hungarica*. **41**(3-4): 277-233.

Satwinder, K., S. Paramjit and V.P. Gupta. (1997). Combining ability analysis for oil yield and its components in *Brassica napus* L. *Crop Improv.* **24** (1): 140-142.

Satyendra, Singh, H.L. and Mahak, S. (2004). Evaluation of heterosis for seed yield and its components in Indian mustard (*Brassica juncia* (L.) Czern and Coss.). *Pl. Arch.* **4**(2): 433-437.

Schuster, W., Alawi, A. and El-Seidy, R.G. (1978). Studies on inbreeding and heterosis phenomenon in black mustard (*Brassica nigra* L). *Angewandte Bulani*, **52**(3/4): 215-232.

Sheikh, I.A. and singh, J. N. (1998). Combining ability analysis of seed yield and oil content in *Brassica juncea* L. Coss & Czern. *Indian J. Genet.* **58**(4): 507-511.

Shen, J. X., Fu, T. D., Yang, G. S., Ma, C. Z. and Tu, J. X. (2005). Genetic analysis of rapeseed self-incompatibility lines reveals significant heterosis of different patterns for yield and oil content traits. *Pl. Breed.* **124**(2): 111-114.

Siddique, S.B., Quddus, M.A., Rahman, M.H, Wazuddin, M., Rahman, L. (1990). Combining ability and heterosis in *Brassica campestris*. *Bangladesh J. Agril.Sci.*, **17**(1): 141-146.

Singh, M., Singh, H., Arya, A.S. and Navecnchandra. (1992). Combining ability analysis and genetic improvement in Ethiopian mustard (*Brassica carinata* Braun). *Crop Res. Hisar.* **5**(2): 279-285.

Singh, A. K., Chauhan, Y.S. and Kumar, K. (1999). Combining ability analysis in rapeseed (*Brassica campestris* L.) using recessive genic male sterility. *J. Oilseeds Res.* **16**(2): 314-316.

Singh, M., Singh, S.P. and Dhirendra, S. (2000). Genetic analysis for seed yield and its genotypes in yellow sarson (*Brassica campestris* L.). *Indian J Agric. Sci.* **70**(9): 624-626.

Singh, O.N. and Chauhan. Y. S. (1987). Triple test cross analysis for seed and oil yield and its components in Indian mustard (*Brassica juncea* L. Czern and Coss) [Poster]. In

7th International rapeseed congress, Poznan. Poland, 11-14 may 1987. Poznan, Poland (1987) l l l. [Plant Breeding Abstract. **58**(10): 964]

Singh, R.S., Singh, P. and Dixit, R.K. (1987). Combining ability analysis of yield and developmental traits in Indian colza (*Brassica campestris* L.var. Yellow Sarson Prain). *Farm Sci*. J. **2**(2): 170-174.

Singh, V.S., Srivasta, A.N. and Ahmad, Z. (1989). Combining ability in F_1 and F_2 generations of diallel cross in Indian mustard. *Crop Improvement.* **16**(2): 164-167.

Srivastava, K. and Rai, B. (1993). Expression of heterosis for yield and its attributes in rapeseed (*Brassica napus*) *Indian J. Agril. Sci*. **63** (4): 243-245.

Swarnkar, G.B., Mahak, S., Lalta, P., Dixit, R.K, Singh, M. and Prasad, L. (2001) Heterosis in relation to seed yield and its components in Indian mustard [*Brassica juncea* L. Czern and Coss]. *Plant. Arch*. **1**(1-2): pp. 75-80.

Tamber, KS., Singh M. and Gupta, M.L. (1991). Combining ability for earliness in Indian mustard (*Brassica juncea* L. Czern). *Indian J. Genet.* **49**: 223-226.

Thakur, H.L. and Segwal, J.C. (1997). Heterosis and combining ability in rapeseed (*Brassica napus* L.). *Indian J. Genet. and Pl Breed*. **57**(2): pp. 163-167.

Thakur, H.L., Zarger, MA., (1989). Heterosis in relation to genetic divergenece and specific combining ability in Indian mustard *Brassica juncea* (Czern. and Coss.). *Indian J. Genet. Pl. Breed*. **49(**2): 223-226.

Trivedi. H.B.P. and Mukharjee, B. K. (1986). Genetic parameter and their implication in breeding high-oil varieties of Indian mustard *Indian J. of Agric. Sci.* **56**(1):10-14

Tyagi, M.K., Chauhan, J.S., Kumar, P.R. and Singh, K.H. (2001). Estimation of heterosis in Indian mustard [*Brassica juncea* (L.) Czern and Coss.]. *Annals of Agri. Bio. Res.* **6**(2): pp. 193-200.

Varshney, S.K. and Rao, C.S. (1997). Combining ability, heterosis and inbreeding depression for yield and yield components of in yellow sarson. *Indian J. Genet. and Pl. Breed*. **57**(1): 91-97.

Verma, N. K., Singh, B. and Sachan, J.N. (1989). Combining ability and Heterosis in yellow sarson. *J. Oilseeds Res.* **6**: 32-40.

Wani, S.A. and Srivatava, A.N. (1989). Combining ability analysis in Indian mustard. *Crop Improvement*. **16**(1): 72-75.

Wu, X.M., Huang. H.L., Wing, Z.L., and Ding, D.J. (2001). Studies on breeding and application of thermo-sensitive genic male sterile line 402S in *Brassica napus*. II. Evaluation of heterosis and combining ability. *Hunan Agril. Sci. Tech. Newsletter*. **2**(4): 16-21.

Yadav, C.B., Chauhan, Y.S., Kumar, K. and Chaudhary, R.K. (2005). Combining ability analysis using CMS systems in rapeseed (*Brassica napus* L.). *Farm Sci. J.* **14**(1): 72-74.

Yadav, L.S., Yadava, T.P., Kumar, P. and Thakral, N.K. (1998). Heterosis for seed yield and its components in rapeseed under rainfed conditions. *Cruciferae Newsletter*. **20**: 79.

Yadav, O.P., Yadava, T.P. and Kumar, P. (1996). Combining ability studies for seed yield, its component characters and oil content in Indian mustard (*Brassica juncea* L. Czern. and Coss.). *J. oilseeds Res.* **9**(1): 14-20.

Yadav, OP., Yadava, T.P., Kumar, P. (1992). Combining ability studies for seed yield, its component characters and oil content in Indian mustard (*Brassica juncea* L.Coss). *J. 0ilseed Res.* **9(1)**: 14-20.

Yadav, T.P., Kumar, P., Raj, L. and Thakral, N.K. (1997). A study of heterosis in toria (*Brassica campestris* var. toria). *Cruciferae Newsletter*. **19**: 101-102.

Yarnell, S.H. (1965). Cytogenetics of the vegetable crops. II. *Crucifers. Bot Rev*. **22**(2): 18-166.

Zhang, S.F., Tian, B., Wang J., Wen, Y.C., Zhu J.C. and Ren L.J. (2002). Predicting double low hybrid crosses heterosis by genetic methods in *Brassica napus*. *Cruciferae-Newsletter*. **24**: 73-74.

Zheng, Y.J. and Fu, T.D. (1991). Study on heterosis in CMS line-derived hybrids of rapeseed (*Brassica napus* L.). *Oil Crops China.* **1**: 7-11.

Zuberi, M. I. and Ahmed, S.V. (1973). Genetic study of yield and some of its components in *Brassica campestris* var. Toria. *Crop Sci.* **13**(1): 13-15.

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, 1952
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, 1955
10	CEC	11.23	Chapman, 1965

Appendix II. Monthly average temperature, relative humidity and total rainfall of Dhaka during the period from October, 2018 to February, 2019

Month	Air temperature (^0c)		Relative humidity (%)	Rainfall (mm)	Sunshine (hr.)
	Minimum	Maximum			
November, 2018	19.2	29.6	53	34.4	11
December,2018	14.1	26.4	50	12.8	11
January, 2019	12.7	25.4	46	7.7	11
February, 2019	15.5	28.1	37	28.9	11

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