HETEROSIS AND COMBINING ABILITY IN 7×7 DIALLEL POPULATIONS OF WHITE MAIZE (*Zea mays* L.)

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CERTIFICATE

*This is to certify that the thesis entitled, "**HETEROSIS AND COMBINING ABILITY IN 7×7 DIALLEL POPULATIONS OF WHITE MAIZE (Zea mays L.)**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of* **MASTER OF SCIENCE *in GENETICS AND PLANT BREEDING***, *embodies the result of a piece of bona fide research work carried out by* ***IMRAN AHMED***, *Registration number:* ***17-08267*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated: December, 2018

Dhaka, Bangladesh

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TO

MY BELOVED PARENTS

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ABSTRACT

The study was conducted to evaluate the forty-two F_1 lines derived from 7×7 full diallel cross of white maize for yield and yield components. Seven(7) inbred lines of white maize were mated using complete 7×7 diallel fashion during rabi season 2017-18 and then evaluated their combining ability and heterosis of forty-two hybrids over two check varieties BARI hybrid maize-12 and BARI hybrid maize-13 at research farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during rabi season 2018-19. The variances for general combining ability (GCA) were found significant for all the characters except ear diameter, while specific combining ability (SCA) was significant for all the characters except ear height and plant height suggesting that non-additive gene action was important for inheritance of yield and yield related characters in the hybrid progeny. GCA variances were much higher in magnitude than SCA for all the characters except number of row per ear and ear diameter indicating the superiority of additive gene effects for the inheritance of these traits. The analysis of GCA revealed that parents P7 and P4 were the best general combiner for yield related character, while parents P7 and P3 for earliness and dwarf plant type. The analysis of SCA showed that crosses P7×P1, P1×P3, P7×P4, P6×P3, P3×P5, P4×P6, P6×P7, P5×P7, P3×P7 and P4×P5 exhibited maximum positive SCA effects for yield related character *viz*. ear length, ear diameter, number of row per ear, number kernel per row and hundred kernel weight and kernel yield per plant. The heterosis showed that percent heterosis for grain yield varied from -9.412% to 40.421% and -16.304 to 38.361%, considering BARI hybrid maize-12 and BARI maize hybrid-13 as check varieties respectively. Twenty crosses exhibited significant and positive heterosis over the check varieties. The highest positive heterosis showed by cross P5×P7 (40.421% and 38.361%), P3×P7 (39.50% and 37.45%), P1×P3 (37.99% and 35.97%), P5×P4 (37.81% and 35.79%), P4×P7 (36.26% and 34.26%), P6×P7 (33.10 and 31.15%), P6×P4 (32.28 and 30.34%), P1×P7 (32.19% and 30.25%) ,P4×P6 (26.39% and 24.54%) and P4×P5 (21.86 and 20.07%) over the checks BARI hybrid maize 12 and BARI hybrid maize 13, respectively. Considering the performance of SCA effects and heterosis, the crosses P5×P7, P3×P7, P1×P3, P6×P7, P4×P6 and P4×P5 could be utilized for developing promising hybrid varieties as well as for exploiting the hybrid potency.

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF CONTENTS (Cont'd)

LIST OF TABLE

LIST OF PLATE

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Maize (*Zea mays* L., 2n=20*)* is the world's most widely grown cereal and is the staple food in many developing countries one of the staple food (Morris *et al.,* 1999). It is ranked first among the cereal with an annual global production of 1.13 billion metric tons (FAOSTAT, 2017). Superior position of maize is due to its wide and diverse utilization. During the centuries maize plant was known for it's multifariously use. Maize is used as a human food, livestock feed, for producing alcohol and no alcohol drinks, built material, like a fuel, and like medical and ornamental plant (Huma *et al.,* 2019).

Maize is widely cultivated crop throughout the world. The world area planted with maize was 1970 million hectares, and the total maize production was 1130 million tons (FAOSTAT, 2017). The United States of America alone has the largest producing 370.96 million tons , followed by China producing 215.89 million tons, Brazil with 82.00 million tons (Statista, 2018). Globally 67% of maize is used for livestock feed, 25% human consumption, industrial purposes and balance is used as seed and its demand for grain food is increasing worldwide (Reddy *et al.,* 2013).

Maize occupied 2nd position next to rice (BBS, 2017) and occupied 3.89 lakh ha land area in Bagladesh (FAOSTAT, 2017). Though it was introduced in Bangladesh during 1960 after the Second World War through testing some varieties provided by the CIMMYT mainly for research purpose (Karim, 1992). Very recently its total cultivated area about 963 thousand acres and total annual production was 3026 thousand M. tons (BBS, 2017). The area under maize has been expanding since the early 2000s, driven by demand from the poultry feed industry and more than 98% maize areas are covered by hybrids (Karim, 2006). Only the tribal people in Chittagong hilly areas cultivate open pollinated varieties (OPVs). Most of the maize fields are irrigated, and farmers cultivate hybrid maize with improved production technology which is the secret behind higher production in Bangladesh.

Maize can be grown in both kharif and rabi seasons, but the potentiality of realizing higher yield is possible only during the rabi season. In kharif, farmers face various problems such as water logging, high incidence of diseases, pests etc. However, kharif cultivation is also suitable in areas gradually increasing due to T. Aman-Potato-Maize cropping pattern (Ahmed *et al.,* 2017).

Though Bangladesh is self-sufficient in rice production in recent year, the challenge ahead is of a bigger magnitude as more people are added to current population (about 160 million) every year. Furthermore global warming effect rice and wheat production. So policy maker need to adopt new crop to mitigate this challenge. Maize can play a dominant role along with other important cereals in meeting future food, feed and nutritional security due to temperature has no remarkable impact on maize production (Alam *et al*., 2008). Maize is now mainly grown in north-western, south-western and central districts of Bangladesh and the production is targeted mostly for poultry, fish feed and livestock which made this sector vulnerable.

There are two major types of maize depending on kernel color viz. white maize and yellow maize. Between them white maize is more preferable than yellow one to use as human food in worldwide (Cribb, 2010).While yellow maize uses extensively in feed industry. Maize grains have great nutritional value as they contain 72% starch, 10% protein, 4.8% oil, 8.5% fibre, 3.0% sugar and 1.7% ash (Nuss and Tanumihardjo, 2010). But comparative studies of white and yellow maize shown that per 100 g grain of white and yellow maize supplied beta carotene zero (0) mg and 11-20 mg respectively. It was clearly reveals the white maize lack of beta carotene while yellow maize contained more Beta-carotene (11-20 mg). In case of vitamin B_6 white and yellow maize provided 0.475 mg and 0.304 mg respectively. White maize provided more nutritive value than yellow maize for vitamins *viz.* thiamine, riboflavin, niacin while, yellow maize exhibited high value than white maize for vitamin E and pantothonic acid. Proteins content of white and yellow maize are 9.28 g and 8.12 g, respectively from 100 g. White maize supplied more calories than yellow maize. Calcium (Ca) provides more by white maize (136 mg) than yellow maize (6 mg). In case of iron (Fe) white maize exhibited more value than yellow maize (Muzhingi *et al.,* 2011). White maize also has a medium GI (Glycemic Index) which help in reducing the obesity. Moreover, market prices are usually higher for white maize compared to the yellow type.

White maize is grown throughout the world. In Bangladesh BARI is the chief responsible institute developed High yielding maize variety. Though it has succeeded to develop fifteen hybrid maize and seven composite/open pollinated (OP) varieties along with their production technologies (BARI, 2018). Most of the BARI released maize hybrids are yellow kernel except three varieties BHM 12, BHM 13 and BHM 14. Among the BARI developed maize varieties (hybrid/OP), Shuvra is the only open pollinated variety of white maize. Besides, the Plant Breeding Division of BARI has developed some advance lines of white maize (Ahmed *et al.,* 2017). A single cross hybrid variety of white maize (cv. Uttara 3) has also developed by the Non-government Organization 'Bangladesh Rural Advancement Committee (BRAC). Therefore, there is less number of white maize hybrid variety is available for increasing its cultivation area and production. So more initiative need to take to developed hybrid white maize to ensure future food security.

The diallel mating scheme is probably the most frequently used mating design in plant research and is an excellent scheme to determine how parents perform in crosses. These were devised, specifically, to investigate the combining ability of the parental lines for the purpose of identification of superior parents for use in hybrid development programs. Analysis of diallel data is usually conducted according to the methods of Griffing (1956) which partition the total variation of diallel data into GCA of the parents and SCA of the crosses (Yan and Hunt, 2002). A diallel is simple to manipulate in maize and supplies important information about the studied populations for various genetic parameters (Vacaro *et al.,* 2002).

The expression of heterosis in hybrids has been exploited in many different plant species (Coors and Pandey, 1999). Heterosis occurs when the crosses exceed the average of the parents because of non-additive genetic effects. During the 20th century when the inbred-hybrid concept in maize became a functional and commercially viable method to develop improved yielding cultivars, greater emphasis was given the hybrid breeding methods. Because of the information on heterosis and combining ability considered together will be more meaningful. If the heterotic hybrids involve both the parents with high general combining ability effects, then it implies that the parental contribution to heterosis is mainly through additive gene action (Mahantesh, 2006).

The objective of this study was to evaluate the performance of seven maize inbred lines, their diallel, and reciprocal crosses for the following parameters:

1. Combining ability of parents and specific for diallel and reciprocal hybrids.
2. Heterosis of the F_1 hybrids
3. Gene action controlling the inheritance of yield and its contributing trait

CHAPTER 2

REVIEW OF LITERATURE

The nature and magnitude of gene action are important factors in developing effective breeding program. Combining ability analysis is an important tool to select desirable parents together with the information regarding to the nature and magnitude of gene effects controlling quantitative traits. Diallel cross technique provided information on gene action and combining ability of parental lines (Kabir *et al.,* 1993). It will provide valuable information to the researcher to develop the improved variety.

2.1 Diallel analysis

A set of crosses produced by involving number of lines in all possible combination is designated as diallel cross and the analysis of such crosses is known as diallel analysis. .Baktash (1995). Hayman (1954) and Griffing (1956) proposed the concept of diallel cross as the recombination of genetic variability available in the program, performing crosses among all lineages.

Different types of progenies can be produced with the diallel mating design. As a consequence, different analyses can be used. There are four methods of producing progenies:

1. Method I = $n^{2.}$ It includes all possible crosses and parents.
2. Method II = n (n+1) / 2. This method is the most widely used and it includes one set of crosses and the parents (no reciprocals).
3. Method III = n (n−1). It includes two sets of crosses without parents.
4. Method IV = n (n−1) / 2. It only includes one set of crosses with neither reciprocals nor parents.

The option will change depending on the material used. In maize, for pure lines the most logical choice would be to use both crosses and recipocals with parents. Otherwise, competition effects would be important. Contrarily, if we use synthetic varieties we can use diallel mating designs including not only crosses but also parents to compare mean performance and heterosis. Based on the previous information we can see that one limitation of the diallel design is the numbert of parents that can practically be included (Griffing, 1956).

In order to choose appropriate parents and crosses, and to determine the combining abilities of parents in the early generation, the diallel analysis method has been widely used by plant breeders. This method was applied to improve self- and cross-pollinated plants (Jinks and Hayman, 1953; Hayman, 1954; Jinks, 1956; Griffing, 1956; Hayman, 1960).

Griffing's biometrical analysis has been widely used in plant improvement programs to identify superior parents for crossing and for characterizing general, specific, and reciprocal effects. This analysis is not hindered by the requirements of numerous genetic assumptions and interpretations from this evaluation are usually straightforward. However, several important factors must be considered when using the analysis (Shattuck *et al.,* 1993).

Diallel crosses have been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. These were devised, specifically, to investigate the combining ability of the parental lines for the purpose of identification of superior parents for use in hybrid development programs (Malik *et al.,* 2004).

Diallel cross is prospective technique, because it's provide comprehensive evaluation of hybrid combinations from inbred lines crosses (Chukwu *et al.,* 2016). Plant breeders frequently need overall information on average performance of individual inbred lines in crosses- known as general combining ability, for subsequent choosing the best amongst them for further breeding. For this purpose, diallel crossing techniques are employed (Himadri and Ashish, 2003).

Diallel analysis is used to estimate general combining ability and specific combining ability effects and their implications in breeding (Makumbi, 2005).

Diallel mating designs provide the breeders with useful genetic information, such as general combining ability GCA and specific combining ability SCA, to help them devise appropriate breeding and selection strategies (Zhang *et al.,* 2005).

The diallel cross method enables to estimate useful genetic parameters to select genitors for hybridization, as the identification of gene action of character control along with it allows to identify the best lineages combination to be used as male or female genitor in order to provide the maximum heterotic expression for the hybrids (Vencovsky, 1987).

Cruz and Regazzi (1997); Paterniani and Viegas, (1987) and Vencovsky (1987) mentioned that the diallel method of analysis allows to estimate useful genetic parameters to select parental lines and verify the combining ability effects.

Vencovsky (1987) also mentioned that diallel crosses allow the genetic parameters estimating, thereby increasing information to the breeder and contributing for decision making.

The diallel mating system has proved very effective in genetic research for determining the inheritance of important traits among genotypes, investigating the GCA of the parents, identifying superior parents for hybrid cultivars development and categorizing inbred genotypes into various heterotic groups and for identifying appropriate testers for breeding purpose (Bhatnagar *et al*., 2004, Menkir *et al*., 2003 and Yallou *et al*., 2009).

2.2 Combining Ability

Determination of combining ability may inform gene action both additive and non-additive from GCA and SCA magnitudes that are essential for crop improvement . The effects of General Combining Abilities (GCA) and Specific Combining Abilities (SCA) are important indicators of potential value for inbred lines in hybrid combinations (Karim *et al*., 2018).

The theory of general combining ability (GCA) and specific combining ability (SCA) introduced by Sprague and Tatum (1942) and its scientific modeling was established by Griffing (1956) in his established paper in conjunction with the diallel crosses has been extensively used to determine the specific combining ability (SCA) and general combining ability (GCA) of lines derived from diallel cross technique (Malik *et al*., 2004, Machikowa *et al*., 2011, Werle *et al*., 2014, Zare *et al*., 2011, Moneam *et al*., 2015).

The variances of general and specific combining ability are related to the type of gene action involved. Variance for GCA includes additive portion, while that of SCA includes non-additive portion of total variance arising largely from dominance and epistatic deviations (Rojas and Sprague, 1952).

Breeding methods for improvement of allogamous crops should be based on the nature and magnitude of genetic variance controlling the inheritance of quantitative traits.

Selection of crosses may be based on specific combining ability and percent performance linked with heterosis and inbreeding depression for cross exploitation (Pandey, 2007).

Combining ability analysis is important in identifying the best parents or parental combinations for a hybridization program. General combining ability (GCA) is associated to additive genetic effects while specific combining ability (SCA) is associated to non-additive genetic effects. GCA is the average performance of a line in hybrid combination and SCA is the deviation of crosses based on average performance of the lines involved (Makumbi, 2005).

Combining ability is a powerful tool in identifying the best combiners for hybridization especially, when a large number of advance inbred lines are available and most promising ones are to be selected on the basis of their ability to give superior maize hybrids (Kumar *et al*., 2017).

Pal and Prodhan (1994), founded higher magnitude of SCA component in comparison to GCA component for grain yield, oil content, number of grains per row, number of rows per ear, and ear length indicating the importance of non-additive gene effects in controlling these traits. While, Alika (1994) reported that predominance of additive gene action for ear length, number of kernels per row and days to silking.

Satyanarayana and Kumar (1995) founded that both additive and non-additive gene effects were important for days to 50 per cent tasseling and yield.

Mohammed (1995) witnessed that genetic variances for ear length and number of ears per plant were mainly additive, while plant height, ear weight, grain weight per ear, hundred grain weight and yield were non-additive.

Mathur *et al*. (1998) observed that there was a significant GCA variance for days to silking, ear length, ear diameter, number of rows per ear, number of grains per row and grain yield per plant. The SCA variance was significant for ear length.

Konak *et al*. (1999) showed that higher SCA variances were noted for grain yield, 1000-grain weight, ear height, ear length and earliness. Higher GCA variances were noted for plant height and number of rows per ear.

Kumar *et al*. (1999) founded that for grain yield and yield component characters non-additive gene action was predominant. Talleci and Kochaksaraci (1999) observed significant GCA effects for plant height, number of grain rows per ear, number of grains per row, ear weight, hundred grain weight and grain yield per plant.

Geetha and Jayaraman (2000) revealed that additive and dominance components were significant for plant height, ear height, days to silking, days to tasseling, ear length and yield per plant. Positive relationship between SCA effect of grain yield and yield contributory characters were reported by Ivy and Howlader (2000).

Akanda (2001) observed GCA variance was highly significant for grain yield, ear length, ear breath and number of kernel/row. It indicated that the expressions of these characters were controlled by additive gene effects. Significant GCA and SCA variance for days to silk, number of row/ear and 1000 kernel weight suggested additive and non-additive gene actions in expression of these characters. However, higher magnitude of GCA variance than corresponding SCA variance indicated predominance of additive gene action. He also showed that CML 329 and CML 323 was good general combiner for grain yield. The hybrid CML 325 x CML 329 showed significant SCA effect produced the highest grain yield. He also suggested that *persent* performance and SCA effect should be considered simultaneously in selecting the promising hybrids.

Vacaro *et al*. (2002) reported that mean square for GCA effects was greater than that for SCA effects for the traits like plant height, point of insertion of the first ear, number of ears per plant, number of grains per ear, root and stalk lodging and grain yield indicating the performance of additive gene effects.

Katna *et al*. (2005) observed both the GCA and SCA effects were significant for leaf area per plant, plant height, ear height, ear length, ear circumference, kernel rows per ear, kernels per row, hundred seed weight and grain yield per plant. They also reported preponderance of additive gene effects was important in the expression of all the above traits.

Ahmed *et al*. (2008) observed that variances due to both general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters indicated the presence of additive as well as non-additive gene effects for controlling the traits. However, relative magnitude of these variances indicated that additive gene effects were more prominent for all the characters studied except grain yield/plant.

Uddin *et al.* (2008) showed GCA and SCA variance for yield per plant, number of kernels per row and 100-kernels weight were significant, which indicated importance of additive as type of gene action for these characters. The ratio of SCA and GCA variances were high for the all character studied that revealed the preponderance of non-additive type of gene action. The lines IPB 911-16, IPB 911-12, IPB 911-2, IPB 911-18 and IPB 911-47 showed significant positive GCA effect and simultaneously possessed high mean value indicating that the per se performance of the parents could prove as an useful index for combining ability. The crosses exhibited significant SCA effects involved high x high, high x low, low x high, average x low and low x low general combining parents.

Alam *et al*. (2008) founded significant general and specific combining ability variances for all the characters except ear height. Almost equal role of additive and non-additive gene actions was observed for days to maturity. Additive genetic variance was preponderant for grains per ear and 1000-grain weight and non-additive gene action was involved in plant height, ear height, days to silking and days to maturity.

Kadir (2010) founded that specific combining ability (SCA) variances were non-significant for ear length and ear diameter suggests that these two traits were predominantly controlled by additive type of gene action. The mean squares showed that the non-additive effects (SCA) were more important than additive effects (GCA) for plant height, ear height, days to pollen shedding, days to silking, number of kernel per row, 100-seed weight, percent poor husk cover and grain yield per plant.

Badu-Apraku *et al.* (2011) reported that general combining ability (GCA) mean squares of grain yield and other traits were larger than those of specific combining ability (SCA), indicating that additive gene action was more important in the inheritance.

Elmyhum (2013) observed Genetic differences were observed from mean squares of treatments for all traits except days to maturity, ear diameter, number of kernel rows per cob, protein content (%) and oil content (%).

Amiruzzaman *et al*. (2013) observed that variance GCA and SCA were highly significant for the characters studied, indicating both additive and non-additive type of gene action were important for controlling the traits. Predominance of non-additive gene action was observed for all the traits. Plant and ear height showing desirable significant negative GCA effects and simultaneously possessed desirable high mean values, indicating that per se performance of the parents could prove as an useful index for combining ability. Additive x additive, additive x dominance and dominance x dominance gene interactions were involved in deriving good specific cross for yield.

Kamara *et al.* (2014) revealed some inbred lines possessed the highest negative and significant GCA effects towards earliness, dwarfness and lower ear placement, respectively and some exhibited positive and significant GCA effects for grain yield (ard/fed) and most of the other yield component traits. some crosses exhibited desirable SCA effects for grain yield and some of its components' traits.

Khan *et al.* (2014) founded that general combining ability effects were highly significant for all traits. Among the parents, namely days to pollen shedding, days to mid silking, days to tasseling, plant height and ear height. For yield and yield associated traits viz. ear length and grain yield parental genotype population. Specific combining ability effects were also founded significant for all the mentioned traits.

Haydar and Paul (2014) observed GCA to SCA ratios were less than one for plant height, ear diameter, ear length and number of kernels row/ear indicating a preponderance of additive over non-additive gene action. The crosses P1xP2, P3xP5 and P5xP6 were exhibited significant and positive SCA effects for yield and ear diameter, number of row per ear and number of grains per ear of yield contributing characters. The parents P1 (IL4), P3 (IL18) and P5 (m23) were good general combiner for grain yield and yield attributing characters.

Ahmed *et al*. (2014) observed significant mean sum of squares due to GCA and SCA for all the characters studied. Higher magnitude of SCA variance than GCA variance clearly indicated the predominance of non-additive gene action for all the traits. The parental lines P4, P7 and Q6 were founded to be the best general combiner for yield components and these parents could be used as donor parents in hybridization to improve traits like days to tasseling, days to silking, plant height, ear height, ear length, ear diameter, grains per ear and 1000 grain weight by accumulation of favorable genes.

Amin *et al*. (2014) observed significant general and specific combining ability variances for all the characters studied. They founded that additive genetic variance was preponderant in plant height, ear height, ear length, ear diameter, and kernel weight and non-additive gene action was involved in days to silking, number of kernels per ear and kernel yield. The good combining parents for different traits could be used in hybridization to improve yield and other desirable traits as donor parents for the accumulation of favorable genes.

Erdal *et al.* (2015) founded the significant differences in GCA and SCA were detected between genotypes for number of days to anthesis, anthesis-silking interval, plant height, thousand kernel weight, number of ears per plant, number of kernels per ear and grain yield.

Ram *et al*. (2015) observed that interaction of Line x Tester was highly significant for all the traits. Both, non-additive and additive types of gene action were observed to influence the expression of traits among the crosses. Among the lines, CM 141, V335 and V351 were promising as observed to be the superior general combiner. Cross CM 141 x CML 161 was among the best cross as the cross recorded positive and significant SCA effect, high heterosis and high per se performance for grain yield and other important traits.

Seyoum *et al*. (2016) revealed GCA mean squares due to lines were highly significant for most of the traits, while SCA mean squares were significant for some traits. The higher the percentage relative contribution of GCA sum square over SCA sum of square in all studied trait indicated the predominance of additive gene effect in controlling the inheritance of these traits.

Hoque *et al*. (2016) founded that variances due to GCA were much higher in magnitude than SCA indicated additive gene effects were much more important for all characters except ear length, thousand grain weight and ear height. The Parent P5 was the best general combiner for yield and most of the yield contributing characters. The Parent P1 and P2 were best general combiner for both dwarf and earliness. The crosses which showed significant SCA effects for yield were involving average x average, average x low and low x low general combining parents.

Talukder *et al*. (2016) observed significance GCA and SCA variances suggested the importance of both additive and non-additive gene actions for the expression studied traits. Parents P1 and P4 were excellent general combiner for days to tasseling and silking while parents P1 and P5 for early maturity. Parent P4 for short height; parents P4 and P7 for higher thousand kernel weight. The parents P4 and P6 having good combining abilities for yield.

Singh *et al.* (2017) founded the ratio of σ 2 sca / σ 2 gca was greater than one for all the traits except days to 50 per cent silking, anthesis - silking interval , number of leaves per plant, grain yield (per plant). Among female inbred lines significant GCA effects for grain yield per plant and yield component traits like number of grain rows per ear, harvest index, maturity traits like, days to 50 per cent tasseling, indicated that best general combiner for these traits, while in male parent was the best general combiner for yield contributing traits viz., grain yield per plant, harvest index, number of grain rows per ear and quality traits. Maximum positive significant sca effects for yield per plant was showed by hybrid showed positive significant effects for most of the traits like grain yield per plant, harvest index, number of grain rows per ear, 100 – grain weight .

Ejigu *et al*. (2017) founded there were significant differences with respect of general combining ability (GCA) effects of the lines and specific combining ability (SCA) of the crosses, the ratio of GCA variance to SCA variance was less than unity, except for days to 50% anthesis and anthesis-silking interval.

Rovaris et al. (2014) reported that some genotypes were the best general combining ability for plant height (PH), ear height (EH), grain yield (GY). The best estimates for specific combining ability were observed in the traits PH, EH and GY of some hybrids, indicating dominant loci systems in the genetic control of this.

Dhoot *et al*. (2017) observed ratio of GCA/ SCA variance revealed that there was preponderance of additive gene action in the expression of yield and yield contributing characters *viz,.* ear length, number of grain rows per ear, hundred grain weight, grain yield per plant, harvest index under study. Parent P1 (number of grain rows per ear), P6 and P7 were good general combiners yield and yield attributing characters. Hybrid P1 x 135 showed highest positive significant SCA effects (48.60) along good per se performance (151.67 g per plant) and positive significant economic heterosis (26.39 %)

for grain yield per plant. This hybrid also exhibited positive significant SCA effects for hundred grain weight and harvest index.

Sugiharto *et al.* (2018) observed general combining ability effect almost in all of yield component characters, whereas only line possessed the best general combining ability for hundred seeds weight and grain yield. Some Crosses of that line accumulated the best specific combining ability for grain yield as well as yield component characters. Reciprocal crosses demonstrated that several crosses combination has significant effect for ear length, ear diameter and hundred seeds weight.

Karim *et al*. (2018) founded significance variances for general combining ability (GCA) and specific combining ability (SCA) of variance were for all the characters. However, relative magnitude of variances indicated that additive gene effects were more prominent for all the characters studied. GCA and SCA effects both showed significant interaction with environment for all the traits.

Zakiullah *et al.* (2019) founded the variances for general combining ability (GCA) significant for yield, days to pollen shedding, days to silking and ear height while it was founded non-significant for plant height and number of kernels/ear and non-significant general combining ability (GCA) variance for plant height and number of kernels /ear. While, Specific combining ability (SCA) was significant for all the character.

2.3 Heterosis

Heterosis is a phenomenon not well understood but has been exploited extensively in breeding and commercially. Hybrid cultivars are used for commercial production in crops in which heterosis expression is important. The commercial use of hybrids is restricted to those crops in which the amount of heterosis is sufficient to justify the extra cost required to produce hybrid seed. Heterosis, or hybrid vigor, refers to the phenotypic superiority of a hybrid over its parents with respect to traits such as growth rate and reproductive success and plays significant role in evolution (Basal and Turgut, 2003).

Hybrid vigor in maize is manifested in the offspring of inbred lines with high specific combining ability (SCA). Heterosis was first applied by the purposed hybridization of complex hybrid mixtures made by farmers in the 1800s (Enfield, 1866; Leaming, 1883; Waldron, 1924, and Anderson and Brown, 1952).

The information on heterosis and combining ability considered together will be more meaningful. If the heterotic hybrids involve both the parents with high general combining ability effects, then it implies that the parental contribution to heterosis is mainly through additive gene action (Mahantesh, 2006).

In plants, heterosis is known to be a multigenic complex trait and can be extrapolated as the sum total of many physiological and phenotypic traits including magnitude and rate of vegetative growth, flowering time, yield (in terms of inflorescence number, flowers per inflorescence, fruit or grain set and weight), and resistance to biotic and abiotic environmental rigours; each of them contributing to heterosis to a certain extent (Lippman and Zamir, 2007).

However, public scientists East and Shull developed the concept of hybrid vigor or heterosis in maize independently in the early 1900s (East, 1936; Shull, 1952; Wallace and Brown, 1956).

Application of heterosis (hybrid vigor) to agricultural production is a multi-billion dollar enterprise. It represents the single greatest applied achievement of the discipline of genetics (Griffing, 1990).

Debnath, (1989) and Crossa (1990) reported the presence of hybrid vigour in maize. While Beck *et al*. (1990) observed high parent heterosis (9.6%) for grain yield among crosses in CIMMYT's tropical early and intermediate maturity maize .

Beck *et al*. (1991) observed low estimate of high-parent heterosis (16% in U.S. and 9.9% in Mexican environment) in CIMMYT's subtropical and temperate intermediate maturity maize germplasm . On the other hand.Vasal *et al*. (1992) noticed moderate levels of heterosis (13%)in subtropical early maturity germplasm .

Nagda *et al*. (1995) founded significant positive heterosis for grain yield over best check and revealed significant negative heterosis for days to silking, plant height and ear height in all crosses except one cross.

Ling *et al*. (1996) reported heterotic effect was the highest for grain yield per plant followed by grain weight and ear thickness. Saha and Mukherjee (1996) observed significant positive heterosis for grains per ear and the crosses with highest heterosis for hundred grain weight and grain yield per plant had high negative heterosis for percentage grain conversion.

Ling *et al*. (1999) noticed hundred grain weight of all hybrids was greater than the female parents. But heterosis of mid parental value differed according to the relative grain weight of parents.

Kumar *et al*. (1999) reported heterosis over better parent for grain yield which were ranged from 26.31 to 37.30%.

Stojokovic *et al*. (1999) founded that the partial or complete dominance of dominant alleles with additive effects were the main contributors to yield heterosis in maize.

Netaji *et al*. (2000) noticed significant and positive heterosis and hetero beltiosis for grain yield in more than twenty hybrids and expression of hetero beltiosis was most evident for grain yield per plot, followed by test weight, ear length, ear height, plant height and number of seed rows per ear.

Shahwani *et al*. (2001) observed positive and significant heterosis in seventeen hybrids, while 11 hybrids showed hetero beltiosis for ears per plant.

Saleh *et al*. (2002) observed high heterosis for grain yield, ear weight, grain weight per ear, moderate estimates for plant and ear height, shelling percentage, ear diameter, number of kernel rows per ear, number of kernels per ear row and grain weight.

Dickert and Tracy (2002) reported that among early open pollinated sweet corn cultivars, heterosis for silk date was significant, but the difference between parents was very small 1/2 day and no hybrids were earlier than the earliest parent. The average mid parent heterosis was 6.8%, but mid parent heterosis was significant and relatively high for 100-kernel weight, ear length,ear height, plant height and 10-ear weight.

Galad (2003) noticed significant positive and negative standard heterosis for number of rows per ear. Standard heterosis for thousand kernel weight varied from -40.1 to 24.35%. For ears per plant standard heterosis varying from -12.15 to 42.99% was recorded. Nine crosses exhibited positive and significant heterosis over BHQPY-545. This indicated more prolificacy of the test cross over the standard check. Singh *et al.* (2003) observed highly significant negative heterobeltiosis and standard heterosis for early silking.

Kaushik *et al*. (2004) noticed thirty out of seventy two crosses exhibited strandard heterosis for grain yield per plant. They also noticed that one cross showed significant and commercially acceptable standard heterosis for grain yield per plant (17.24%).

Li-Jizhu *et al.* (2004) reported highest heterosis for ear grain weight and lowest for ear row number. All characters studied were controlled by additive gene action. Ear length had significant additive and dominance effects, whereas, ear row number and ear grain weight had dominant and epistatic effects, respectively.

Uddin *et al*. (2006) noticed that different crosses exhibited heterobeltiosis ranged from 8.23 to 25.78 per cent and -0.22 to -8.31 per cent, respectively, for grain yield and days to silking and ten crosses out of 21 showed significant positive heterosis. They also founded significant negative heterosis for days to tassel, days to silk, plant height and ear height. The better performing four crosses (P1 x P7, P6 x P7, P1 x P4 and P4 x P5) can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

Gissa *et al*. (2007) showed that values for mean mid-parent heterosis (MPH) ranged from 2.9% for days to maturity to 89.2% for grain yield and high-parent heterosis from 0.65% for ear diameter to 64% for grain yield.

Ahmed *et al*. (2008) observed heterobeltiosis ranged from 42.97 to 163.24 % and -3.76 t o -11.92 %, respectively, for grain yield and days to silking.

Uddin *et al*. (2008) founded Standard heterosis ranged from - 28.29 to 28.41%; -12.29 to 24.38%; -1.11 to 24.44%; -14.75 to 6.67%; -17.24 to 11.26% and -10.94 to 20.83% for grain yield per plant, number of grains per row, number of rows per ear, ear length, ear diameter and hundred kernel weight, respectively. While Alam *et al*. (2008) showed significant negative heterosis for days to maturity.

Abdel-Monaem *et al*. (2009) observed positive significant heterosis values as average percentage from mid-parents were 153.96, 182.66 and 479.29% for ear diameter, ear length and grain yield per plant, respectively. On the contrary highest values of heterotic effects over higher parent were 136.61, 144.66 and 325.57% for ear diameter, ear length and grain yield per plant, respectively.

Amiruzzaman (2010) founded out of 21 F_1, four crosses (PI x P2, PI x P7, P2 x P4 and P3 x Ps) expressed significant positive heterosis over the QPM check 131-1-M 5 for kernel yield. The maximum significant positive heterosis 6.35% over the check was recorded by PI x P7 followed by 6.10% in PI x P2, 4.15% in P2 x P4 and 3.15% in P3 x Ps.for this trait. He also observed that, in normal maize hybrids three crosses viz., QI x Q7. Q2 x Q3, and Q4 x Q6 expressed significant positive heterosis for yield coupled with other yield components like ear length, ear diameter, number of kernels per ear and thousand kernel weight over the commercial check variety Pacific11. The other desirable crosses were Q6 x Q7 and QI x Q2 showed significant positive heterosis for kernel yield and yield components like length of ear, ear diameter and kernel weight.

Kadir (2010) observed high positive heterosis over standard check variety and better parent for grain yield/plant. It was evident that CML-162 x CML-191 had the highest heterosis followed by CML-164 x CIVIL-191, CML-191 x CML-162, CM L-162 x CML-170 over standard check variety and better parent while, moderate to high heterosis was observed from CML-188 x CML-16 2, CML-191 x CML-164 and CML-

170 x CML-193. Iqbal *et al*. (2011) also founded that hybrids exhibited heterosis in grain yield varying from 19-40% over the best check.

Amiruzzaman *et al*. (2013) founded that standard heterosis for grain yield ranged from -17.60 to 9.71%. For other traits, desirable heterosis varied from -0.10 to -4.42%; -0.03 to -4.20%; -2.44 to -42.11% and -1.33 to -21.87% for days to tasseling, days to silking, plant height and ear height, respectively.

Izhar and chkraborty (2013) explained that heterosis and combining ability are prerequisite for formulating hybrid breeding programmes and for developing a good economically viable hybrid maize variety. Combining ability analysis is useful to assess the potential inbred lines and to identify the nature of gene action involved in various quantitative characters

Kumar *et al*. (2014) observed all the 60 hybrids showed earliness for days to 50 percent tasseling and days to 50 percent silking over mid parent and 39 hybrids showed earliness over standard checks for days to maturity. The hybrid MRC 13 × BML 14 recorded positive significant heterosis over three standard checks DHM 117, 900M Gold and NK 6240 for grain yield (14.67 %, 12.94 % and 11.89 %, respectively). Over standard check NK 6240, it showed desirable significant heterosis for grain yield per plant, number of kernels per row, number of kernel rows per ear and ear length.

Shushay (2014) observed significant standard heterosis of crosses over the commercial checks for traits such as grain yield, plant height, ear height, ear length, ear diameter, number of kernel rows per ear, number of kernel per row, thousand kernel weight and number of ears per plant. Grain yield of the crosses over the standard checks ranged from -32.16 to 13.02%.

Ruswandi *et al*. (2015) observed not all the crosses exhibited significant positive heterosis over mid parent for grain yield, however, some cross combination revealed higher magnitude of economic heterosis for grain yield. So, the crosses those can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

Ram *et al.* (2015) founded standard heterosis for grain yield ranged from -56.45 to 53.31 %. Based on combining ability and hybrid vigour, the lines V335 and V351 figured to be potential lines which to be converted in to QPM lines to develop local

QPM hybrids. The QPM donor CML 141 based on its GCA, SCA and heterosis estimates seems to be most promising donor for conversion program.

Mahmood *et al*. (2016) noticed that hybrid P3xP5 and P3xP4 was marked as suitable for breeding early maturing hybrids due to negative heterosis values. High heterosis for plant height was recorded for P2xP3 with significant SCA effects. The highest thousand kernel weight was obtained for the hybrid P2xP3 with highly significant heterosis and SCA.

Kumar and Babu (2016) founded cross combination DHK-12-2141 x DHK-12-2047 recorded significant magnitudes of all three types of heterosis in desirable direction for kernel rows per ear while the same cross registered significant relative heterosis and heterobeltiosis for plant height, ear length, hundred seed weight and grain yield per plant.

Sharma *et al.* (2016) founded mid and better parent heterosis were significantly higher for yield and yield attributes viz. ear length, ear diameter, no. of kernel row per ear, no of kernel per row and test weight.

CHAPTER 3

MATERIALS AND METHODS

The experiment was carried out in two subsequent Rabi seasons. In first season the plant materials were developed through crossing in 7×7 diallel fashion during the Rabi season of 2017-18. In second season the combining ability and heterosis in forty-two (42) F_1 hybrids lines in white maize were studied in the Rabi season of 2018-19. The details of material and methods and the experimental procedure implemented during the course of research are described below.

3.1 Location of the experiment

The study on combining ability and heterosis was carried out at the research farm of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from mid October 2018 to March 2019. Earlier the diallel crossing pattern among seven (7) parental lines had performed during mid October 2017 to March 2018 of winter season. The location situated at the sub-tropical climate and AEZ No. 28 called 'Madhupur Tract'. It is located at 23°41N latitude and 90°22E longitude with an elevation of 8.6 meter from the sea level (Appendix-I). In general the site is categorized by high temperature supplemented by moderate high rainfall during Kharif season (April to September) and low temperature in the Rabi season (October to March).

3.2 Climate and soil

The geographical situation of the experimental site was under the subtropical climate, characterized by three distinct seasons, the monsoon or rainy season from November to February and the pre-monsoon period or hot season from March to April and monsoon period from May to October (Edris *et al.,* 1979) and also categorized by heavy precipitation during the month of May to August and scanty precipitation during the period from October to March. The record of air, temperature, humidity and rainfall during the period of experiment were recorded from the Bangladesh Metrological Department, Agargaon, Dhaka (Appendix III -IV). The soil of the experimental site situated at Agro ecological region of Madhupur Tract (AEZ no. 28) of Noda soil series. The soil was loam in texture. 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.

3.3 Experimental materials

The experimental materials consisted of seven (7) parental inbred lines (CLTHW 15004, CLTHW 15006, CLTHW 15007, CLTHW 15008, CLTHW 15010, CLTHW 14001, CLTHW 14003) crossed in 7×7 diallel fashion including the reciprocals. The resulting forty-tow (42) F_1 hybrid progenies were developed and evaluated along with their parents and two (2) checks (BARI Hybrid 12 and BARI Hybrid 13) are presented in Table 1.

Table 1. List of experimental materials of white maize used in the experiment

Table 1(a). List of seven inbred lines used in 7×7 diallel cross experiment

Sl. no	Parents (P)	Name of Lines	Origin
1	P1	CLTHW 15004	CYMMIT, Mexico
2	P2	CLTHW 15006	CYMMIT, Mexico
3	P3	CLTHW 15007	CYMMIT, Mexico
4	P4	CLTHW 15008	CYMMIT, Mexico
5	P5	CLTHW 15010	CYMMIT, Mexico
6	P6	CLTHW 14001	CYMMIT, Mexico
7	P7	CLTHW 14003	CYMMIT, Mexico

Table 1(b). List of Check varieties collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

1	Check variety 1	BARI Hybrid Maize 12
2	Check variety 2	BARI Hybrid Maize 13

Table 1(c). List of forty two F_1 hybrid lines developed from 7×7 diallel cross with reciprocal cosses.

SL. No.	F_1 hybrids of Diallel and Reciprocal Crosses	Pedigree combination
1	P1×P2	CLTHW 15004×CLTHW 15006
2	P1×P3	CLTHW 15004×CLTHW 15007
3	P1×P4	CLTHW 15004×CLTHW 15008
4	P1× P5	CLTHW 15004×CLTHW 15010
5	P1× P6	CLTHW 15004×CLTHW 14001
6	P1× P7	CLTHW 15004×CLTHW 14003
7	P2× P1	CLTHW 15006×CLTHW 15004
8	P2× P3	CLTHW 15006×CLTHW 15007
9	P2× P4	CLTHW 15006×CLTHW 15008
10	P2× P5	CLTHW 15006×CLTHW 15010
11	P2× P6	CLTHW 15006×CLTHW 14001
12	P2× P7	CLTHW 15006×CLTHW 14003
13	P3× P1	CLTHW 15007×CLTHW 15004
14	P3× P2	CLTHW 15007×CLTHW 15006
15	P3× P4	CLTHW 15007×CLTHW 15008
16	P3× P5	CLTHW 15007×CLTHW 15010
17	P3× P6	CLTHW 15007×CLTHW 14001
18	P3× P7	CLTHW 15007×CLTHW 14003
19	P4× P1	CLTHW 15008×CLTHW 15004
20	P4× P2	CLTHW 15008×CLTHW 15006
21	P4× P3	CLTHW 15008×CLTHW 15007
22	P4× P5	CLTHW 15008×CLTHW 15010
23	P4× P6	CLTHW 15008×CLTHW 14001
24	P4× P7	CLTHW 15008×CLTHW 14003
25	P5× P1	CLTHW 15010×CLTHW 15004
26	P5× P2	CLTHW 15010×CLTHW 15006
27	P5× P3	CLTHW 15010×CLTHW 15007
28	P5× P4	CLTHW 15010×CLTHW 15008
29	P5× P6	CLTHW 15010×CLTHW 14001
30	P5× P7	CLTHW 15010×CLTHW 14003
31	P6× P1	CLTHW 14001×CLTHW 15004
32	P6× P2	CLTHW 14001×CLTHW 15006
33	P 6× P3	CLTHW 14001×CLTHW 15007
34	P 6× P4	CLTHW 14001×CLTHW 15008
35	P 6× P5	CLTHW 14001×CLTHW 15010
36	P 6× P7	CLTHW 14001×CLTHW 14003
37	P7× P1	CLTHW 14003×CLTHW 15004
38	P7× P2	CLTHW 14003×CLTHW 15006
39	P7× P3	CLTHW 14003×CLTHW 15007
40	P7× P4	CLTHW 14003×CLTHW 15008
41	P7× P5	CLTHW 14003×CLTHW 15010
42	P7× P6	CLTHW 14003×CLTHW 14001

3.4 Details of the experiment

The experiment was conducted during Rabi season of 2018 and 2019. Seeds were sown in main field on 25th October 2018. No. of plants per row for each genotype were 10 and each plot contains three rows. The plant spacing between rows was 60 cm and between plants of the same row was 25 cm. The total experimental area was 312.9 m^2 whereas each replication area was 72 m^2 . The experiment was carried out in a Randomized Complete Block Design (RCBD). Three replications were utilized in this experiment. While cross seed materials were developed during rabi 2017-18 following 7×7 diallel cross in experimental plot (Plate 1).

3.5 Cultural practices

3.5.1 Land preparation

The experimental plot was opened in the middle of October 2018 with a power tiller and was uncovered to the sun for a week. After a week the land was equipped by several ploughing and cross ploughing followed by laddering and harrowing with power tiller and country plough to bring about good tilth. This was done to manage weeds, ensured good soil aeration and to obtain good seedling emergence and root penetration. Weeds and other stubbles were eliminated carefully from the experimental plot and leveled properly. The final land preparation was done on 24th October 2018. Special care was taken to remove the rhizomes of mutha grass.

3.5.2 Manure and fertilizer application

Generally, cow dung, Urea, TSP and MoP fertilizers are essential for maize cultivation. The field soil was incorporated with 10 ton cow dung per ha during the land preparation. The field was well mixed with 525, 250, 200, 250, 12.5, and 6 Kg/ha Urea, TSP, MoP, Gypsum, Zinc Sulfate and Boric Acid, respectively (Table 2). The entire amount of cow dung was applied seven days before sowing. TSP. MoP, Gypsum, Zinc Sulfate and Boron were incorporated during final land preparation and integrated into the soil. The total amount of urea was separated by three splits. One third of the urea was applied during final land preparation and one third was top dressed after 30 days of seed germination and the rest one splits of the urea top-dressed after 70 days of seed germination (before flowering of the plants), respectively.

b

d

teps of 7 x 7 diallel cross in experimental plot a) Bagging of

Table 2. Fertilizer and manure doses applied in the experiment

Fertilizer	Kg/ha
Cowdung	10 ton
Urea	525
TSP	250
MoP	200
Gypsum	250
Zinc Sulfate	12.5
Boric acid	6.0

3.5.3 Seed sowing

Completing the lay out, forty-two (42) F_1 populations (Tables 1c) of white maize with their seven (7) parents (Tables 1a) and two check varieties (Tables 1b) were sowed to different row in each replication by using random numbers. The row size was 2.5 m. 10 hills were assigning 2.5 m length row. The seeds of each F_1 population, parental lines and check varieties were sown by dibbling two seeds per hill. Seeds were sown in main field on 25th October 2018 (Plate 2).

3.5.4 Thinning of excess seedlings

The weak seedlings were thinned out leaving only one vigorous seedling per hill after 25 days of sowing. The first one-third dose of nitrogen was top dressed at 30 days after sowing. All recommended cultural practices were followed to raise a good white maize crop.

3.5.5 Other operations

The 1st and 2nd weeding were performed respectively after 20 and 40 days of sowing to keep the soil free from weed (Plate 3). Irrigation was given when it is necessary during the crop period. Earthing up was performed twice during growing period. The first earthing up was completed at 45 days after sowing (DAS) and the second earthling up was completed after 65 DAS (Plate 4).

Plate 2. Photograph showing seed sowing in the experimental plot

Plate 3. Photograph showing weeding operation

Plate 4. Photograph showing intercultural operation (earthing up)

Plate 5. Photograph showing spraying of insecticide to control pest

3.5.6 Plant protection

Adult and larva of maize cutworm and maize aphid were founded in the crop during the vegetative and flowering stage of the plant. To control maize cutworm Ripcord 10 EC @1ml/litre were sprayed at 65-75 and 75-85 DAS respectively. To control maize aphid Malathion-57 EC @ 2ml/litre were sprayed at 70 and 90 DAS respectively. The insecticide was applied in the afternoon (Plate 5).

3.6 Observations recorded

Observations were recorded from the 5 randomly selected plants at random from each unit plot per replication. Data were collected in respect of the following parameter

3.6.1 Days to tasselling

Days to tasselling were recorded as number of days from planting to the first plant had fully emerged tassels.

3.6.2 Days to 50% tasseling

Days to tasseling were recorded as number of days from planting to the time 50% of plant had fully emerged tassels.

3.6.3 Plant height (cm)

Plant height refers to the length of the plant from ground level up to the last node (base of the tassel/flag leaf node) of the plant. Height of randomly selected plants of each unit plot was measured and the mean was calculated. It was measured in cm with a graduated measuring stick.

3.6.4 Ear height (cm)

The heights of ear from ground level to the ear node from randomly 5 selected plants were measured from each unit plot in centimeters with a graduated measuring stick. Ear height was taken from the soil surface (ground level) to the node bearing the uppermost ear node. Ear heights were measured from the same plant from which plant heights were recorded.

3.6.5 Days to maturity

Days to maturity were recorded as number of days from planting to the time ear cover turn in straw colour and base of kernel in black colour.

3.6.6 Number of branches in tassel

Number of branches of tassel was recorded by counting the entire tassel from the selected plants of each unit plot and the mean was calculated.

3.6.7 Ear length (cm)

The lengths of ears were measured from the ear base to the apex in centimeter by using measuring scale (Plate 6).

3.6.8 Ear diameter (cm)

The diameter of ears at the top, basal and central part was measured in centimeter by using a measuring tape and the average was recorded (Plate 6).

3.6.9 Number of rows per ear

The total number of rows each ear were counted and the average was recorded (Plate 7).

3.6.10 Number of kernel per row

The total number of kernel from each row of an ear was counted and the average was recorded (Plate 8).

3.6.11 Hundred kernel weight (g)

A sample of 100 seeds were taken at random and weighed was taken in gram (Plate 9).

3.6.12 Kernel yield per plant (g)

All ears were shelled from selected plants and yield was measured as a bulk weight then average was calculated by dividing the number of selected plants to the nearest gram. Yield was measure as gram per plant.

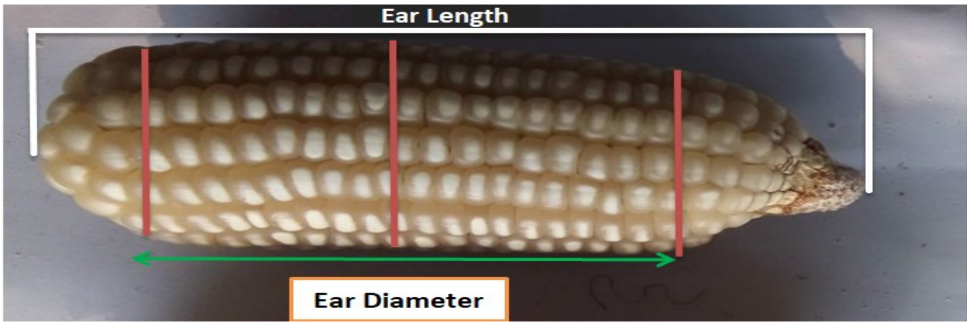

Plate 6. Photograph showing measurement ear diameter and ear

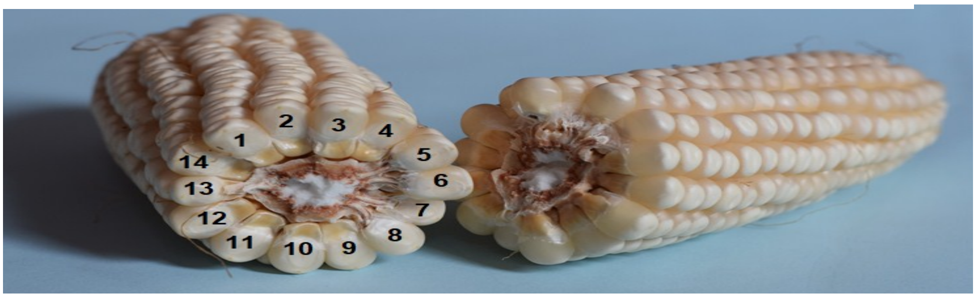

Plate 7. Photograph showing measurement of rows per ear (1, 2, 3… denotes the number of rows)

Plate 8. Photograph showing measurement of kernels per row (1, 2, 3

Plate 9. Photograph showing hundred kernel weighing procedure

Plate 10. Photograph showing the visit by the supervisor in the experimental field

3.7 Genetic Parameters:

3.7.1 Analysis of Variance:

A range of statistical analysis was conducted for each character. A Completely Randomized Block Design (RCBD) with three replications was implemented according to the following linear modeling (Al-Mohammad and Al-Yonis, 2000).

$$Y_{ij} = \mu + \tau_i + \rho_j + \varepsilon_{ij}$$

$$\begin{Bmatrix} i = 1,2,3,\ldots\ldots t \\ j = 1,2,3,\ldots\ldots r \end{Bmatrix}$$

Where:

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

μ: The general mean value,

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

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

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

$\varepsilon_{ij} \sim NID(0, \sigma^2 E)$

3.7.2 Combining Ability Analysis:

Griffing (1956) designed two main models and four methods for the analysis of diallel data. In this study, analysis of the combining ability for each character was done following Griffing's method I Model I, which the inbred lines, F_2’s and reciprocals are included. The data was analyzed with using a fixed model. If the fixed effects model is used, the sampling error becomes the effective residual for testing combining ability mean squares and estimating variance components and standard errors. It should be noted here that the replication values are actually the means of plot over individual observations i.e., c.Thus, we obtained data from a table that containing

$\frac{1}{bc}\sum\sum Y Y_{ijk} = Y_{ij}$ values. Obviously Y_{ij} is the mean of $(i \times j)^{th}$genotype over k and l.

The (GCA) and (SCA) were estimated using the general linear model for

the analysis which takes the formula of (Singh and Chaudhary, 1985).

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

Where:

Yij : observed value of the experimental unit,

μ : populations mean,

gi : general combining ability (GCA) effect for the i th parent,

gj : general combining ability (GCA) for the j th parent,

sij : specific combining ability (SCA) for the diallel crosses involving parent i and j,

Rij :specific combining ability (RCA) for the reciprocal crosses involving parent i and j,

rk : replication (block) effect, and

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

3.7.2.1 Estimation of General and Specific Combining Ability Effect*:*

(Singh and Chaudhary, 1985)

$\hat{g}ii= \frac{1}{2p}(Y_{i.}+Y_{.J}) - \frac{1}{p^2}Y_{..}$

$\hat{s}_{ij}=\frac{1}{2}(Y_{ij}+Y_{ji}) - \frac{1}{2p}(Y_{i.}+Y_{.i}+Y_{j.}+Y_{.j}) +\frac{1}{p^2}Y$

$\hat{r}_{ij}= \frac{1}{2}(Y_{ij}-Y_{ji})$

$\hat{g}ii$ =Effect of general combining ability for parent “i”,

$\hat{s}_{ij}$ =Effect of expected specific combining ability for single diallel crosses ij when i = j,

$\hat{r}_{ij}$ =Effect of specific combining ability for single reciprocal crosses ij
when i=j,

Yij: F_2’s mean as a result of crossing parent “i” with parent “j”,

Y..: Sum of the means of all parents and F_2s hybrids non-reciprocal,

P: Parent's number.

Estimation of standard error for the differences between the effects of the general combining ability of two parents: (Singh and Chaudhary, 1985)

$S.\ E._{(g\,i\text{-}g\,j)} = \sqrt{\frac{MS' e}{p}}$

Estimation of standard error for the differences between the effects of two diallel crosses: (Singh and Chaudhary, 1985).

$S.E._{(S_{ij}-S_{ik})} = \sqrt{\frac{(P-1)MS'e}{p}}$

Estimation of standard error for the differences between the effects of two reciprocal crosses: (Singh and Chaudhary, 1985).

$S.E._{(r_{ij}-r_{ik})} = \sqrt{MS'e}$

3.7.3 Heterosis:

It was estimated as the percentage deviation of F_1's hybrid from Better Parental value:

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

Where: $\overline{F_1}$Mean of hybrid , $\overline{B.P}$= Mean of Better parent

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

Where, $\overline{F}_1$ and $\overline{CV}$ 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.

Table 3. Analysis of Variance for Full Diallel Cross According to Griffing 1956, Method I, Model I (Parents, Diallel Crosses, and Reciprocal Crosses) (Singh and Chaudhary, 1985).

S.O.V	*d.f*	*SS*	*MS*	*E(M.S)*
Blocks	(b-1) =2	$SS_B=\frac{\sum Y^2.k}{P^2} - \frac{Y^2..}{bp^2}$	MS_B	
Genotypes	$(p^2-1)=48$	$SS_G=\frac{\sum Y^2 i j}{b} - \frac{Y^2..}{bp^2}$	MS_G	
GCA	(p-1) =6	$SS_{GCA}=\frac{1}{2p}\sum_i(Yi.+Y j.)^2-\frac{2}{p^2}Y^2$	MS_{GCA}	$\sigma^2_{GCA}=\sigma^2{}_e+\frac{2p}{p-1}\sum g_i^2=\frac{MSGCA-MS'e}{2p}$
SCA	$\frac{p(p-1)}{2}=21$	$SS_{GCA}=\frac{1}{2p}\sum_i\sum_j Y_{ij}(Y_{ij}-Y_{ji})-\frac{1}{2}\sum_i(Y.i+Yi.)^2+\frac{1}{p^2}Y^2$	MS_{SCA}	$\sigma^2_{SCA}=\sigma^2{}_e+\frac{2p}{p(p-1)}\sum\sum s^2 ij=(MS_{SCA}-MS'e)$
RCA	$\frac{p(p-1)}{2}=21$	$\frac{1}{2}\sum_i\sum j(Yij+Yji)^2$	MS_{RCA}	$\sigma^2_{RCA}=\sigma^2{}_e+\frac{2}{p(p-1)}\sum\sum r^2_{ij}=(MS_{RCA}-MS'e)/2$
Error	$(b-1)(p^2-1)=96$	$SSe=SST-SSB-SSG$	MS’e	
Total	$bp^2-1=167$	$SS_{Total}=\sum Y^2_{ijk}-\frac{Y^2_{......}}{b^2}$		

CHAPTER 4

RESULTS AND DISCUSSION

The mean values of corn yield and related characters of parental genotypes and their F_1 progenies are presented in Table 5 and the corresponding analysis of variance (ANOVA) in Table 4

Highly significant ($p<0.001$) differences due to genotypes were observed (Table 4) for almost all the characters under study such as Date of 1st tasseling (D1T), Date of 50% tasseling (D50%T), Date of maturity (DM), Number of branches in tassel (NBT), Ear length (EL), Ear diameter (ED), Number of row per ear (NRPE), Number of kernel per row (NKPR), Hundred kernel weight (100 KW), Kernel yield per plant (KYPP).While Plant height (PH) and Ear height (EH) significant in 0.005.

4.1 Performance Analysis

Mean values (Table 5) showed that flowering tasseling were earliest in P4 (71.667) followed by P7 (72.0). Among the F_1 the hybrids of P5xP7 (V30) (69.00) and P4xP7 (V24) (71.667) showed earliness in tasseling and P4xP2 (V20) (80.33), had most late flowering habit. While 75.667 and 76.333 mean performances were exhibited by check variety 1 and check variety 2, respectively.

Date of 50% tasseling (D 50% T) was also observed (Table 5) earliest in P 4 (75.333) followed by P7 (75.667). Among the F_1 the hybrid of genoypes P5xP7 (V30) (72.333) and P4xP7 (V24) (74.333) showed earliness in tasseling and P4xP2 (V20) (83.00), and P5xP1 (V25) (81.333) had most late 50 % tasseling. While 77.667 and 79.00 mean performances were exhibited by check variety 1 and check variety 2, respectively (Table 5). Ihsan *et al*. (2005) and Begum (2016) noticed significant amount of variation for different morphological traits.

Lowest plant height was founded P6 (171.45 cm) followed by P7 (185.467 cm) and in cross the hybrids of P2xP3 (V8) (174.667 cm), P6xP1 (V31) had plant height (179.783 cm) followed by P6xP7 (V36), (181.00 cm). Again 165.403 cm and 169.800 cm were exhibited by check variety 1 and check variety 2, respectively (Table 5). Dijak *et al.* (1999) founded significant variation among long and short stature maize.

Table 4. Analysis of variances (MS values) of twelve characteristics of White maize

Note:

Source	Df	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
Replication	2	17.261	8.438	291.233	411.998	40.961	3.869	1.762	0.086	0.124	5.438	14.32	276.257
Genotype	50	15.083**	14.289**	220.862*	97.639*	7.755**	3.527**	2.033**	0.077*	2.171**	25.86**	20.626**	1492.966**
Error	100	5.881	5.411	134.843	67.882	3.841	1.089	0.951	0.054	0.831	7.578	4.447	253.725

D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length(cm), ED= Ear diameter(cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW=100 kernel weight(g), KYPP=Kernel yield per plant(g).

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

Table 5. Mean performance of twelve characteristics of 7 parents and 42 F_1 lines derived from 7×7 full diallel cross in White maize

Treatment	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
P 1	79.333	81.667	190.700	82.267	138.667	11.667	13.547	4.870	16.000	25.000	36.333	144.623
P 2	74.667	78.000	189.400	86.733	134.000	10.333	14.473	4.953	15.000	24.000	30.333	108.920
P 3	75.333	78.000	188.633	83.400	135.333	10.000	14.590	4.650	15.000	24.667	34.333	126.560
P 4	71.667	75.333	189.400	81.167	132.667	12.667	14.247	4.420	14.000	27.667	37.333	145.987
P 5	75.667	78.667	194.017	78.167	134.667	11.000	15.100	4.593	16.000	27.333	33.000	143.927
P 6	79.000	81.667	171.450	73.697	138.333	11.333	13.205	4.559	15.333	23.667	34.333	124.187
P 7	72.000	75.667	185.467	82.100	132.667	12.000	14.993	4.763	14.667	28.000	36.667	149.907
V 1 (P1*P2)	78.000	80.333	202.983	96.667	138.667	12.333	15.183	4.960	14.333	29.667	38.333	162.450
V 2 (P1*P3)	73.667	77.667	196.280	84.180	132.667	12.333	17.310	4.857	14.667	34.667	37.667	191.567
V3 (P1*P4)	77.667	80.000	189.453	79.440	136.667	12.667	15.040	4.777	15.000	28.667	33.667	144.480
V4 (P1*P5)	76.333	78.333	202.827	86.113	135.667	11.667	15.073	4.503	13.333	30.333	39.000	157.323
V5 (P1*P6)	74.333	77.667	201.667	88.500	133.333	13.000	14.677	5.033	15.667	24.667	40.333	155.723
V6 (P1*P7)	75.000	77.333	206.633	89.900	134.000	15.000	16.983	4.680	14.000	31.667	42.333	183.500
V7 (P2*P1)	78.333	80.667	194.667	81.300	137.667	12.333	15.393	4.777	15.000	29.667	37.333	165.827

D1T= Days of 1^{St} tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length(cm), ED= Ear diameter(cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW=100 kernel weight(g), KYPP=Kernel yield per plant(g).
*P>0.05, **P>0.01,ns= non-significance.

Table 5. Mean performance of twelve characteristics of 7 parents and 42 F_1 lines derived from 7×7 full diallel cross in White maize (Cont'd)

Treatment	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
V8 (P2*P3)	75.333	77.667	174.667	78.933	134.333	12.667	13.550	4.823	15.000	23.000	34.333	117.917
V9 (P2*P4)	75.333	78.000	184.773	83.693	137.333	13.000	14.493	4.623	15.333	28.667	32.667	142.067
V10 (P2*P5)	72.333	76.000	191.033	81.500	136.667	10.667	14.283	4.770	14.667	26.333	34.333	130.513
V11 (P2*P6)	74.000	76.667	192.633	86.607	134.000	12.333	13.587	4.630	15.000	26.333	37.000	145.067
V12 (P2*P7)	75.333	77.667	192.100	89.067	134.333	11.333	15.210	4.530	14.333	30.000	32.667	139.880
V13 (P3*P1)	71.667	74.667	202.367	85.317	133.000	12.333	15.897	4.667	15.333	32.000	38.667	188.833
V14 (P3*P2)	73.333	76.333	201.467	89.933	134.000	12.333	15.777	4.912	15.333	29.667	39.000	176.950
V15 (P3*P4)	73.000	75.000	195.267	84.067	133.000	11.667	15.467	4.720	14.333	33.667	37.333	177.007
V16 (P3*P5)	73.667	76.000	202.233	85.467	135.333	12.000	15.263	4.647	15.000	31.333	35.333	165.973
V17 (P3*P6)	72.667	75.000	201.813	88.733	135.000	12.667	14.867	5.360	16.000	28.667	38.333	176.053
V18 (P3*P7)	72.000	76.000	189.833	83.950	133.333	10.667	15.607	4.770	15.667	30.667	40.333	193.653
V19 (P4*P1)	78.000	80.667	191.433	80.567	136.667	13.000	16.127	5.020	15.333	32.000	37.333	183.407
V20 (P4*P2)	80.333	83.000	185.200	75.000	137.667	11.667	15.025	4.880	15.333	31.000	36.667	174.327

D1T= Days of 1^{St} tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length(cm), ED= Ear diameter(cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW=100 kernel weight(g), KYPP= Kernel yield per plant(g).
*P>0.05, **P>0.01,ns= non-significance.

Table 5. Mean performance of twelve characteristics of 7 parents and 42 F_1 lines derived from 7×7 full diallel cross in White maize (Cont'd)

Treatment	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
V21 (P4*P3)	77.333	82.000	191.980	80.233	137.000	13.333	16.200	4.937	13.000	32.667	38.000	161.250
V22 (P4*P5)	75.333	79.333	189.820	71.800	136.667	12.333	15.593	4.807	14.667	31.000	37.000	169.160
V23 (P4*P6)	76.333	78.667	187.960	79.800	135.667	11.667	15.143	4.813	16.333	28.667	37.667	175.467
V24 (P4*P7)	71.667	74.333	187.033	81.333	134.667	12.667	15.833	4.733	15.333	31.667	39.000	189.150
V25 (P5*P1)	77.667	81.333	185.267	74.567	136.333	10.667	14.810	4.743	16.333	29.000	33.000	157.443
V26 (P5*P2)	76.000	79.667	188.053	75.053	136.000	10.000	15.287	4.763	15.667	28.000	37.667	164.663
V27 (P5*P3)	75.667	79.000	183.933	74.000	135.333	10.000	14.993	4.450	14.333	25.000	35.667	125.750
V28 (P5*P4)	76.333	78.667	196.467	80.650	136.000	11.333	15.990	4.643	15.333	31.667	39.333	191.307
V29 (P5*P6)	73.667	76.333	188.800	82.967	134.333	12.000	15.323	4.720	15.667	30.000	38.000	178.667
V30 (P5*P7)	69.000	72.333	194.417	88.133	133.667	10.333	15.623	4.837	16.333	29.667	40.333	194.933
V31 (P6*P1)	74.667	77.333	179.783	83.950	134.333	12.333	14.997	4.733	16.333	24.000	34.667	136.090
V32 (P6*P2)	75.000	77.333	187.567	78.800	135.000	11.667	14.070	4.650	15.000	22.333	40.000	133.557
V33 (P6*P3)	75.667	77.333	187.000	85.387	134.333	10.667	14.167	4.783	14.333	27.667	36.667	145.120
V34 (P6*P4)	74.667	77.667	192.267	84.033	134.667	12.000	15.493	4.844	15.667	30.667	38.333	183.633

D1T= Days of 1^{St} tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length(cm), ED= Ear diameter(cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW=100 kernel weight(g), KYPP=Kernel yield per plant(g).

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

Table 5. Mean performance of twelve characteristics of 7 parents and 42 F_1 lines derived from 7×7 full diallel cross in White maize (Cont'd)

Treatment	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
V35 (P6*P5)	75.667	78.667	188.327	80.753	134.667	11.333	14.143	4.653	14.333	27.000	37.333	144.213
V36 (P6*P7)	74.333	77.000	181.000	82.733	134.667	12.333	14.777	4.853	15.667	32.333	37.333	184.773
V37 (P7*P1)	74.000	77.000	191.267	84.667	133.333	13.333	15.360	4.877	16.000	29.667	36.333	175.787
V38 (P7*P2)	76.000	78.000	192.433	91.067	135.333	12.667	14.907	4.857	16.000	29.000	37.000	171.640
V39 (P7*P3)	72.667	75.667	181.933	79.867	133.000	13.333	14.863	4.740	15.333	26.667	40.000	163.550
V40 (P7*P4)	73.000	75.000	184.600	81.133	133.333	12.000	13.940	4.723	14.667	25.000	35.333	129.360
V41 (P7*P5)	73.333	76.000	196.667	80.633	133.333	11.000	14.827	4.760	15.000	26.667	41.667	166.193
V42 (P7*P6)	75.333	77.667	181.067	79.933	135.333	12.667	15.053	4.580	14.333	29.667	39.667	168.750
CV 1	75.667	77.667	165.403	66.900	135.667	13.667	15.713	4.687	13.000	30.333	35.333	138.820
CV 2	76.333	79.000	169.800	67.333	134.667	14.333	13.900	4.750	13.000	25.333	43.000	140.887
Average	74.967	77.778	189.828	82.004	135.039	12.007	15.019	4.758	15.026	28.562	37.124	158.957
LSD	1.03	0.99	1.20	1.07	.99	1.03	1	1.01	1	0.9	3.48	4.5
CV %	3.25	8.4	7.3	10.1	1.67	8.00	10.30	11.3	10.84	8.7	5.76	13.2

Note:
D1T= Days of 1^{St} tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length(cm), ED= Ear diameter(cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW=100 kernel weight(g), KYPP=Kernel yield per plant(g).
*P>0.05, **P>0.01,ns= non significance.

Lowest ear height was founded P6 (73.697 cm) followed by P5 (78.167 cm) and in cross P4xP5 (V22) (71.80 cm) followed by P5xP3 (V27) (74.00 cm). While 66.90 cm and 67.333 cm in ear height check variety 1 and check variety 2, respectively (Table 5).

Lowest days of maturity was founded P7 and P4 (132.667) and in cross P1xP3 (V2) had the lowest dayes for maturity (132.667) followed by P3xP1 (V13) and P3xP4 (V15) (133.00). While 135.667 and 134.667 in check variety 1 and check variety 2, respectively (Table 5). Seyoum *et al.* (2016) founded significant amount of variability for different morphological traits in maize inbred lines and its crosses.

Number of branches in tassels was founded highest in P4 (12.667) followed by P7 (12.0) and in cross P1xP7 (V6) (15.00) followed by P4xP3 (V21), P7xP1 (V37) and P7xP3 (V39) (13.33), respectively. Furthermore 13.667 and 14.333 in check variety 1 and check variety 2 (Table 5).

Ear length was highest in P5 (15.10 cm) followed by P 7 (14.993 cm) and in cross P1 xP3 (V2) showed the maximum ear length (17.31 cm) followed by each of P1xP7 (V6) (16.98 cm). While 15.713 cm and 13.9 cm in check variety 1 and check variety 2, respectively (Table 5). Begum *et al.* (2018) observed significant amount of variability for different morphological traits in maize inbred lines.

Ear diameter was highest founded in P2 (4.953 cm) followed by P1 (4.870 cm) and cross P3xP6 (V17) showed maximum ear diameter (5.360 cm) followed by P1xP6 (V5) (5.033 cm) and P4xP1 (V19) (5.020 cm). Check variety 1 and check variety 2 exhibited 4.687 cm and 4.750 cm, respectively (Table 5). Begum (2016) and Huda *et al.* (2016) support this finding.

Number of row per ear was highest founded in both P1 (16.00) and P5 (16.00) and each of cross P4xP6 (V23) (16.333), P5xP1 (V25) (16.333), P5xP7 (V30) (16.333), and P6xP1 (V31) (16.333) . While 13 in both check variety 1 and 2 (Table 5). Seyoum *et al.* (2016) founded significant amount of variability for this traits in maize inbred lines and its crosses.

Number of kernel per row was highest and founded in P7 (28.00) followed by P4 (27.667), and cross P1xP3 (V2) showed the maximum kernel per row (34.667) followed by P3xP4 (V15) (33.667). In case of check variety number of kernel per row were 30.333 and 25.333, respectively in check variety 1 and check variety 2 (Table 5) . Ahmed *et al*. (2014) founded significance differences both inbred line and its crosses.

Hundred kernel weight was highest founded in parent P4 (37.333 g) followed by P7 (36.667 g) and cross P1xP7 (V6) had the highest thousand kernelweight (42.333 g) followed by P7xP5 (V41) (41.667 g) .While 35.333 g and 43.000 g in check variety 1 and check variety 2, respectively (Table 5). Karim *et al.* (2018) founded significance differences both inbred line and crosses.

Kernel per yield per plant was highest in P7 (149.907 g) followed by P4 (145.987 g) and among the hybrids the cross P5xP7 (V30) showed the maximum kernel yield per plant (194.933 g) followed by P3xP7 (V18) (193.653 g) and check variety 1 (138.820 g) and check variety 2 (140.887 g), respectively (Table 5). Huda *et al*. (2016) and Begum *et al*. (2018) observed variation in kernel yield.

4.2 Combining ability

The knowledge of combining ability is indispensable 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 programs, breeders must have information on the nature of combining ability of parents, their behavior 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).

Results of general combing ability (GCA) and specific combining ability (SCA) variance are presented in Table 6. The study revealed significant mean squares for general and specific combining abilities for most of the studied characters which indicated significant differences that recommended presence of notable genetic variability among the GCA as well as SCA effects. Derera *et al.* (2008), Karim *et al.* (2018) and Murtadha *et al.* (2018) also reported highly significant differences for most of the sources of variation. Earlier Mathur and Bhatnagar, (1995) have also been reported significant differences for GCA and SCA variances for different traits in maize. It specified that both additive and non-additive components of genetic variance in controlling these characters. Rokadia and Kaushik (2005) stated the importance of both additive and non-additive gene effects in maize in their studied materials.

The combining ability analysis revealed highly significant GCA differences for all character except ear diameter (Table 6). SCA variance were also significant for all the characters except plant height and ear height which indicated that both types of gene actions i.e. additive and non-additive are involved for controlling these traits (Table 6). Uddin *et al*. (2008) observed significance for all characters excepts row per ear ,ear diameter and ear length while Matin *et al*. (2016) and Begum (2016) founded highly significant differences for GCA except ear of kernel per row and thousand grain weights .The ratio of GCA and SCA variance was observed close to unity for number of row per ear,ear diameter, ear length, kernel per row, hundred kernel weight and kernel yield (Table 6).

Table 6. Analysis of variances (MS values) for GCA and SCA for twelve plant characters in 7×7 diallel of white maize

Source	df	D 1T	D 50% T	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
GCA	6	14.067**	12.634**	94.987**	50.453**	6.637**	3.107**	1.367**	0.0273	0.447*	15.789**	9.224**	781.169**
SCA	18	6.015**	4.925**	43.280	18.439	4.213**	0.943**	0.769**	0.0332*	0.550**	11.641**	7.612**	553.463**
Reciprocal	18	3.127*	4.009**	71.891	29.514	0.725	0.815**	0.562*	0.0286*	0.836**	6.284**	6.296**	526.201**
Error	96	1.726	1.554	45.828	22.044	1.223	0.258	0.315	0.0183	0.274	2.598	1.452	87.954
GCA: SCA		2.339	2.565	2.195	2.736	1.575	3.295	1.777	0.822	0.812	1.356	1.212	1.411

Note:
D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height (cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length (cm), ED= Ear diameter (cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW= 100 kernel weight(g), KYPP= Kernel yield per plant(g).
*P>0.05, **P>0.01,ns= non-significance.

Murtadha *et al.* (2018) mentioned that the closer the ratio of GCA: SCA is to unity, the greater the predictability of progeny performance based on the GCA alone and the better the transmission of trait to the progenies. The ratio of the components exposed that GCA variance was higher than SCA for days to tasseling, plant height, number of tassel, ear height, ear length, number of kernel per row, hundred kernel weight and kernel yield per plant 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. Earlier reports of Malik *et al.* (2004) showed closer ratio for days to tasseling, plant height, ear height and grain yield. While Matin *et al.* (2016) also founded predominant additive genetic variance in the inheritance of days to tasseling, plant height and ear height in maize.

In this present study combining ability analysis exposed that estimates of GCA variances were higher than SCA variances for all the character except number of row per ear and ear diameter (Table 6) suggesting predominance of non-additive or dominant gene action and ratio was almost unity for thousand kernel weight and kernel yield indicated equal importance of both additive and non-additive gene effects. Amiruzzaman *et al.* (2013) also stated that the importance of both additive and non-additive genetic variances with higher magnitude of SCA over GCA for yield-related characters of QPM in their study.

So the present study uncovered that both additive and non-additive gene interaction influenced the expression of traits. The choice of efficient breeding method and incorporation of concerned genes into new materials are determined by the component of genetic variation which is estimated through combining ability analysis.

4.2.1 General combining ability

The estimates of general combining ability effects for twelve characters of the parental lines are presented in Table 7. A parent with higher significant GCA effects is reflected as a good general combiner. Parents possessed significant but negative or undesirable GCA effects were designated as poor or low combiners (Ahmed *et al*., 2014). However, in case of days to tasseling, plant height and ear height negative GCA effects were desirable.

The detailed results of combining ability are presented and discussed character wise as follows:

4.2.1.1 Days to 1st tasselling

The estimates of GCA effect ranged from -1.663 in P7 to 1.361 in P1 (Table 7). 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 P7 and P3 were desirable for negative GCA effect. Among them P7 considered the best general combiner for early flowering. The genotype P1and P2 were the latest flowering parent, so, P1 and P2 could be termed as poor general combiners. Early maturing inbred lines based on GCA effects were also noticed by Ahmed *et al.* (2014) and Karim *et al.* (2018).

4.2.1.2 Days to 50% tasselling

Through the estimation the highest and lowest significant GCA were observed 1.269 in P1 and -1.66 in P7, respectively (Table 7). The parents P7 and P3 showed the negative GCA effect 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 P2 were the latest flowering parent. Among them P7 considered the best general combiner for early flowering, so the parents P1 and P2 could be termed as poor general combiners. Early maturing inbred lines based on GCA effects were also noticed by Aminu *et al*. (2014) and Sentayehu and Warsi (2015).

Table 7. Estimates of General Combining Ability (GCA) for twelve plant characters in 7×7 diallel of white maize

	D 1T	D 50% F	PH	EH	DM	NBT	EL	ED	NRPE	NKPR	100 KW	KYPP
P 1	1.361**	1.269**	3.981**	1.653^{ns}	0.656**	0.527**	0.254^{ns}	0.052^{ns}	0.129^{ns}	0.408^{ns}	0.197^{ns}	3.955^{ns}
P 2	0.694**	0.626**	-0.280^{ns}	1.752^{ns}	0.609**	-0.235^{ns}	-0.334**	0.031^{ns}	-0.037^{ns}	-1.330**	-1.493**	-13.829**
P 3	-0.830**	-0.731**	1.125^{ns}	0.736^{ns}	-0.677**	-0.211^{ns}	0.197^{ns}	0.023^{ns}	-0.228^{ns}	0.337^{ns}	0.102^{ns}	0.031^{ns}
P 4	0.241^{ns}	0.316^{ns}	-1.089^{ns}	-2.320**	0.299^{ns}	0.408**	0.175^{ns}	-0.020^{ns}	-0.228^{ns}	1.456**	-0.112^{ns}	5.448**
P 5	-0.187^{ns}	0.031^{ns}	1.827^{ns}	-2.756**	0.204^{ns}	-0.830**	0.073^{ns}	-0.083**	0.082^{ns}	0.027^{ns}	-0.279^{ns}	-0.165^{ns}
P 6	0.384^{ns}	0.150^{ns}	-4.108**	-0.498^{ns}	0.109^{ns}	0.027^{ns}	-0.549**	0.009^{ns}	0.248^{ns}	-1.497**	0.388^{ns}	-4.344^{ns}
P 7	-1.663**	-1.660**	-1.456^{ns}	1.433^{ns}	-1.201**	0.313**	0.184^{ns}	-0.013^{ns}	0.034^{ns}	0.599^{ns}	1.197**	8.905**
SEgij	0.325	0.308	1.675	1.162	0.274	0.126	0.139	0.033	0.13	0.399	0.298	2.321
SE (gi-gj)	0.497	0.471	2.559	1.775	0.418	0.192	0.212	0.051	0.198	0.609	0.455	3.545

Note:
D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height (cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length (cm), ED= Ear diameter (cm), NRPE= Number of row per ear, NKPR= Number of kernel per row, 100KW= 100 kernel weight(g), KYPP= Kernel yield per plant(g).
*P>0.05, **P>0.01,ns= non-significance.

4.2.1.3 Plant height (cm)

Among the three parental lines *viz.* P2 , P4 and P6 showed negative GCA effects and low mean values. However, only -4.108 in P6 showed negative significance and indicated good combiner for short plant. The highest GCA 3.981 in P1 was also observed and indicated poor combiner for short plant (Table 7). Uddin *et al.* (2006), Haydar and Paul (2014) and Ahmed *et al.* (2014) observed good general combiner parents for short plant type in maize.

4.2.1.4 Ear height (cm)

The estimation showed two parental line exhibiting negative GCA -2.320 in P4 and -2.756 in P5 (Table 7). Both the parents P4 and P5 were good combiner for the ear height. Earlier Rodrigues and Chaves (2002), Malik *et al.* (2004), Kumar and Babu (2016) observed significant and negative GCA effect for ear height also in this character.

4.2.1.5 Datys to maturity

As in days to maturity negative GCA is desirable. The estimates of GCA effects ranged from -1.201 in P7 to 0.665 in P1 (Table 7). The parental genotypes P7 and P3 were desirable for negative GCA effect. Among parents. P7 and P3 considered the best general combiner for early flowering. The genotype P1 and P2 were the latest flowering parent, so the parents P1 and P2 could be termed as poor general combiners.

4.2.1.6 Number of branches in tassel

Positive GCA is preferable to number of branches in tassel GCA effect ranged from -0.830 in P5 to 0.527 in P1 (Table 7). Among the parents P1, P4 and P7 were the moderate combiner of this character.

4.2.1.7 Ear length (cm)

Among seven parents two parents P2 and P6 showed significant GCA effects in a negative direction (-0.334 and -0.549 respectively) for ear length (Table 7) suggesting that these lines were not good combiners. Negative GCA effect was also obtained by Bayisa *et al.* (2008) and Ahmed *et al.* (2014) for ear length. Positive but insignificant value of GCA was recorded in five parent.s 0.254 in P1, 0.197 in P3, 0.175 in P4, 0.073

in P5 and 0.184 in P7. Azad *et al*. (2014) and Purushottam and Shanthakumar (2017) noticed positive GCA for ear length in some maize inbred lines.

4.2.1.8 Ear diameter (cm)

Positive but insignificant value of GCA was recorded in four parents i.e. 0.052 in P1 0.031 in P2, 0.023 in P3 and 0.009 in P6 (Table 7). Earlier Prodhan and Rai (1999), Mousa (2014) and Zeleke (2015) founded significant GCA effects for ear diameter in maize. One parent P5 exhibited negative significance GCA value. Sugiharto *et al*. (2016) founded undesirable significant negative value for ear diameter.

4.2.1.9 Number of row per ear

Positive and significant GCA effects are desirable for number of row per ear which is consider one of the yields contributing character. P1, P5, P6 and P7 had positive but non-significant. GCA effects for number of row per ear making them good combiners for improving the trait (Table 7). Packiaraj (1995) founded significance GCA on this character. However, P2, P3 and P4 revealed negative and non- significant GCA effect for number of row per ear.

4.2.1.10 Number of kernel per row

Among the seven parents only one parent i.e. 1.456 in P4 showed significant GCA effects in a positive direction for number of kernel per row implying the tendency of the lines to increase kernel number (Table 7). Ahmed *et al*. (2014) and Purushottam and Shanthakumar (2017) mentioned positive and significant GCA effects for this trait. Two parents P2 and P6 revealed negative and significant GCA effect, suggesting that these lines were not good combiners.

4.2.1.11 Hundred kernel weight (g)

The estimation showed that parental line P7 exhibiting positive significance GCA 1.197 and positive but non significance in P1, P3 and P6 (Table 7) implying the tendency of the lines to increase yield of corn . However, significance negative GCA also observed -1.493 in parental line P2. This result was supported by Karim *et al.* (2018) and Ahmed *et al*. (2014).

4.2.1.12 Kernel yield per plant (g)

Among seven parents only two parent P4 (5.448) and P7 (8.905) showed significant GCA effects in a positive direction for kernel yield per plant suggesting the tendency of the lines to increase yield (Table 7). This directs the potential advantage of the parents for development of high-yielding hybrids. Earlier Amiruzzamam *et al*. (2013), Hussain *et al*. (2003) and Ivy and Hawlader (2000) observed similar findings.

4.2.2 Specific combining ability (SCA) effects

Estimates specific combining ability effects for twelve characters of the parental lines are presented in Table 8. The SCA effects involved mainly dominance, additive x dominance, dominance x dominance effects. The crosses showing SCA effects toward positive direction indicated good performer of that character.

4.2.2.1 Days to 1st tasseling

Negative estimates are desirable for days to tasseling as they are considered to be related with earliness. Twenty-nine crosses showed desirable negative SCA but non-significance effects for days to tasseling and two cross viz. P2xP4 (V9) and P2xP7 (V12) showed significance positive SCA considered as poor combiner of this character (Table 8). Ahmed *et al*. (2014) and Karim *et al*. (2018) observed significance earliness on different crosses and significance positive SCA on other crosses.

4.2.2.2 Days to 50% tasseling

Negative estimates are considered desirable for days to 50% tasseling as they are associated with earliness. Twenty-four crosses showed desirable negative SCA but non-significance effects for days to tasseling and one cross *viz.* P2xP4 (V9) showed significance positive SCA considered as poor combiner of the character (Table 8).

Table 8. Estimates Specific Combining Ability (SCA) for twelve plant characters in 7×7 diallel of white maize

Crosses	**D 1T**	D 50% F	PH	EH	DM	NBT	EL	ED	NRPC	NKPR	100 KW	KYPP
V1 (P1*P2)	1.187^{ns}	0.850^{ns}	4.389^{ns}	2.967^{ns}	1.867**	0.116^{ns}	0.341^{ns}	0.025^{ns}	-0.534^{ns}	1.997*	2.088**	14.277*
V2 (P1*P3)	-2.789^{ns}	-2.126^{ns}	3.483^{ns}	-0.252^{ns}	-2.180^{ns}	0.092^{ns}	1.125**	-0.073^{ns}	-0.010^{ns}	3.997**	0.827^{ns}	26.478**
V3 (P1*P4)	1.306^{ns}	0.993^{ns}	-3.184^{ns}	-1.941^{ns}	0.677^{ns}	-0.027^{ns}	0.127^{ns}	0.107^{ns}	0.156^{ns}	-0.122^{ns}	-1.626^{ns}	-5.196^{ns}
V4 (P1*P5)	0.901^{ns}	0.779^{ns}	-2.497^{ns}	-1.168^{ns}	0.105^{ns}	-0.456^{ns}	-0.413^{ns}	-0.106^{ns}	-0.486^{ns}	0.639^{ns}	-0.959^{ns}	-6.142^{ns}
V5 (P1*P6)	-2.170^{ns}	-1.673^{ns}	0.117^{ns}	2.459^{ns}	-1.966^{ns}	0.187^{ns}	0.104^{ns}	0.062^{ns}	0.514^{ns}	-3.170^{ns}	-0.126^{ns}	-13.440^{ns}
V6 (P1*P7)	-0.122^{ns}	-0.197^{ns}	5.689^{ns}	1.586^{ns}	-0.823^{ns}	1.401**	0.706*	-0.021^{ns}	-0.272^{ns}	1.068^{ns}	0.898^{ns}	7.047^{ns}
V7 (P2*P1)	-0.167^{ns}	-0.167^{ns}	4.158^{ns}	7.683*	0.500^{ns}	0.000^{ns}	-0.105^{ns}	0.092^{ns}	-0.333^{ns}	0.000^{ns}	0.500^{ns}	-1.688^{ns}
V8 (P2*P3)	-0.456^{ns}	-0.650^{ns}	-3.513^{ns}	-0.666^{ns}	-0.799^{ns}	1.020**	-0.227^{ns}	0.053^{ns}	0.323^{ns}	-1.265^{ns}	1.017^{ns}	1.495^{ns}
V9 (P2*P4)	1.973*	1.803*	-4.380^{ns}	-2.697^{ns}	1.558*	0.235^{ns}	-0.110^{ns}	-0.020^{ns}	0.490^{ns}	1.116^{ns}	-0.769^{ns}	6.841^{ns}
V10 (P2*P5)	-1.265^{ns}	-0.578^{ns}	-2.739^{ns}	-3.330^{ns}	0.486^{ns}	-0.527^{ns}	0.018^{ns}	0.058^{ns}	0.014^{ns}	-0.122^{ns}	0.731^{ns}	1.847^{ns}
V11 (P2*P6)	-1.503^{ns}	-1.531^{ns}	3.753^{ns}	-1.162^{ns}	-1.252^{ns}	0.282^{ns}	-0.317^{ns}	-0.161^{ns}	-0.320^{ns}	-1.432^{ns}	2.565**	-2.251^{ns}
V12 (P2*P7)	1.711*	1.112^{ns}	3.267^{ns}	4.271^{ns}	0.391^{ns}	-0.003^{ns}	0.180^{ns}	-0.086^{ns}	0.061^{ns}	1.639^{ns}	-1.912^{ns}	0.948^{ns}
V13 (P3*P1)	1.000^{ns}	1.500^{ns}	-3.043^{ns}	-0.568^{ns}	-0.167^{ns}	0.000^{ns}	0.707^{ns}	0.095^{ns}	-0.333^{ns}	1.333^{ns}	-0.500^{ns}	1.367^{ns}
V14 (P3*P2)	1.000^{ns}	0.667^{ns}	-13.400^{ns}	-5.500^{ns}	0.167^{ns}	0.167^{ns}	-1.113^{ns}	-0.044^{ns}	-0.167^{ns}	-3.333^{ns}	-2.333^{ns}	-29.517^{ns}
V15 (P3*P4)	0.830^{ns}	1.160^{ns}	2.852^{ns}	1.122^{ns}	0.344^{ns}	0.378^{ns}	0.434^{ns}	0.065^{ns}	-0.986^{ns}	2.782**	0.636^{ns}	3.913^{ns}
V16 (P3*P5)	0.759^{ns}	0.446^{ns}	-0.604^{ns}	-0.858^{ns}	0.772^{ns}	0.116^{ns}	-0.169^{ns}	-0.152^{ns}	-0.296^{ns}	-0.789^{ns}	-1.364^{ns}	-13.740^{ns}
V17 (P3*P6)	-0.313^{ns}	-1.007^{ns}	6.655^{ns}	4.210^{ns}	0.201^{ns}	-0.075^{ns}	-0.159^{ns}	0.279**	0.037^{ns}	0.735^{ns}	-0.031^{ns}	5.164^{ns}
V18 (P3*P7)	-0.099^{ns}	0.469^{ns}	-4.521^{ns}	-2.872^{ns}	0.010^{ns}	-0.027^{ns}	-0.174^{ns}	-0.016^{ns}	0.585^{ns}	-0.861^{ns}	1.827*	9.929^{ns}
V19 (P4*P1)	-0.167^{ns}	-0.333^{ns}	-0.990^{ns}	-0.563^{ns}	0.000^{ns}	-0.167^{ns}	-0.543^{ns}	-0.122^{ns}	-0.167^{ns}	-1.667^{ns}	-1.833^{ns}	-19.463^{ns}
V20 (P4*P2)	-2.500^{ns}	-2.500^{ns}	-0.213^{ns}	4.347^{ns}	-0.167^{ns}	0.667^{ns}	-0.266^{ns}	-0.128^{ns}	0.000^{ns}	-1.167^{ns}	-2.000^{ns}	-16.130^{ns}
V21 (P4*P3)	-2.167^{ns}	-3.500^{ns}	1.643^{ns}	1.917^{ns}	-2.000^{ns}	-0.833^{ns}	-0.367^{ns}	-0.108^{ns}	0.667^{ns}	0.500^{ns}	-0.333^{ns}	7.878^{ns}
V22 (P4*P5)	0.854^{ns}	0.898^{ns}	1.669^{ns}	-1.310^{ns}	0.796^{ns}	0.330^{ns}	0.516^{ns}	0.068^{ns}	0.037^{ns}	1.259^{ns}	1.517*	15.214**
V23 (P4*P6)	-0.051^{ns}	-0.054^{ns}	4.575^{ns}	2.123^{ns}	-0.276^{ns}	-0.527^{ns}	0.664^{ns}	0.079^{ns}	0.871**	1.116^{ns}	0.684^{ns}	18.710**
V24 (P4*P7)	-1.170^{ns}	-1.745^{ns}	-2.374^{ns}	-0.491^{ns}	-0.133^{ns}	-0.313^{ns}	-0.500^{ns}	0.001^{ns}	0.085^{ns}	-2.313^{ns}	-0.959^{ns}	-14.835^{ns}
V25 (P5*P1)	-0.667^{ns}	-1.500^{ns}	8.780^{ns}	5.773^{ns}	-0.333^{ns}	0.500^{ns}	0.132^{ns}	-0.120^{ns}	-1.500^{ns}	0.667^{ns}	3.000**	-0.060^{ns}

D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height (cm), EH= Ear height (cm), DM= Dates of maturity; NBT= Number of branches in tassels; EL= Ear length (cm), ED= Ear diameter (cm), NRPE=Number of row per ear, NKPR= Number of Kernel per row; 100KW= Hundred Kernel weight (g), KYPP=Kernel yield per plant(g). *P>0.05, **P>0.01,ns= non-significance.

Table 8. Estimates Specific Combining Ability (SCA) for twelve plant characters in 7×7 diallel of white maize (Cont'd)

Crosses	D 1T	D 50% F	PH	EH	DM	NBT	EL	ED	NRPC	NKPR	100 KW	KYPP
V26 (P5*P2)	-1.833^{ns}	-1.833^{ns}	1.490^{ns}	3.223^{ns}	0.333^{ns}	0.333^{ns}	-0.502^{ns}	0.003^{ns}	-0.500^{ns}	-0.833^{ns}	-1.667^{ns}	-17.075^{ns}
V27 (P5*P3)	-1.000^{ns}	-1.500^{ns}	9.150^{ns}	5.733^{ns}	0.000^{ns}	1.000**	0.135^{ns}	0.098^{ns}	0.333^{ns}	3.167**	-0.167^{ns}	20.112**
V28 (P5*P4)	-0.500^{ns}	0.333^{ns}	-3.323^{ns}	-4.425^{ns}	0.333^{ns}	0.500^{ns}	-0.198^{ns}	0.082^{ns}	-0.333^{ns}	-0.333^{ns}	-1.167^{ns}	-11.073^{ns}
V29 (P5*P6)	-0.456^{ns}	-0.435^{ns}	0.109^{ns}	2.503^{ns}	-0.847^{ns}	0.544^{ns}	0.181^{ns}	0.000^{ns}	-0.439^{ns}	1.378^{ns}	0.517^{ns}	6.214^{ns}
V30 (P5*P7)	-1.908^{ns}	-1.959^{ns}	4.435^{ns}	3.096^{ns}	-0.537^{ns}	-0.741^{ns}	-0.060^{ns}	0.133^{ns}	0.442^{ns}	-1.051^{ns}	3.041**	12.087*
V31 (P6*P1)	-0.167^{ns}	0.167^{ns}	10.942*	2.275^{ns}	-0.500^{ns}	0.333^{ns}	-0.160^{ns}	0.150^{ns}	-0.333^{ns}	0.333^{ns}	2.833**	9.817^{ns}
V32 (P6*P2)	-0.500^{ns}	-0.333^{ns}	2.533^{ns}	3.903^{ns}	-0.500^{ns}	0.333^{ns}	-0.242^{ns}	-0.010^{ns}	0.000^{ns}	2.000^{ns}	-1.500^{ns}	5.755^{ns}
V33 (P6*P3)	-1.500^{ns}	-1.167^{ns}	7.407^{ns}	1.673^{ns}	0.333^{ns}	1.000**	0.350^{ns}	0.288**	0.833*	0.500^{ns}	0.833^{ns}	15.467*
V34 (P6*P4)	0.833^{ns}	0.500^{ns}	-2.153^{ns}	-2.117^{ns}	0.500^{ns}	-0.167^{ns}	-0.175^{ns}	-0.015^{ns}	0.333^{ns}	-1.000^{ns}	-0.333^{ns}	-4.083^{ns}
V35 (P6*P5)	-1.000^{ns}	-1.167^{ns}	0.237^{ns}	1.107^{ns}	-0.167^{ns}	0.333^{ns}	0.590^{ns}	0.033^{ns}	0.667^{ns}	1.500^{ns}	0.333^{ns}	17.227*
V36 (P6*P7)	1.187^{ns}	1.088^{ns}	-4.138^{ns}	-2.213^{ns}	1.058^{ns}	0.235^{ns}	0.252^{ns}	-0.040^{ns}	-0.391^{ns}	3.306**	-0.126^{ns}	12.464*
V37 (P7*P1)	0.500^{ns}	0.167^{ns}	7.683^{ns}	2.617^{ns}	0.333^{ns}	0.833*	0.812*	-0.098^{ns}	-1.000^{ns}	1.000^{ns}	3.000**	3.857^{ns}
V38 (P7*P2)	-0.333^{ns}	-0.167^{ns}	-0.167^{ns}	-1.000^{ns}	-0.500^{ns}	-0.667^{ns}	0.152^{ns}	-0.163^{ns}	-0.833^{ns}	0.500^{ns}	-2.167^{ns}	-15.880^{ns}
V39 (P7*P3)	-0.333^{ns}	0.167^{ns}	3.950^{ns}	2.042^{ns}	0.167^{ns}	-1.333^{ns}	0.372^{ns}	0.015^{ns}	0.167^{ns}	2.000^{ns}	0.167^{ns}	15.052*
V40 (P7*P4)	-0.667^{ns}	-0.333^{ns}	1.217^{ns}	0.100^{ns}	0.667^{ns}	0.333^{ns}	0.947*	0.005^{ns}	0.333^{ns}	3.333**	1.833*	29.895**
V41 (P7*P5)	-2.167^{ns}	-1.833^{ns}	-1.125^{ns}	3.750^{ns}	0.167^{ns}	-0.333^{ns}	0.398^{ns}	0.038^{ns}	0.667^{ns}	1.500^{ns}	-0.667^{ns}	14.370*
V42 (P7*P6)	-0.500^{ns}	-0.333^{ns}	-0.033^{ns}	1.400^{ns}	-0.333^{ns}	-0.167^{ns}	-0.138^{ns}	0.137^{ns}	0.667^{ns}	1.333^{ns}	-1.167^{ns}	8.012^{ns}
Max	1.973	1.803	10.942	7.683	1.867	1.401	1.125	0.288	0.871	3.997	3.041	29.895
Min	-2.789	-3.500	-13.400	-5.500	-2.180	-1.333	-1.113	-0.163	-1.500	-3.333	-2.333	-29.517
SE (sij)	0.807	0.766	4.160	2.885	0.680	0.312	0.345	0.083	0.322	0.990	0.740	5.763
SE (sij-sik)	1.216	1.154	6.267	4.347	1.024	0.470	0.520	0.125	0.485	1.492	1.115	8.683
SE (sij-skl)	1.110	1.054	5.721	3.968	0.935	0.429	0.475	0.114	0.443	1.362	1.018	7.926

D1T D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height (cm), EH= Ear height (cm), DM= Dates of maturity, NBT= Number of branches in tassels, EL= Ear length (cm), ED= Ear diameter (cm), NRPE=Number of row per ear, NKPR= Number of Kernel per row; 100KW= Hundred Kernel weight (g), KYPP= Kernel yield per plant(g).*P>0.05, **P>0.01,ns= non-significance

4.2.2.3 Plant height (cm)

Negative estimates are also desirable in cross combination for plant height. Among 42 crosses the F_1 hybrid P2xP1 (V7) was the tallest and showed the highest positive and significant SCA effect, while the eighteen crosses showed negative but non-significant SCA effects in desirable direction for plant height (Table 8) indicating that the crosses had poor specific combination for shorter ear shorter height. Begum *et al.* (2018) and Kamara *et al*. (2014) also founded non-significant and negative SCA effects for plant height. Ahmed *et al*. (2014) and Karim *et al*. (2018) founded significance dwarf type and tall type plant in their observation.

4.2.2.4 Ear height (cm)

Again negative estimates are also desirable in cross combination for ear height. Among 42 cross the F_1 hybrid P6xP1 (V31) was the highest ear height and showed the highest positive and significant SCA effect, while eighteen other crosses showed negative but non-significant SCA effects in desirable direction for ear height (Table 8). This indicated that the crosses had poor specific combination for shorter ear shorter height. Ahmed *et al*. (2014) and Karim *et al*. (2018) founded significance dwarf type and tall type plant in their observation.

4.2.2.5 Days to maturity

The estimation showed that out of 42 crosses only two cross P1xP2 (V1) and P2xP4 (V9) exhibited positive significance SCA (Table 8). Negative significance SCA was desirable for this character. Among 42 crosses eighteen crosses showed negative but non-significance SCA i.e. all the crosses were poor combiner founded for the character.

4.2.2.6 Number of branches in tassel

Among the F_1 progenies of the crosses five crosses *viz.* P1xP7 (V6), P2xP3 (V8), P5xP3 (V27), P6xP3 (V33) and P7xP1 (V37) were showed positive significance effect considered as good combiner of the character of number of branches in tassel (Table 8). The cross combination P1xP7 (V6) produced the highest significant positive effects followed by P1xP7 (V6) , P2xP3 (V8), P5xP3 (V27) and P6xP3 (V33) considered as the best specific combiner for the trait concerned. So for obtaining desirable hybrid with highest number of branches in tassel these cross combinations could be selected for future breeding program.

4.2.2.7 Ear length (cm)

Out of forty-two cross combinations there were four crosses founded to have positive significant SCA effects for ear length (Table 8). The cross combination P1xP3 (V2) produced the highest significant positive effects followed by P7xP4 (V40), P7xP1 (V37) and P1xP7 (V6) considered as the best specific combiner for the trait concerned. So for obtaining desirable hybrid with longer ear length these cross combinations could be selected for future breeding program. Premalatha *et al*. (2011) and Zeleke (2015) supported this finding.

4.2.2.8 Ear diameter (cm)

The highest significant and positive SCA effects for ear diameter was obtained in the cross P6 xP3 (V33) which was followed by P3xP6 (V17). Thus the two combinations P6xP3 (V33) and P3xP6 (V17) were considered as the best specific combiner for this trait which indicated that these combinations would be effective for thick ear as well as higher yield (Table 8). Sugiharto *et al*. (2018), and Purushottam and Shanthakumar (2017) also estimated positive significance SCA effects for ear diameter.

4.2.2.9 Number of row per ear

Out of forty-two cross combination, there were two crosses exhibited positive significant SCA effects for number of row per ear (Table 8). The cross combination P6xP3 (V33) produced the highest significant positive effects followed by P4xP6 (V23), considered as the best specific combiner for the trait concerned. So for obtaining desirable hybrid with highest number of row per ear these cross combinations could be selected for future breeding program. Uddin *et al*. (2008) and Zeleke (2015) supported this finding.

4.2.2.10 Number of kernel per row

Among forty two crosses five cross combinations P1xP3 (V2), P3xP4 (V15), P5xP3 (V27), P6xP7 (V36) and P7xP4 (V40) produced the highest positive and one cross P1xP2(V1) possessed less significant positive SCA effect on this character (Table 8). P1xP3 (V2), P3xP4 (V15), P5xP3 (V27), P6xP7 (V36) and P7xP4 (V40) might be selected as the best specific combiner for number of kernal per row which has been considerd as one of the important yield contributing traits. Kamara *et al*. (2014), Uddin *et al*. (2008) and Ahmed *et al*. (2014) were also founded positive significance on some crosses for this character

4.2.2.11 Hundred kernel weight (g)

Higher kernel weight is one of the most yield contributing traits for getting higher yield in maize. There were six crosses *viz.* P1xP2 (V1), P2xP6 (V11), P5xP1 (V25), P5xP7 (V30), P6xP1 (V31) and P7xP1 (V37) founded to have highly positive significant SCA effects and three crosses P3xP7 (V18), P4xP5 (V22) and P7xP4 (V40) showed positive significance for hundred kernel weight (Table 8). So for obtaining desirable hybrid with highest hundred kernel weight these cross combinations could be selected for future breeding program. Kumar *et al*. (2017) and Uddin *et al*. (2008) supported this finding. While Sugiharto *et al*. (2018) and Karim *et al*. (2018) also founnd some good combination for 1000 kernel weight.

4.2.2.12 Kernel yield per plant (g)

Incase of kernel yield per plant out of forty-two F_1 hybrids, five crosses viz. showed P1xP3 (V2), P4xP5 (V22), P4xP6 (V23), P5xP3 (V27) and P7xP4 (V40) founded to have positive highly significant SCA effects and five crosses P1xP2 (V1), P5xP7 (V30), P6xP3 (V33), P6xP7 (V30), and P7xP5 (V41) showed positive significance SCA for yield per plant (Table 8). So for obtaining desirable hybrid with highest yield kernel per plant cross with highly positive significant value could be selected for future breeding program. Singh *et al*. (2017), Kumar *et al*. (2017) and Uddin *et al.* (2008) agreed with this finding.

4.3 Analysis of Heterosis

The magnitude of heterosis provides information on extent of genetic diversity of parents in developing superior F_1 so as to exploit hybrid. Usually standard heterosis is measured over a commercially cultivated popular variety or hybrid variety. In this experiment two standard check varieties BARI hybrid Maize 12 (CV1) and BARI hybrid maize 13 (CV2) were included as check variety for better comparison of twelve yield contributing characters of the forty-two experimental hybrids. Percent heterosis for different characters of the F_1 hybrids over better parent (BP) and standard check values are shown in Table 9. The result of percent of heterosis in crosses varied from character to character or from cross to cross.

4.3.1 Days to 1st tasseling

Days to tasseling revealed the earliness or lateness of a hybrid. Negative heterosis is desirable for this trait. Out of forty-two cross twelve hybrids showed significance heterosis over better parent (BP) and among them three hybrids showed significant negative value. Highly negative significant heterosis (-5.90%) was provided by the hybrid P1xP6 (V5) for days to tasseling over their better parent P6 (Table 9). In case of standard hererosis three F_1 *viz*. P1xP3 (V13), P4xP7 (V24) and P5xP7 (V30) possessed desirable significant negative heterosis over both check variety BARI hybrid vhutta 12 and BARI hybrid vhutta 13. Among three P5xP7 (V30) showed highest negative significance heterosis -8.81 and -9.60 over check 1 and check 2, respectively (Table 9). While two crosses showed negative significantheterosis over check 2 variety, Karim *et al*. (2018) noticed negative significant heterotic values for days to tasseling over check variety .

4.3.2 Days to 50% tasselling

Negative heterosis is desirable for this trait. Out of forty-two cross ten hybrids showed significance heterosis over better parent and among them three hybrids showed significant negative value. Highly negative significant heterosis (-4.89%) was provided by the hybrid P1xP6 (V5) for days to 50% tasseling over their better parent P6. Incase of standard hererosis one F_1 viz. P5xP7 (V30) possessed desirable significant negative heterosis over both check variety BHM 12 and BHM 13 (Table 9). While five crosses *viz.* P3xP1 (V13), P3xP4 (V15), P3xP6 (V17), P4xP7 (V24),

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F$_1$ hybrids derived from 7×7 diallel cross in White maize

Crosses	D 1T			D 50% F			PH			EH		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V1 (P1*P2)	4.46^{ns}	3.08^{ns}	2.18^{ns}	2.99^{ns}	3.43^{ns}	1.68^{ns}	7.17^{ns}	22.72**	19.54**	17.50*	44.49**	43.56**
V2 (P1*P3)	-2.21^{ns}	-2.64^{ns}	-3.49^{ns}	-0.42^{ns}	0.00^{ns}	-1.68^{ns}	4.05^{ns}	18.66**	15.59**	2.32^{ns}	25.83**	25.02**
V3 (P1*P4)	8.37**	2.64^{ns}	1.74^{ns}	6.19**	3.00^{ns}	1.26^{ns}	0.02^{ns}	14.54**	11.57**	-2.12^{ns}	18.74^{ns}	17.98^{ns}
V4 (P1*P5)	0.88^{ns}	0.88^{ns}	0.00^{ns}	-0.42^{ns}	0.85^{ns}	-0.84^{ns}	6.35^{ns}	22.62**	19.45**	10.16^{ns}	28.71**	27.89**
V5 (P1*P6)	-5.90**	-1.76^{ns}	-2.62^{ns}	-4.89*	0.00^{ns}	-1.68^{ns}	17.62**	21.92**	18.76**	20.08*	32.28**	31.43**
V6 (P1*P7)	4.16^{ns}	-0.88^{ns}	-1.74^{ns}	2.20^{ns}	-0.43^{ns}	-2.11^{ns}	11.41*	24.92**	21.69**	9.50^{ns}	34.38**	33.51**
V7 (P2*P1)	4.91*	3.52^{ns}	2.62^{ns}	3.41^{ns}	3.86^{ns}	2.11^{ns}	2.78^{ns}	17.69**	14.64**	-1.17^{ns}	21.52**	20.74**
V8 (P2*P3)	0.89^{ns}	-0.44^{ns}	-1.31^{ns}	-0.42^{ns}	0.00^{ns}	-1.68^{ns}	-7.40^{ns}	5.60^{ns}	2.86^{ns}	-5.35^{ns}	17.98^{ns}	17.22^{ns}
V9(P2*P4)	5.11*	-0.44^{ns}	-1.31^{ns}	3.54^{ns}	0.42^{ns}	-1.26^{ns}	-2.44^{ns}	11.71**	8.81^{ns}	3.11^{ns}	25.10**	24.29**
V10 (P2*P5)	-3.12^{ns}	-4.40^{ns}	-5.24**	-2.56^{ns}	-2.14^{ns}	-3.79^{ns}	0.86^{ns}	15.49**	12.50**	4.26^{ns}	21.82**	21.04**
V11 (P2*P6)	-0.89^{ns}	-2.20^{ns}	-3.05^{ns}	-1.70^{ns}	-1.28^{ns}	-2.95^{ns}	12.35*	16.46**	13.44**	17.51*	29.45**	28.62**
V12 (P2*P7)	4.62^{ns}	-0.44^{ns}	-1.31^{ns}	2.64^{ns}	0.00^{ns}	-1.68^{ns}	3.57^{ns}	16.14**	13.13**	8.48^{ns}	33.13**	32.27**
V13 (P3*P1)	-4.86*	-5.28**	-6.11**	-4.27*	-3.86^{ns}	-5.48**	7.28^{ns}	22.34**	19.18**	3.70^{ns}	27.52**	26.70**
V14 (P3*P2)	-1.78^{ns}	-3.08^{ns}	-3.93^{ns}	-2.13^{ns}	-1.71^{ns}	-3.37^{ns}	6.80^{ns}	21.80**	18.65**	7.83^{ns}	34.42**	33.56**
V15 (P3*P4)	1.86^{ns}	-3.52^{ns}	-4.36^{ns}	-0.44^{ns}	-3.43^{ns}	-5.06**	3.51^{ns}	18.05**	14.99**	3.57^{ns}	25.66**	24.85**
V16 (P3*P5)	-2.21^{ns}	-2.64^{ns}	-3.49^{ns}	-2.56^{ns}	-2.14^{ns}	-3.79^{ns}	7.21^{ns}	22.26**	19.10**	9.33^{ns}	27.75**	26.93**
V17 (P3*P6)	-3.53^{ns}	-3.96^{ns}	-4.80^{ns}	-3.84^{ns}	-3.43^{ns}	-5.06**	17.71**	22.01**	18.85**	20.40*	32.63**	31.78**
V18 (P3*P7)	0.00^{ns}	-4.84^{ns}	-5.67**	0.44^{ns}	-2.14^{ns}	-3.79^{ns}	2.35^{ns}	14.77**	11.79**	2.25^{ns}	25.48**	24.67**
V19 (P4*P1)	8.83**	3.08^{ns}	2.18^{ns}	7.08**	3.86^{ns}	2.11^{ns}	1.07^{ns}	15.73**	12.74**	-0.73^{ns}	20.42**	19.65^{ns}
V20 (P4*P2)	12.09**	6.16**	5.24**	10.17**	6.86**	5.06**	-2.21^{ns}	11.96**	9.06^{ns}	-7.59^{ns}	12.10^{ns}	11.38^{ns}
V21 (P4*P3)	7.90**	2.20^{ns}	1.31^{ns}	8.85**	5.57**	3.79^{ns}	1.77**	16.06**	13.06**	-1.15^{ns}	19.93**	19.15^{ns}
V22 (P4*P5)	5.11*	-0.44^{ns}	-1.31^{ns}	5.31*	2.14^{ns}	0.42^{ns}	0.22^{ns}	14.76**	11.79**	-8.14^{ns}	7.32^{ns}	6.63^{ns}
V23 (P4*P6)	6.51**	0.88^{ns}	0.00^{ns}	4.42*	1.28^{ns}	-0.42^{ns}	9.63*	13.63**	10.69^{ns}	8.28^{ns}	19.28^{ns}	18.51^{ns}
V24 (P4*P7)	0.00^{ns}	-5.28**	-6.11**	-1.32^{ns}	-4.29^{ns}	-5.90**	0.84^{ns}	13.07**	10.14^{ns}	0.20^{ns}	21.57**	20.79**
V25 (P5*P1)	2.64^{ns}	2.64^{ns}	1.74^{ns}	3.38^{ns}	4.72^{ns}	2.95^{ns}	-2.84^{ns}	12.00**	9.10^{ns}	-4.60^{ns}	11.46^{ns}	10.74^{ns}
V26 (P5*P2)	1.78^{ns}	0.44^{ns}	-0.43^{ns}	2.13^{ns}	2.57^{ns}	0.84^{ns}	-0.71^{ns}	13.69**	10.75^{ns}	-3.98^{ns}	12.18^{ns}	11.46^{ns}

D1T= Days of 1St tasseling, D50%T= Days of 50% tasseling, PH= Plant height(cm), EH= Ear height(cm).
P>0.05,**P>0.01, ns = non-significance.

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F_1 hybrids derived from 7×7 diallel cross in White maize (Cont'd)

Crosses	D 1T			D 50% F			PH			EH		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V27 (P5*P3)	0.44^{ns}	0.00^{ns}	-0.87^{ns}	1.28^{ns}	1.71^{ns}	0.00^{ns}	-2.49^{ns}	11.20^{ns}	8.32^{ns}	-5.33^{ns}	10.61^{ns}	9.90^{ns}
V28 (P5*P4)	0.88^{ns}	0.88^{ns}	0.00^{ns}	0.00^{ns}	1.28^{ns}	-0.42^{ns}	1.26^{ns}	18.78**	15.70**	3.17^{ns}	20.55**	19.77^{ns}
V29 (P5*P6)	-2.64^{ns}	-2.64^{ns}	-3.49^{ns}	-2.96^{ns}	-1.71^{ns}	-3.37^{ns}	10.12*	14.14**	11.19**	12.57^{ns}	24.01**	23.21**
V30 (P5*P7)	-4.16^{ns}	-8.81**	-9.60**	-4.40*	-6.86**	-8.43**	4.82^{ns}	17.54**	14.49**	12.75^{ns}	31.73**	30.89**
V31 (P6*P1)	-5.48*	-1.32^{ns}	-2.18^{ns}	-5.30**	-0.43^{ns}	-2.11^{ns}	4.86^{ns}	8.69^{ns}	5.87^{ns}	13.91^{ns}	25.48**	24.67**
V32 (P6*P2)	0.44^{ns}	-0.88^{ns}	-1.74^{ns}	-0.85^{ns}	-0.43^{ns}	-2.11^{ns}	9.40^{ns}	13.40**	10.46^{ns}	6.92^{ns}	17.78^{ns}	17.03^{ns}
V33 (P6*P3)	0.44^{ns}	0.00^{ns}	-0.87^{ns}	-0.85^{ns}	-0.43^{ns}	-2.11^{ns}	9.07^{ns}	13.05**	10.13^{ns}	15.86*	27.63**	26.81**
V34 (P6*P4)	4.18^{ns}	-1.32^{ns}	-2.18^{ns}	3.09^{ns}	0.00^{ns}	-1.68^{ns}	12.14*	16.24**	13.23**	14.02^{ns}	25.61**	24.80**
V35 (P6*P5)	0.00^{ns}	0.00^{ns}	-0.87^{ns}	0.00^{ns}	1.28^{ns}	-0.42^{ns}	9.84*	13.85**	10.91^{ns}	9.57^{ns}	20.70**	19.93**
V36 (P6*P7)	3.24^{ns}	-1.76^{ns}	-2.62^{ns}	1.76^{ns}	-0.85^{ns}	-2.53^{ns}	5.57^{ns}	9.43^{ns}	6.59^{ns}	12.26^{ns}	23.66**	22.87**
V37(P7*P1)	2.77^{ns}	-2.20^{ns}	-3.05^{ns}	1.76^{ns}	-0.85^{ns}	-2.53^{ns}	3.12^{ns}	15.63**	12.64**	3.12^{ns}	26.55**	25.74**
V38 (P7*P2)	5.55*	0.44^{ns}	-0.43^{ns}	3.08^{ns}	0.42^{ns}	-1.26^{ns}	3.75^{ns}	16.34**	13.32**	10.92^{ns}	36.12**	35.24**
V39 (P7*P3)	0.92^{ns}	-3.96^{ns}	-4.80^{ns}	0.00^{ns}	-2.57^{ns}	-4.21^{ns}	-1.90^{ns}	9.99^{ns}	7.14^{ns}	-2.72^{ns}	19.38^{ns}	18.61^{ns}
V40 (P7*P4)	1.86^{ns}	-3.52^{ns}	-4.36^{ns}	-0.44^{ns}	-3.43^{ns}	-5.06**	-0.46^{ns}	11.60**	8.71^{ns}	-0.04^{ns}	21.27**	20.49**
V41 (P7*P5)	1.85^{ns}	-3.08^{ns}	-3.93^{ns}	0.44^{ns}	-2.14^{ns}	-3.79^{ns}	6.03^{ns}	18.90**	15.82**	3.15^{ns}	20.52**	19.75^{ns}
V42 (P7*P6)	4.62^{ns}	-0.44^{ns}	-1.31^{ns}	2.64^{ns}	0.00^{ns}	-1.68^{ns}	5.60^{ns}	9.47^{ns}	6.63^{ns}	8.46^{ns}	19.48^{ns}	18.71^{ns}

D1T= Days of 1St tasseling; D50%T= Days of 50% tasseling; PH= Plant height(cm); EH= Ear height(cm);
* P>0.05,**P>0.01, ns = non-significance.

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F_1 hybrids derived from 7×7 diallel cross in White maize (Cont'd)

Crosses	DM			NBT			EL			ED		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V1 (P1*P2)	3.48^{**}	2.21^{ns}	2.97^{**}	5.7^{ns}	-9.76^{ns}	-13.95^{**}	4.91^{ns}	-3.37^{ns}	9.23^{ns}	0.14^{ns}	5.83^{ns}	4.42^{ns}
V2 (P1*P3)	-1.97^{ns}	-2.21^{ns}	-1.48^{ns}	5.71^{ns}	-9.76^{ns}	-13.95^{**}	18.64^{**}	10.16^{**}	24.53^{**}	-0.27^{ns}	3.63^{ns}	2.25^{ns}
V3 (P1*P4)	3.01^{**}	0.73^{ns}	1.48^{ns}	0.00^{ns}	-7.31^{ns}	-11.62^{ns}	5.57^{ns}	-4.28^{ns}	8.20^{ns}	-1.91^{ns}	1.92^{ns}	0.57^{ns}
V4 (P1*P5)	0.74^{ns}	0.00^{ns}	0.74^{ns}	0.00^{ns}	-14.63^{**}	-18.60^{**}	-0.18^{ns}	-4.07^{ns}	8.44^{ns}	-7.54^{*}	-3.93^{ns}	-5.20^{ns}
V5 (P1*P6)	-3.61^{**}	-1.72^{ns}	-0.99^{ns}	11.43^{ns}	-4.88^{ns}	-9.30^{ns}	8.34^{ns}	-6.59^{ns}	5.59^{ns}	3.35^{ns}	7.38^{ns}	5.96^{ns}
V6 (P1*P7)	1.00^{ns}	-1.22^{ns}	-0.49^{ns}	25.00^{**}	9.75^{ns}	4.65^{ns}	13.27^{**}	8.08^{ns}	22.18^{**}	-3.90^{ns}	-0.15^{ns}	-1.47^{ns}
V7 (P2*P1)	2.73^{**}	1.47^{ns}	2.22^{ns}	5.71^{ns}	-9.76^{ns}	-13.95^{**}	6.36^{ns}	-2.04^{ns}	10.74^{ns}	-3.55^{ns}	1.92^{ns}	0.57^{ns}
V8 (P2*P3)	0.24^{ns}	-0.98^{ns}	-0.24^{ns}	22.59^{**}	-7.31^{ns}	-11.62^{ns}	-7.13^{ns}	-13.77^{**}	-2.52^{ns}	-2.62^{ns}	2.90^{ns}	1.54^{ns}
V9(P2*P4)	3.51^{**}	1.22^{ns}	1.98^{ns}	2.63^{ns}	-4.88^{ns}	-9.30^{ns}	0.14^{ns}	-7.76^{ns}	4.27^{ns}	-6.66^{*}	-1.37^{ns}	-2.67^{ns}
V10 (P2*P5)	1.99^{ns}	0.73^{ns}	1.48^{ns}	-3.03^{ns}	-21.95^{**}	-25.57^{**}	-5.41^{ns}	-9.10^{ns}	2.76^{ns}	-3.69^{ns}	1.771^{ns}	0.42^{ns}
V11 (P2*P6)	0.00^{ns}	-1.22^{ns}	-0.49^{ns}	8.82^{ns}	-9.76^{ns}	-13.95^{**}	-6.12^{ns}	-13.53^{**}	-2.25^{ns}	-6.52^{ns}	-1.22^{ns}	-2.53^{ns}
V12 (P2*P7)	1.25^{ns}	-0.98^{ns}	-0.24^{ns}	-5.56^{ns}	-17.07^{**}	-20.93^{**}	1.45^{ns}	-3.20^{ns}	9.42^{ns}	-8.54^{*}	-3.35^{ns}	-4.63^{ns}
V13 (P3*P1)	-1.72^{ns}	-1.96^{ns}	-1.23^{ns}	5.71^{ns}	-9.76^{ns}	-13.95^{**}	8.96^{ns}	1.17^{ns}	14.37^{**}	-4.17^{ns}	-0.43^{ns}	-1.75^{ns}
V14 (P3*P2)	0.00^{ns}	-1.22^{ns}	-0.49^{ns}	19.36^{**}	-9.76^{ns}	-13.95^{**}	8.14^{ns}	0.41^{ns}	13.50^{**}	-0.83^{ns}	4.80^{ns}	3.41^{ns}
V15 (P3*P4)	0.25^{ns}	-1.96^{ns}	-1.23^{ns}	-7.89^{ns}	-14.63^{**}	-18.60^{**}	6.01^{ns}	-1.57^{ns}	11.27^{ns}	1.51^{ns}	0.70^{ns}	-0.63^{ns}
V16 (P3*P5)	0.49^{ns}	-0.24^{ns}	0.49^{ns}	9.09^{ns}	-12.19^{ns}	-16.27^{**}	1.08^{ns}	-2.86^{ns}	9.81^{ns}	-0.06^{ns}	-0.85^{ns}	-2.17^{ns}
V17 (P3*P6)	-0.24^{ns}	-0.49^{ns}	0.24^{ns}	11.77^{ns}	-7.31^{ns}	-11.62^{ns}	1.90^{ns}	-5.38^{ns}	6.96^{ns}	15.27^{**}	14.36^{**}	12.84^{**}
V18 (P3*P7)	0.50^{ns}	-1.72^{ns}	-0.99^{ns}	-11.11^{ns}	-21.95^{**}	-25.57^{**}	4.10^{ns}	-0.68^{ns}	12.28^{**}	0.15^{ns}	1.77^{ns}	0.42^{ns}
V19 (P4*P1)	3.01^{**}	0.73^{ns}	1.48^{ns}	2.63^{ns}	-4.88^{ns}	-9.30^{ns}	13.20^{**}	2.64^{ns}	16.02^{**}	3.08^{ns}	7.11^{ns}	5.68^{ns}
V20 (P4*P2)	3.76^{**}	1.47^{ns}	2.22^{ns}	-7.89^{ns}	-14.63^{**}	-18.60^{**}	3.81^{ns}	-4.38^{ns}	8.10^{ns}	-1.47^{ns}	4.12^{ns}	2.74^{ns}
V21 (P4*P3)	3.26^{**}	0.98^{ns}	1.73^{ns}	5.26^{ns}	-2.44^{ns}	-6.97^{ns}	11.03^{ns}	3.10^{ns}	16.55^{**}	6.17^{ns}	5.33^{ns}	3.94^{ns}
V22 (P4*P5)	3.01^{**}	0.73^{ns}	1.48^{ns}	-2.6^{ns}	-9.76^{ns}	-13.95^{**}	3.26^{ns}	-0.76^{ns}	12.18^{**}	4.66^{ns}	2.56^{ns}	1.20^{ns}
V23 (P4*P6)	2.26^{*}	0.00^{ns}	0.74^{ns}	-7.89^{ns}	-14.63^{**}	-18.60^{**}	6.29^{ns}	-3.628^{ns}	8.94^{ns}	5.57^{ns}	2.68^{ns}	1.32^{ns}
V24 (P4*P7)	1.50^{ns}	-0.73^{ns}	0.00^{ns}	0.00^{ns}	-7.31^{ns}	-11.62^{ns}	5.60^{ns}	0.76^{ns}	13.90^{**}	-0.63^{ns}	0.98^{ns}	-0.35^{ns}
V25 (P5*P1)	1.23^{ns}	0.49^{ns}	1.23^{ns}	-8.57^{ns}	-21.95^{**}	-25.57^{**}	-1.92^{ns}	-5.74^{ns}	6.54^{ns}	-2.61^{ns}	1.19^{ns}	-0.14^{ns}
V26 (P5*P2)	1.49^{ns}	0.24^{ns}	0.99^{ns}	-9.09^{ns}	-26.83^{**}	-30.23^{**}	1.24^{ns}	-2.71^{ns}	9.97^{ns}	-3.84^{ns}	1.62^{ns}	0.27^{ns}

DM = Dates to maturity, NBT = Number of branches in tassel, EL =Ear length, ED = Ear diameter, * P>0.05,**P>0.01, ns =non-significance.

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F_1 hybrids derived from 7×7 diallel cross in White maize (Cont'd)

Crosses	DM			NBT			EL			ED		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V27 (P5*P3)	0.49^{ns}	-0.24^{ns}	0.49^{ns}	-9.09^{ns}	-26.83**	-30.23**	-0.71^{ns}	-4.58^{ns}	7.86^{ns}	-4.30^{ns}	-5.05^{ns}	-6.31^{ns}
V28 (P5*P4)	0.99^{ns}	0.24^{ns}	0.99^{ns}	3.03^{ns}	-17.07**	-20.93**	5.89^{ns}	1.76^{ns}	15.03**	1.09^{ns}	-0.93^{ns}	-2.25^{ns}
V29 (P5*P6)	-0.24^{ns}	-0.98^{ns}	-0.24^{ns}	5.89^{ns}	-12.19^{ns}	-16.27**	1.48^{ns}	-2.48^{ns}	10.23^{ns}	2.77^{ns}	0.70^{ns}	-0.63^{ns}
V30 (P5*P7)	0.75^{ns}	-1.47^{ns}	-0.74^{ns}	-13.89*	-24.39**	-27.90**	3.46^{ns}	-0.57^{ns}	12.39**	1.55^{ns}	3.20^{ns}	1.83^{ns}
V31 (P6*P1)	-2.89**	-0.98^{ns}	-0.24^{ns}	5.71^{ns}	-9.76^{ns}	-13.95**	10.70*	-4.55^{ns}	7.89^{ns}	-2.81^{ns}	0.98^{ns}	-0.35^{ns}
V32 (P6*P2)	0.74^{ns}	-0.49^{ns}	0.24^{ns}	2.95^{ns}	-14.63**	-18.60**	-2.78^{ns}	-10.45**	1.22^{ns}	-6.12^{ns}	-0.78^{ns}	-2.10^{ns}
V33 (P6*P3)	-0.73^{ns}	-0.98^{ns}	-0.24^{ns}	-5.88^{ns}	-21.95**	-25.57**	-2.90^{ns}	-9.83^{ns}	1.92^{ns}	2.86^{ns}	2.04^{ns}	0.69^{ns}
V34 (P6*P4)	1.50^{ns}	-0.73^{ns}	0.00^{ns}	-5.27^{ns}	-12.19^{ns}	-16.27**	8.75^{ns}	-1.40^{ns}	11.46**	6.25^{ns}	3.35^{ns}	1.97^{ns}
V35 (P6*P5)	0.00^{ns}	-0.73^{ns}	0.00^{ns}	0.00^{ns}	-17.07**	-20.93**	-6.34^{ns}	-9.99^{ns}	1.74^{ns}	1.31^{ns}	-0.72^{ns}	-2.04^{ns}
V36 (P6*P7)	1.50^{ns}	-0.73^{ns}	0.00^{ns}	2.78^{ns}	-9.76^{ns}	-13.95**	-1.44^{ns}	-5.95^{ns}	6.30^{ns}	1.89^{ns}	3.54^{ns}	2.16^{ns}
V37(P7*P1)	0.50^{ns}	-1.72^{ns}	-0.99^{ns}	11.11^{ns}	-2.44^{ns}	-6.97^{ns}	2.45^{ns}	-2.24^{ns}	10.50^{ns}	0.14^{ns}	4.05^{ns}	2.67^{ns}
V38 (P7*P2)	2.01^{ns}	-0.24^{ns}	0.49^{ns}	5.56^{ns}	-7.31^{ns}	-11.62^{ns}	-0.57^{ns}	-5.13^{ns}	7.24^{ns}	-1.94^{ns}	3.62^{ns}	2.25^{ns}
V39 (P7*P3)	0.25^{ns}	-1.96^{ns}	-1.23^{ns}	11.11^{ns}	-2.44^{ns}	-6.97^{ns}	-0.87^{ns}	-5.41^{ns}	6.92^{ns}	-0.48^{ns}	1.13^{ns}	-0.21^{ns}
V40 (P7*P4)	0.50^{ns}	-1.72^{ns}	-0.99^{ns}	-5.27^{ns}	-12.19^{ns}	-16.27**	-7.02^{ns}	-11.28**	0.28^{ns}	-0.84^{ns}	0.76^{ns}	-0.56^{ns}
V41 (P7*P5)	0.50^{ns}	-1.72^{ns}	-0.99^{ns}	-8.33^{ns}	-19.51**	-23.25**	-1.81^{ns}	-5.63^{ns}	6.66^{ns}	-0.06^{ns}	1.55^{ns}	0.21^{ns}
V42 (P7*P6)	2.01^{ns}	-0.24^{ns}	0.49^{ns}	5.56^{ns}	-7.31^{ns}	-11.62^{ns}	0.40^{ns}	-4.200^{ns}	8.295^{ns}	-3.84^{ns}	-2.28^{ns}	-3.57^{ns}

DM = Dates to maturity, NBT = Number of branches in tassel, EL =Ear length, ED = Ear diameter,
* P>0.05,**P>0.01, ns =non-significance.

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F$_1$ hybrids derived from 7×7 diallel cross in White maize (Cont'd)

Crosses	NRPC			NKPR			100 KW			KYPP		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V1 (P1*P2)	-10.42*	10.25^{ns}	10.25^{ns}	18.67*	-2.19^{ns}	17.11^{ns}	5.50^{ns}	8.50^{ns}	-10.85**	12.33^{ns}	17.02^{ns}	15.31^{ns}
V2 (P1*P3)	-8.33*	12.82**	12.82**	38.67**	14.29^{ns}	36.85**	3.67^{ns}	6.61^{ns}	-12.40**	32.46**	37.99**	35.97**
V3 (P1*P4)	-6.25^{ns}	15.39**	15.39**	3.61^{ns}	-5.49^{ns}	13.16^{ns}	-9.82*	-4.72^{ns}	-21.71**	-1.03^{ns}	4.08^{ns}	2.55^{ns}
V4 (P1*P5)	-16.67**	2.56^{ns}	2.56^{ns}	10.98^{ns}	0.000^{ns}	19.74**	7.34^{ns}	10.38**	-9.30**	8.78^{ns}	13.33^{ns}	11.67^{ns}
V5 (P1*P6)	-2.08^{ns}	20.52**	20.52**	-1.33^{ns}	-18.68**	-2.63^{ns}	11.01**	14.15**	-6.20^{ns}	7.68^{ns}	12.18^{ns}	10.53^{ns}
V6 (P1*P7)	-12.5**	7.69^{ns}	7.69^{ns}	13.10^{ns}	4.40^{ns}	25.00**	15.45**	19.81**	-1.55^{ns}	22.41**	32.19**	30.25**
V7 (P2*P1)	-6.25^{ns}	15.39**	15.39**	18.67*	-2.20^{ns}	17.11^{ns}	2.75^{ns}	5.66^{ns}	-13.18**	14.66^{ns}	19.46**	17.70^{ns}
V8 (P2*P3)	0.00^{ns}	15.39**	15.39**	-6.76^{ns}	-24.18**	-9.21^{ns}	0.00^{ns}	-2.83^{ns}	-20.16**	-6.83^{ns}	-15.06^{ns}	-16.30^{ns}
V9(P2*P4)	2.22^{ns}	17.95**	17.95**	3.61^{ns}	-5.49^{ns}	13.16^{ns}	-12.5**	-7.55^{ns}	-24.03**	-2.69^{ns}	2.34^{ns}	0.84^{ns}
V10 (P2*P5)	-8.33*	12.82**	12.82**	-3.66^{ns}	-13.19^{ns}	3.95^{ns}	4.04^{ns}	-2.83^{ns}	-20.16**	-9.32^{ns}	-5.98^{ns}	-7.36^{ns}
V11 (P2*P6)	-2.17^{ns}	15.39**	15.39**	9.72^{ns}	-13.19^{ns}	3.95^{ns}	7.77^{ns}	4.72^{ns}	-13.95**	16.81^{ns}	4.50^{ns}	2.97^{ns}
V12 (P2*P7)	-4.45^{ns}	10.25^{ns}	10.25^{ns}	7.14^{ns}	-1.10^{ns}	18.42**	-10.9**	-7.55^{ns}	-24.03**	-6.69^{ns}	0.76^{ns}	-0.72^{ns}
V13 (P3*P1)	-4.17^{ns}	17.95**	17.95**	28.00**	5.496^{ns}	26.32**	6.42^{ns}	9.44^{ns}	-10.08**	30.57**	36.03**	34.03**
V14 (P3*P2)	2.22^{ns}	17.95**	17.95**	20.27**	-2.20^{ns}	17.11^{ns}	13.59**	10.38**	-9.30**	39.82**	27.47**	25.60**
V15 (P3*P4)	-4.45^{ns}	10.25^{ns}	10.25^{ns}	21.69**	10.99^{ns}	32.90**	0.00^{ns}	5.66^{ns}	-13.18**	21.25**	27.51**	25.64**
V16 (P3*P5)	-6.25^{ns}	15.39**	15.39**	14.63*	3.30^{ns}	23.69**	2.91^{ns}	0.00^{ns}	-17.83**	15.32^{ns}	19.56**	17.81^{ns}
V17 (P3*P6)	4.35^{ns}	23.08**	23.08**	16.22*	-5.49^{ns}	13.16^{ns}	11.65**	8.49^{ns}	-10.85**	39.11**	26.82**	24.96**
V18 (P3*P7)	4.45^{ns}	20.52**	20.52**	9.53^{ns}	1.10^{ns}	21.06**	10.00*	14.15**	-6.20^{ns}	29.18**	39.50**	37.45**
V19 (P4*P1)	-4.17^{ns}	17.95**	17.95**	15.66*	5.50^{ns}	26.32**	0.00^{ns}	5.66^{ns}	-13.18**	25.63**	32.12**	30.18**
V20 (P4*P2)	2.22^{ns}	17.95**	17.95**	12.05^{ns}	2.20^{ns}	22.37**	-1.78^{ns}	3.78^{ns}	-14.73**	19.41*	25.58**	23.74**
V21 (P4*P3)	-13.33*	0.00^{ns}	0.00^{ns}	18.07**	7.70^{ns}	28.95**	1.79^{ns}	7.55^{ns}	-11.63**	10.46**	16.16^{ns}	14.45^{ns}
V22 (P4*P5)	-8.33*	12.82**	12.82**	12.05^{ns}	2.19^{ns}	22.37**	-0.89^{ns}	4.71^{ns}	-13.95**	15.87*	21.86**	20.07**
V23 (P4*P6)	6.52^{ns}	25.63**	25.63**	3.61^{ns}	-5.49^{ns}	13.16^{ns}	0.89^{ns}	6.60^{ns}	-12.40**	20.19**	26.39**	24.54**
V24 (P4*P7)	4.54^{ns}	17.94**	17.94**	13.10^{ns}	4.39^{ns}	25.00**	4.47^{ns}	10.37**	-9.30**	26.18**	36.26**	34.25**
V25 (P5*P1)	2.08^{ns}	25.63**	25.63**	6.10^{ns}	-4.39^{ns}	14.47^{ns}	-9.17*	-6.60^{ns}	-23.26**	8.86^{ns}	13.41^{ns}	11.75^{ns}
V26 (P5*P2)	-2.08^{ns}	20.51**	20.51**	2.44^{ns}	-7.69^{ns}	10.52^{ns}	14.14**	6.60^{ns}	-12.40**	14.41^{ns}	18.61**	16.87^{ns}

NRPE= Number of row per ear , NKPR= Number of Kernel l per row, 100KW= Hundred Kernel weight (g), KYPP=Kernel yield per plant(g).
* P>0.05, **P>0.01, ns= non-significance.

Table 9. Estimation of Heterosis over better parent (BP), Check varieties CV1 (BARI Hybrid maize 12) and CV2 (BARI Hybrid maize 13) in 42 F_1 hybrids derived from 7×7 diallel cross in White maize (Cont'd)

Crosses	NRPC			NKPR			100 KW			KYPP		
	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2	BP	CV1	CV2
V27 (P5*P3)	-10.42*	10.25^{ns}	10.25^{ns}	-8.54^{ns}	-17.58**	-1.31^{ns}	3.89^{ns}	0.94^{ns}	-17.05**	-12.6^{ns}	-9.41^{ns}	-10.74^{ns}
V28 (P5*P4)	-4.17^{ns}	17.94**	17.94**	15.86*	4.39^{ns}	25.00**	19.19**	11.32**	-8.52**	32.92**	37.80**	35.78**
V29 (P5*P6)	-2.08^{ns}	20.51**	20.51**	9.76^{ns}	-1.09^{ns}	18.42**	10.68*	7.54^{ns}	-11.62**	24.14**	28.70**	26.81**
V30 (P5*P7)	2.08^{ns}	25.63**	25.63**	5.95^{ns}	-2.19^{ns}	17.10^{ns}	10.00*	14.15**	-6.20^{ns}	30.04**	40.42**	38.36**
V31 (P6*P1)	2.08^{ns}	25.63**	25.63**	-4.00^{ns}	-20.87**	-5.26^{ns}	-4.59^{ns}	-1.88^{ns}	-19.37**	-5.9^{ns}	-1.96^{ns}	-3.40^{ns}
V32 (P6*P2)	-2.17^{ns}	15.38**	15.38**	-6.95^{ns}	-26.37**	-11.84^{ns}	16.51**	13.20**	-6.97^{ns}	7.55^{ns}	-3.79^{ns}	-5.20^{ns}
V33 (P6*P3)	-6.52^{ns}	10.25^{ns}	10.25^{ns}	12.16^{ns}	-8.78^{ns}	9.21^{ns}	6.80^{ns}	3.77^{ns}	-14.72**	14.66^{ns}	4.53^{ns}	3.00^{ns}
V34 (P6*P4)	2.18^{ns}	20.51**	20.51**	10.84^{ns}	1.10^{ns}	21.05**	2.68^{ns}	8.49^{ns}	-10.85**	25.79**	32.28**	30.34**
V35 (P6*P5)	-10.42*	10.25^{ns}	10.25^{ns}	-1.22^{ns}	-10.98^{ns}	6.58^{ns}	8.74*	5.66^{ns}	-13.17**	0.20^{ns}	3.88^{ns}	2.36^{ns}
V36 (P6*P7)	2.18^{ns}	20.51**	20.51**	15.48*	6.59^{ns}	27.63**	1.82^{ns}	5.66^{ns}	-13.17**	23.2**	33.10**	31.15**
V37(P7*P1)	0.00^{ns}	23.07**	23.07**	5.95^{ns}	-2.19^{ns}	17.10^{ns}	-0.91^{ns}	2.83^{ns}	-15.5**	17.26*	26.62**	24.77**
V38 (P7*P2)	6.67^{ns}	23.07**	23.07**	3.57^{ns}	-4.39^{ns}	14.47^{ns}	0.91^{ns}	4.71^{ns}	-13.9**	14.50^{ns}	23.64**	21.82**
V39 (P7*P3)	2.22^{ns}	17.94**	17.94**	-4.76^{ns}	-12.08^{ns}	5.26^{ns}	9.09*	13.20**	-6.97^{ns}	9.10^{ns}	17.81^{ns}	16.08^{ns}
V40 (P7*P4)	0.00^{ns}	12.82**	12.82**	-10.7^{ns}	-17.58**	-1.31^{ns}	-5.36^{ns}	0.00^{ns}	-17.8**	-13.71^{ns}	-6.81^{ns}	-8.18^{ns}
V41 (P7*P5)	-6.25^{ns}	15.38**	15.38**	-4.76^{ns}	-12.08^{ns}	5.26^{ns}	13.64**	17.92**	-3.10^{ns}	10.86^{ns}	19.71**	17.96^{ns}
V42 (P7*P6)	-6.52^{ns}	10.25^{ns}	10.25^{ns}	5.95^{ns}	-2.19^{ns}	17.10^{ns}	8.18*	12.26**	-7.75^{ns}	12.57^{ns}	21.56**	19.77**

NRPE= Number of row per ear , NKPR= Number of Kernel l per row, 100KW= Hundred Kernel weight (g), KYPP=Kernel yield per plant(g).

* P>0.05, **P>0.01, ns=non-significance.

and P7xP4 (V40) showed negative significant heterosis over check 2 variety. Earlier Amiruzzaman et al. (2013), Sentayehu and Warsi (2015) and Begum (2016) reported negative significant heterotic values for days to teaseling over check variety.

4.3.3 Plant height (cm)

In case of plant height negative heterosis is also desirable which helps to develop dwarf type plant. The estimated heterosis value ranged -7.40 % to 17.71% over better parent (Table 9) and 5.60 to 24.92% heterosis over check variety 1 in addition 2.86 to 21.69% heterosis over check variety 2. Eight hybrids expressed negative but non-significant heterosis over better parent and eight hybrids expressed positive significant heterosis over better parent. Among forty-two hybrids twenty eight hybrids showed standard heterosis in positive direction in respect of plant height over both check varieties CV1 and CV2. Kumar *et al.* (2014) founded -9.05% to 12.51 % heterosis over the check. Karim *et al*. (2018) founded both positive and negative heterosiss on this character.

4.3.4 Ear height (cm)

Normally shorter plants with low ear height are linked with resistance to lodging. The estimated heterosis value ranged -8.14 % to 20.40% over better parent and 7.32 to 44.49% and 6.63 to 38.36% heterosis over check variety 1 and check variety 2, respectively (Table 9). Eleven hybrids expressed negative but non-significant heterosis over better parent and five hybrids expressed positive significant heterosis over better parent. Among forty two hybrids twenty seven hybrids showed standard heterosis in positive direction in respect of ear height over both check variety. Sentayehu and Warsi (2015) and Ram *et al*. (2016) observed heterosis value in negative direction for ear height. Kumar *et al*. (2014) founded 17.17% to 29. 88% heterosis over the checks. Karim *et al*. (2018) founded both positive and negative heterosis on this character.

4.3.5 Days to maturity

In case of dates of maturity negative heterosis is also desirable. Out of forty-two cross eleven hybrids showed significant heterosis over better parent (BP) and among them two hybrids showed significant negative values. Highest negative significant heterosis (-3.61%) was provided by the hybrid P1xP6 (V5) for days to maturity over their better parent P6. Incase of standard hererosis none of F_1 possessed desirable significant negative heterosis over both check variety BARI hybrid vhutta 12 (CV1) and BARI hybrid vhutta 13 (CV2) (Table 9). Kumar *et al*. (2014) founded -5.14 to 2.29 heterosis over the check.

4.3.6 Number of branches in tassel

Positive heterosis is desirable for number of branches in tassel. Out of forty-two crosses three F_1 *viz.* P1xP7 (V6) , P2xP3 (V8) , P3xP2 (V14) possessed significance heterosis over better parent. Among 42 three F_1 showed positive heterosis over better parent. Highest heterosis obtained 25.00% in P1xP7 (V6) over better parent. None of the F_1 showed positive significant heterosis over none of check variety 1 and 2 (Table 9).

4.3.7 Ear length (cm)

Significant positive heterosis was desirable for the trait ear length. Out of forty-two hybrids, four showed positive significance heterosis over better parent (BP). The highest heterosis over better parent showed 18.64 % in P1xP3 (V2) was followed by 13.27% in P1xP7 (V6), 13.20 in P4xP1 (V19) and 10.70 in P6xP1 (V31) (Table 9). The results of standard heterosis computed relative to check variety 1 and check variety 2 one tested hybrids *viz.* P1xP2 (V2) manifested 10.16% and 24.53% significant positive heterosis over check variety 1 and check variety 2, respectively. Among the crosses eleven F_1 possessed significance positive heterosis over check variety 2. P1xP7 (V6) produced 22.18% positive heterotic value over check variety 2 (Table 9). Amiruzzamam *et al*. (2013), Sentayehu and Warsi (2015) and Begum (2016) observed positive and negative heterosis for ear length.

4.3.8 Ear diameter (cm)

In case of ear diameter positive significance heterosis was desirable for yield. Out of the forty two hybrid four F_1 showed significance heterosis over better parent and among these crosses one F_1 viz. P3xP6 (V17) possessed significant 15.27% over better parent (Table 9). Only P3xP6 (V17) was also showed positive significance heterosis 14.36% and 12.84% over over check variety 1 (CV1) and check variety 2 (CV1), respectively. So these combinations might be selected for the getting maximum ear diameter. Uddin *et al.* (2008) founded both positive and negative heterosis.

4.3.9 Number of row per ear

Positive heterosis is desirable for number of row per ear which was desirable for yield. Among forty two hybrids five F_1 showed negative significance heterosis over better parent (BP) but thirty-two hybrid showed standard heterosis over both check variety 1 (CV1) and check variety 2 (CV2). Out of forty-two crosses P4xP6 (V23), P5xP1 (V25), P5xP7 (V30) and P6xP1 (V31) showed highest 25.63% heterosis over both check variety 1 and check variety 2 (Table 9). Uddin *et al.* (2008), Azad *et al.* (2014) and Mahmood *et al.* (2016) reported maximum number of row associated with higher yield.

4.3.10 Number of kernel per row

Out of forty-two tested hybrids twelve of them showed significant positive heterosis over better parent (Table 9). Tested F_1 P1xP3 (V2) showed highest 38.67% heterosis over better parent. The result of standard heterosis computed relative to check variety 1 (CV1). Hybrids performance showed that none of them exhibited significant positive heterosis while six tested F_1 showed significant negative heterosis. When check variety 2 (CV2) was considered as a check, among tested hybrids showed seventeen exhibited significant positive heterosis (Table 9). The highest standard heterosis was exhibited 36.85% in F_1 P1xP3 (V2) followed by 32.90 in F_1 P3xP4 (V15) and 27.63% in F_1 P6xP7 (V36) over check variety 2. Positive and negative heterosis for number of kernel per row was also agreed by Azad *et al.* (2014) and Mahmood *et al.* (2016).

4.3.11 Hundred kernel weight (g)

In case of thousand kernel weight positive heterosis was desirable for contributing yield. The ranged of heterosis varied from -12.50% to 19.19%, -7.55% to 19.81% and - 24.03% to -1.55% over better parent, check variety 1 and check variety 2 respectively for the character hundred kernel weight. Out of forty-two tested hybrids thirteen showed significant positive heterosis over better parent (Table 9). Tested F_1 P5xP4 (V28) showed the highest 19.19% followed by F_1 P6xP2 (V32) about 16.51% heterosis over better parent (BP), while the twelve tested hybrids showed significant positive heterosis over the check variety 1 (Table 9).The highest standard heterosis was exhibited 19.81% in F_1 P1xP7 (V6) followed by 17.92% in F_1 P7xP5 (V41) and 14.15% in F_1 P3xP7 (V18) and P5xP7 (V30). In compare of check variety none of the tested hybrids exhibited significant positive value. Hence thirty-three showed significant negative heterosis over check variety 2. Uddin *et al.* (2006), Kumar *et al.* (2014) supported this finding, while Matin *et al.* (2016) and Begum (2016) also observed positive and negative heterosis for thousand grain weight (g).

4.3.12 Kernel yield per plant (g)

The ranged of heterosis varied from -13.71% to 39.82%, -15.06% to 40.42% and -16.30% to 38.36% over better parent, check variety 1 and check variety 2 respectively (Table 9). Among forty-two F_1 nineteen exhibited positive heterosis over better parent. The hybrid P3xP6 (V14) exhibited highest 39.82% kernel yield followed by 39.11 % in P3xP6 (V17) and 32.92% P5xP4 (V28), respectively. In case of heterosis over both check varieties twenty combination *viz.* P1xP3 (V2), P1xP7 (V6), P3xP1 (V13), P3xP2 (V14), P3xP4 (V15), P3xP6 (V17), P3xP7 (V18), P4xP1 (V19), P4xP2 (V20), P4xP5 (V22) , P4xP6 (V23), P4xP7 (V24), P5xP4 (V28), P5xP6 (V29), P5xP7 (V30), P6xP4 (V34), P6xP7 (V36), P7xP1 (V37), P7xP2 (V38) and P7xP2 (V42) exhibited significance positive heterosis. While twenty-three tested F_1 showed positive significance standard heterosis over check variety 1. The highest 40.42% in P5xP7 (V30) heterosis followed by 39.49% in P3xP7 (V18), 37.99% in P1xP3 (V2) and 37.80% in P5xP4 (V28) standard heterosis over check variety 1. Out of forty-two tested hybrids nineteen showed significant positive heterosis over the check variety 2 (Table 9). P5xP7 (V30) showed highest 38.36% was followed by 37.45% in P3xP7 (V18), 35.97% in P1xP3 (V2) and 35.78% in P5xP4 (V28), respectively over the check variety 2. Uddin *et al.* (2008), Amiruzzamam *et al.* (2013), Azad *et al.* (2014), Sentayehu and Warsi (2015) and Begum (2016) were also founded approximately ranged heterosis. Cobs of 7 parents, 42 F_1 hybrids and 2 check varieties are presented in plate 11.

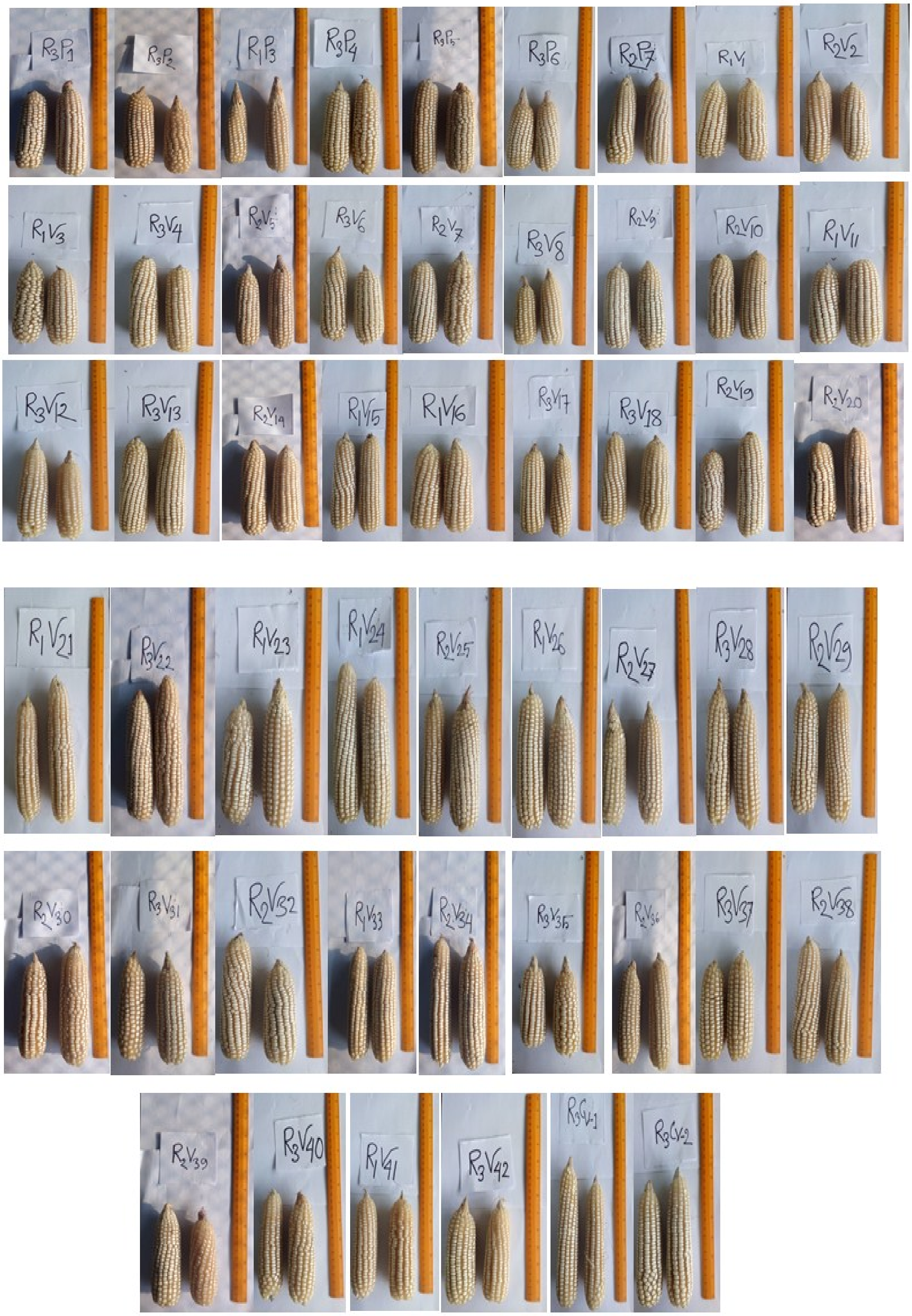

Plate 11. Photograph of cobs of 7 parents, 42 F_1 hybrids and two Check variteits of White maize

CHAPTER 5

SUMMARY AND CONCLUSION

In the present study significance GCA and SCA variance were observed for all the characters except plant height and ear height which possessed significance GCA effect only. So it can be concluded that non-additive gene action was 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 tasseling, days to 50%, plant height, ear height, days to maturity, ear length, number of kernel per row, hundred kernel weight and kernel yield per plant 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 gene. Combining ability analysis also exposed that estimates of SCA variances were higher than GCA variances for the characters ear diameter and number of rows per ear suggesting predominance of non-additive or dominant gene action. Combining ability study also revealed that ratio of GCA and SCA variance was observed close to unity for number of row per ear, ear length, ear diameter, kernel per row, hundred kernel weight and kernel yield indicating equal importance of both additive and non-additive gene effects.

In the study considering general combining ability towards desirable direction among the seven inbreed line revealed that P3 and P7 showed significance negative GCA for days to tasseling, days to 50% tasseling and days to maturity which were considered as good combiners for earliness as importance of early maturity and lower values of days to tasseling and days to 50% tasseling . Only one parental line P6 possessed significance negative GCA towards plant height considered as good combiner of the character as dwarf type plant which was desirable. Two parental lines i.e. P4 and P5 exhibited significant and higher negative GCA effects for ear height, specified good combiner for low ear placement of the line. Thus the parents possess high frequency of favorable genes for these characters. The study also showed that the parents P1, P4 and P7 were the best general combiner for number of branches in tassel. The estimation of GCA revealed no parental line exhibited positive significant effects toward ear length and ear diameter which was desirable for yield contributing character. Among the seven parent P4 exhibited positive significant effect for number of kernel per row and kernel yield per plant which was desirable for yield contribution. While P7 parent exhibited the highest significance positive GCA for hundred seed weight and yield per plant kernel specified good combiner for yield. Thus P4 and P7 were the best combiner for yield and kernel yield related characters. While the inbred lines which exhibited good general combining ability for at least one character can be used as donor parents for the accumulation of favorable genes which implied that for improvement of respective traits in hybridization program these lines can be utilized for producing better hybrid due to their good combining ability.

In the study one cross P5xP7 (V30) showed considerable negative significance SCA effects for days to tasselling, days to 50% tasselling, and days to maturity which were desirable for these character and none of cross exhibit negative heterosis for plant height and ear height. Among forty two F_1 five crosses, viz. P1xP7 (V6), P2xP3 (V8), P5xP3 (V27), P6xP3 (V33) and P7xP1 (V37) showed significant positive SCA effects for number of branches in tassel out of forty-two tested F_1 twelve crosses *viz.* P4xP6 (V23), P7xP1 (V37), P7x P4 (V40), P6xP3 (V33), P1xP2 (V1), P1xP3 (V2), P6xP7 (V36), P4xP5 (V22), P5xP7 (V30), P5xP3 (V27), P3xP7 (V18) and P7xP5 (V41) exhibited positive significance SCA for yield and yield related traits. Among them most promising crosses for improving kernel yield was P7xP4(V 40) due to its highest positive significant SCA for this trait along with positive significant SCA effect for ear length, number of kernel per row and hundred kernel weight. The cross combination P1xP3 (V2) was also showed second highest SCA effects for kernel yield and positive significant SCA effects for ear length and number of kernel per row. So the results indicated that the hybrids P4xP6 (V23), P7xP1 (V37), P7xP4 (V40), P6xP3 (V33), P1xP2 (V1), P1xP3 (V2), P6xP7 (V36), P4xP5 (V22), P5xP7 (V30), P5xP3 (V27), P3xP7 (V18) and P7xP5 (V40) were best specific combiner for yield which may be exploited.

Analysis of the cross combination observed the cross combination P5xP7 (V30) represented the maximum significant and negative heterosis over BHM 12 (CV1) and BHM 13 (CV1) in respect of tasseling and days to 50% taselling while P4xP7 and P3xP1 exhibited significant and negative heterosis over BHM 12 and BHM 13 in respect of tasseling and over BHM 13 for days to 50% taselling. None of the cross combination showed significance negative standard heterosis for plant height, ear height and days to maturity. In case of number of branches in tassel none of the combination exhibited positive significance heterosis over BHM 12 and BHM 13 .Out of forty-two F_1 twenty cross viz. P1xP3 (V2), P1xP7 (V6), P3xP1 (V13), P3xP2 (V14), P3xP4 (V15), P3xP6 (V17), P3xP7 (V18), P4xP1 (V19) , P4xP2 (V20), P4xP5 (V22) , P4xP6 (V23), P4xP7 (V24), P5xP4 (V28), P5xP6 (V29), P5xP7 (V30), P6xP4 (V34), P6xP7 (V36), P7xP2 (V38), P7xP1 (V37) and P7xP6 (V42)showed significance positive heterosis over the check varieties BHM 12 and BHM 13. The highest significant positive heterotic value for yield was exhibited by P5xP7 (V30) was followed by P3xP7 (V18), P1xP3 (V2) and P5xP4 (V28). Positive significant positive heterotic value for yield is desirable in this study.

Recommendations:

- Considering the combining ability and standard heterosis for yield and yield related characters six tested hybrid *viz*. P5xP7 (V30), P3xP7 (V18), P1xP3 (V2), P6xP7 (V36), P4xP6 (V23) and P4xP5 (V22) were recommended as superior white maize hybrids.
- Further investigation might be carried out to justify the findings of the present study findings.
- Multilocation trial of these six test hybrid identified maize hybrid might be conducted to find out adaptability of white maize hybrids variety.
- Based upon the performance of multilocation trial one or two hybrids would be processed for varietal resistration for release as hybrid variety of white maize in Bangladesh.

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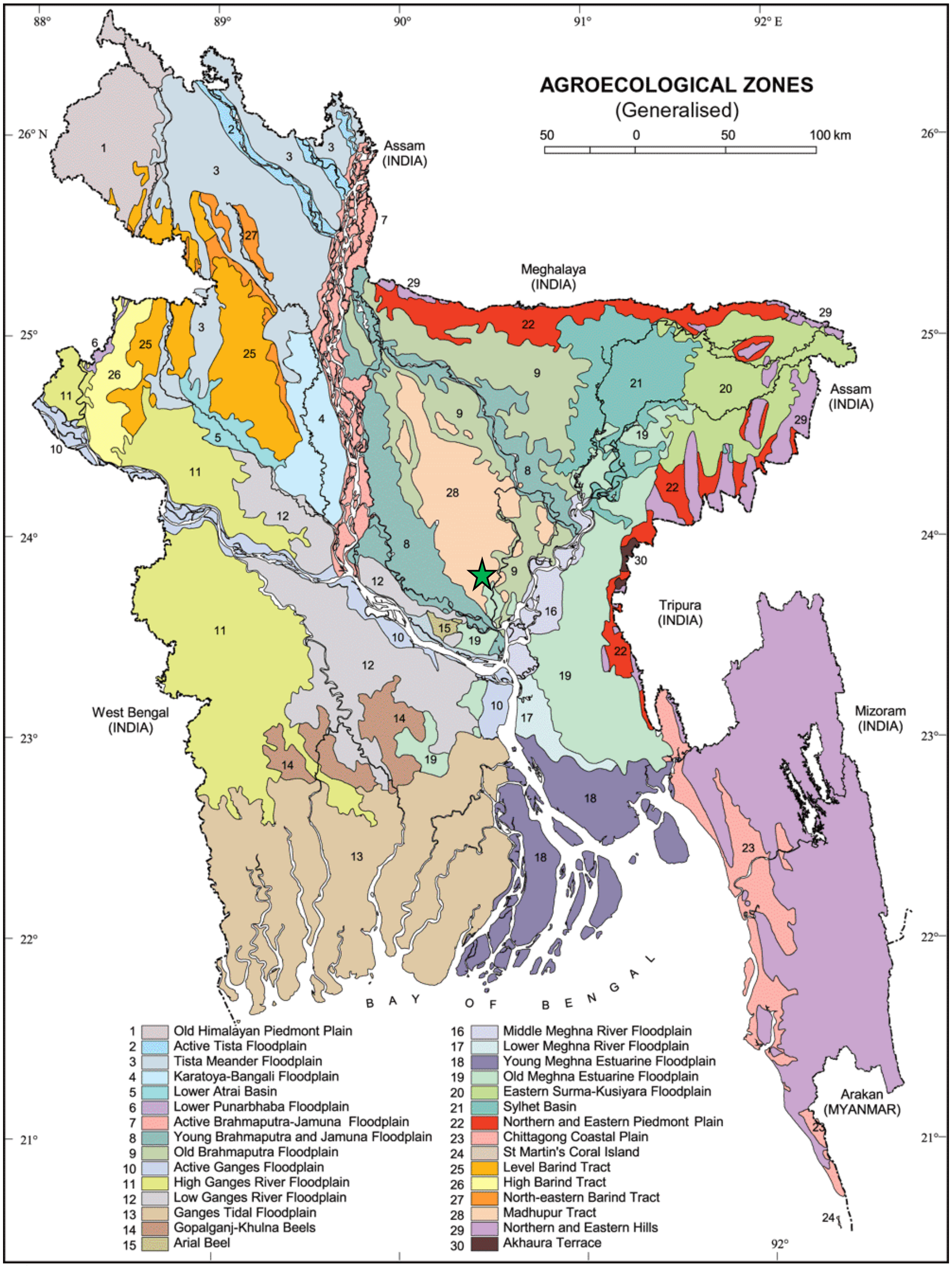
APPENDICESssss

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

Month	Average temperature (ºc)		Average RH (%)	Rainfall (mm) (total)	Average sunshine (hr)
	Minimum	Maximum			
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 – 1212

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

Month	Average temperature (ºc)		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 – 1212