COMBINING ABILITY AND HETEROSIS IN F_1 POPULATIONS DERIVED FROM 6×6 HALF DIALLEL CROSS OF MUSTARD *(Brassica rapa)*

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CERTIFICATE

This is to certify that thesis entitled, **“COMBINING ABILITY AND HETEROSIS IN F_1 POPULATIONS DERIVED FROM 6×6 HALF DIALLEL CROSS OF MUSTARD *(Brassica rapa)* ”** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING,** embodies the result of a piece of bona fide research work carried out by **SHIKHA CHAKRABORTY**, Registration no.: 18-09305 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: December, 2020
Place: Dhaka, Bangladesh

……………………………..
Prof. Dr. Jamilur Rahman
Supervisor

Dedicated

To

Beloved Parents

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LIST OF ABBREVIATIONS

Abbreviation	**Full Name**
%	Percentage
ANOVA	Analysis of variances
AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BP	Better Parent
cm	Centimeter
CV	Check variety
df	Degrees of freedom
etc.	Etcetera
e.g.	For example
et al.	and others
FAO	Food and Agricultural Organization
F_1	First Filial Generation
g	Gram
GCA	General Combining Ability
HYV	High yielding varieties
i.e.	That is
viz.	For example
MoP	Muriate of Potash
MP	Mid parent
m	Meter
m^2	Square Meter
No.	Number
Ns	Not Significant
RCBD	Randomized Complete Block Design
SAU	Sher-e-Bangla Agricultural University
SCA	Specific Combining Ability
t/ha	Tonne per Hectare
TSP	Triple Super Phosphate

COMBINING ABILITY AND HETEROSIS IN F_1 POPULATIONS DERIVED FROM 6×6 HALF DIALLEL CROSS OF MUSTARD *(Brassica rapa)*

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ABSTRACT

The experiment was conducted to evaluate the fifteen F_1 lines derived from 6×6 half diallel cross of *Brassica rapa* for yield and yield components. Six (6) parents of mustard were mated using half 6×6 diallel fashion during Rabi season 2017-18 and then evaluated the combining ability and heterosis of fifteen F_1 hybrids over two check varieties BARI sharisha-14 (CV1) and local variety Maghi (CV2) at research farm of Sher-e-Bangla Agricultural University, Dhaka during Rabi season 2018-19. The analysis of mean performance showed that the hybrid combination P2×P6 (80.00) matured with the lowest growth duration, while the cross P1×P4 and P4×P6 had taken the longest duration. The hybrid P3×P5 produced the highest number of seeds per silique, while P2×P4 produced the lowest number of seeds per silliqua. The heaviest or the boldest seeds were produced by the hybrid P3× P5 (4.00 g). Again, the highest seed yield per plant was observed in the hybrid P1×P3 (7.40 g), while the lowest seed yield per plant was observed in hybrid P2 ×P4 (2.33 g). The variances for general combining ability (GCA) and specific combining ability (SCA) were found significant for all the characters which indicated that both type of gene actions such as additive and non-additive were involved for the controlling of yield and yield related characters in the hybrid progenies. GCA variances were higher in magnitude than SCA for all the characters except no. of primary branches per plant, number of siliqua per plant and seed yield per plant indicating the superiority of non-additive or dominant gene effects for the inheritance of these traits. The analysis of GCA revealed that parents P1, P3 and P5 were the best general combiner for yield related character, while parents P6 and P1 for earliness and tall plant type. The SCA analysis revealed that crosses P1×P3, P2×P6 and P4×P6 exhibited maximum positive effects for yield related characters. In heterosis analysis, the test hybrid combinations *viz*., P1×P2, P1×P6, P2×P3, P2×P4, P2×P5, P2×P6, P3×P4, P3×P6, P4×P5, P4×P6 and P5×P6 manifested the negative significant heterosis over CV1 but none of the crosses showed significant negative heterosis over CV2 as well as over their better parent for days to first flowering. Again, none of the crosses showed significant negative heterosis over CV1 and BP for days to maturity. The cross combinations *viz*., P1×P3, P1×P5 and P1×P6 showed positive standard heterosis over CV1 and CV2 for yield and yield contributing characters such as siliqua length, no. of seeds per siliqua, thousand seeds weight and seed yield per plant. Interestingly, only hybrid P1×P3 showed standard hetersosis over both the check varieties for seed yield. Considering the standard heterosis for yield and yield attributes, the tested hybrids *viz*., P1×P2, P1×P3 and P1×P5 might be selected as superior *B. rapa* hybrid lines. Moreover, the hybrid lines *viz*., P1×P4, P2×P5, P2×P6, P3×P4, P3×P5, P3×P6, P4×P5 and P4×P6 could also be selected as potential lines because these hybrids could produce transgressive segregants in advanced or later generations.

CHAPTER-I
INTRODUCTION

CHAPTER -I
INTRODUCTION

Brassica rapa L. commonly known as field mustard or rapeseed and the major sources of vegetable oil which is herbaceous cross pollinated crop. In the world it is the third important oilseed crop (Downey, 1990). In Bangladesh rapeseed is grown widely and occupies the first position in respect of area and production among the oil crops (Islam, 2013). In 2019-2020, the edible oil production in the world is amounted to 203.91 million metric tons, where rapeseed contributes 27.67 million metric tons (www.statistica.com).

B. rapa (2n = 20) belongs to Brassicaceae family and it has been proposed to originate from two independent centers in Asia and Europe (Zhao *et al.*, 2005). Various types of mustard are grown in Bangladesh. Oleiferous *Brassica* belongs to the genus *Brassica* of the family Brassicaceae includes three major species *viz. B. rapa* L. (AA, 2n = 20), *B. juncea* Czern and Coss (AABB, 2n = 36) and *B. napus* L. (AACC, 2n = 38). Among the Oleiferous *Brassica* species the varieties of *B. rapa* and *B. napus* are commonly known as rape seed, while those of *B. nigra* (black mustard), *B. carinata* (Ethiopian mustard) and *B. juncea* (Indian mustard/Rai) as mustard (Yarnell, 1965).

Rapeseed oil contains high energy and good source of fat soluble vitamins (*viz*. A, D, E and K). The seeds of rapeseed contain 42% oil, and 25% protein (Khaleque, 1985). Edible vegetable oils are the main source of nutritionally required fatty acids in human diet. Mustard, soybean, sunflower and groundnut oil are among the edible vegetable oils mostly consumed in Bangladesh. However, none of these oils alone provide many of the lipid soluble nutrients as per the recommendation of health agencies. Rapeseed oil contains a high amount of selenium and magnesium, which gives anti-inflammatory properties. It also helps stimulating sweat glands and helps lowering body temperature. In traditional to the medicinal value, it is used to relieve the pain associated with arthritis, muscle sprains and strains (Sood *et al.*, 2010).

Rapeseed-mustard occupies the first position in oil crops in Bangladesh with cultivated area 6,67,242 acres which produced 3,11,740 metric tons oil seed during 2018-2019 (BBS, 2019). Total consumption of oils and fats was 3.04 million tons and import edible oil which cost 1161 million US$ (BER, 2019).

Rapeseed was globally grown on area of approximately 34.5 million ha with the total production 70 million metric tons (FAO, 2019). About 13.2% of the world edible oil supply comes from this crop (Downey and Robbelen, 1989). According to MPOC (2019) the consumption of edible oil and fat is about 3 million tones and due to the insufficient domestic production almost 90% of these annual requirements of oils and fats are met through import. Though, a range of *Brassica* oilseed are grown in the country, the local production of edible oil meets only fourth of the required quantity, the rest has to be imported by spending valuable foreign currency.

Mustard oil plays a great role as a fat substitute in our daily diet. Fat and oil are vital components of the human diet because they are important sources of energy and act as a carrier of fat soluble vitamins. Low intake of fat and oil limit the availability of fat soluble vitamin and caused dietary imbalance and food wastage. For human health, in a balanced diet 20-25% of calories should come from fats and oils and the average need of fats and oils is about 37g/day (Rahman, 1981). Rapeseed oil (RSO) is the most useful of all cooking oils and it contains a significant amount of ω-3 and ω-6 fatty acids. RSO contains mostly of the fatty acid such as oleic, linoleic, linolenic, palmitic and strearicacid (Gunstone *et al.*, 1994 and Hui, 1996). RSO consists 95% of tri-acyl glycerols (TAG) and 5% non-tri-acyl glycerols, known as minor components like free fatty acids, mono and di-acyl glycerols, phospholipids, tocopherols, tocotrienols, flavonoids, other phenolic compounds, pigments (chlorophylls), sterols etc. (Shahidi and Shukla, 1996).

The climatic and edaphic factors of Bangladesh are quite favorable for the cultivation of rape seed and mustard (Haque *et al.*, 1987). Although rape and mustard is the most important oil crop in Bangladesh, farmer usually cultivates them in less fertile lands followed by low management with least investment and almost all the cultivars are brown seeded and smaller in size (2-2.5 g/1000 seed). Yellow seed contains 1-2% more oil than the same sized brown seeded type due to its thinner seed coat. Bold seeded Indian mustard varieties may increase total production of oil seed in Bangladesh. *B. rapa* (toria) covers about 75% area of the total mustard grown in Bangladesh (Wahhab *et al.*, 2001). There is no improved short duration variety of *B. rapa* which is available to replace Tori-7. However, farmers are being advised to cultivate the improved Tori and BARI shorisha 14 and BARI shorisha 15 varieties.

The above scenario indicates there should be an attempt to develop short duration and high yielding varieties with more oil percentage in seed, tolerant to biotic and abiotic stresses to fulfill the requirement of edible oils of the country by increasing the production. The improved variety also should fit well into cropping pattern *viz.* T. Amon-Mustard-Boro.

The nature and magnitude of gene action is an important factor in developing an effective breeding programme. Among the various mating designs developed for the determination of the genetic architecture of quantitative characters, the diallel cross method, out lined by Jinks (1954, 1955) and Hayman (1954 and 1958) has received considerable attention of the geneticists and plant breeders. Considerable amount of gene action for seed yield and its components in rape seed have been reported by various workers (Duhoon *et al.,* 1980; Yadav and Yadava, 1985; Jindal and Labana, 1986; Singh *et al.,* 2001; Chowdhury *et al.,* 2004.)

The phenomenon of heterosis of F_1 hybrids can also reflect specific combining ability and general combining ability of parental lines. Combining ability concepts are the basic tools for improved production of crops in the form of F_1 hybrids. Identifying parental combinations with strong heterosis for yield and obtain genetic parameters are the most important steps in the development of new cultivars (Diers *et al.* 1996; Becker *et al*. 1999; Melchinger 1999), and heterosis effects are generally more pronounced in crosses between genetically distinct materials. The ultimate goal would be the development of hybrids of rapeseed that can potentially utilize the total amount of heterosis available.

Combining ability studies highlight the predominance effects of GCA on yield and most of the yield components indicating the importance of additive gene action (Wos *et al*., 1999). While pandey *et al.* (1999) reviewed evidence for the presence of significant SCA effects for yield and yield components indicating importance of non-additive gene action. It is imperfect that before understanding any breeding approach, the preponderance of the gene action and combining ability should be accessed for the development of high yielding genotypes and it would be desirable to identify the superior parents (Kempthorne, 1957).

Therefore, keeping the view in mind, the present study has been undertaken with the aim of estimation of combining ability and heterosis in F_1 diallel populations for different yield contributing characters of rapeseed (*B. rapa* L), and to identify the potential parents and promising cross combinations to develop high yielding varieties (HYV) that have the potentiality to mature early and to give high yield.

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

1. To study the combining ability in the reference populations for yield and yield contributing characters;
2. To estimate the heterosis in the F_1 hybrids; and
3. To select some potential F_1 hybrids having high yielding and early maturity.

CHAPTER- II

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

Rapeseed *(B. rapa L.)* is an important oil seed crop of tropical and sub-tropical agro-ecological zone. In Bangladesh the average productivity of mustard is low in comparison to the developed countries. Identification of superior parents, promising cross combination and suitable breeding methodology are the important pre-requisite for the development of high yielding varieties or cultivars. The combining ability studies are frequently utilized to understand gene effects of yield and yield attributes which helps in formulating proper breeding methodology. Evaluation of heterosis is an important factor in developing a high yielding variety or cultivar. It also finds out the breeding potential of parents as well as different cross combinations which helps in the advancement of breeding programme. The diallel analysis provides information of the genetic control of a set of parents in the early generation (Jinks, 1954). Therefore, relevant information available in the literature pertaining to the combining ability and heterosis of rapeseed or mustard are reviewed in below:

2.1 Combining ability

Determining of combining ability may inform gene action both additive and non-additive from GCA and SCA magnitudes that are an essential for crop improvement. General combining ability (GCA) is the average performance of a given genotype in hybrid combinations with other genotypes, while the specific combining ability (SCA) is expressed through average performance of the cross in relation to the genotypes.

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

Sheoran *et al.* (2000) recorded on 9 characters in brown sarson using a 9 × 3 line × tester set. Both general combining ability (GCA) and specific combining ability (SCA) components were significant for all the evaluated characters *viz.*, plant height, main shoot length, number of primary branches, number of secondary branches, number of siliqua on main shoot, siliqua length, seeds per siliqua, 1000-seed weight and seed yield per plant.

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

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

Dharmendra-Singh *et al.* (2001) working on 1000-seed weight and oil content was studied in F_1 and F_2 generations of a 20 parent partial diallel analysis (S=7) in yellow sarson (*B. campestris* var. *sarson*). Non additive gene effect was important in the inheritance of these characters. Parents AJL17 for 1000-seed weight and AJL6 and AJL64 for oil content were the good general combiners in both the generations.

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

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

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

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

Mahto and Haider (2004) studied on yield and yield characteristics of 45 Indian mustard genotypes and their progenies. The analysis of variance for combining ability showed highly significant general combining ability (GCA) for all traits, except number of seeds per siliqua, which had significant GCA. Specific combining ability (SCA) was also highly significant for all traits, except for number of primary branches per plant.

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

Singh *et al.* (2005) was studied on seed yield and its components in Indian mustard crosses involving the cultivars Seeta, BR 40, Pusa Barani, Pusa Bold, CM 3, Varuna, Narendra Rai and RCC 4 were investigated during winter 1999-2001 in Ranchi, Jharkhand, India. CM 3, Pusa Barani, Pusa Bold and BR 40 were good general combiners for seed yield/plant, seeds/siliqua, oil content percentage siliquea number/plant and number of primary branches/plant.

Mahak and Singh (2005) studied on combining ability for seed yield and its attributes (days to 50% flowering, days to maturity, plant height, number of primary branches, number of secondary branches, length of main raceme, number of siliquae on main raceme, 1000-seed weight and oil content) was assessed in 10 cultivars of Indian mustard (Varuna, Rohini, NDR-8501, RH-30, RLM-198, KR-5610, CSR-1017, Pusa Basant, B-85 and Mathura Rai) and their 45 F_1 and F_2 hybrids during the winter season of 2002/03, at Kanpur, Uttar Pradesh, India. Analysis of variance showed that variances due to general combining ability (GCA) were significant for all characters except for primary branches, while variances due to specific combining ability (SCA) were significant for all characters. Estimates of GCA variances were generally higher than SCA variances for 7 of 10 characters. Rohini was a good general combiner for seed yield per plant, days to 50% flowering and number of siliquae on main raceme. NDR-8501 × Mathura Rai was a good specific combiner for days to 50% flowering, length of main raceme, number of siliquae on main raceme and oil content, while CSR-1017 × Mathura Rai was a good specific combiner for days to maturity, number of secondary branches, number of siliquae on main raceme and seed yield.

Gupta *et al.* (2006) conducted line × tester analysis using 15 female and 3 male parents. The data recorded showed that general combining ability was significant for the traits days to maturity, plant height, number of primary branches, number of secondary branches, 1000-seed weight and seed yield per plant. The specific combining ability was also significant for all the traits showing that the non-additive genetic effects were controlling these traits except days to maturity and plant height. He also observed that out of 45 crosses 3 crosses showed significant heterosis for seed yield. The maximum heterosis was given by the cross TKG-865-2 × GSL-1 over better-parent.

Marijanovic-Jeromela *et al*. (2007) studied GCA and SCA of five rapeseed varieties positive general combining ability was observed for all the traits. Significant value of SCA of the hybrids suggested that at least one parent have high value of the general combining ability.

Noshin *et al*. (2007) conducted experiment on brown mustard *B. juncea* to determine general and specific combining abilities for number of primary branches, length of the main raceme, pods in the main raceme, seed yield per plant. The results showed that variance due to GCA and SCA was significant for all the traits except SCA for seed yield per plant. Mean square of GCA was higher than mean square of SCA indicating that all these traits were controlled by additive type of gene action.

Chapi *et al*. (2008) conducted the studies on thirty hybrids and six canola varieties to reveal that mean square of general and specific combining abilities were significant for all traits. Ratio of mean square GCA to SCA in all traits was significant indicating additive and non-additive genetic effects for all the traits but low narrow sense heritability indicated that non-additive genetic effects played major role controlling these traits.

Gholami *et al.* (2008) crossed eight genotypes of rapeseed in a Line × tester fashion to understand the general (GCA) and specific combining ability (SCA). Mean of squares of GCA and SCA were significant for many of traits indicating significant differences for GCA effects of parents and SCA effects of hybrids. Estimated degree of dominance more than one indicated that plant height, pods per plant and seed yield were governed by over-dominance gene effects and non-additive gene effect for controlling these traits. For days to maturity, 1000-seed weight and oil contents, additive gene effects were more important. Significant GCA effects were observed for seed yield and other traits in some parents.

Lohia (2008) obtained the results of combining ability of 21 hybrids by crossing parents in Diallel mating fashion. The results indicated that both additive and non additive genes controlled the traits i.e. length of the main raceme, days to flowering, plant height, days to maturity, number of pods per plant, secondary branches per plant, 1000-seed weight, oil contents and seed yield per plant. Out of twenty-one crosses ten cross showed highly significant specific combining ability.

Haung *et al.* (2009) evaluated combining abilities of rapeseed using five genotypes as female and nine genotypes as male to produce 45 hybrids. The mean square of the hybrids had significant difference for all the traits. The ratios of sum of squares of GCA to sum of squares of hybrids were higher for seed yield, oil content, days to flowering and days to maturity while SCA effects were significant for all characters except for days to maturity. It indicated that both additive and non-additive gene effects were important in governing these traits.

Nigam and Alka (2009) revealed that significant general and specific combining ability differences present among forty-five hybrids of *Brassica*. GCA and SCA variance were important indicating that additive and non additive gene action involved in controlling these traits. Sixteen hybrids exhibited good general combining ability for seed yield was found to be controlled pre-dominantly by non additive gene actions.

Diallel analysis involving ten parents and forty-five crosses of Indian mustard (*B. juncea*) was performed by Aghao *et al.* (2010) to estimate the general and specific combining abilities of parents and their hybrids. The effects of GCA and SCA showed wide range of variation in significance level for yield contributing traits, On the basis of significant GCA effects two parents were identified best combiner for days to flowering, days to maturity, plant height, number of pods per plant, 1000-seed weight. Among the hybrids Varuna × Seeta was identified as the best cross, which can be forwarded to the next generation by single seed descent method.

Rameeh (2010) evaluated 15 F_2 progenies derived from half diallel cross of six parents of *Brassica napus* for number of pods per main axis, number of pods per plant, length of the pod, seeds per pod, 1000-seed weight, grain yield and oil content. Analysis revealed significant GCA and SCA for all these traits which indicated both additive and non-additive gene action but degree of dominance less than unity observed for length of the pod and 1000-seed weight indicating predominance effects of additive gene action.

Turi *et al.* (2010) conducted experiment on *B. juncea* to determine the good combiner lines using 8 × 8 diallel crosses. General combining ability was highly significant for oil percentage and glucosinolates. Specific combining ability effects were highly significant for all traits except for oleic acids. The magnitude of GCA effects was greater than SCA effects for glucosinolate, erucic acid and protein content. Both additive and non-additive genetic effects were important, suggesting the integrated breeding program which can efficiently utilize both additive and non-additive genetic effects.

Azizinia (2011) performed complete diallel analysis using eight genotypes. Significant variance was observed among genotypes for plant height, number of lateral branches, number of pods in the main raceme, number of seeds per pod, 1000-seed weight, seed yield and oil contents. 1000-seed weight, oil contents and seed yield exhibited significant GCA and SCA.

Dar *et al.* (2011) analyzed the combining abilities of *B. rapa* sp. *brown sarson* genotype. The results showed that the estimated variance due to dominance genetic effects were much higher than the additive variance for number of primary branches, secondary branches, pods per plant, number of seeds per pod, 1000-seed weight and oil contents. The ratio if GCA to SCA was less than unity for all the traits, performance on GCA of parents alone would not be advisable to select materials in segregating generations, but a combination involving both GCA and SCA of the parents and their crosses would be more useful. He determined the heterosis of *B. rapa* lines over mid and better parent. The cross CR-1485 × CR-1607 sowed significant heterosis for seed yield per plant, 1000-seed weight, number of primary branches and number of seeds per pod. A few cross also showed significant heterosis over mid and better parent for secondary branches per plant, pods on main shoot, pods per plant, days to maturity and oil contents.

Using half diallel analysis Gupta *et al.* (2011) determined the general and specific combining ability among eight lines of *B. juncea* and their crosses. Analysis showed that significant GCA and SCA was present among parents and hybrids for number of primary branches, number of secondary branches, 50% flowering, seed yield per 100 pods, number of pods per main axis 1000-seed weight, seed yield per plant and harvest index. It was also found that GCA variance was higher than SCA variance for days to 50% flowering, days to maturity, plant height, and 1000-seed weight whereas variance due to SCA was higher for seed yield, number of primary branches, number of secondary branches, and seed yield per 100 pods. Significant heterosis and heterobeltiosis was observed for seed yield per 100 pods, days to 50% flowering, number of primary branches per plant, and harvest index, days to maturity, number of secondary branches per plant, plant height and 1000-seed weight in different crosses.

Using half diallel analysis Nasrin *et al.* (2011) determined the general and specific combining abilities of seven Indian mustard genotypes. Significant general combining ability was observed for days to flowering, days to maturity, primary branches per plant, 1000-seed per plant and seed yield. Number of primary branches, number of secondary branches, number of pods per plant, seed yield per plant and 1000-seed weight showed significant specific combining ability in different hybrids. It was observed that variance of GCA was higher than the variance of SCA for plant height, days to maturity, length of pod, number of seeds per pod and thousand seed weight. She also identified the heterosis among the genotypes of Indian mustard. Significant heterosis present over mid and better parent for primary branches per plant, secondary branches per plant, seed yield, 1000-seed weight and oil contents.

Parmar *et al.* (2011) Performed line × Testers to identify the general and specific combining abilities for plant height, days to flowering, days to maturity, number of primary and secondary branches and oil contents. Results revealed that both additive and non additive genetic variance were important for controlling these traits. The ratio of variance of GCA over variance of SCA revealed that non additive gene action for these traits except for days to maturity.

Rameeh (2011a) determined the combining abilities. Significant ratio of GCA to SCA mean square and high narrow-sense heritability was observed for 1000-seed weight which indicated that additive genetic effects were controlling this trait. It is also observed that SCA effects for siliquae per plant had main role for seed yield. However, most of the crosses having significant positive SCA effects for seed yield had at least one parent with significant positive GCA effect for yield components.

Rameeh (2011b) studied the combining abilities of some winter and spring rapeseed genotypes using line × tester analysis. Non-additive gene effects for plant height and grain yield were indicated by significant mean square of line × tester. Significant specific combining ability for plant height and grain yield was observed in few crosses. Average heterosis was significant for seeds per pod, 1000-seed weight and seed weight except pods per plant. The mean square of line × tester was also significant for seeds per pod, 1000-seed weight and seed yield but non significant for pods per plant. For seed yield most of the crosses showed significant positive heterosis over spring parent which indicated that winter rapeseed is suitable for improving this trait using hybrid method.

Rameeh (2011c) performed line × tester analysis to estimate GCA and SCA for seed yield and its components. All the traits except pods per plant showed significant Line × tester mean squares. Significant positive general combining ability effects for seed yield and number of pods per plant were observed and almost all crosses showed significant positive specific combining ability effects for pods per plant and seed yield. For days to flowering, days to end of flowering, duration of flowering, days to end of maturity, plant height and grain yield parent vs. crosses mean square was significant which indicated the presence of significant heterosis. Non-additive genetic effects were significant for plant height and grain yield as indicated by significant value of mean square Line × tester. Days to flowering, days to end of flowering, and plant height showed significant negative heterosis over winter parent in all the crosses while days to maturity significant positive heterosis over spring parent in most of the crosses.

Sincik *et al.* (2011) estimated the combining abilities using diallel crosses of four rapeseed genotypes. Analysis revealed that GCA was highly significant for plant height and pods per main raceme. While SCA were significant for plant height, number of pods per main raceme, number of seeds per pod and seed yield per plant except 1000-seed weight. It was indicated by the analysis of variance that significant heterosis present among the parents and their hybrids for plant height, number of pods per main raceme, number of seeds per pod and seed yield per plant except for 1000-seed weight, which was non-significant. All 12 hybrids showed positive better-parent heterosis for seed yield per plant.

Verma *et al.* (2011) used a Line × tester of 12 lines and 3 testers in Indian mustard. The non-additive gene action was of greater importance for all the characters studied. Among parents HUJM-05-1, RGN-181, Varuna and HUJM-04-6 were appeared to be the best general combiners for seed yield/plant. The cross combinations HUJM05-1 × Kranti, RGN-173 × NDR 8501, RG-173 × Kranti, NPJ-113 × NDRE-4 and Varuna × Kranti possessed superior specific cross combinations for seed yield and its contributing traits. The best hybrid combinations for seed yield were HUJM-05-1 × Kranti followed by RGN-H3 × NDR 8501 which showed significant heterosis over better parent to the extent of 80.97 and 77.75%, respectively

Azizinia (2012) determined the combining abilities of eight parents using diallel cross. The traits under study were plant height, number of lateral branches, number of pods per main branch, number of seed per pod, 1000-seed weight, seed yield and oil content. 1000-seed weight, oil content and seed yield showed significant GCA and SCA effects. There were significant positive effects for yield and yield components.

In a Line × tester analysis Rameeh (2012) studied general and specific combining abilities of six lines and two testers of spring rapeseed (*B. napus* L.). It is reported that non-additive genetic effects controlled the number of pods per plant and seed yield. Most of the crosses showed negative SCA which indicated that at least one parent had significant negative GCA effects.

Yadava *et al*. (2012) conducted an experiment in line × tester design involving 14 lines and 5 testers and reported that both additive and non-additive gene actions were important in controlling yield-contributing traits. Variety Pusa Mustard 25 was identified as best general combiner among the parents. Significant and positive SCA effects were observed for seed yield in 17 hybrids, 1000-seed weight in nine hybrids, number of siliquae on main shoot in nine hybrids, number of primary branches in six hybrids, point to first siliqua in six hybrids, main shoot length in five hybrids and number of secondary branches in four hybrids; and significant negative SCA effects for point to first branch in four crosses and plant height in two crosses. Ten hybrids exhibited >15% heterobeltiosis, highly significant SCA effects and higher per se performance.

Patel *et al*. (2015) found all crosses showed significant SCA effects and *per se* performance for all the characters which indicates yield is complex character which is cumulative effects of all other traits. But Bio-902 × NUDHYJ-3, Pusa Bold× EC-287711, Pusa Bold × GM-3, Bio-902 × TM-2 and Bio-902 × JM-3 were good specific combiner for seed yield per plant and at least one important yield contributing characters like average siliquae length, test weight, number of siliquae per plant, number of secondary branches per plant and oil content.

Meena *et al.* (2015) reported combining ability that mean squares due to lines, testers, and line × testers were highly significant for all the traits, except for the number of primary branches in testers and plant height, number of siliqua on main shoot and number of primary branches. This shows that considerable amount of genetic variability was present in the experimental material and both GCA and SCA were involved in the genetic expression of studied traits. The high yielding cross combinations can further be exploited for their commercial utilization and the parents involved in developing heterotic hybrids.

Tomar *et al.* (2015) the studied general combining ability effects in the parents namely; Vaibhav, Varuna, Durgamani and Kranti were found good general combiners for seed yield per plant (g). Specific combining ability effects revealed that the crosses namely; Vaibhav × Mathura Rai, Pusa Jai Kisan× Pusa Agrani and KR-5610 × Pusa Agrani were found good specific combiners for seed yield per plant (g). The above lines and cross combiners may be utilized to improve particular traits in Indian mustard.

Patel *et al.* (2015) investigated general combining ability effect of parents revealed that none of the parents was found good general combiner simultaneously for all the characters. However, the parents CJ 3761, DRMR-659-49, ZEM 1, ZEM 2, GM 1 and GM 3 were good combiners for seed yield per plant. Among these parents, CJ 3761 was also good general combiner for one or more of its component traits i.e.,days to maturity, number of branches per plant and number of siliquae per plant, oleic acid, erucic acid and linoleic acid, while parent DRMR-659-49 was proved to be good donor for number of siliquae per plant and linolenic acid. The cross CJ 3761 × GM 3 registered high *per se* performance, standard heterosis and SCA effects for seed yield per plant and component traits i.e., number of branches per plant and number of silique per plant and the parents (CJ 3761, GM 3) were also good combiners.While for quality trait hybrid DRMR 659-49 × GM 3 was registered high SCA effects for oil content. The hybrid CJ 3761 × GM 2 was the best for erucic acid content with high SCA effect and involved both good combiners as parents.

Ali *et al*. (2015) studied on combining ability an 8 × 8 F_1's diallel cross of (*B. juncea* L.) genotypes for various quantitative traits. According to combining ability analysis, mean squares due to general combining ability (GCA) were significant ($p \leq 0.01$) for all the traits except days to 50% flowering and maturity. Mean squares due to specific combining ability (SCA) and reciprocal combining ability (RCA) were significant ($p \leq 0.01$) for all the traits except SCA mean squares for seed yield per plant. Mean squares due to RCA were even greater than GCA and SCA for some variables, and therefore maternal effects cannot be ignored. The variations among genotypes for earliness and plant height were controlled by non-additive gene action, while morphological and seed yield traits were governed by additive gene action. Results suggested the use of integrated breeding strategies which can efficiently utilize the additive as well as non-additive genetic variations.

Gautam and Chauhan (2016) analysed line × tester of twenty lines and three testers of Indian mustard (*B. juncea* L. Czern & Coss.) cultivars to estimated general combining ability (GCA) and specific combining ability (SCA) effects for plant height, yield components and seed yield. Significant variance of line × tester for the traits like pods per plant and seed yield indicating non- additive genetic effects have important role for controlling these traits. Most of the crosses with negative SCA effect for plant height had at least one parent with significant negative or negative GCA effect for this trait. For most of the traits except pods per plant, the efficiency of high parent heterosis effect was more than SCA effect for determining superior cross combinations.

Singh *et al.* (2017) investigated lines namely Urvashi in E1, PR 08-5 in E2 & P, and PRL 08-6 in E3 as well as testers namely RH 0304 in E1, E2 & P, and JMWR 08-3 in E3 exhibited highest GCA for seed yield. These genotypes in series of crosses showed high GCA effects in desirable direction for at least four yield contributing traits. For seed yield, five top ranking crosses were found entirely different for each environment indicating that heterosis manifestation was cross and environment specific. The most outstanding heterotic crosses for different environments were Urvashi × RH 0304 in E1, PR 08-5 × JMWR 08-3 in E2, PRL 08-6 × RH 0304 in E3 and across environments for seed yield along with high heterosis for 4-6 component traits.

2.2. Heterosis

Heterosis is the superiority of F_1 hybrids over its parents in relation to height, yield and so on. Parents may be inbred lines, DHs, clones, hybrids, breeding populations, cultivars or different species. In mustard a number of workers have reported varying extent of heterosis for yield and yield contributing traits. A summarized account of information with respect to these attributes has been given as follows:

Singh *et al.* (2001) evaluated 30 hybrids made between 12 diverse genotypes of yellow sarson in diallel mating design and found highly significant differences in parents and crosses for all the characters except for days to maturity, primary branches per plant, seeds per siliqua and 1000-seed weight. Variation among parents and hybrids observed for all the characters indicated wide range of variability. The crosses showed significant heterosis of upto 20 %for days to flowering, 70 per cent for days to maturity, 50% for plant height, 80% for primary branches per plant, 100% for siliquae per plant, 76.67% for seeds per siliqua, 13.33% for seed yield per plant and 90% for 1000-seed weight.

Ghosh *et al.* (2002) studied 29 promising female and 7 male parents along with their 203 F_1's in line × tester mating design for 10 quantitative characters in Indian mustard. The significant desirable heterosis over better parent was observed for days to 50 per cent flowering, days to maturity, plant height, main shoot length and primary branches per plant among most of the hybrids. Six crosses also showed highly significant heterosis over better-parent for oil content while, YSRL-10 × Pusa Bold expressed the highest better-parent heterosis of 73.75 percent, followed by AD-2041 × Pusa Bold (63.40%), DBS-10 × Pusa Bold (53.31%) and KBJ-3 × Pusa Bold (50.42%) for seed yield.

Singh *et al.* (2003) observed high heterosis for seed yield in Varuna × Rohini (56.74%), Vardan × Rohini (53.43%), Varuna × RK-9501 (52.86%), Vardan × NDR-8501 (36.73%), Pusa Bold × Rohini (37.68%) and Varuna × NDR-8501 (32.54%). The inbreeding depression in these hybrids was very low. These hybrids can be grown for 2 or 3 generations.

Satyendra *et al.* (2004) evaluated 21 Indian mustard hybrids and their parents for 8 quantitative traits. High heterosis was obtained for seed yield in the crosses Basanti × NDR 8501, Basanti × Kranti and Basanti × RH 30. These hybrids showed high heterosis over the best cultivar. Among the crosses, Basanti × Kranti may be used for selecting for seed yield and quality traits.

Mahto and Haider (2004) observed high heterotic crosses in *B. juncea* for days to 50% flowering, primary and secondary branches per plant, plant height, days to maturity, harvest index, 1000- seed weight, seed yield per plant and oil content. The cross combinations RH-843 × RH 851 and RH 18 × BR-40 showed high relative heterosis and heterobeltiosis, respectively, for most of the characters.

Parmar *et al*. (2004) showed significant negative heterosis for number of days to 50% flowering and plant height. Significant relative heterosis for seed yield was recorded for 18 crosses, heterobeltiosis for 14 crosses and standard heterosis for 9 crosses.

Goswami *et al*. (2004) reported 30 crosses of Indian mustard found that cross RH-9404 × RH-30 had the maximum heterosis for seed yield per plant in E1 and E2, respectively. This cross also showed high heterosis for 1000seed weight. The crosses RH-9617 × RWH-1 and RH-9621 × RWH-1 were selected because of high heterosis for all the parameters tested.

Bhatt *et al.* (2005) reported wide range of heterosis for seed yield per plant (50 to 150%) and for erucic acid was (-76.45 to 5.25%).

Monalisa *et al*. (2005) reported that cross combination TM-4 × Local Yella for siliquae per plant, Varuna × TM-4 for 1000-seed weight, Varuna × NPJ-100 for seed yield per plant and Pusa Bold × Local Yella for oil content had highest heterosis.

Rai *et al*. (2005) studied 15 lines and 4 testers in line × tester mating design along with their 60 crosses. Out of 60 crosses, 45 displayed heterosis over better parent and 49 over standard variety of which 43 were common crosses for seed yield. As regard oil content, 51 crosses registered significant heterosis over standard variety, which was mainly due to low *per se* performance of standard variety for oil content (39.21%).

Nair *et al.* (2005) evaluated fifteen elite genotypes of mustard were crossed with two testers in line × tester fashion and estimated the magnitude of heterosis for yield and yield contributing characters in mustard. The highest magnitude of heterosis for seed yield per plant was obtained in crosses *viz*., Vardhan × TM-17, Vardhan × Laxmi and vardhan × RL-1359. Hence, these crosses may be utilized to identify superior recombinants after homozygosity has reached in mustard improvement programme.

Turi *et al.* (2006) estimated mid-parent and better-parent heterosis in *B. juncea* L. genotypes. Out of 56 hybrids, negative mid-parent and better-parent heterosis for days to 50% emergence, days to 50% flowering, days to physiological maturity and plant height, respectively; whereas positive heterosis for number of primary branches per plant. Better-parent heterosis reduced to 27% for emergence, 3.85% for flowering, 4.08% for maturity and 22.63% for plant height; whereas it reached to 44% for branches per plant. Among parents, four parents proved to be superior when used as parents in most of the hybrid combinations.

Aher *et al.* (2008) reported the extent of heterosis in *B. juncea* and observed medium heterosis for number of secondary branches, number of siliqua per plant and seed yield and low magnitude of heterosis was found in remaining traits. The highest heterosis for seed yield was observed in RSK-87 × GM-2, SKM-95-85 × GM-2 and RSK-87 × Varuna.

Han-zhong *et al.* (2009) tested the heterosis of oil content in *Brassica napus* L. and identified the having high oil contents. Out of 62 crosses, 30 showed significant mid-parent heterosis and seven showed significant heterosis over better parent for seed oil contents.

Aher *et al*. (2009) Analyzed heterosis using a Line × tester of 10 lines and 4 testers in Indian mustard. In the present study, moderate heterosis was observed for seed yield per plant, number of siliqua per plant and number of secondary branch per plant whereas, in the remaining character low amount of heterosis was reported. The highest standard heterosis for seed yield was observed in RSK-87 × GM-2 (42.95%) followed by SKM-95-85 × GM-2 (40.11%) and RSK-87 × Varuna (37.67%).

Nigam and Richa (2009) reported heterotic response for seed yield per plant in the crosses CSR-1017 × T-6342, RK-8601 × RK8608, A-11× B-85, T-6342 × B-85 and CSR-1017 × RK-8608, A11 × B-85, T-6342 × B-85 and CSR-1017 × RK-8901. These crosses have also exhibited significant heterosis for days to flowering, number of primary and secondary branches and dry matter per plant. Thus, these crosses may be of utility for developing hybrids in Indian mustard.

Das *et al.* (2010) studied 12 *B. juncea* × *B. compestris* F_1 crosses for some yield contributing traits. Heterosis was calculated over mid parent and better parent. The hybrids RLM-514 × M-91, M-261 × Sampad, RLM-514 × Sampad, RLM-514 × M-91, M-7 × Sampad, M-261 Dholi and RLM-514 × M-91 were considered excellent for days to flowering, pollen sterility percentage, plant height, secondary branches per plant, number of siliqua per plant and seed yield on the basis of heterosis value.

Sabhaghnia (2010a) observed the significant positive heterotic effects including mid-parent and high parent heterosis were observed for all the traits studied but for different number of crosses.

Sabaghnia *et al.* (2010b) developed 36 hybrids through diallel cross and measured heterosis for plant height, lateral branches per plant, stem length, seeds per pod, days to start of flowering, 1000-seed weight, harvest index and oil contents. Significant heterosis was observed for all the traits it implies that the utilization of the heterosis could be effective for genetic improvement of oil contents and other traits.

Gupta *et al*. (2010) identified the high heterotic crosses (*B. juncea*) Czern and Coss. The relative heterosis and heterobeltiosis were observed to be the highest with respect to seed yield per 100 siliquae and days from sowing to 50% flowering, number of primary branches per plant and harvest index, length of main axis, number of siliquae on main axis, biological yield per plant and seed yield per plant. Different cross combinations exhibited the maximum value of better and mid parent heterosis for the remaining traits, *viz.*, days to maturity, number of secondary branches per plant, plant height and 1000-seed weight.

Patel *et al*. (2010) reported that magnitude of standard heterosis was highest for RH 819× SKM 9928 followed by GM 1 × GM 2 and GM 1 × RH 819. Amongst hybrids, RH 819 × SKM 9928 was heterotic over GM 2 for various yield components, whereas, the hybrids GM 1 × GM 2 and GM 1 × RH 819 were also heterotic for primary branches per plant and oil content in Indian mustard.

Cuthbert *et al.* (2011) determined the better parent or commercial heterosis in high erucic acid *Brassica napus* canola genotypes for seed quality traits. 45 hybrids produced from twelve distinct genotypes were assessed for seed oil, protein, sum of oil and protein, glucosinolate, and erucic acid concentrations. Seed oil showed significant heterosis from better parent and from commercial hybrids. Low parent heterosis for protein and glucosinolate concentrations was also observed. Commercial heterosis was displayed by Erucic acid concentration. Many hybrids also showed nearly zero percent heterosis for any seed quality traits.

Malviya *et al.* (2012) carried out triple test cross analysis in Indian mustard using twelves Indian mustard strains and 3 testers to study the heterosis for seed yield, oil content, silique on main raceme, seeds per siliqua, seed yield per plant, 1000-seed weight and harvest index. A wide range of variation in the estimates of standard heterosis in positive and negative direction was observed for seed yield per plant. Four crosses showed significant standard heterosis for seed yield along with high mean performance. Single crosses were in general superior in comparison to three-way crosses for seed yield and its contributing traits. Exploitation of heterosis through use of commercial single cross hybrids has bright future, provided technology of commercial hybrid seed production is available.

Patel *et al*. (2012) reported hybrids GM 1 × GM 3, GM 3 × SKM 139 and GM 1 × RK 9501 having high mean value, high heterosis over mid parent as well as better parent for seed yield per plant and number of its component characters. It is also found clear that high magnitude of non-additive type of gene action for seed yield per plant and its important component traits observed in the present study, favours hybrid breeding programme. These highly significant heterotic hybrids could be utilized to exploit non-additive gene action by heterosis breeding.

Kumar *et al*. (2013) highest economic heterosis was observed in case of five crosses *viz.,* RK03-3 × RK03-4 (43.90%), RK03-2 × RK03-4 (34.55%), Varuna × RK03-4 (31.75%), RH-819× RH9801 (25.00%) and RH-819× RK02-4 (24.22%).

Tomar *et al*. (2014) reported the crosses, viz., Maya × Mathura Rai, Vaibhav × PusaAgrani, Pus Jai Kisan× PusaAgrani and Ashirwad × Mathura Rai were found superior over economic parent. These crosses may be utilized to get transgressive segregants in segregating generations for the development of an improved pure line variety. Moreover, if there is feasibility of hybrid development in the crop, then these crosses could be exploited for hybrid development in Indian mustard.

Synrem *et al.* (2015) reported hybrid RL-1359 ×JM-2 exhibited superior performance for seed yield and its component traits as reflected by significant positive estimates for relative heterosis, heterobeltiosis and economic heterosis. Desirable negative heterosis for days to 50 percent flowering, days to maturity and plant height was noted in PM-67 × Pusa bold. Five crosses *viz*., GM-1 × VARUNA RL1359 × JM-2, KRISHNA × JM-2, CS-54 × VARUNA and GM-2 × JM2 also possessed positive significant relative heterosis and heterobeltiosis for seed yield per plant and other associated characters like primary branches per plant, secondary branches per plant, siliquae main per branch, number of seeds per siliqua and length of siliquae. The crosses with favourable traits obtained from this study can be utilized in further breeding programmes for development of high seed yielding cultivars.

Chaurasia and Bhajan (2015) reported high heterobeltiosis in six crosses namely CS 609B-10 × NDRE-4, PRQ -2005 × NDRE-4, RGN142 × PRB-2006-12, CS 609B-10 × Kanti, PRB-2006-12 × Kanti and PAB-9534 × Kanti. These crosses also manifested significant heterosis over mid-parent and standard variety. Three crosses namely SKM-401 × Vardan, PRB-2006-12 × Vardan and NDRE-4 × PWR-9541, manifested significant low heterosis over MP over SV for oil content.

Tomar *et al*. (2015) observed top five crosses namely; Krantix Mathura Rai, Maya × RK 9807, B-85 × Mathura Rai, KR-5610 × RK -9808 and Pusa Bold × Mathura Rai showed significant economic heterosis for oil content. For seed yield per plant the crosses namely; Rohini × Mathura Rai, Maya × RK-9807, Pusa Bahar × Pusa Agrani, KR-5610 × Pusa Agrani, Pusa Jai Kisan × PusaAgrani showed significant and positive economic heterosis.

Akabari and Sasidharan (2016) studied using line x tester analysis involving three lines, and twenty testers for fourteen characters including seed yield, its components, and quality characters. Three crosses depicted significant positive heterotic effect for seed yield per plant viz., GM-2× PYM-7, GM-3 × PAB-9511 and GM-3 × NUDH-45-1. Among these crosses, GM-2 × PYM-7, and GM-3× PAB-9511 also exhibited significant and desirable heterotic effect for numbers of siliquae per plant, primary branches per plant and secondary branches per plant. Hence, could be further evaluated in heterosis breeding programme, and simultaneously advanced in segregating generations to obtain desirable sergeants for the development of superior genotypes.

Sanakal *et al.* (2017) observed from data of hetero-beltiosis and useful heterosis and concluded that crosses with high magnitude of heterosis had higher magnitude of SCA effects and better *per se* performance. Hence selection of superior crosses for development of hybrids should necessarily base not only on the magnitude of heterosis, but also high mean performance. The first cross ACN-9 x ACN-169 exhibited significant useful heterosis (H2) for seed yield per plant. The same cross also exhibited significant SCA and mean for seed yield per plant and number of siliqua per plant and significant heterosis in to (H1and H2) for number siliqua per plant. Another cross Pusa bold × ACN-164 also exhibited significant desirable heterosis (H1 and H2) for seed yield as well as number of siliqua per plant, significant SCA for seed yield and number of siliqua per plant and significant mean for seed yield per plant.

Singh *et al*. (2018) developed forty-four yellow sarson hybrids by line x testers mating design (3 pistillate lines x 9 male parents) were studied along with parents and a standard check for heterosis of yield determinant characters in two environments. Significant desired hetero-beltiosis ranged from 4.52 to 44.86 percent in E1and 13.42 to 62.07 percent in E2 while, standard heterosis ranged from -6.64 to 23.01 per cent in

E1and -6.30 to 21.85 per cent for seed yield plant-1. Other characters also showed considerable heterosis over better parent and standard check. The crosses L2 × T1 and L3 × T1 were identified as potential for commercial exploitation of heterosis both for seed yield plant-1 and oil content. High heterotic hybrids in both the environments viz., L8 × T1 and L9 × T1 showed stability in performance for nine characters including seed yield plant-1where as among parent NDYS-141 showed near unity ratio of stability factor for five characters. L9 × T1 followed by L8 × T1 could be identified as most promising crosses on the basis of stability, *per se* performance, standard heterosis.

CHAPTER - III

MATERIALS AND METHODS

CHAPTER-III
MATERIALS AND METHODS

The materials which were used for experiments and the techniques used for collection, analysis and interpretation have been described in this chapter.

3.1 Experimental Site

The experiment was conducted in the experimental farm of Sher-e-Bangla Agricultural University (SAU), Dhaka. In first year, the diallel crossing pattern among the six (6) selected parental lines were performed during November 2017- March 2018 to develop fifteen (15) F_1 hybrids lines. These 15 F_1 hybrids were then evaluated for their assessment of combing ability and heterosis during November 2018- March 2019. The location situated at the AEZ No. 28 called "Madhupur Tract". It is located at 23°4′ N latitude and 90°22′ E longitude with an elevation of 8.6 meter from the sea level (Appendix I).

3.2 Soil and Climate

The soil of the experimental plots was clay loam, land was medium high with medium fertility level. The site was suited in the subtropical climate zone, wet summer and dry winter is the general climatic feature of this region. The experimental site was medium high land and the pH was 5.6 to 5.8 and organic carbon content was 0.82%. The physical and chemical characteristics of the soil have been presented in Appendix-II. During the Rabi season the rainfall generally is scant and temperature moderate with short day length. Meteorological data on rainfall, temperature, relative humidity from October 2018 to March 2019 were obtained from the Department of Meteorological Centre, Agargaon, Dhaka (Appendix III-IV).

3.3 Materials

A total number of 21 (twenty-one) plant materials were used in this experiment which included the fifteen (15) were F_1 hybrids (Table 1b) developed from (6 × 6) half-diallel fashion cross excluding the reciprocals and their 6 parents (Table 1a). BARI-14 and local variety Maghi were used as check variety (CV) which were also used as parents. All the plant materials were collected from Department of Genetics and Plant

Breeding, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The materials used in the experiment are shown in Table 1.

Table 1 Materials used in 6×6 half diallel cross experiment

Table 1 (a) List of six (6) parents used in the experiment

Sl. No.	Parents	Name of Parents	Source
1	P1	BARI 6	BARI
2	P2	BARI 12	BARI
3	P3	BARI 14	BARI
4	P4	BARI 15	BARI
5	P5	BARI 17	BARI
6	P6	Maghi	Local (Manikgonj)

Table 1(b) List of F_1's developed from 6×6 half-diallel crosses without reciprocals

Sl. No.	F_1 hybrids of half-diallel crosses	Crosses combinations
1	P1 × P2	BARI 6 × BARI 12
2	P1 × P3	BARI 6 × BARI 14
3	P1 × P4	BARI 6 × BARI 15
4	P1 × P5	BARI 6 × BARI 17
5	P1 × P6	BARI 6 × Maghi
6	P2 × P3	BARI 12 × BARI 14
7	P2 × P4	BARI 12 × BARI 15
8	P2× P5	BARI 12 × BARI 17
9	P2 × P6	BARI 12 × Maghi
10	P3 × P4	BARI 14 × BARI 15
11	P3 × P5	BARI 14 × BARI 17
12	P3× P6	BARI 14 × Maghi
13	P4 × P5	BARI 15 × BARI 17
14	P4× P6	BARI 15 × Maghi
15	P5 × P6	BARI 17 × Maghi

3.4 Methods

The following precise methods have been followed to carry out the experiment:

3.4.1 Land Preparation

The experimental plot was prepared by several ploughing and cross ploughing followed by laddering and harrowing with power tiller to bring about good tilth. Weeds and other stubbles were removed carefully from the experimental plot and leveled properly. Land preparation was shown in plate 1.

3.4.2 Fertilizer application

Fertilizers such as urea, triple super phosphate (TSP), muriate of potash (MP), gypsum, boric acid, zinc oxide and cow dung were applied at the rate shown in Table 2. Urea was applied by two installments. Total amount of TSP, MP, gypsum and boric acid, zinc oxide and cow dung along with half of the urea were applied at the time of final land preparation as a basal dose. The second half of the urea was top-dressed at the time of initiation of flowers.

Table 2 List of fertilizers with doses and application procedures

SL. No.	**Fertilizer**	**Doses (kg/300 m^2)**	**Application procedure**
01	Urea	7.5 kg	50% basal and 50% at the time of first flower initiation
02	TSP	5.5 kg	As basal
03	MP	2.5 kg	As basal
04	Gypsum	4.5 kg	As basal
05	Boric acid	0.25 kg	As basal
06	Zinc oxide	0.5 kg	As basal
07	Cowdung	100 kg	As basal

Plate 1 Photograph showing experimental plot preparation

Plate 2 Photograph showing flowering stage of the crop

3.4.3 Experimental design

Field layout was done after final land preparation. The seeds of 6 parents and 15 F_1 materials were laid out in a Randomized complete block design (RCBD) with three replications. The plot size was 10 m × 30 m. A distance of 0.75 m from replication to replication, 30 cm from row to row and around 5 cm from plant to plant was maintained. F_1 seeds were sown in lines in the experimental plots on 01 November, 2018. The seeds were sown at about 1.5 cm depth in the soil. Seed germination started from 3 days after sowing.

Plate 3 Evaluation of 15 F_1's with check varieties during the Rabi season of 2018-19

3.4.4 Intercultural operations

Intercultural operations, such as weeding, thinning, irrigation etc. were done uniformly in all the plots. Irrigation was done by sprinkler after sowing of seeds to bring proper moisture condition of the soil to ensure uniform germination of the seeds. A good drainage system was maintained for immediate release of rainwater from the experimental plot during the growing period. The first weeding was done after 15 days of sowing. During the same time, thinning was done for maintaining a distance of 10 cm from plant to plant in rows. Second weeding was done after 35 days of sowing.

3.4.5 Harvesting

Harvesting was started from 10 February, 2019 depending upon the maturity of the plants. When 80% of the plants showed straw colour of siliqua, leaves, stem and desirable seed colour in the matured siliqua, it was indicated the maturity. Five plants were selected at random from each parental line and five plants from F_1 progeny's line in each replication. The sample plants were harvested by uprooting and then they were tagged properly. Data were collected from these plants.

Plate 4 Ripening stage of 15 F_1's

3.4.6 Collection of data

For studying heterosis and combining abilities, data from eleven characters were recorded as follows.

3.4.6.1 Methods of data collection

1. **Days to first flowering:** Difference between the date of sowing to the date of first flowering of a line was counted as days to first flowering.

2. **Days to 50% flowering:** Difference between the date of sowing to the date of 50% flowering of a line was counted as days to 50% flowering.

3. **Plant height (cm):** It was measured in centimeter from the base of the plant to the tip of the longest inflorescence. Data were taken after harvesting.

4. **Number of primary branches/plant:** The total number of branches produced from the main stem of a plant was counted as the number of primary branches per plant.

5. **Number of secondary branches/plant:** The total number of branches arisen from the primary branch of a plant was counted as the number of secondary branches per plant.

6. **Days to maturity:** Number of days required from sowing to siliquae maturity of 80% plants of each line.

7. **Siliqua length (cm):** For this character measurement was taken in centimeter from the base to the tip of a siliqua including the beak of siliqua from the five representative siliquae.

8. **Number of siliquae/plant:** Total number of siliquae of each plant was counted and considered as the number of siliquae/plant.

9. **Number of seeds/siliqua:** Well filled seeds were counted from five representative siliqua, which was considered as the number of seeds/siliqua.

10. **1000 seed weight (g):** Weight in grams of randomly counted thousand seed was recorded.

11. **Seed yield/plant (g):** All the seeds by a representative plant was weighed in gram and considered as the seed yield/plant.

3.4.7 Statistical analysis

The mean values of five randomly selected plants used for recording the data. The observed data were computed for each of eleven traits of the genotypes in each replication and were subjected to statistical analysis. Duncan’s Multiple Range Test (DMRT) was performed for all the characters to test the differences between the mean of the genotypes. All the collected data were statistically analyzed using Statistix 10 (trial version) computer package program. Mean value for each characters were calculated and analysis of variance was performed by F-test (variance ratio). Difference between treatments was assessed by least significant difference (lsd) test at 5% level of significance (Gomez and Gomez, 1984). OP State computer software was used for analyzing combining ability.

3.4.7.1 Analysis for variance

All the observational records were subjected to analysis of variance (ANOVA). The total variances of each character were partitioned into replication, genotype and error differences. The genotypic variances were also partitioned into parent and F_1. The level of significance was tested at 5% and 1% using F-test. A Completely Randomized Block Design with three replications was implemented according to the following linear modeling (Al-Mohammad and Al-Yonis, 2000). The mathematical model used in the analysis was as follows:

$$Y_{ij} = \mu + \tau i + \rho j + \varepsilon ij \begin{Bmatrix} i = 1,2,3,\dots\dots t \\ j = 1,2,3,\dots\dots r \end{Bmatrix}$$

Where,

Y_{ij}: The value of observation belongs to the experimental unit designated

μ: The general mean value,

τi: The value of the actual effect of the treatment “i”,

ρj: The value of the actual effect of the block “j”, and

εij: The value of the actual effect of the experimental error belongs to the observation designated as treatment “i” in the block “j”.

$\varepsilon ij \sim$ NID (0, σ^2E)

3.4.7.2 Combining ability analysis in relation to diallel cross:

Griffing (1956) proposed four methods of analysis depending on the materials involved. Griffing 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 2 (excluding reciprocals) and Model-I.

The mathematical model for the analysis was:

$$Y_{ij} = m + g_i + g_j + s_{ij} + \frac{1}{bc} \sum\sum \varepsilon_{ijkl}$$

Where,

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

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

L=l,2..................... c

p = Number of parents

b = Number of blocks or replications

c = Number of observation in each plot

Yij= The mean of i x j^{th} genotype over K and L

m = The population mean.

gi = The general combining ability (GCA) effect to i^{th} parent

gj = The GCA of j^{th} parent

S_{ij} = The SCA effect such that sij = sji

$\frac{1}{bc}\frac{1}{bc}\sum\sum$ εijkl: means error effect.

The restriction imposed are $\Sigma\ g_i=0$ and Σ Sij+Sji = 0 (for each i)

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

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

Where,

GCA = General combining ability

SCA = Specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

Y_i = Array total of the i^{th} parent

Y_{ii} = Mean value of the i^{th} parent

Y = Grand total of the 1/2 p(p-1) crosses and parental lines

Yij = Progeny mean values in the diallel table

S_e= Sum of square due to error

$$Sg = \frac{1}{(P+2)} [\Sigma_i (Y_i + Y_{ii})^2 - \frac{4}{P} Y..^2]$$

$$S_s = \Sigma_i \Sigma_j Y_{ij}^2 \frac{1}{(P+2)} \Sigma(Y_i + Y_{ii})^2 + \frac{2}{(P+1)(P+2)} Y..^2$$

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

$$g_i = \frac{1}{(P+2)} [\Sigma_i (Y_i + Y_{ii})^2 - \frac{4}{P} Y..^2]$$

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

The variance of GCA and SCA were,

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

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

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

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

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

3.4.7.3 Estimation of heterosis

For estimation of heterosis in each character the mean values of the 15 F_1's have been compared with better parent (BP) for heterobeltosis and with check variety for standard heterosis. Heterosis for each trait was computed by using following formulae.

It was estimated as the percentage deviation of F_1's hybrid from better parental value:

Heterosis over better parent (H)% $= \frac{\overline{\mathrm{F_1}} - \overline{\mathrm{B.P}}}{\overline{\mathrm{B.P}}} \times 100$

Where,

$\overline{\mathrm{F_1}}$ Mean of hybrid; $\overline{\mathrm{B.P}}$= Mean of better parent

Standard heterosis (%) = [$\overline{\mathrm{F}}_1$- $\overline{\mathrm{CV}}$)/ $\overline{\mathrm{CV}}$] ×100

Where,

$\overline{\mathrm{F}}_1$ and $\overline{\mathrm{CV}}$ represented the mean performance of hybrid and standard check variety. The significance test for heterosis was done using the standard error of the value of check variety.

CHAPTER -IV

RESULTS AND DISCUSSION

CHAPTER- IV

RESULTS AND DISCUSSION

The mean value of mustard yield and related characters of parents and their F_1 progenies are presented in table 4 and corresponding analysis of variance in table 3.

Highly significant ($p<0.001$) differences were observed in the genotypes (Table 3) for all the characters under the study such as days to first flowering (DFF), days to 50% flowering (D50%F), days to maturity (DM), plant height (PH), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), number of siliquae per plant (NSP), siliqua length (LS), number of seeds per siliqua (NSS), thousand seed weight (TSW) and seed yield per plant (SYP).

4.1 Mean performance

4.1.1 Days to first flowering: For parents, days to first flowering was found earlier in P6 (24.67), while P4 (34.00) showed late. Among the F_1 hybrids of V13 (P4×P5) (25.00), V1 (P1×P2) (26.00) and V5 (P1×P6) (26.00) showed earliness in days to first flowering, on the other hand V3 (P1×P4) (32.67) showed the most late first flowering (Table 4).

4.1.2 Days to 50% flowering: In case of days to 50% flowering for parent, it was ranged from 28.67 to 40.33 days (Table 4). However, the parent P6 (28.67) flowered with the lowest time but the parent P4 (40.33) taken the highest duration. On the other hand, the hybrid combination V13 (P4×P5) (27.67) produced 50% flowers at the lowest duration and V3 (P1×P4) (36.00) showed the highest duration.

4.1.3 Days to maturity: Considering earliness, the parent P3 (81.33) and P5 (81.67) showed the lowest duration for maturation but the parent P1 (85.67) had taken the highest duration. On the other hand, the hybrid combination V9 (P2×P6) (80.00) matured with the lowest growth duration, which was earlier than its both parents. But the hybrid combinations V3 (P1×P4) and V14 (P4×P6) (83.67) had taken the highest duration (Table 4).

Table 3 Analysis of variances (MS values) of eleven characters of Mustard (*B. rapa*)

Source	**d.f.**	**DFF**	**D50%F**	**DM**	**PH**	**NPB**	**NSB**	**NSP**	**LS**	**NSS**	**TSW**	**SYP**
Replication	2	17.73	30.11	12.63	42.68	7.30	0.61	13.67	0.56	3.13	0.08	3.10
Genotype	20	15.33**	28.02**	6.81**	285.87**	8.15**	6.95**	5961.87**	0.99**	51.28**	0.23**	4.80**
Error	40	5.69	4.89	1.48	27.88	1.14	0.63	64.13	0.21	3.09	0.03	1.35

DFF= Days to first flowering, D50%F= Days to 50% flowering, DM=Days to maturity, PH= Plant height (cm), NPB= Number of primary branches per plant, NSB= Number of Secondary branches per plant, NSP= Number of siliquae per plant, LS= Siliqua length (cm), NSS= Number of seeds per siliqua, TSW=1000 seed weight (g), SYP=Seed yield per plant (g). *P>0.05, **P>0.01, ns = non significant.

Table 4 Mean performance of eleven characters of 6 parents and 15 F$_1$'s derived from 6×6 half diallel cross in mustard (*Brassica rapa*)

Genotype	DFF	D50%F	DM	PH	NPB	NSB	NSP	LS	NSS	TSW	SYP
P1	30.00a-c	33.00bc	85.67a	104.87a	4.63d	1.00e	116.33ij	5.79ab	17.63a-d	3.27b-e	7.10ab
P2	28.00a-c	31.00bc	84.33ab	99.97a-c	5.93cd	5.73a	151.80fg	5.41a-c	14.83b-g	2.90e	6.33ab
P3	29.00a-c	31.67bc	81.33bc	92.26a-e	6.23cd	1.57c-e	120.67h-j	4.22c	15.33b-f	3.33b-e	6.83ab
P4	34.00a	40.33a	83.33a-c	85.57c-f	5.67cd	1.00e	86.77k	4.53a-c	19.43ab	3.17b-e	5.57a-c
P5	29.33a-c	33.00bc	81.67bc	86.01b-f	5.25cd	1.12de	117.30ij	5.92a	21.77a	3.47a-e	7.69a
P6	24.67c	28.67c	82.00a-c	78.64ef	4.84cd	4.23ab	130.57g-i	4.71a-c	12.86c-g	2.93de	4.73a-c
V1 (P1×P2)	26.00bc	28.00c	80.33c	101.57a-c	5.40cd	2.80b-e	143.40gh	5.17a-c	12.20d-g	3.53a-c	4.60a-c
V2 (P1×P3)	28.33a-c	31.67bc	82.67a-c	103.52a	7.00b-d	2.00b-e	247.93a	5.61a-c	17.00a-e	3.73ab	7.40a
V3 (P1×P4)	32.67ab	36.00ab	83.67a-c	97.91a-d	5.60cd	0.33e	100.40jk	4.59a-c	14.53b-g	3.67ab	5.47a-c
V4 (P1×P5)	28.33a-c	31.67bc	81.00bc	103.12a	7.33b-d	2.60b-e	170.13ef	5.34a-c	17.97a-c	3.47a-e	5.20a-c
V5 (P1×P6)	26.00bc	28.33c	80.67bc	85.43c-f	6.13cd	3.73a-c	136.67g-i	5.59a-c	15.20b-f	3.00c-e	4.87a-c
V6 (P2×P3)	26.67bc	30.00bc	80.33c	98.18a-d	5.67cd	2.27b-e	140.73g-i	4.33c	9.60gh	3.40b-e	4.57a-c
V7 (P2×P4)	27.67a-c	30.33bc	81.67bc	69.83f	5.47cd	1.80b-e	132.13g-i	4.22c	5.33h	3.63ab	2.33c
V8 (P2×P5)	28.67a-c	31.00bc	81.00bc	104.01a	8.07a-c	1.93b-e	173.73d-f	4.67a-c	10.13f-h	3.50a-d	6.27ab
V9 (P2×P6)	26.67a-c	28.67c	80.00c	89a-e	5.07cd	3.50a-d	183.27de	5.53a-c	10.47f-h	3.40b-e	5.33a-c
V10 (P3×P4)	26.33bc	28.33c	81.33bc	82.23d-f	5.33cd	2.27b-e	196.27cd	5.77ab	14.47b-g	3.73ab	5.13a-c
V11 (P3×P5)	29.00a-c	33.33bc	82.00a-c	83.09d-f	5.80cd	0.87e	79.00k	5.05a-c	21.03a	4.00a	4.47a-c
V12 (P3×P6)	26.33bc	28.33c	80.33c	92.47a-e	10.73a	1.00e	186.20c-e	4.53a-c	10.47f-h	3.73ab	5.20a-c
V13 (P4×P5)	25.00bc	27.67c	80.67bc	102.23ab	10.27ab	1.00e	224.33ab	4.40bc	11.73e-g	3.50a-d	5.93a-c
V14 (P4×P6)	28.00a-c	29.67bc	83.67a-c	86.29b-e	8.00a-c	5.53a	210.40bc	4.41bc	10.60f-g	3.43a-e	5.80a-c
V15 (P5×P6)	28.00a-c	29.33bc	82.00a-c	90.97a-e	6.33cd	3.60a-c	152.80fg	4.88a-c	11.87e-g	3.30b-e	3.60bc
SE(±)	1.38	1.28	0.70	3.05	0.62	0.46	4.62	0.26	1.01	0.12	0.67
CV (%)	8.51	7.14	1.48	5.72	16.64	33.43	5.25	9.17	12.53	5.33	21.33
LSD(0.05)	7.43	6.88	3.77	16.45	3.33	2.47	24.94	1.42	5.47	0.57	3.62

DFF= Days to 1st flowering, D50%F= Days to 50% flowering, DM=Days to maturity, PH= Plant height (cm), NPB= No. of primary branches per plant, NSB= No. of secondary branches per plant, NSP= No. of siliquae per plant, LS= Siliqua length (cm), NSS= No. of seeds per siliqua, TSW=1000 seed weight (g), SYP= Seed yield per plant (g). SE=Standard error, CV%=Coefficient of variation & lsd=Least significant difference.

4.1.4 Plant height (cm): For parent, the lowest plant height was observed in P6 (78.64 cm) and for hybrid V7 (P2× P4) (69.83 cm). The parent P1 showed the highest (104.87 cm) plant height. In table 4, the highest plant height 104.01 cm was found in the hybrid V8 (P2 ×P5).

4.1.5 Number of primary branches per plant: For the character, number of primary branches per plant, parents showed a range from 4.63 to 6.23 (Table 4). But in the hybrids, the highest performance was found by the combination (V12) P3×P6 (10.73) followed by (V13) P4×P5 (10.27) which were higher than both of their parents.

4.1.6 Number of secondary branches per plant: For the number of secondary branches per plant, parents showed a range from 1.00 to 5.73 secondary branches per plant (Table 4). But in case of hybrids, the highest value of number of secondary branches per plant provided by the cross combination V14 (P4 × P6) (5.53) and lowest number of secondary branches per plant was found in V3 (P1×P4) (0.33).

4.1.7 Number of siliquae per plant: In parents, number of siliquae per plant were varied from 86.77 to 151.80 where the parent P2 (151.80) produced the highest and P4 (86.77) the lowest number of siliquae per plant. Considering hybrid performance, it was ranged from 79.00 to 247.93. The hybrid combination V2 (P1× P3) (247.93) provided the highest number which was much higher than its both parents and the lowest number of siliquae per plant found in V11 (P3×P5) 79.00 (Table 4).

4.1.8 Siliqua length (cm): Siliqua length of parents was ranged from 4.22cm to 5.92 cm. The parent, P5 produced the longest siliqua while the parent P3 produced least siliqua length. On the other hand, for hybrids the siliqua length was varied from 4.22 cm to 5.77 cm (Table 4). In this regard, the hybrid combination V10 (P3 × P4) exhibited the highest length of siliqua and that was a little bit higher than that it's either parent.

4.1.9 Number of seeds per siliqua: Seeds per siliqua were varied from 12.86 to 21.77 in parents and from 5.33 to 21.03 in hybrids (Table 4). The hybrid V11 (P3×P5) produced the highest number of seeds per siliqua and V7 (P2×P4) produced the lowest number of seeds per silliqua which was much less than both of its parents.

4.1.10 Thousand seed weight (g): Thousand seed weight in *B. rapa* varied with some extent i.e. from 2.90 g to 3.47 g in parents and that of from 3.00 g to 4.00 g in hybrids. However, the heaviest or the boldest seeds were produced by the parent P5 (3.47 g) and also by the hybrid combination V11 (P3× P5) (4.00 g) (Table 4). The hybrid provided the highest weighted seeds which were higher than its both parent.

4.1.11 Seed yield per plant (g): Seed yield per plant was diversely varied in different genotypes including parents and hybrids. Seed yield of the genotypes varied from 4.73 g to 7.69 g in parents and from 2.33 g to 7.40 g in hybrids. The highest seed yield of the parent was found in P5 (7.69 g) whereas lowest in P6 (4.73 g). Similarly, the highest seed yield was observed in the hybrid V2 (P1 × P3) (7.40 g) while the lowest seed yield was also observed in hybrid V7 (P ×P4) (2.33 g) (Table 4).

4.2 Combining ability

The study of combining ability is necessary for selection of suitable parents for hybridization and identification of promising hybrids for the development of improved varieties for a diverse agro-ecology (Alabi *et al.* 1987). To conduct a sound basis for any breeding program, breeders must have information on the nature of combining ability of parents, their behaviour and performance in hybrid combinations (Chawla and Gupta, 1984). Combining ability studies recommend information on the genetic mechanisms controlling the inheritance of quantitative traits and enable the breeders to select suitable parents for further improvement or use in hybrid breeding for commercial purposes (Hayder and Paul, 2014).

ANOVA of general combing ability (GCA) and specific combining ability (SCA) variance are presented in Table 5. The study revealed significant mean squares for general and specific combining abilities for all of the studied characters which indicated significant differences that recommended presence of notable genetic variability among the GCA as well as SCA effects. Sarkar and Singh (2001), Matho and Haider (2004) reported GCA and SCA variance were significantly different among parents and crosses for most of the characters. Yadava *et al*. (2012) have also reported significant differences for GCA and SCA variances for different traits in mustard. It specified that both additive and non-additive components of genetic variance for controlling the characters.

The higher magnitude of GCA variance was observed than that of SCA variance for the characters days to 1st flowering, days to 50% flowering, days to maturity, plant height, number of secondary branches, siliqua length, number of seeds per siliqua and thousand seeds weight indicating the predominance of additive gene action for these traits and there is always a good chance of improving those traits by accumulation of favorable gene. Using half diallel analysis Nasrin *et al.* (2011) found significant general combining ability for days to flowering, days to maturity, primary branches per plant, 1000-seed per plant and seed yield.

SCA variance was higher than GCA variance for the characters number of primary branches, number of siliquae per plant and seed yield per plant. In an earlier study of Chowdhury *et al*. (2004) reported SCA variance was higher than GCA variance (non-additive type) for all the characters except number of primary branches, number of siliquae per plant, seed yield per plant. So the present study covered that both additive and non-additive gene interaction influenced the expression of traits.

Table 5 Analysis of variances (MS values) for GCA and SCA for eleven characters of 6 parents and 15 F_1's derived from 6×6 half diallel cross in mustard (*Brassica rapa*)

Source	**d.f.**	**DFF**	**D50%F**	**DM**	**PH**	**NPB**	**NSB**	**NSP**	**LS**	**NSS**	**TSW**	**SYP**
GCA	5	27.43**	42.99**	7.11**	504.75**	3.53*	15.29**	596.31**	1.37**	88.45**	0.32**	3.88*
SCA	15	11.29*	23.03**	6.71**	212.90**	9.69**	4.17**	7,750.39**	0.86**	38.88*	0.20**	5.11**
Error	40	5.69	4.88	1.47	27.88	1.14	0.63	64.12	0.21	3.09	0.03	1.35
GCA: SCA		2.43	1.87	1.06	2.37	0.36	3.67	0.08	1.61	2.28	1.60	0.76

DFF= Days to 1st flowering, D50%F= Days to 50% flowering, DM=Days to maturity, PH= Plant height (cm), NPB= Number of primary branches per plant, NSB= Number of secondary branches per plant, NSP= Number of siliquae per plant, LS= Siliqua length (cm), NSS= Number of seeds per siliqua, TSW=1000 seed weight (g), SYP=Seed yield per plant (g). *P>0.05, **P>0.01, ns = non significant.

4.2.1 General Combining Ability (GCA) effect

The GCA effects represent the additive nature of gene action. Besides *per se* performance of the parent was also considered together with GCA effects since the former offers authenticity to GCA effects as guidance to select the parent. Variances due to GCA and SCA with each parent play significant role in the choice of parents. A parent with higher positive significant GCA effects is considered as a good general combiner. A parent showing high GCA and SCA variances is considered as a better parent for creating high yielding with specific combinations.

The estimates of GCA effects are given in Table 6. The magnitude and direction of the significant effects for the six parents provide meaningful comparisons and would give knowledge to the future breeding programme. The results of GCA effects of different characters are presented below:

4.2.1.1 Days to first flowering: The estimates of GCA effect ranged from -1.49 in P6 to 1.56 in P4 (Table 6). Negative GCA effect is preferable for flowering character, because it directs the general capacity of early parent to transmit its behavior to progenies in cross combination with other parents. The parental genotypes P6, P2 and P3 were desirable for negative GCA effect. Among them P6 was considered the good general combiner for early flowering but it had non-significant. But significant general combining ability (GCA) effects were noticed for days to first flowering by Aghao *et al.* (2010).

4.2.1.2 Days to 50% flowering: Through the estimation the highest and lowest GCA were observed 2.01 in P4 and -1.90 in P6, respectively (Table 6). The parents P6, P3 and P2 showed the negative GCA effect which is preferable for flowering character because it indicated the general capacity of early parent to transmit its behavior to progenies in cross combination with other parents. The genotype P1 and P4 were the late flowering parent. Among the parents P6 was considered the good general combiner for early flowering and the parents P1 and P4 could be termed as poor general combiners. Significant general combining ability (GCA) effects were also noticed by Mahak-Singh (2005) and Gupta *et al.* (2011) for days to 50% flowering.

Table 6 Estimation of general combining ability (GCA) of eleven characters of 6 parents in mustard (*Brassica rapa*)

Parents	**DFF**	**D50%F**	**DM**	**PH**	**NPB**	**NSB**	**NSP**	**LS**	**NSS**	**TSW**	**SYP**
P1	0.64	0.64	0.81	6.95**	-0.52	-0.40	-4.47**	0.38	1.75	-0.01	0.45
P2	-0.69	-0.86	-0.15	2.10	-0.42	0.90	1.24	-0.02	-2.59*	-0.10	-0.30
P3	-0.32	-0.19	-0.49	-0.21	0.26	-0.63	3.07*	-0.15	0.64	0.15	0.29
P4	1.56	2.01	0.56	-4.51**	0.14	-0.46	-3.74 **	-0.30	-0.33	0.03	-0.29
P5	0.31	0.31	-0.40	1.21	0.42	-0.55	-4.04**	0.16	2.26	0.08	0.34
P6	-1.49	-1.90	-0.32	-5.54**	0.13	1.15	7.94 **	-0.07	-1.73	-0.16	-0.49
Max	1.56	2.01	0.81	6.95	0.42	1.15	7.94	0.38	2.26	0.15	0.45
Min	-1.46	-1.90	-0.49	-5.54	-0.52	-0.63	-4.47	-0.30	-2.59	-0.16	-0.49
SE gij	0.45	0.41	0.23	0.98	0.20	0.15	1.49	0.09	0.33	0.03	0.22
SE (gi-gj)	0.69	0.64	0.35	1.52	0.31	0.23	2.31	0.13	0.51	0.05	0.34

DFF= Days to 1st flowering, D50%F= Days to 50% flowering, DM=Days to maturity, PH= Plant height (cm), NPB= Number of primary branches per plant, NSB= Number of secondary branches per plant, NSP= Number of siliqua per plant, LS= Siliqua length (cm), NSS= Number of seeds per siliqua, TSW=1000 seed weight (g), SYP=Seed yield per plant (g). *P>0.05, **P>0.01.

4.2.1.3 Days to maturity: Like flowering trait, negative GCA is desirable for selection of early maturing parents. The estimates of GCA effects ranged from -0.49 in P3 to 0.81 in P1 (Table 6). The parental genotypes P6, P5, P3 and P2 were desirable for negative GCA effect for this trait. Among the parents, P3 and P5 considered the best general combiner for early maturity. The genotype P1 and P4 were the late maturing parents, so the parents P1 and P4 could be termed as poor general combiners. Gupta *et al.* (2006) and Patel *et al.* (2015) investigated general combining ability of parents for days to maturity.

4.2.1.4 Plant height (cm): Among the three parental lines viz. P3, P4 and P6 showed negative GCA effects. However, parents P4 (-4.51) and P6 (-5.54) showed negative significant GCA and indicated good combiner for developing dwarf stature variety. The highest GCA was found in P1 (6.95) indicating the poor combiner for developing dwarf stature lines (Table 6). Sincik *et al.* (2011) and Parmar *et al.* (2011) observed good general combiner parents for plant height in mustard.

4.2.1.5 Number of primary branches per plant: Positive GCA is preferable for number of primary branches per plant. The GCA effect was ranged from - 0.52 in P1 to 0.43 in P5 (Table 6). Among the parents P3, P4, P5 and P6 were the moderate combiner of this character. Parmar *et al.* (2011) and Nasrin *et al.* (2011) investigated general combining ability effect of parents for number of primary branches per plant.

4.2.1.6 Number of secondary branches per plant: Among six parents, the parent P6 showed the highest positive GCA effect (1.15) followed by P2 (0.90) while the rest of parents showed negative GCA value (Table 6) for number of secondary branches per plant. The result indicated all the parents except P6 and P2 were poor combiner of this character. Sarkar and Singh (2001) and Gupta *et al.* (2006) studied general combining ability effect of parents for number of secondary branches per plant.

4.2.1.7 Number of siliquae per plant: Among the six parents, three parents viz. in P6 (7.94), P3 (3.07) and P2 (1.24) showed GCA effects in a positive direction for number of siliquea per plant implying the tendency of the plant to increase seed number (Table 6). Dar *et al.* (2011) and Rameeh (2012) mentioned positive and significant GCA effects for this trait. Three parents P1, P4 and P5 revealed negative GCA effect, suggesting that these parents were not good general combiners.

4.2.1.8 Siliqua length (cm): Among the six parents, P1 and P5 showed positive but non-significant value of GCA effects (0.38 and 0.16 respectively) for siliqua length (Table 6) suggesting these parents were not good combiners for the trait. Nasrin *et al.* (2011) noticed GCA effects for siliqua length in mustard.

4.2.1.9 Number of seeds per siliqua: Among six parents, the parents P5 (2.26) and P1 (1.75) showed positive GCA effects. On the contrary, the highest negative value was obtained by the parent P2 (-2.59) followed by P6 (-1.73) (Table 6). Thus the parent P5 was the best general combiner in this trait for increasing number of seeds per siliqua. Azizinia (2011) reported some good general combiners for number of seeds per siliqua.

4.2.1.10 Thousand seed weight (g): This trait showed that parental line P3 exhibited the highest positive GCA (0.15) followed by in P5 (0.08) and P4 (0.03) (Table 6) implying the tendency of the lines to increase yield of mustard. However, the highest negative GCA also observed -0.16 in parental line P6. This result was supported Azizinia (2012) and Sincik *et al.* (2011).

4.2.1.11 Seed yield per plant (g): Among the parents, P1 (0.45), P3 (0.29) and P5 (0.34) showed GCA effects in a positive direction for seed yield per plant suggesting the tendency of the parents to increase yield (Table 6). This directs the potential advantage of the parents for development of high-yielding hybrids. Earlier Tomar *et al.* (2015) and Nigam and Alka (2009) observed similar findings.

4.2.2 Specific Combining Ability (SCA) effect

Estimates specific combining ability effects for eleven characters of the fifteen F_1 hybrid lines are presented in Table 7. The SCA effects involved mainly dominance, additive × dominance, dominance × dominance effects. The crosses showing SCA effects toward positive direction indicated good performer of that character.

4.2.2.1 Days to first flowering: Negative estimates are desirable for days to flowering as they are considered to be related with earliness trait. Nine crosses showed desirable negative SCA. However, among the nine combinations only three crosses *viz*. P1× P2 (V1), P3× P4 (V10) and P4× P5 (V13) showed significant negative SCA which were considered as good combiner of this character (Table 7). Haung *et al.* (2009) observed significance earliness on different crosses in mustard.

4.2.2.2 Days to 50% flowering: Negative estimates are considered desirable for days to 50% flowering as they are associated with earliness. Nine crosses showed desirable negative SCA but only three crosses *viz.* P1×P2 (V1), P3×P4 (V10) and P4×P5 (V13) showed significance negative SCA considered as good combiner of the character (Table 7). Gupta *et al.* (2011) observed significance earliness on different crosses.

4.2.2.3 Days to maturity: The estimation showed that out of fifteen crosses only five crosses exhibited positive SCA (Table 7). Negative significant SCA was also desirable for this character. Among fifteen crosses, only nine crosses showed negative and non-significant SCA but only one cross P1×P2 (V1) showed significant negative SCA. So, cross P1×P2 (V1) was considered as good combiner for the character. Haung *et al.* (2009) evaluated SCA effects were significant for all the studied characters except for days to maturity.

4.2.2.4 Plant height (cm): The F_1 hybrid P4×P5 (V13) showed the highest plant height and showed the highest positive and significant SCA effect, while four other crosses *viz.* V5 (P1×P6), V7 (P2×P4), V10 (P3×P4) and V11 (P3×P5) showed negative significant SCA effects (Table 7). Negative SCA is desirable for developing dwarf stature plant type. Among four crosses V7 (P2×P4) (-20.01) showed the highest negative significant SCA that indicated that these cross had good specific combination for shorter plant height. Sheoran *et al.* (2000) founded dwarf type and tall type plants in their observation.

4.2.2.5 Number of primary branches per plant: Among the crosses, seven crosses showed positive SCA effect, but only two crosses *viz.* P3×P6 (V12) and P4×P5 (V13) showed positive significance effect considered as good combiner of the character of number of primary branches per plant (Table 7). The cross combination P3×P6 (V12) produced the highest significant positive effects followed by P4×P5 (V13) considered as the best specific combiner for the trait concerned. Yadava *et al.* (2012) reported significant SCA effects for number of primary branches per plant.

Table 7 Estimation of specific combining ability (SCA) of eleven characters of 15 F_1's derived from 6×6 half diallel cross in mustard (*Brassica rapa*)

Crosses	DFF	D50%F	DM	PH	NPB	NSB	NSP	LS	NSS	TSW	SYP
V1 (P1×P2)	-1.98 *	-2.71**	-2.21*	0.27	-0.07	-0.07	-5.79 **	-0.17	-0.98	0.21	-1.00
V2 (P1×P3)	-0.02	0.29	0.46	4.54**	0.85	0.66	96.92 **	0.40	0.59	0.16	1.22
V3 (P1×P4)	2.44*	2.41*	0.42	3.23**	-0.43	-1.18	-43.82 **	-0.46	-0.91	0.21	-0.14
V4 (P1×P5)	-0.64	-0.21	-1.29	2.70**	1.02	1.18	26.22 **	-0.18	-0.07	-0.04	-1.04
V5 (P1×P6)	-1.19	-1.34	-1.71	-8.22**	0.11	0.55	-19.23 **	0.29	1.16	-0.26	-0.55
V6 (P2×P3)	-1.35	0.12	-0.92	4.05**	-0.59	-0.37	-15.99 **	-0.49	-2.46*	-0.09	-0.87
V7 (P2×P4)	-1.23	-1.76	-0.63	-20.01**	-0.66	-1.01	-17.79 **	-0.44	-5.77**	0.26	-2.53 **
V8 (P2×P5)	1.02	0.62	-0.33	8.45**	1.65	-0.79	24.12 **	-0.45	-3.56**	0.08	0.78
V9 (P2×P6)	0.82	0.16	-1.42	0.18	-1.06	-0.91	21.67 **	0.64	0.77	0.23	0.67
V10 (P3×P4)	-2.94**	-4.42**	-0.63	-5.29**	-1.48	0.99	44.52 **	1.23	0.14	0.11	-0.31
V11 (P3×P5)	0.98	2.29*	1.00	-10.16**	-1.30	-0.33	-72.44 **	0.05	4.11**	0.33	-1.61
V12 (P3×P6)	0.12	-0.51	-0.75	0.19	3.93**	-1.88	22.77 **	-0.25	-2.46*	0.31	-0.05
V13 (P4×P5)	-3.89**	-5.59**	-1.38	13.29**	3.29**	-0.37	79.69 **	-0.44	-4.23**	-0.05	0.44
V14 (P4×P6)	-0.10	-1.38	1.54	4.09 **	1.32	2.48*	53.77 **	-0.20	-1.37	0.13	1.13
V15 (P5×P6)	1.15	-0.01	0.83	3.04 **	-0.64	0.63	-3.52 **	-0.20	-2.69**	-0.05	-1.70
Max	**2.44**	**2.41**	**1.54**	**13.29**	**3.93**	**2.48**	**96.92**	**1.23**	**4.11**	**0.33**	**1.22**
Min	**-3.89**	**-5.59**	**-2.21**	**-20.01**	**-1.30**	**-1.88**	**-72.44**	**-0.49**	**-5.77**	**-0.26**	**-2.53**
SE (sij)	**1.22**	**1.13**	**0.62**	**2.70**	**0.55**	**0.41**	**4.10**	**0.23**	**0.90**	**0.09**	**0.60**
SE (sij-skl)	**1.69**	**1.56**	**0.86**	**3.73**	**0.76**	**0.56**	**5.66**	**0.32**	**1.24**	**0.13**	**0.82**

DFF= Days to 1st flowering, D50%F= Days to 50% flowering, DM= Days to maturity, PH= Plant height (cm), NPB= Number of primary branches per plant, NSB= Number of secondary branches per plant, NSP= Number of siliquae per plant, LS= Siliqua length (cm), NSS= Number of seeds per siliqua, TSW=1000 seed weight (g), SYP=Seed yield per plant (g). *P>0.05, **P>0.01.

4.2.1.6 Number of secondary branches per plant: Among the fifteen F_1 progenies of the crosses, six crosses showed positive SCA effect but among them only one cross *viz.* P4×P6 (V14) showed positive significance effect. So, cross P4×P6 (V14) was considered as good combiner for number of secondary branches per plant (Table 7).

4.2.2.7 Number of siliquae per plant: For number of siliquae per plant eight cross combinations out of fifteen cross combinations showed positive significant SCA effect. The highest positive significant SCA effect showed in P1×P3 (V2). The crosses with the highest positive SCA was generally considered as the best specific combiner for this trait. Patel *et al.* (2015) found significant SCA effects for number of siliquae per plant in mustard.

4.2.2.8 Siliqua length (cm): The cross combination P3×P4 (V10) showed the highest but non-significant positive SCA effects for siliqua length. This result indicated that the cross P3×P4 was the poor specific combiner for siliqua length. Superior hybrids for siliqua length in mustard were reported by Rameeh (2010).

4.2.2.9 Number of seeds per siliqua: For number of seeds per siliqua, out of fifteen cross combinations five crosses *viz.* V2 (P1×P3), V5 (P1×P6), V9 (P2×P6), V10 (P3×P4) and V11 (P3×P5) showed positive SCA effects. Among them only V11 (P3×P5) showed significant positive SCA effects. The result indicated that this cross was the best specific combiner for increasing seeds per siliqua. But Sarkar and Singh (2001) found some hybrids showed significant positive SCA effect for seeds per siliqua.

4.2.2.10 Thousand seed weight: Higher seed weight is one of the most yield contributing traits for getting higher yield in mustard. There were ten crosses *viz.* V1 (P1×P2), V2 (P1×P3), V3 (P1×P4), V7 (P2×P4), V8 (P2×P5), V9 (P2×P6), V10 (P3×P4), V11 (P3×P5), V12 (P3×P6) and V14 (P4×P6) were founded highly positive SCA effect but non-significant for thousand seed weight (Table 7). Thus for obtaining desirable hybrid combinations with the highest thousand seed weight this V1 (P1×P2), V7 (P2×P4), V11 (P3×P5) and V12 (P3×P6) cross combinations could be selected for future breeding program. Azizinia (2012) found some good combination for 1000 seed weight in mustard.

4.2.2.11 Seed yield per plant: For seed yield per plant, five cross combinations showed positive SCA effects. For this trait, the positive but non-significant SCA was obtained by the cross P1×P3 (V2) followed by P4×P6 (V14), P2×P5 (V8), P2×P6 (V9), P4×P5 (V13). The result indicated that none of the cross combinations were the best general combiner for increasing seed yield per plant. However, ten crosses showed negative non-significant SCA effects (Table 7). Tomar *et al.* (2015) found some good specific combiners for seed yield per plant.

4.3 Analysis of Heterosis

The enormity of heterosis provides information on extent of genetic diversity of parents in developing superior F_1 hybrids to exploit the hybrid vigor. Usually standard heterosis is measured over a commercially cultivated popular variety or hybrid variety. In this experiment, two standard check varieties BARI sharisha-14 (CV1) and a local cultivar collected from Manikgonj (Maghi) (CV2) were included as check varieties for comparison of eleven yield contributing characters of the fifteen hybrids. Percent heterosis for different characters of the F_1 hybrids over better parent (BP) and standard check values are shown in Table 8. The result of percent of heterosis in crosses were varied from character to character or from cross to cross.

4.3.1 Days to first flowering: Days to first flowering revealed the earliness or lateness of a hybrid. Negative heterosis is desirable for this trait for selection of hybrid combinations for developing early lines. Out of fifteen crosses fourteen hybrids manifested significant heterosis over better parent (BP), however among them none of the F_1 hybrids showed significant negative value (Table 8). In case of standard hererosis thirteen F_1 possessed desirable significant negative heterosis over check variety BARI sharisha-14. Among them V13 (P4×P5) showed highest negative significant heterosis -13.45% over check 1 (Table 8) while none of the F_1 hybrid combinations showed negative significant heterosis over the check CV2 (Maghi cultivar). Nigam and Richa (2009) reported significant heterosis for days to flowering in mustard.

4.3.2 Days to 50% flowering: Negative heterosis is desirable for this trait also. Out of fifteen crosses nine hybrids showed significant heterosis over better parent and among them one hybrid showed significant negative value. Negative significant heterosis (-3.49%) was provided by the F_1 hybrid V13 (P4×P5) for days to 50% flowering over their better parent P6. Ghosh *et al*. (2002) and Mahto and Haider (2004) and Turi *et al.* (2006) observed negative significant heterosis over better parent was observed for days to 50% flowering. In case of standard hererosis ten F_1 hybrids possessed desirable significant negative heterosis over CV1 and among them V13 (P4×P5) showed highest significant negative heterosis (-12.63%) over CV1 (Table 8). In case of standard hererosis one F_1 hybrid V13 (P4×P5) showed significant negative heterosis (-3.49%) over CV2. Parmar *et al.* (2004) and Synrem *et al.* (2015) observed negative significant heterosis for days to 50% flowering over check variety.

Table 8 Estimation of heterosis over BP, CV1 and CV2 in 15 F$_1$'s derived from 6×6 half diallel cross in Mustard (*Brassica rapa)*

F$_1$ hybrids	**DFF**			**D50%F**			**DM**		
	BP	**CV1**	**CV2**	**BP**	**CV1**	**CV2**	**BP**	**CV1**	**CV2**
V1 (P1×P2)	5.39 **	-10.35**	5.39**	-2.34^{ns}	-11.59**	-2.34^{ns}	-1.23^{ns}	-1.23^{ns}	-2.04*
V2 (P1×P3)	14.84**	-2.31^{ns}	14.84**	10.46**	0.00^{ns}	10.46**	1.65^{ns}	1.65^{ns}	0.82 ^{ns}
V3 (P1×P4)	32.43**	12.66**	32.43**	25.57**	13.67**	25.57**	2.88 **	2.88 **	2.04 *
V4 (P1×P5)	14.84**	-2.31^{ns}	14.84**	10.46**	0.00^{ns}	10.46**	0.41^{ns}	0.41^{ns}	-1.22 ^{ns}
V5 (P1×P6)	5.39 **	-10.35**	5.39**	-1.19^{ns}	-10.55**	-1.17^{ns}	-0.81^{ns}	-0.81^{ns}	-1.62 ^{ns}
V6 (P2×P3)	4.05*	-11.48**	4.05*	4.64**	-5.27**	4.64**	-1.23^{ns}	-1.23^{ns}	-2.04 *
V7 (P2×P4)	12.16**	-4.59**	12.16**	5.79**	-4.23**	5.79**	0.42^{ns}	0.42^{ns}	-0.40 ^{ns}
V8 (P2×P5)	16.21**	-3.45*	16.21**	8.13**	2.12^{ns}	8.13**	0.41^{ns}	0.41^{ns}	-1.22 ^{ns}
V9 (P2×P6)	8.11 **	-8.03**	8.11**	0.00^{ns}	-9.47**	0.00^{ns}	-1.64^{ns}	-1.64^{ns}	-2.44 **
V10 (P3×P4)	6.73 **	-9.21**	6.73**	-1.19^{ns}	-10.55**	-1.19^{ns}	0.00^{ns}	0.00^{ns}	-0.82 ^{ns}
V11 (P3×P5)	17.55**	0.00^{ns}	17.55**	16.25**	5.24**	16.25**	0.82^{ns}	0.82^{ns}	0.00 ^{ns}
V12 (P3×P6)	6.73 **	-9.21**	6.73**	-1.19^{ns}	-10.55**	-1.19^{ns}	-1.23^{ns}	-1.23^{ns}	-2.04 *
V13 (P4×P5)	1.34^{ns}	-13.79**	1.34^{ns}	-3.49*	-12.63**	-3.49*	-0.81^{ns}	-0.81^{ns}	-1.62 ^{ns}
V14 (P4×P6)	13.50**	-3.45*	13.50**	3.49*	-6.32**	3.49*	2.88 **	2.88 **	2.04 *
V15 (P5×P6)	13.50**	-3.45*	13.50**	2.30^{ns}	-7.39**	2.30^{ns}	0.82^{ns}	0.82^{ns}	0.00 ^{ns}

DFF= Days to 1st flowering, D50%F= Days to 50% flowering, DM=Days to maturity, BP = better parent, CV1 = check variety 1, CV2 = check variety 2.

*P>0.05, **P>0.01, ns = non significant.

Table 8 Estimation of heterosis over BP, CV1 and CV2 in 15 F_1's derived from 6×6 half diallel cross in Mustard (*Brassica rapa)* (Cont'd)

F_1 hybrids	**PH**			**NPB**			**NSB**		
	BP	**CV1**	**CV2**	**BP**	**CV1**	**CV2**	**BP**	**CV1**	**CV2**
V1 (P1×P2)	-3.15^{ns}	10.09 **	29.16 **	-12.90**	-12.90**	12.50 **	-50.88**	75.00 **	-33.33 **
V2 (P1×P3)	-1.29^{ns}	12.21**	31.64 **	12.90**	12.90**	45.83 **	-64.91**	25.00 **	-52.38 **
V3 (P1×P4)	-6.64 ^{ns}	6.12 ^{ns}	24.50 **	-9.68**	-9.68**	16.67 **	-94.74**	-81.25 **	-92.86 **
V4 (P1×P5)	-1.67 ^{ns}	11.77**	31.13 **	17.74**	17.74**	31.69 **	-54.39**	62.50 **	-38.10 **
V5 (P1×P6)	-18.54**	-7.40 ^{ns}	8.63*	-1.61*	-1.61*	27.08 **	-35.09**	131.25 **	-11.91 **
V6 (P2×P3)	-6.38 ^{ns}	6.42 ^{ns}	24.85 **	-8.07**	-8.07**	18.75 **	-59.65**	43.75 **	-45.24 **
V7 (P2×P4)	-33.41**	-24.31**	-11.20 **	-11.29**	-11.29**	14.58 **	-68.42**	12.50 **	-57.14 **
V8 (P2×P5)	-0.82 ^{ns}	12.74**	32.26 **	30.65**	30.65**	68.75 **	-66.67**	18.75 **	-54.76 **
V9 (P2×P6)	-15.13**	-3.53 ^{ns}	13.17 **	-17.74**	-17.74**	6.25 **	-38.60**	118.75 **	-16.67 **
V10 (P3×P4)	-21.59**	-10.87**	4.57 ^{ns}	-14.52**	-14.52**	10.42 **	-59.65**	43.75 **	-45.24 **
V11 (P3×P5)	-20.77**	-9.94*	5.66 ^{ns}	-6.45**	-6.45**	20.83 **	-84.21**	-43.75 **	-78.57 **
V12 (P3×P6)	-11.82**	0.23 ^{ns}	17.59 **	72.58**	72.58**	122.92 **	-82.46**	-37.50 **	-76.19 **
V13 (P4×P5)	-2.52 ^{ns}	10.81**	29.99 **	66.13**	66.13**	114.58 **	-82.46**	-37.50 **	-76.19 **
V14 (P4×P6)	-17.72**	-6.47 ^{ns}	9.73*	29.03**	29.03**	66.67 **	-3.51**	743.75 **	30.95 **
V15 (P5×P6)	-13.26**	-1.40 ^{ns}	15.68 **	1.61*	1.61*	31.25 **	-36.84**	125.00 **	-14.27 **

PH= Plant height (cm), NPB= Number of primary branches per plant, NSB= Number of secondary branches per plant, BP = better parent, CV1 = check variety 1, CV2 = check variety 2.

*P>0.05, **P>0.01, ns = non significant.

Table 8 Estimation of heterosis over BP, CV1 and CV2 in F$_1$'s derived from 6×6 half diallel cross in Mustard (*Brassica rapa)* (Cont'd)

F$_1$ hybrids	**NSP**			**LS**			**NSS**		
	BP	**CV1**	**CV2**	**BP**	**CV1**	**CV2**	**BP**	**CV1**	**CV2**
V1 (P1×P2)	-5.53^{ns}	18.84^{ns}	98.83**	-11.86 **	23.81 **	10.64 **	-43.96 **	-20.42 **	-5.13^{ns}
V2 (P1×P3)	63.33*	105.46 **	89.88**	-5.09 **	33.33 **	19.15 **	-21.91 **	10.89 **	32.19 **
V3 (P1×P4)	-33.86^{ns}	-16.80^{ns}	-23.11^{ns}	-22.03 **	9.52 **	-2.13 **	-33.26 **	-5.22^{ns}	12.99 **
V4 (P1×P5)	12.08^{ns}	40.99^{ns}	30.30^{ns}	-10.17 **	26.19 **	12.77 **	-17.46 **	17.22 **	39.74 **
V5 (P1×P6)	-9.97^{ns}	13.26^{ns}	4.67^{ns}	-5.09 **	33.33 **	19.15 **	-30.18 **	-0.85^{ns}	18.20 **
V6 (P2×P3)	-7.29^{ns}	16.62^{ns}	7.78^{ns}	-27.12 **	2.38 **	-8.51 **	-55.90 **	-37.38 **	-25.35 **
V7 (P2×P4)	-12.96^{ns}	9.50^{ns}	1.20^{ns}	-28.81 **	0.00^{ns}	-10.64 **	-75.52 **	-65.23 **	-58.55 **
V8 (P2×P5)	14.45^{ns}	43.97^{ns}	33.06^{ns}	-20.34 **	11.91 **	0.00^{ns}	-53.47 **	-33.92 **	-21.23 **
V9 (P2×P6)	20.73^{ns}	51.88^{ns}	40.36^{ns}	-6.78 **	30.95 **	17.02 **	-51.91 **	-31.70 **	-18.59 **
V10 (P3×P4)	29.30^{ns}	62.65*	50.32^{ns}	-1.70 **	38.10 **	23.40 **	-33.53 **	-5.61^{ns}	12.52 **
V11 (P3×P5)	-47.96^{ns}	-34.53^{ns}	-39.50^{ns}	-13.56 **	21.43 **	8.51 **	-3.40^{ns}	37.18 **	63.53 **
V12 (P3×P6)	22.66^{ns}	54.31^{ns}	42.61^{ns}	-23.73 **	7.14 **	-4.26 **	-51.91 **	-31.70 **	-18.59 **
V13 (P4×P5)	47.78^{ns}	85.90**	71.81*	-25.42 **	4.73 **	-6.38 **	-46.12 **	-23.48 **	-8.79 **
V14 (P4×P6)	38.60^{ns}	74.36*	61.14*	-25.42 **	4.76 **	-6.38 **	-51.31 **	-30.86 **	-17.57 **
V15 (P5×P6)	0.66^{ns}	26.63^{ns}	17.03^{ns}	-16.95 **	16.67 **	4.26 **	-45.48 **	-22.57 **	-7.70 *

NSP= Number of siliquae per plant, LS= Siliqua length (cm), NSS= Number of seeds per siliqua, BP = better parent, CV1 = check variety 1, CV2 = check variety 2

*P>0.05, **P>0.01, ns = non significant.

Table 8 Estimation of heterosis over BP, CV1 and CV2 in 15 F_1's derived from 6×6 half diallel cross in Mustard (*Brassica rapa)*

F_1 hybrids	**TSW**			**SYP**		
	BP	**CV1**	**CV2**	**BP**	**CV1**	**CV2**
V1 (P1×P2)	0.00 ^{ns}	6.06**	20.69**	-40.26 **	-32.35**	-2.13 *
V2 (P1×P3)	5.71**	12.12**	27.5**	-3.90 **	8.82 **	57.45 **
V3 (P1×P4)	5.71**	12.12**	27.5**	-28.57 **	-19.12**	17.02 **
V4 (P1×P5)	0.00 ^{ns}	6.06**	20.69**	-32.47 **	-23.53**	10.64 **
V5 (P1×P6)	-14.29**	-9.09**	3.45**	-36.36 **	-27.94**	4.26 **
V6 (P2×P3)	-2.86**	3.03**	17.24**	-40.26 **	-32.35**	-2.13 *
V7 (P2×P4)	2.86**	9.09**	24.14**	-70.13 **	-66.18**	-51.06 **
V8 (P2×P5)	0.00 ^{ns}	6.06**	20.69**	-18.18 **	-7.35 **	34.04 **
V9 (P2×P6)	-2.86**	3.03**	17.24**	-31.17 **	-22.06**	12.77 **
V10 (P3×P4)	5.71**	12.12**	27.59**	-33.77 **	-25.00**	8.51 **
V11 (P3×P5)	14.29**	21.21**	37.93**	-41.56 **	-33.82**	-4.26 **
V12 (P3×P6)	5.71**	12.12**	27.57**	-32.47 **	-23.53**	10.64 **
V13 (P4×P5)	0.00 ^{ns}	6.06**	20.69**	-23.38 **	-13.24**	25.53 **
V14 (P4×P6)	-2.86**	3.03**	17.24**	-24.68 **	-14.71**	23.40 **
V15 (P5×P6)	-5.71**	0.00 ^{ns}	13.79**	-53.25 **	-47.06**	-23.40 **

TSW=1000 seed weight (g), SYP=Seed yield per plant (g), BP = better parent, CV1 = check variety 1, CV2 = check variety 2

*P>0.05, **P>0.01, ns = non significant.

4.3.3 Days to maturity: In case of days to maturity negative heterosis is also desirable. Out of fifteen crosses two hybrids *viz.* V3 and V14 showed significant positive heterosis over BP but no hybrids showed significant negative heterosis over better parent P3. In case of standard hererosis none of F_1 possessed desirable significant negative heterosis over CV1 but three hybrids showed significant negative heterosis over CV2 (Table 8). Among them V9 (P2×P6) showed the highest negative standard heterosis (-2.44%) over CV2. Synrem *et al.* (2015) reported desirable negative heterosis for days to maturity in mustard over check variety.

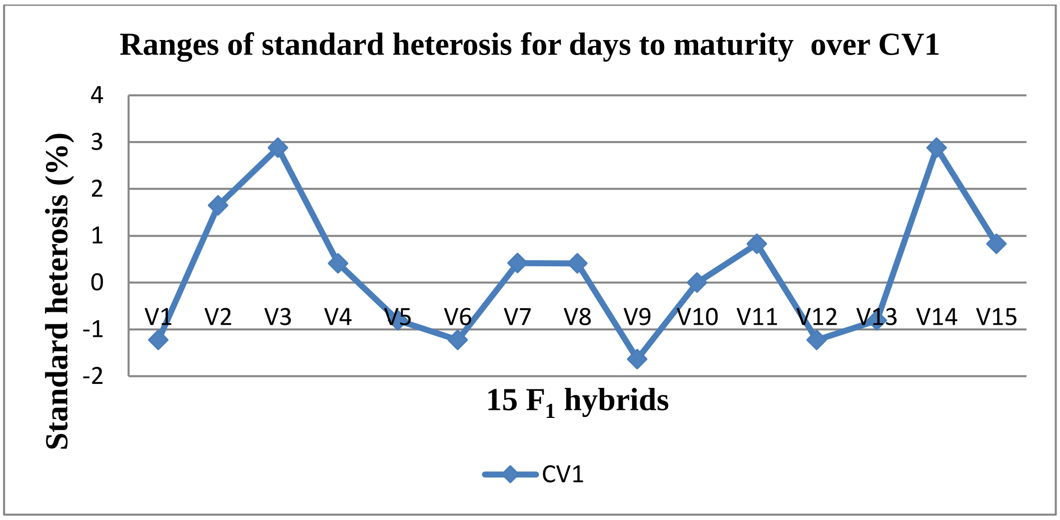

Figure 1 (a) Standard heterosis for the days to maturity in 15 F_1's over CV1

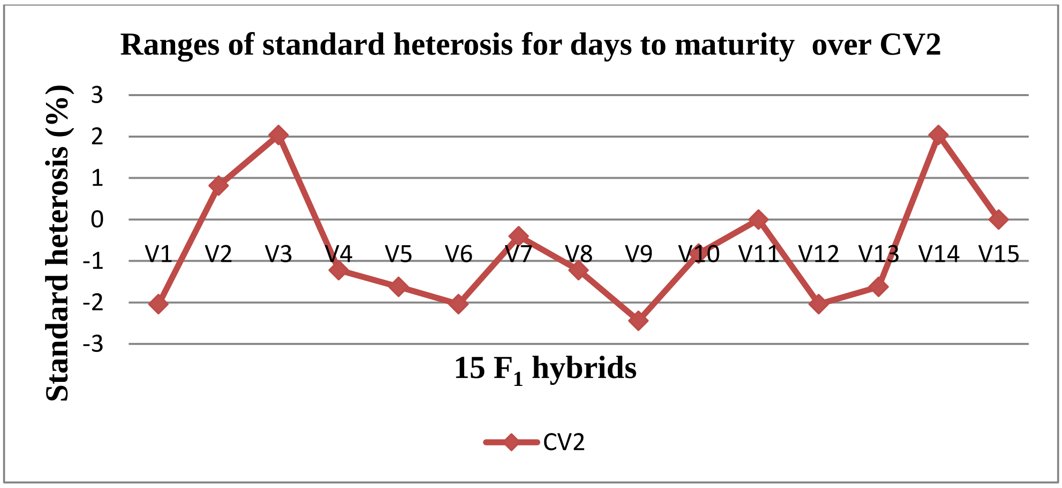

Figure 1 (b) Standard heterosis for the days to maturity in 15 F_1's over CV2

4.3.4 Plant height (cm): In case of plant height negative heterosis is also desirable which helps to develop dwarf stature plant. Out of fifteen F_1 hybrids eight hybrids showed highly significant negative heterosis over BP. Among them V7 (P2 × P4) possessed highly negative heterosis (-33.41%) over BP (Table 8). Synrem *et al.* (2015) and Turi *et al.* (2006) reported desirable negative heterosis for plant height over better parent. In case of standard heterosis -24.31% to 12.73% significant heterosis over CV1 and -11.20 to 32.26% significant heterosis over CV2 were found. Among fifteen hybrids five hybrids manifested significant standard heterosis in positive direction in respect of plant height over CV1 and twelve hybrids showed positive significant standard heterosis over CV2 where V8 (P2 × P5) showed the highest positive standard heterosis over CV1 and CV2. V7 (P2 × P4) showed the highest negative standard heterosis (-24.31%) over CV1 and only V7 (P2 × P4) showed negative standard heterosis (-11.20%) over CV2 (Table 8). Parmar *et al.* (2004) showed significant negative heterosis for plant height in mustard over check variety.

Plate 5 Photograph showing the F_1 (V8) showed the highest positive standard heterosis over CV1 and CV2 for plant height

4.3.5 Number of primary branches per plant: In case of primary branches, positive heterosis is desirable which helps to produce more siliqua in a plant. The estimated heterosis value were ranged from -17.74% to 72.58% over BP and V12 (P3 × P6) found the highest positive significant heterosis 72.58% over BP (Table 8). The F_1 hybrid combination V12 (P3 × P6) showed the highest positive significant standard heterosis (72.58%) over CV1 and (122.92%) over CV2 (Table 8). Turi *et al.* (2006) and Nigam and Richa (2009) and Akabari and Sasidharan (2016) estimated positive significant heterosis for number of primary branches per plant in mustard.

4.3.6 Number of secondary branches per plant: Positive heterosis is desirable for number of secondary branches per plant in mustard. Out of fifteen there is no positive significant heterosis over BP. Among the fifteen hybrids, eleven hybrids showed positive heterosis over CV1 and only one hybrid V14 (P4×P6) showed positive significant heterosis (30.95%) over CV2 (Table 8). Akabari and Sasidharan (2016) and Synrem *et al.* (2015) reported positive significant heterosis for number of secondary branches per plant in mustard.

4.3.7 Number of siliquae per plant: For the number of siliquae per plant, among the fifteen cross combinations only one cross showed positive significant heterosis over the BP. The heterosis over better parent showed in V2 (P1×P3) (63.33%). The highest significant positive heterosis was observed in the cross V2 (P1×P3) (105.46%) over the CV1. Again the highest significant positive heterosis was observed in the cross V1 (P1×P2) (98.83%) followed by V2 (P1×P3) (89.88%) over CV 2 (Table 8). Aher *et al.* (2008) and (2009) found moderate heterosis for number of siliquae per plant.

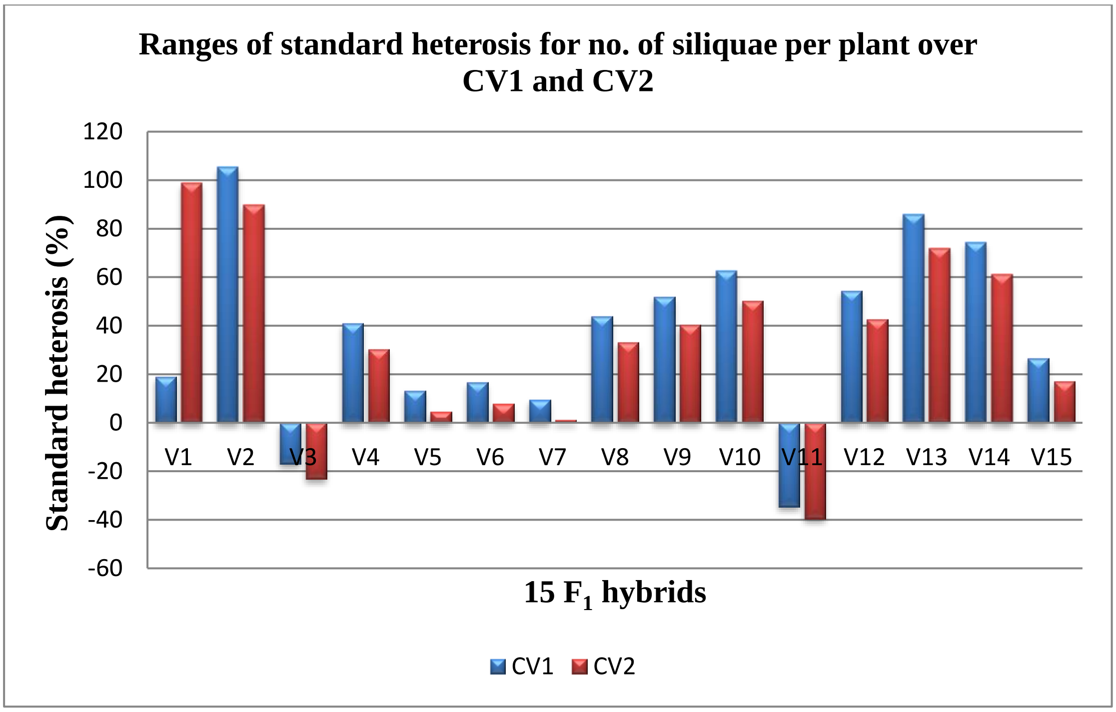

Figure 2 Standard heterosis for the number of siliquae per plant in 15 F_1’s

4.3.8 Siliqua length (cm): In case of siliquae length positive significant heterosis was desirable for yield. Interestingly all the fifteen hybrids showed negative significant heterosis over BP. Out of fifteen hybrids, fourteen hybrids showed positive significant heterosis over CV1 and hybrid V10 (P3×P4) showed highest significant positive heterosis (38.10%). In comparison of CV2, eight crosses showed positive and six crosses showed negative significant heterosis. Hybrid V10 (P3×P4) showed the highest significant positive heterosis (23.40%) over CV2 (Table 8). Synrem *et al*. (2015) reported positive heterosis for siliqua length in mustard.

Plate 6 Photograph showing the F_1 (V10) showed the highest positive standard heterosis over CV1 and CV2 for siliqua length

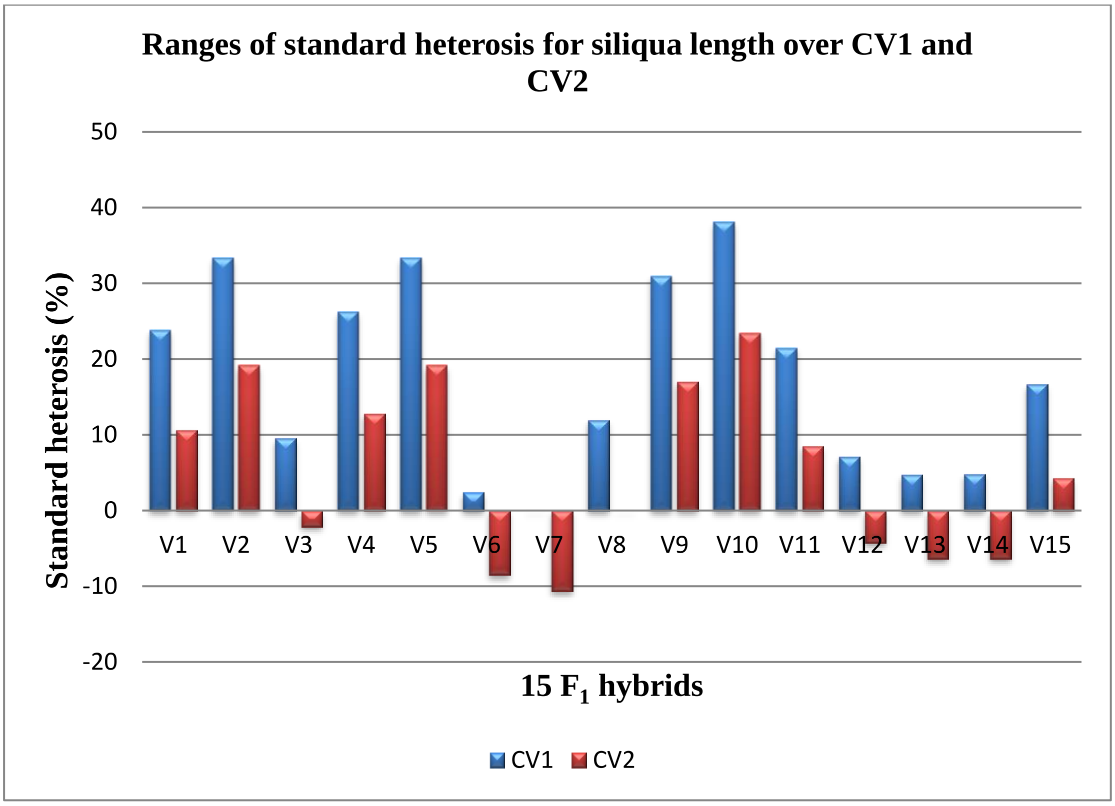

Figure 3 Standard heterosis for siliqua length in 15 F_1's

4.3.9 Number of seeds per siliqua: For number of seeds per siliqua, out of fifteen hybrids, fourteen crosses showed negative significant heterosis over BP. Interestingly none of the F_1 crosses showed positive significant heterosis over BP (Table 8). In case of standard heterosis three crosses showed positive significant heterosis over CV1. The highest significant positive heterosis was observed in the cross V11 (P3×P5) (37.18%) over CV1. The estimate of significant heterosis ranges from – 58.55% to 63.53% over the CV2 and the highest significant positive heterosis was observed in the cross V11 (P3×P5) (63.53%) over CV2. The heterosis for number of seeds per siliqua was also reported by several workers like Synrem *et al.* (2015) and Malviya *et al.* (2012).

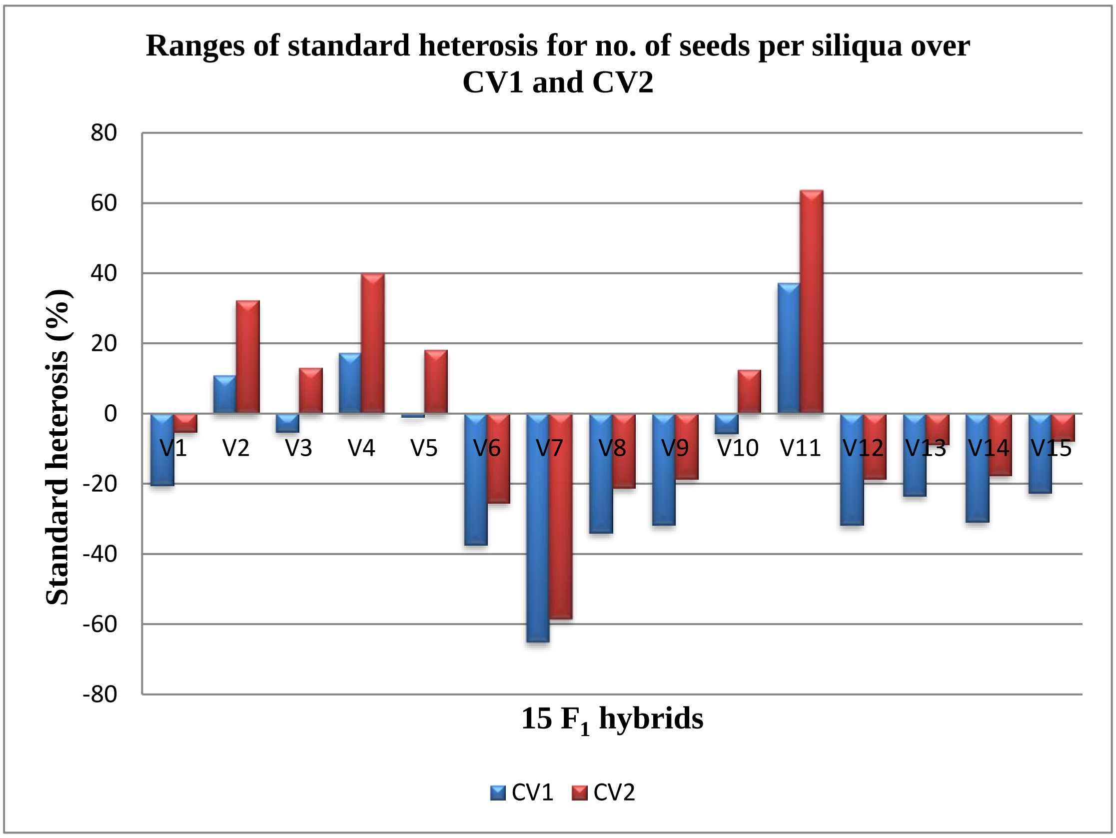

Figure 4 Standard heterosis for no. of seeds per siliqua in 15 F_1's

4.3.10 Thousand seed weight (g): In case of thousand seeds weight positive heterosis was desirable for contributing yield. The ranged of heterosis varied from -14.29% to 14.29%, -9.09% to 21.21% and 3.45% to 37.93% over BP, CV1 and CV2 respectively for the character of thousand seed weight. Out of fifteen tested hybrids six manifested significant positive heterosis over BP (Table 9). Tested hybrid V11 (P3 × P5) showed the highest 14.29% over BP, while the thirteen tested hybrids showed significant positive heterosis over the CV1 and the highest positive heterosis was found in hybrid V11 (P3×P5) (21.21%). The highest standard heterosis was exhibited 37.93% in V11 (P × P5) (Table 8). Malviya *et al*. (2012), Gupta *et al.* (2010) and Monalisa *et al.* (2005) supported this.

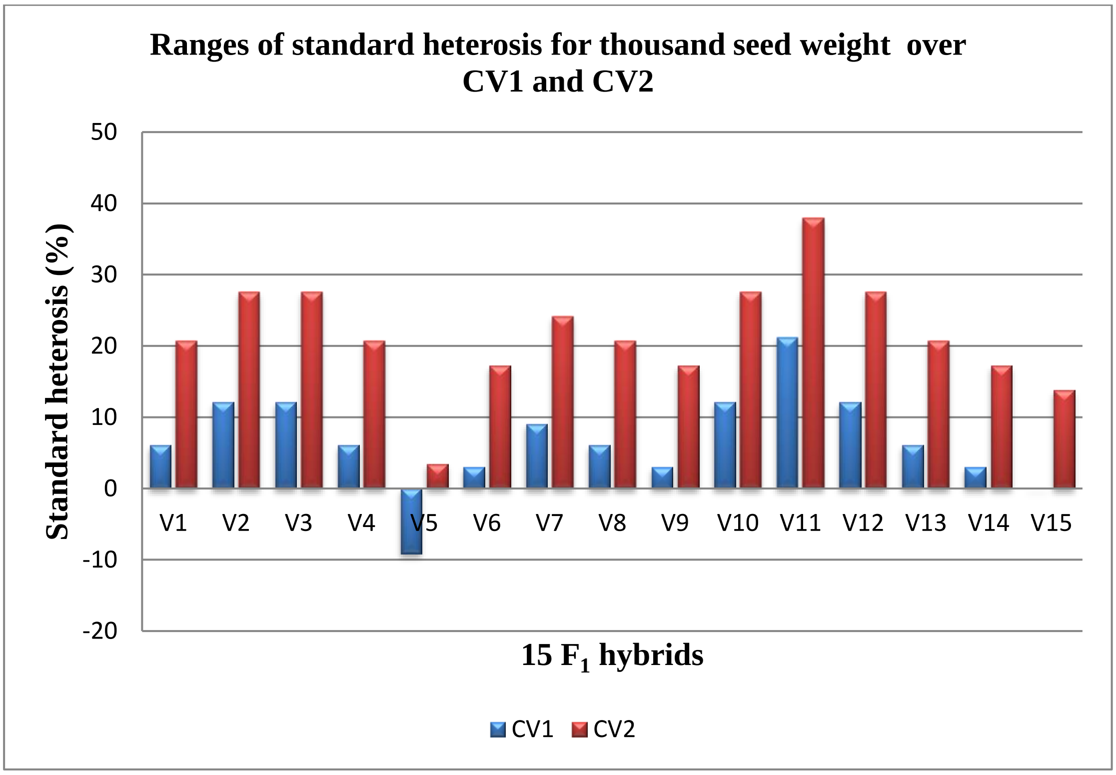

Figure 5 Standard heterosis for thousand seed weight in 15 F_1's

4.3.11 Seed yield per plant (g): For seed yield per plant, fifteen hybrids manifested negative significant heterosis over the better parent (Table 8). In case of standard heterosis one significant positive heterosis found in V2 (P1×P3) (8.82%) over CV1 and ten hybrids manifested significant positive heterosis over CV2. Among these ten hybrids, the highest significant positive heterosis was observed in the cross V2 (P1×P3) (57.47%) followed by V8 (P2×P5) (34.04%), and V13 (P4×P5) (25.53%) over CV2. Snakal *et al.* (2017), Tomar *et al.* (2015), Synrem *et al.* (2015) and Malviya *et al.* (2012) also reported the similar result for seed yield per plant.

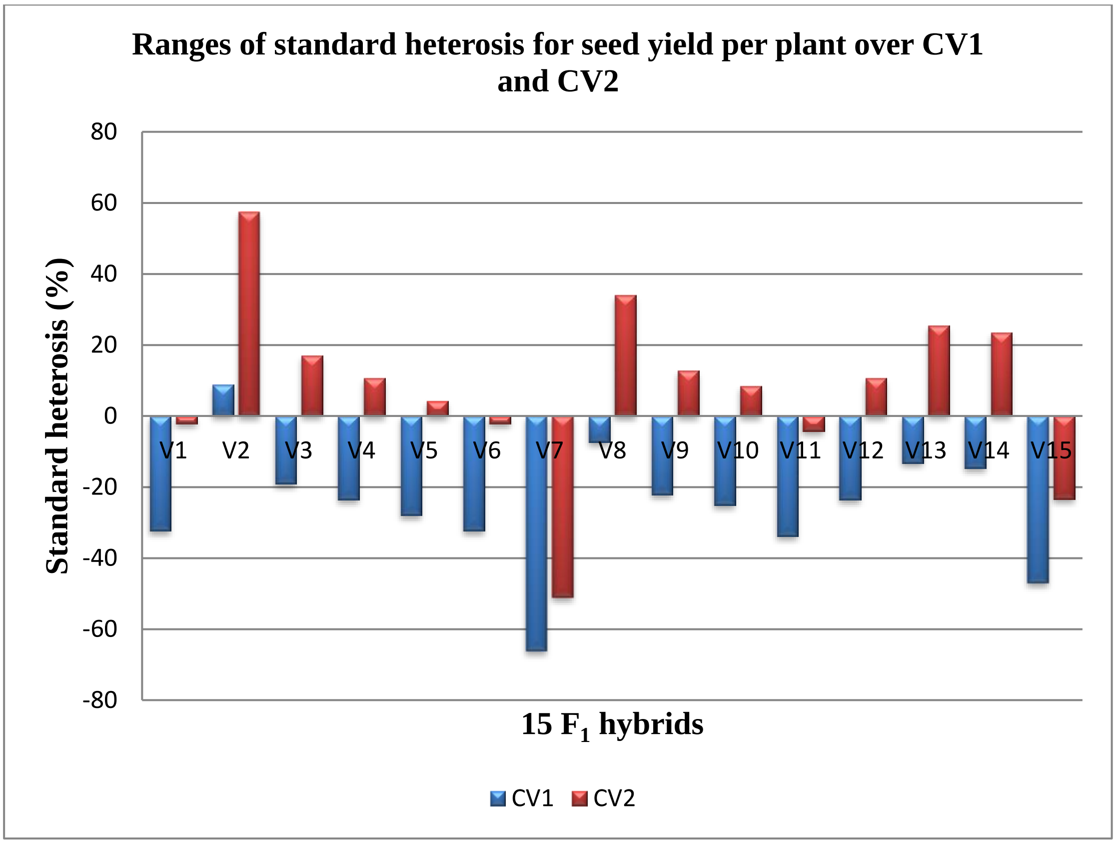

Figure 6 Standard heterosis for seed yield per plant in 15 F_1's

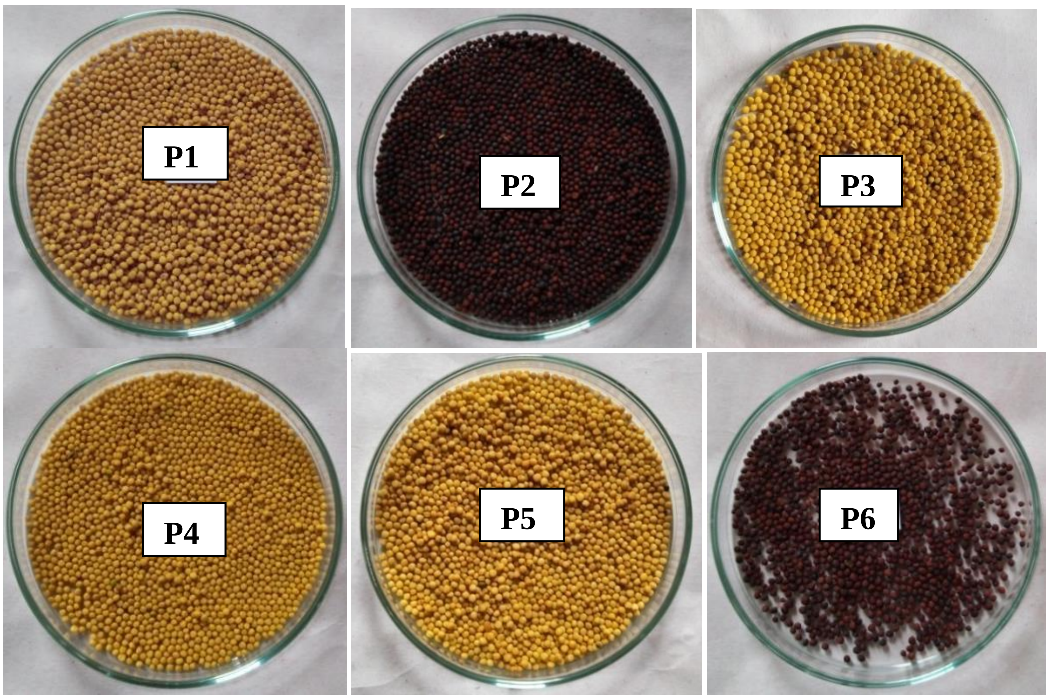

Plate 7 Photograph showing the seeds of 6 parents of *Brassica rapa*

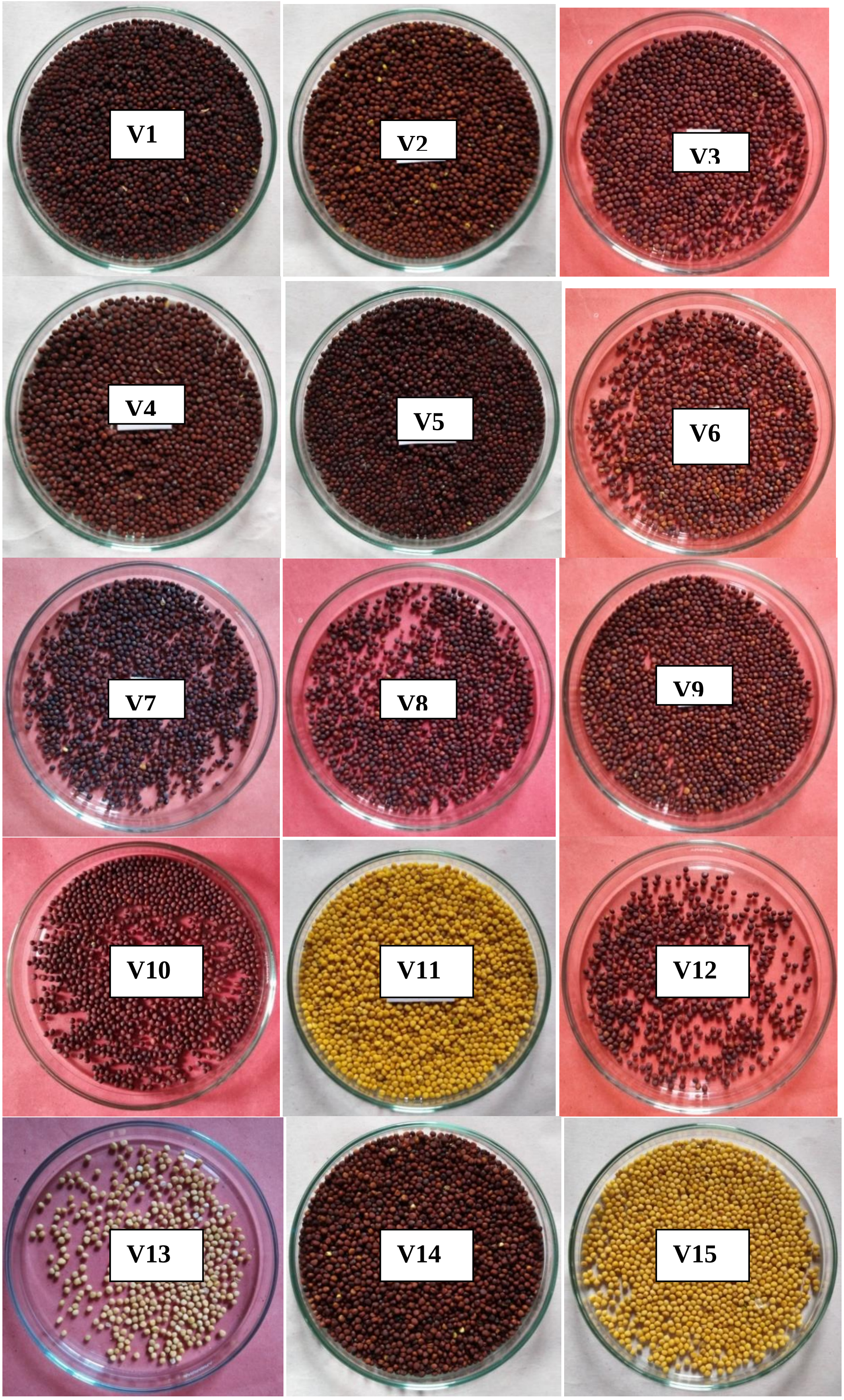

Plate 8 Photograph showing the seeds of 15 F_1’s of *Brassica rapa*

CHAPTER - V

SUMMARY AND CONCLUSION

CHAPTER-V

SUMMARY AND CONCLUSION

The study was conducted on a 6×6 half diallel cross to evaluate the fifteen F_1 hybrids of mustard for different agronomic traits. To develop the F_1 hybrids, six parental genotypes were matted in half 6×6 diallel fashion during the Rabi season 2017-18. And then the developed fifteen F_1 hybrids excluding reciprocal crosses with their six parents were evaluated for their combining ability and heterosis over check variety BARI sharisha-14 and local cultivar Maghi and corresponding better parent at the research farm of Sher-e-Bangla Agricultural University, Dhaka during rabi season 2018-19. The experiment on evaluation of F_1 hybrids was laid in RCBD design using three replications. All the required intercultural operations were done during the experiment.

From the analysis of variances, highly significant ($p<0.001$) differences were observed among the genotypes studied in the experiment for almost all the eleven traits viz. days to first flowering, days of 50% flowering, days to maturity, plant height, number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, siliqua length, number of seeds per siliqua, thousand seed weight and seed yield per plant.

In the present study significance GCA and SCA variance were observed for all the characters. So, it can be concluded both of the additive and non-additive gene actions were important for inheritance of yield characters in the progeny. The ratio of the components exposed that GCA variance was higher than SCA for almost all character including days to first flowering, days of 50% flowering, days to maturity, plant height, number of secondary branches per plant, siliqua length, number of seed per siliqua and thousand seed weight showing the predominance of additive gene action for these traits and there is always a good chance of improving those traits by accumulation of favorable genes. The higher magnitude of SCA variance was observed than that of GCA variance for number of primary branches per plant, number of siliquae per plant and seed yield per plant which indicated the preponderance of non additive or dominant gene action.

In the study considering general combining ability towards desirable direction among the six parental lines revealed that P6 showed negative GCA for days to first flowering, days to 50% flowering and days to maturity which were considered as good combiners for earliness as importance of early maturity. Only two parental lines P4 and P6 possessed significance negative GCA towards plant height considered as good combiner of the character as dwarf stature plant and P1 possessed significance positive GCA towards plant height considered as good combiner of the character as tall type plant. Three parental lines i.e. P1, P4 and P5 exhibited significant and higher negative GCA effects for number of siliqua per plant, specified good combiner for low siliqua set of the parental lines. The study also showed that the parents P1, P3 and P5 were good general combiner for yield and yield related characters.

In the study crosses P1×P2 (V1), P3×P4 (V10) and P4×P5 (V13) showed considerable negative significant SCA effects for days to first flowering, days to 50% flowering and days to maturity which were desirable for these character and eight crosses exhibit positive s ignificant SCA effect for plant height. Among fifteen F_1 hybrids, two crosses, *viz*. P3×P6 (V12) and P4×P5 (V13) and one cross viz. P4×P6 (V14) showed significant positive SCA effects for number of primary branches per plant and number of secondary branches per plant. For number of siliqua per plant, eight cross combinations out of fifteen showed positive significant SCA effect and the highest positive significant SCA effect showed in P1×P3 (V2). Out of fifteen tested F_1 hybrids, three crosses *viz.* P1×P3 (V2), P2×P6 (V9) and P4×P6 (V14) exhibited positive significance SCA for yield and yield related traits.

The hybrids P1×P2 (V1), P1×P6 (V5), P2×P3 (V6), P2×P4 (V7), P2×P5 (V8), P2×P6 (V9), P3×P4 (V10), P3×P6 (V12), P4×P5 (V13), P4×P6 (V14) and P5×P6 (V15) showed the negative significant heterosis over CV1 for the character days to first flowering. None of the crosses showed significant negative heterosis over CV2 and over BP for days to first flowering. In case of days to 50% flowering, cross combination P4×P5 (V13) showed the highest negative significant heterosis over the two check varieties *viz* CV1, CV2 and BP. None of the crosses showed significant negative heterosis over CV1 and BP for days to maturity. Cross combination P2×P4 (V7) showed the highest negative significant heterosis over CV1, CV2 and BP for plant height. Cross combination P3×P6 (V12) showed the highest positive significant heterosis over CV1, CV2 and BP for the character of number of primary branches per plant and none of the crosses showed significant positive heterosis over BP for number of secondary branches per plant. None of the crosses showed significant positive heterosis over BP for siliqua length, number of seeds per siliqua and seed yield per plant. Cross combinations viz. P1×P2 (V1), P1×P3 (V2), P1×P4 (V3) and P3×P5 (V11) showed positive standard heterosis over CV1 and CV2 for yield and yield contributing characters. The hybrids *viz.* P1×P3 (V2), P1×P4 (V3), P1×P5 (V4), P1×P6 (V5), P2×P5 (V8), P2×P6 (V9), P3×P4 (V10), P3×P6 (V12), P4×P5 (V13) and P4×P6 (V14) and among them the highest significant positive heterosis for yield was exhibited by P1×P3 (V2). Positive significant heterotic value for yield is desirable in this study.

Recommendations:

Considering the combining ability and standard heterosis for yield and yield related characters three tested hybrids *viz*. P1×P2 (V1), P1×P3 (V2) and P1×P5 (V4) could be recommended as superior *B. rapa* hybrids. The V1, V2 and V4 hybrids which showed early maturity and comparatively good yield performers could be selected to advance further to F_5\ F_6 stages for selection of early segregating recombinant lines. Multi-location trial of these three identified hybrids might be conducted to find out the adaptability of the hybrids.

CHAPTER-VI
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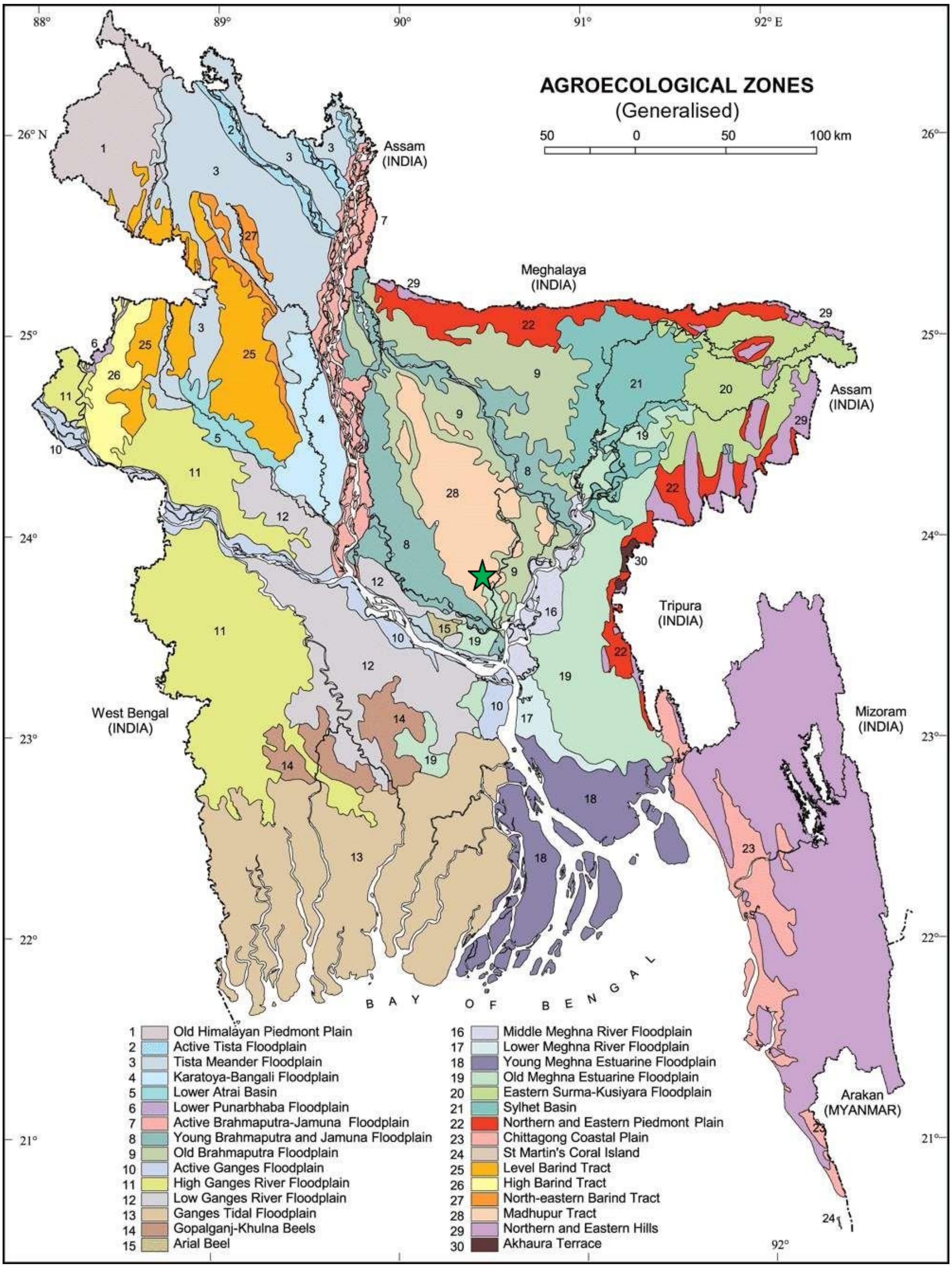
APPENDICES

Appendix I. Map showing the geographical locations under the study



★ The experimental site under the study

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

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. Physical composition of the soil

Soil separates	%	Methods employed
Sand	26	Hydrometer method (Day, 1915)
Silt	45	Do
Clay	29	Do
Texture class	Silty loam	Do

C. Chemical composition of the soil

SL No	Soil characteristics	Analytical data	Methods employed
1	Organic carbon (%)	0.45	Walkley and Black, 1947
2	Total N (%)	0.03	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (ppm)	20.54	Olsen and Dean, 1965
7	Exchangeable K (me/100 g soil)	0.10	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	pH (1:2.5 soil to water)	5.6	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Source: Soil Resource and Development Institute (SRDI), Farmgate, Dhaka

Appendix III: Monthly average temperature, average relative humidity and total rainfall and average sunshine of the experimental site during the period from October, 2017 to March, 2018

Months	Average temperature (°c)		Average RH (%)	Rainfall (mm) (total)	Average sunshine (hr)
	Minimum	**Minimum**			
October, 2017	25	32	79	175	6
Novenber, 2017	21	30	65	35	8
December, 2017	15	29	74	15	9
January, 2018	13	24	68	7	9
February, 2018	18	30	57	25	8
March, 2018	20	33	57	65	7

Source: Bangladesh Meteorological department (Climate & Weather Division), Agargoan, Dhaka-1207

Appendix IV: Monthly average temperature, average relative humidity and total rainfall and average sunshine of the experimental site during the period from October, 2018 to March, 2019

Months	Average temperature (°c)		Average RH (%)	Rainfall (mm) (total)	Average sunshine (hr)
	Minimum	**Maximum**			
October, 2018	23.8	31.6	77	172.3	11.6
Novenber, 2018	19.2	29.6	64	34.4	8
December, 2018	14.1	26.4	73	12.8	9
January, 2019	12.7	25.4	67	7.7	9
February, 2019	16	28.1	56	28.9	8.1
March, 2019	20.4	32.5	56	65.8	7

Source: Bangladesh Meteorological department (Climate & Weather Division), Agargoan, Dhaka-1207