

**EVALUATION OF SINGLE AND DOUBLE CROSS
HYBRIDS IN MAIZE (*Zea mays* L.)**

157955

THESIS

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By

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled "**EVALUATION OF SINGLE AND DOUBLE CROSS HYBRIDS IN MAIZE (*Zea mays* L.)**" or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Nagpur

Date: 24.06.2015 .



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CERTIFICATE


This is to certify that thesis entitled "EVALUATION OF SINGLE AND DOUBLE CROSS HYBRIDS IN MAIZE (*Zea mays* L.)" submitted in partial fulfilment of the requirement for the degree of "Master of Science in Agriculture (Agricultural Botany)" of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Ghanwat Pavankumar Ramrao** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.






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(B)**Abbreviations**

| | | |
|---------------------|---|---------------------------|
| % | : | Per cent |
| / | : | or |
| amsl | : | above mean sea level |
| cm | : | centimeter |
| CD | : | Critical difference |
| DC | : | Double cross |
| df | : | degrees of freedom |
| EC | : | Exotic collection |
| eg | : | For example |
| <i>et al.</i> | : | et alia (and associâtes) |
| etc | : | et cetera |
| g | : | gram |
| ha | : | hectare |
| hrs | : | hours |
| IC | : | Indigenous collection |
| i.e. | : | that is |
| Kg | : | Kilogram |
| Kg ha ⁻¹ | : | Kilogram per hectare |
| m | : | meter |
| NM | : | Nagpur maize |
| No. / no. | : | Number |
| OP | : | Open pollinated |
| OPV | : | Open pollinated varieties |

| | | |
|-------------|---|------------------------------|
| SC | : | Single cross |
| S.E. | : | Standard error |
| SE (d) | : | Standard error of difference |
| SE (m) | : | Standard error of mean |
| SV | : | Synthetic varieties |
| TWC | : | Three way cross |
| <i>viz.</i> | : | Namely |
| <i>vs.</i> | : | Versus. |

(C)

THESIS ABSTRACT

- a) Title of the Thesis : "EVALUATION OF SINGLE AND DOUBLE CROSS HYBRIDS IN MAIZE (*Zea mays* L.)"
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ABSTRACT

The present study was carried out to evaluate single and double cross hybrids in maize (*Zea mays* L.) derived from six parental inbred lines which were used to assess the possibility of estimating the amount of heterosis of single and double cross hybrids, to predict the performance of single and double crosses and assess the reliability of prediction methods. Thirty six double crosses were produced from nine single crosses. These thirty six double crosses along with nine single crosses, six inbreds and one check (Rajarshi) were raised in Randomised Complete Block Design with three replications. The observations on days to 50 % tasseling, days to 50 % silking, days to maturity, plant height (cm), cob length (cm), cob girth (cm), number of grains cob⁻¹, 100 grain weight (g), grain yield plant⁻¹ (g) and grain yield plot⁻¹ (Kg) were recorded. Heterosis for the single and double crosses were recorded for all the ten characters studied. The significant useful heterosis among the double crosses were recorded for all the ten characters while single crosses recorded the significant useful heterosis for most of the characters like plant height, days to 50% silking and days to 50% tasseling. Among the single and double crosses, only the double crosses DC- 4X2 i.e. [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 44-5], DC-4X3 i.e. [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 62-4-1] and DC-6X1 i.e. [NM 44-3-1 X NM 62-4-1] X [NM 32-1-1 X NM 60-4] were identified as best crosses on the basis of high *per se* performance, high significant heterosis and usefull heterosis in the desirable direction. Hence, it is suggested that these three identified double crosses could be used directly for heterosis breeding in maize. Jenkins (1934) prediction method based on the parental inbreds *per se* performance was not effective for anticipating the single and double cross hybrids performance.

INTRODUCTION

1.1 Background information

Maize (*Zea mays* L., $2n=20$) is an important crop in many developing countries and ranks third in the world after wheat and rice in cereal grain crops. Maize is of American origin, particularly from Southern Mexico has been domesticated about 7000 years ago. Maize belongs to family Poaceae and genus *Zea* which is typically characterized by terminal male inflorescences with paired staminate spikelets and lateral female inflorescences with single or paired pistillate spikelets contains four species as *Zea mays* ($2n = 20$), *Zea Mexicana* ($2n = 20$), *Zea perennis* ($2n = 40$) and *Zea diploperennis* ($2n = 20$). Poehlman and Sleper (1995) have given a detailed account of maize breeding including its evolution. According to this compilation, it is generally now accepted that the progenitor of cultivated maize is teosinte (*Zea Mexicana*). Transformation of maize from teosinte involved evolutionary forces such as mutation, hybridization, genetic drift and selection aided by selective and useful interventions by human beings.

Maize is grown as a multipurpose crop throughout the world for food, feed, fuel and fibre. It is well adaptable to tropical, subtropical and temperate regions. It possesses a remarkable diversity of vegetative types having a wide range of ecological adaptation. The unique energy capturing capability and efficient use of CO_2 as C_4 plant have made it capable of producing maximum grain yield per unit area as compared to all other cereal crops. Therefore maize is also called as miracle crop or queen of cereals.

Maize kernel contains about 70 % starch, 9.9 % protein, 4.8 % oil, 3.0 % sugar, 2.8 % crude fibre and 15 % ash. Maize is primarily used as food for human in African and Asian sub continents, while in United States about 85 % of the crop is used as cattle feed. Maize is

not only used as food, feed and fodder but also used for some five hundred different industrial purposes for manufacturing viz. starch, alcohol, acetic acid, glucose, paper, furfural, rayon, dyes, synthetic rubber and resin etc. It is mainly used for the production of starch due to its high starch content. Maize seed oil contains highest polyunsaturated fatty acids (PUFA), Linoleic acid (61.99 %) and it remains as liquid at fairly low temperature which is helpful in combating heart disease. Maize seed oil is also low in linolenic acid (0.7%) and contains a high level of natural flavour.

Maize is the world's leading crop cultivated with more than 967 million tonnes of production from acreage of about 177 million hectares with average productivity of 5500 Kg ha⁻¹. From average yield point of view, maize occupies first rank among cereals (more than 3000 kg/ha). Major maize producing countries are USA (36.54 %), China (21.81 %), Brazil (7.59 %), European Union (7.48 %), Ukraine (2.73 %), Argentina (3.0 %) and India (2.22 %). USA, Brazil, Ukraine and Argentina, these four countries have around 80-85 % of the world's total exports in maize (Anonymous, 2013-2014a).

Maize can play an important role in the Indian economy of a country as it occupies a pride place among coarse cereal crops in India. It is grown in 24.34 million tonnes of production from area of about 9.42 million hectares with average productivity of 2583 Kg ha⁻¹ (Anonymous, 2013-14b). Among the major maize producing states, Andhra Pradesh tops the list with a contribution of 20.37 % to the total Indian maize production. Other states are Karnataka (16.35 %), Maharashtra (12.61 %), Bihar (8.25 %), Madhya Pradesh (6.88 %), Tamil Nadu (6.57 %), Rajasthan (6.16 %) and Uttar Pradesh (5.05 %).

In Maharashtra, maize cultivation is getting importance as it is being considered a crop for replacing the cereal like *kharif* sorghum, pearl millet and ragi. Similarly, there is an increased demand from industries for processing maize and as a result, farmers are getting increased price. The area under maize in Maharashtra is 12 lakh

hectares with a production of 30.75 lakh tonnes and productivity is 2544 kg ha⁻¹ (Anonymous, 2013-14b).

In Vidarbha, the maize is grown on 31.5 thousand hectares with a production of 54.3 thousand tonnes and productivity is 1734 kg ha⁻¹ during *kharif* season. It is mostly cultivated in Buldhana (73.84%), Gadchiroli (10.12%), Amravati (8.28%), yavatmal (2.02%), Akola (2.02%) and Washim (1.10%) districts. It is grown in *kharif* under rainfed condition and in *rabi* and summer under irrigated conditions (Anonymous, 2012-13).

Maize has been widely cultivated as a rainfed crop in India. Recent studies have shown that maize can be successfully grown during *rabi* in many parts of the country due to the evolution of new improved cultivars and assured irrigation facility as well. The yield level of maize during *rabi* season is considerably higher than that of *kharif* due to its higher water and fertilizer use efficiencies. Moreover recent emphasis on the development of hybrids meant for both the seasons has paid rich dividends in terms of higher maize production and productivity in the country.

Maize belongs to tribe Maydeae and family Graminae now known as Poaceae (the grass family). Maize plant has 2-3 m tall single stem with single leaf at each node. The leaves are arranged on the principal stalk in two opposite ranks. Each leaf has a sheath surrounding the stem, and an expanded leaf blade connected to the sheath by a blade joint. The number of leaves on a plant may range from 8 to 48. Maize is monoecious i.e. the male and female flowers are borne separately on the same plant. The male inflorescence (tassel) is a branched panicle which is located at the top of the stem while the female inflorescence (cob or ear) is considered as a modified lateral branch arising from an axillary bud which is placed at somewhat mid height at node on the main stem or stalk. The internodes of this lateral branch are telescoped to form a stout axis. There are modified leaves in the form of overlapping sheaths originating from the lower node of

the axis to cover the female inflorescence or the cob. These overlapping leaf-sheaths are called as husks. On ear shoot / cob, pistillate spikelets are borne in pairs in longitudinal rows. There are two flowers / florets in each spikelet, one flower is fertile and the other sterile. Because of this, there are even numbers of rows of kernels on each ear / cob. One stalk may bear 1-3 cobs. The hair-like structures emerging out of top of the husks are known as silk. Silk functions both as stigma and style. The corn pollen tubes are the longest known in plant kingdom.

Maize is highly cross-pollinated crop where about 95% of the pistillate flowers on a cob receive pollen from nearby other plants. About 5% of the kernels on a cob are produced as a result of self-pollination. Maize is generally protandrous, i. e. male spikelets mature earlier than the female spikelets. The pollen shedding normally begins 1-3 days before the emergence of silk and continues 3-4 days after the silks are receptive and ready for pollination. According to Poehlman (1987), a single tassel may produce as many as 25×10^6 pollen grains. Pollen grains are very small, not visible to naked eye, light in weight, and easily carried by wind. Wind borne nature of pollen and protandry facilitate cross-pollination, but 5% self-pollination may happen. Pollen grain viability is for about 12-18 hrs and there after they may be killed in few hrs by heat or desiccation. In hot, dry and windy conditions, the pollen shedding may be over early. Under these conditions, the tassel may be injured or the silk may lost the moisture and as a result, barren cobs are produced.

1.2 Importance of study

Maize being a highly cross pollinated crop and there is a wide scope for the development of stable hybrids and varieties of maize. In recent years, there has been a improvement in maize production in the state but the production and productivity of India is much less when compared to country like U.S.A. The varieties / hybrids, which are cultivated in the recent years, are not stable. Therefore, we require

stable inbred lines which can help in the development of stable hybrids / varieties.

Selection of parents for crossing is the first and most important task to evolve superior hybrid or strains. The selection of parents for hybridization is difficult task as yield is a complex character involving number of components, each of which are polygenically controlled and hence sensitive to environmental fluctuations. The initial selection of suitable parents is stated to be of immense importance by all workers for utilization of heterosis to its maximum extent.

The invention of heterosis phenomenon, the development of hybrid breeding technology and successful commercial exploitation of heterosis in maize are considered to be significant achievements and land marks in the history of biological sciences during the present century. Maize being a versatile crop, in order to harness its yield potential several genetic and agro technique improvement strategies have been used in the past and present viz. single crosses, double crosses, three way crosses, varietal hybrids, multiple hybrids, composites, synthetics, gene pools, populations etc. These techniques are feasible to maize growing farmers for commercial cultivation by virtue of the crop being a highly cross pollinated species.

Large scale exploitation of heterosis in maize was given by East (1908) on inbreeding, Shull (1908) on single crosses, and Jones (1918) on double crosses. Shull and East conducted independent experiments on inbreeding and cross-breeding in maize and observed depression due to inbreeding and restoration of vigour on crossing. The proposed method of Shull (1909) was associated with some problems on single cross hybrids like, 1) lack of good inbred lines capable of producing significant yield advantage to single cross hybrids, 2) poor germination and planting problems due to small and mis-shaped hybrid seed, 3) expensive hybrid seed due to low yield of female inbred parent and substantial proportion of the land devoted to the male inbred parent.

Jones (1918) suggested the use of double cross hybrids to overcome these difficulties associated with the single cross hybrids. The first double cross hybrids in 1920s yielded about 15% higher than the better OP varieties (Duvick, 1999). With the improvements in vigour and yield potential of inbred lines and the development of better cultural practices, single crosses were adapted for commercial cultivation. But Jones (1958) reported that double cross hybrids are genetically more variable, stable and consistent in performance than single crosses. Although double cross hybrids show slightly higher variation in plants and ear characters as compared to single crosses, which might affect the grain yield, the cost of seed production could be reduced because they are produced on single cross hybrids as parents which produce more seeds as compared to inbred parents, as in the case of single cross hybrids. Now, single cross and double cross hybrids pre-dominate the commercial hybrids world over.

The evaluation of a large number of single and double crosses in maize for their performance in experimental plots needs enormous time, labour and financial resources. To save the precious resources, there are several methods to predict the performance of single and double cross hybrids. Therefore, with the ability to accurately predict the performance of single and double cross hybrids, from that only promising single and double crosses need to be developed and the yield performance confirmed in actual yield tests. Based on the parental inbreds *per se* performance, Jenkins (1934) advocated the prediction method for the single and double cross hybrids. By this method, single crosses were predicted by the mean phenotypic values of two parents involved in their respective single crosses and double crosses were predicted by the mean phenotypic values of four parents involved in their respective double crosses. Keeping in mind the above ideas, this study was planned to evaluate the performance of some single and double cross hybrids and to compare their performance with the predicted ones. Anderson (1938) also realized the fact and found

close correspondence between predicted and realized yield of single and double crosses in maize.

Similarly, the knowledge about nature of gene action governing the expression of various traits could help in predicting the effectiveness of selection. The partitioning of genetic variance into its components helps in formulating an effective and sound breeding programme. Hence, this research work was taken up to evaluate nine single crosses and thirty six double crosses along with six inbreds and one check to find out the performance and the significance of predictability of these hybrids for their exploitation in maize with the following objectives.

1.3 Objective of the study

- 1) To estimate the heterosis of single and double cross hybrids.
- 2) To predict the performance of single and double crosses and assess the reliability of prediction methods.

1.4 Scope and limitations

This study will help in identifying good single and double cross hybrids by predicting the performance of these hybrids from a large source of inbred lines and which can be reduce the number of single and double cross hybrids obtained from these sources for actual field testing. Therefore, it can be involved in the development of single and double cross hybrids for commercial cultivation. Thus this study has a wide scope as it will help in developing new hybrids of maize with high yield and additional traits for cultivation.

This study will also shows the reliability of prediction methods by giving the strong correlation between the predicted and actual performances of the single and double cross hybrids.

The limitations in the implementation of this study are prediction of single and double cross hybrids based on the parental inbreds *per se* performance, so the precision of prediction may be low.

The limitations in the implementation of this study are synchronisation of flowering in male and female parents, percentage of seed set after crossing and protecting the crossed cobs till harvest from getting lost due to various sources.

1.5 Hypothesis

The Information derived from this research work will help in realizing the performance and the significance of predictability of single and double crosses and also will help in identifying superior hybrids for their exploitation in maize.

REVIEW OF LITERATURE

Maize (*Zea mays* L.) is a highly cross pollinated crop and scope for the exploitation of hybrid vigour will depend on the direction and magnitude of heterosis, biological feasibility and the type of gene action involved. Exploitation of hybrid vigour in maize has gained much significance in view of its tremendous yield increase and is considered as outstanding accomplishment of plant breeding. There is a continuous need to evolve new hybrids which should exceed the existing hybrids in yield and quality (Dass *et al.*, 2010). The magnitude of heterosis provides information on extent of genetic diversity of parents in developing superior F_1 , so as to exploit hybrid vigour and has direct bearing on the breeding methodology to be adapted for varietal improvement. Maize has great potential for heterotic manifestation and its exploitation. This could be the reason that number of hybrid varieties in maize is much higher than any other varietal types. Development of single and double cross hybrids of maize depends on the *per se* performance of inbreds, and their extent of heterosis for the important characters. The information about the heterotic pattern facilitate breeders in the selection and development of single and double cross hybrids.

Therefore, exploitation of heterosis is considered to be one of the outstanding achievement of plant breeding. Considering the significance of heterosis for their exploitation in maize, this research work carried out on these aspects by the different maize breeders are reviewed below:

2.1 Heterosis

Heterosis works as a basic tool for improved production of crops in the form of F_1 hybrids. Plant breeders have widely exploited and used heterosis in boosting up yield of many self as well as cross pollinated crops. Therefore, the heterotic studies can provide basis for

the exploitation of valuable hybrid combinations in the future breeding programmes and their commercial utilization.

Heterosis of varying magnitude has been observed in almost all the crop plants. Any of the genetic phenomenon known to influence qualitative or quantitative characters is expected to influence heterosis but over the years that dispersion of completely or incompletely dominant genes and over-dominance along with some contribution of non-allelic interactions have been considered to be the main causes of heterosis.

Heterosis breeding has received more attention than other branches of plant breeding in several crop plants and maize is one such cross fertilized crop in which an array of hybrids have been released over decades. Heterosis is the deviation of F_1 from the reference for the particular character (East, 1936).

The term heterosis was coined by Shull. Heterosis is the superiority of F_1 over the mean of the parents or over the better parent or over the standard check with respect to agriculturally useful traits. The genetic causes involved in the expression of heterosis are dominance and non allelic interactions. The magnitude of heterosis can be maximized if the parents are genetically diverse from each other. Parents should differ for maximum number of yield influencing loci, so that F_1 exhibits the dominance effect at as many of the yield influencing loci as possible. Exploiting heterosis is one of the methods to increase maize yield. According to Miranda (1999), heterosis is the genetic expression of the superiority of a hybrid in relation to its parents. Two major types of estimation of heterosis are reported namely, mid-parent or average heterosis, which is increased vigour of the F_1 over the mean of two parents; and high-parent or better parent heterosis (Sinha and Khanna, 1975). Heterosis (usually considered to be synonym with hybrid vigour) is one of the primary reasons for the success of the commercial maize industry (Stuber, 1994). Although several economically important crops benefit from the manifestation of

heterosis, both the genetic and physiological mechanisms underlying this phenomenon are still unexplained (Hallauer and Miranda, 1988).

Three major theories such as dominance, over-dominance and epistasis have been proposed as the main theories to explain mechanisms underlying the phenomenon of heterosis. However, it is generally accepted that heterosis to a large extent is due to dominance gene action (Singh, 2005). To overcome many of the difficulties that are encountered in the interpretation of heterosis for complex traits, component analysis approaches have been used to study the effect of heterosis on grain yield. Grain yield has been subdivided into ear number, kernel number and weight in an attempt to understand how heterosis influences grain yield (Sinha and Khanna, 1975). These grain yield components, however, are static attributes that do not lend themselves to a process-based analysis of grain yield formation (Tollenaar *et al.*, 2004).

Heterosis is an important in maize breeding and is dependent on level of dominance and differences in gene frequency. The manifestation of heterosis depends on genetic divergence of the two parental varieties (Moll *et al.*, 1965). Low grain yield heterosis is observed for crosses among genetically similar germplasm and for crosses among broad genetic base germplasm (Beck *et al.*, 1990). Higher levels of heterosis were seen with increased divergence within a certain range, but that heterosis declined in extremely divergent crosses. Genetic divergence of the parents is inferred from the heterotic patterns manifested in a series of crosses (Prasad and Singh, 1986).

Heterosis has been observed for most of the agronomically important quantitative traits in maize which have been widely discussed and reported by many of the maize breeders. Some of the works related to heterosis carried out by the maize breeders are reviewed in this chapter.

Saleh *et al.* (2002) evaluated a series of tropical maize hybrids, involving ten single, four double and four three way crosses with their parental inbred lines and three control varieties in a randomized complete block design with three replications. The hybrids varied highly for grain yield and most other traits measured. High estimates of heterosis were shown by grain yield, ear weight and grain weight ear⁻¹, moderate for plant and ear heights, shelling percentage, ear diameter, number of kernel rows ear⁻¹, number of kernels ear row⁻¹ and 100 grain weight. The hybrids flowered and matured earlier than their respective inbred parents. Based on the overall performance of the hybrids, the single cross SC2, the double cross DC11 and the threeway cross TWC15 had high potential. No obvious differences were observed in the performance among the three categories i. e. single, double and threeway crosses of hybrids.

Souza *et al.* (2002) carried out an experiment to compare the performance and variability among double cross hybrids (DC) derived from the F₁ and F₂ generations, and from intercrossed plants of the F₂ generation of some single cross hybrids (SC). Experiments were carried out in two agricultural seasons, 42 double cross hybrids were obtained from seven commercial single cross hybrids, that is, 21 from F₁ and 21 from F₂ generations of the respective single cross hybrids. The grain yield of some DC hybrids was as high as the yield of the best SC hybrid recommended for the region.

Srivastava and Singh (2003) obtained eighty single crosses by mating 20 lines and 4 testers which were evaluated along their parents in three environments. The cross L₁₇ x T₄ showed the highest mean along with high positive relative heterosis. The cross L₁₅ x T₁ exhibited the highest relative heterosis for grain yield and 1000-kernel weight and negative heterosis for days to 50% silking.

Devi and Prodhan (2004) mated eighteen high oil inbred line with three testers. They revealed that the hybrids ICRISAT-346 x FRD 73, RHORYD x Iowa 2E.H.O, ICRISAT-98354 x Iowa 2E.H.O and

ICRISAT-1849 x FRD 73 showed significant positive heterosis for grain yield and oil content. The cross ICRISAT-346 x FRD 73 followed by RHORYD x Iowa 2E.H.O and ICRISAT-1849 x FRD 73 showed desirable economic heterosis.

Kumar and Satyanarayana (2006) identified superior hybrids through estimation of heterosis for yield and yield contributing characters. Twenty four F_1 hybrids obtained from ten inbreds AKH-102, APN-36, APN-105, GK-814, DMV-11, CMP-910, CM-119, CM-120, CM-211 and CM-131. These crosses along with their parents and a standard double cross check, DHM-105 were evaluated in a randomized block design with three replications. The cross DMV-11 x CM-120 recorded highest standard heterosis for grain yield per plot in addition to positive significant heterosis for 100 seed weight, plant height and ear girth.

Kumari *et al.* (2006) studied 45 crosses developed from 10 parental lines ('DMB101'-'DMB110') and grown along with their parental lines and check 'PEHM 2' in three replications using randomized block design to identify early maturing elite maize hybrids among them. On the basis of F_1 mean performance, 'DMB101' x 'DMB 109' was found significant for plant height, ear height, grain weight and grain yield plant⁻¹ followed by 'DMBI03' x 'DMBI04' with 18% superiority over 'PEHM 2'. Additional potential hybrids 'DMBI03' x 'DMB110', 'DMBI05' x 'DMBI09', 'DMBI07' x 'DMBI09', 'DMBI02' x 'DMB109' and 'DMBI03' x 'DMBI09' also identified for further multilocation evaluations.

Bajaj *et al.* (2007) studied 20 high quality protein maize inbred lines. They found that mid parent heterosis ranged from -29.746 to 53.081 % for grain yield. The crosses (I_3 x S), (I_4 x S) and (I_7 x S) showed significant positive mid parent heterosis for most of the characters. The cross (I_3 x S) showed positive heterosis for plant height (21.58%), ear length (4.13%), ear height (38.40%), ear diameter (5.43%), 100-kernel weight (14.16%) and grain yield (27.57%).

Corcuera *et al.* (2007) evaluated twenty single cross maize hybrids (CIG) along their parents in the range 5326-8701 kg/ha for CIG133, CIG141, CIG144, CIG158, CIG159 and CIG161. High parent heterosis values were in the range 102-169.9%. Two hybrids, CIG109 and CIG187, obtained by crossing very closely related inbreds, showed negative high parent heterosis values. All hybrids showed negative high parent heterosis values for cob percentage. The correlation between yield and kernel weight ear⁻¹ is highly significant.

Wani *et al.* (2007) estimated heterosis with 30 hybrids and 13 parental lines with two standard checks and from that revealed the cross PMI-105 x C-15 showed higher magnitude of economic heterosis (27.89%) and good *per se* performance for grain yield plant⁻¹. The PMI-114 x PMI-401 cross combination involving the inbred line PMI-401 as tester displayed its superiority by recording the highest magnitude of economic heterosis (35.96%) and showed positive effect for grain yield plant⁻¹.

Saidaiyah *et al.* (2008) studied 40 F₁'s obtained by crossing 10 inbred lines with four testers and raised along with 14 parents and two standard checks. Out of 40 crosses, 23 crosses over better parent and 11 crosses over standard check were significantly out yielded for grain yield. The crosses DMR 274 x HOL 34, DMR 201 x EI 34 and DMR 156 x EI 34 showed high heterosis over better parent and standard check DHM 103 for grain yield per plant, for 100 seed weight, ear girth, ear length, and plant height.

Corcuera *et al.* (2009) crossed twenty-seven high-quality single-cross maize hybrids (HC) with dent commercial hybrid ACA 2000 for yield and yield components. This experiment showed that the majority (70.4%) of the hybrids had medium-sized ears (15-19.9 cm), whereas only 29.6% of the hybrids produced long ears (20-25 cm), which were similar to those in ACA 2000.

Iqbal *et al.* (2010) evaluated heterosis for morphological traits in maize crosses. Mid-parent heterosis was significant for days to silking, plant height and days to maturity in all crosses except for one cross. Significant better parent heterosis was only found in one of the four crosses. Magnitudes of heterosis, both mid-parent and better parent were positive and higher for plant height compared to those for days to flowering and maturity. Mid-parent heterosis ranged from 29.30%-37.85%, -6.03% to -9.74% and 0.82% to -9.53% for plant height, days to silking and days to maturity respectively. Based on the consideration of the level of heterosis, the study suggested Pop 9804xFRW4 as the best hybrid combination for early maturity.

Singh and Gupta (2009) developed fifteen single crosses and reported that high percentage of positive significant heterosis (193.2% to 154.82%) over better parent (heterobeltiosis) for grain yield plant⁻¹ among the hybrids LM11 x CM135, LM12 x CM135, CML228 x CM13 and LM11 x Y-500 respectively. High percentage of positive significant standard heterosis for grain yield plant⁻¹ (99.91% to 94.25%) over best check was recorded by hybrids LM11 x Y-500, LM9 x Y-500, LM9 x CM139 and LM11 x CM135. The hybrid LM11 x CM135 also recorded highest percentage of better parent heterosis for days to 50 per cent silking and highest standard heterosis for plant height and kernel row ear⁻¹.

Premlatha and Kalamani (2010) studied heterosis for grain yield and growth characters using nine lines and four testers along with check COH(M)4. The hybrid UMI 278 x UMI 217 and UMI 334 x UMI 217 had significant and superior *per se* performances for grain yield plant⁻¹. Growth influencing characters positively influenced hybrid performance in grain yield. The hybrid UMI 278 x UMI 217 was observed as best and followed by UMI 334 x UMI 217 are potential hybrids for exploitation of yield heterosis.

Wali *et al.* (2010) studied eighty seven single cross hybrids of maize obtained by crossing twenty nine new lines developed from the

National Yellow Pool with three testers for all three types of heterosis. They reported that the heterosis for mid parent (MP), better parent (BP) and standard check were shown by the crosses for number of kernel ear⁻¹, number of kernel rows⁻¹, 100 grain weight and grain yield plant⁻¹. The highest positive significant heterosis for mid parent (MP), better parent (BP) and standard check were shown by the cross YP4307-20 X CI-5 followed by YP4307-04 X Prabha which showed 53.3 and 40.2% standard heterosis respectively over standard check Pinnacle.

Amanullah *et al.* (2011) developed thirty F₁ crosses including reciprocals and planted along with their six parents. The analysis of variance revealed that mean squares due to progenies and parents were highly significant for days to maturity, plant height, ear height, kernels ear⁻¹, 1000-grain weight and grain yield kg ha⁻¹. Twenty one crosses had positive heterosis for grain yield kg ha⁻¹ and ranged from +0.39 % (Kisan x Jalal) to +16.86 % (Jalal x Azam) and two hybrids having heterobeltiosis i.e Kisan x Azam (+3.99 %) and Sarhad white x Kisan (+5.44 %). For days to maturity 16 F₁ hybrids shown heterosis, while only one hybrid (Sadaf x Azam) enunciated heterobeltiosis ranged from +0.14 % (Sarhad White x Azam) to +5.39 % (Kisan x Jalal). The 19 hybrids revealed positive heterosis and 5 hybrids showed heterobeltiosis for plant height and ranged from +0.33 % (Sarhad White x Jalal and Sarhad yellow x Azam) to +7.60 (Azam x Kisan) and heterobeltiosis ranged from +0.38 (Sarhad x Azam and Sadaf x Sarhad white) to 2.21 % (Azam x Kisan). For ear height 13 hybrids showed positive heterosis and one hybrid showed heterobeltiosis and ranged from +0.80% (Jalal x Azam) to +14.69 % (Jalal x Kisan) and from +4.83% (Sarhad white x Sadaf). Heterotic and heterobeltiotic ranged from +0.06% (Sarhad White x Jalal) to +19.92% (Azam x Sadaf) and +0.29% (Sarhad yellow x Jalal) to +7.38% (Azam x Sadaf) for kernels ear⁻¹ respectively. The heterosis and heterobeltiosis for 1000 seed weight was 12.92% (Azam x Sarhad white) and 4.57 % (Sarhad white x Sarhad Yellow).

Avinashe *et al.* (2012) studied forty five hybrids obtained by crossing fifteen lines with three testers and raised in a randomized block design with three replications. The crosses 1-07-8-4 x CLQ-47, 1-07-56 x CLQ-47 and 1-07-10-1 x HKI-163 had high mean performance for days to 50% tasseling, days to 50% silking, plant height, length of ear and grain yield plant⁻¹. These crosses also had significant *per se* performance for their respective characters. The mean squares due to interaction effects of parents vs. hybrids were found to be significant for grain yield plant⁻¹ indicating the choice of exploitation of heterosis. The results revealed that, among the forty five hybrids the hybrids 1-07-8-4 x CLQ-47, 1-07-56 x CLQ-47 and 1-07-10-1 x HKI-163 were identified as superior hybrids as it recorded high percentage of relative heterosis and heterobeltiosis for grain yield plant⁻¹.

Khan *et al.* (2012) studied the potential of five commercial single crosses, ten double crosses, five F₂ progenies and four open pollinated varieties (OPVs) of maize. Highly significant differences were found among these genotypes for days to 50% tasselling, days to 50% silking, ear height (cm), ear weight plot⁻¹, grain moisture percentage, 100-grain weight and grain yield. Significant differences were noted for plant height and number of grains row⁻¹. All genotypes having different genetic make-up showed variable behavior for the characters studied. The single crosses, double crosses and even F₂, produced more grain yield than open pollinated varieties. The results further indicated that single crosses proved better in yield than OPVs even in their second generation i.e. F₂ population.

Kiplangat and Charles Melil (2012) planted thirty four experimental hybrids and two commercial maize varieties (standards) in a 6 x 6 balanced lattice design with three replicates in each of the three sites. The results showed that there was significant difference in grain yield in Kitale double cross (F = 0.83, df = 16, P < 0.05) and also Kitale top cross (F = 0.66, df = 18, P < 0.05). In Kakamega both the

double cross ($F = 0.84$, $df = 16$, $P < 0.05$) and top cross ($F = 1.14$, $df = 18$, $P < 0.05$) showed significant differences, while in Lurende the double cross ($F = 0.64$, $df = 16$, $P > 0.05$) showed no significant difference however top cross ($F = 0.56$, $df = 18$, $P < 0.05$) showed significant difference. Four hybrids (AxF) x R'2C", (95xF) x 82x93, 64 x FxR'2C" and 56x44 x R'2C10 indicated promise in all the sites.

Patil *et al.* (2012) obtained thirty crosses by crossing ten lines and three testers and raised along their parents and check (Apranji) in randomized complete block design with two replications. The crosses NM-0913 X NM-0973, NM-099 X NM-0973 and NM-0984 X NM-0914 had high mean performance for days to 50% tasseling, days to 50% silking, days to maturity, plant height, cob length, cob girth, number of grain cob⁻¹, 100 grain weight and grain yield plant⁻¹ (g). The mean squares due to interaction effects of parents vs. hybrids were found to be significant for all the characters indicating the choice of exploitation of heterosis. Four crosses namely NM-0913 XNM-0973, NM-099 X NM-0973, NM-0969 XNM-0973 and NM-0984 X NM-0914 were identified as promising crosses as they exhibited significant useful heterosis for yield and yield contributing traits. These crosses also had significant *per se* performance for their respective characters. The mean squares for lines were significant for days to 50% tasseling, days to 50% silking, plant height, cob girth, number of grain cob⁻¹, 100 grain weight and grain yield plant⁻¹ (g), while testers were significant for plant height, cob girth, number of grain cob⁻¹, 100 grain weight and grain yield plant⁻¹ (g). Out of thirty crosses studied four crosses namely NM-0981 XNM-0914, NM-099 X NM-0973, NM-0969 XNM-0967 and NM-0984 X NM-0914 were identified as the most potential crosses for hybrid production. However, out of them only two crosses NM-099 X NM-0973 and NM-0984 X NM-0914 were found to be the best crosses based on high *per se* performance and high significant useful heterosis.

Avinashe *et al.* (2013) studied forty-five crosses obtained by crossing fifteen lines with three testers. They observed that considerable variability existed among the genotype for all the characters studied as observed from the significant mean squares due to genotypes. The crosses I-07-10-1 X HKI-163, I-07-8-6 X CLQ-30 and I-07-7-4 X CLQ-30 had high mean performance for grain yield plant⁻¹ and recorded positive and significant heterosis. Crosses I-07-10-1 X CLQ-30 (36.83) recorded highest significant and positive standard heterosis for number of kernel row⁻¹.

Izhar and Chakraborty (2013) crossed twelve inbred lines with each of five testers and evaluated along with three checks and the parents to identify promising hybrids of maize for various characters like, 50% tasseling, 50% silking, ear length, ear diameter, kernels ear⁻¹ and grain yield. The hybrids, L6 × T5 was identified as a potential cross combination for grain yield while the cross L9 × T2 recorded highest magnitude of economic heterosis of 84.60% over the best standard check Vivek hybrid-9. So the crosses L6 × T5 and L9 × T2 can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

Kumar *et al.* (2013) derived 40 crosses from 13 parents (eight sweet corns and five field corns) and raised along one standard check (Madhuri sweet corn) in a randomized block design with three replications. The crosses DMSC4 X HUZM185, Dulce Amanillo X HUZM536, DMSC36 X HKI323 and Win Sweet Corn X HUZM 536 exhibited high positive significant heterosis over better parent and standard check for marketable yield and yield related traits. The top three crosses DMSC36 X HUZM185 (73.32%), DMSC19 X HUZM536 (64.90%) and DMSC9 X HKI323 (53.28%) observed for better parent heterosis and the crosses DMSC36 X HUZM185 (45.70%), DMSC19 X HUZM536 (38.18%) and Dulce Amanillo X CM119 (28.14%) showed high standard parent Heterosis for plant height. The cross Dulce Amanillo X CM119 (125.23%) expressed highest magnitude of

heterosis followed by Dulce Amanillo X HUZM185 (123.92%) and Dulce Amanillo X HUZM536 (115.36%) over standard check for 100 kernal weight. Crosses DMSC4 X HUZM185, Dulce Amanillo X HUZM536, DMSC36 X HKI323 and Win Sweet Corn X HUZM 536 were expressed high magnitude of standard parent and better parent heterosis for marketable yield and yield traits.

Singh *et al.* (2013) developed 45 crosses by including 15 lines, 3 testers along with 3 checks and sown in a Randomized Block Design with three replications. The crosses L9 x T1 and L9 x T2 showed desirable and significant heterosis both over mid parent and better parent, crosses L6 x T2 and L7 x T1 showed heterosis over standard check for days to 50% tasseling & silking. Cross L6 x T2 exhibited negative and significant heterosis over standard check. Crosses L2 x T3 and L1 x T3 showed heterosis over mid parent and better parent and L14 x T2, L10 x T2 exhibited standard heterosis for ear diameter. crosses L13 x T3, L13 x T2 showed mid parent, L10 x T3, L2 x T3 showed heterobeltiosis and L12 x T2, L10 x T3¹ exhibited standard heterosis. The crosses L5 x T3, L6 x T2 and L1 x T2 were early in maturity whereas, the crosses L6 x T1, L14 x T2 were high yielding. Crosses L11 x T2 and L10 x T3 showed highest heterosis over best check hybrid.

Rajitha *et al.* (2014) obtained fifteen hybrids by crossing five lines with three testers to study heterosis for days to 50% tasseling, days to 50% silking, 100-seed weight, and grain yield plant⁻¹. The crosses namely BM-256 X BM-85, BM-256 X BM-143, BM-3 X RNBL - 4351, BM-421 X BM-85 recorded higher level of significant relative heterosis and heterobeltiosis for grain yield plant⁻¹. The cross BM-421 X BM-143 recorded highest positive significant heterosis over mid parent and better parent. The hybrid BM-256 X BM-143 recorded maximum grain yield plant⁻¹ (130.03) over the standard check.

2.2 Prediction of hybrid performance

Identifying single and double cross hybrids with superior yield performance is of fundamental importance in commercial maize (*Zea mays* L.) breeding programmes. Several hundred single and double cross combinations are tested by breeders each year in extensive yield trials. The test procedure is expensive and time-consuming, therefore, only a limited subset of all possible single and double crosses can be tested. Maize breeders of particular interest, identify genetic factors contributing to heterosis as well as a suitable method that could predict heterosis with some accuracy before field evaluation of test hybrids. Prediction methods for the performance of single and double crosses have always been a major issue in hybrid breeding owing to the potential to greatly improve the efficiency of commercial breeding programmes. As maize germplasm is commonly organised in genetically divergent heterotic groups, predicting the performance of inter-group hybrids is of greatest interest to maize breeders.

The identification of superior single and double cross hybrids is the major objective in hybrid maize breeding. Hybrid maize (*zea mays* L.) breeders have been developing a large number of inbred lines and evaluating their performance in crosses (Hallauer 1990). The evaluation of a large number of single and double crosses in maize for their performance in experimental plots needs enormous time, labour and financial resources. To save the precious resources and time Jenkins (1934) suggested four prediction models called Jenkins methods A, B, C, and D to predict the performance of single and double-cross hybrids. Out of which, one of the prediction method was found to be based on the *per se* performance of their parental inbred lines involved.

Anderson (1938) also realized the fact and found close correspondence between predicted and realized yield of double crosses in maize.

In a hybrid breeding programme, the production and testing of a relatively large number of cross combinations is the only way to trace a desirable hybrid. Choice of parents to produce a hybrid cultivar directly is usually the result of extensive testing of a number of combinations of potential parents. One of the major problems faced by the breeder to reduce the number of possible hybrids to be tested to a reasonable number. The identification of superior hybrid between inbred lines is the last phase of a hybrid breeding programme, requires considerable resources when compared with those available for the total programme. Thus, methods that could predict F_1 hybrid performance with some accuracy prior to field evaluation are of particular interest. The performance of single and double cross hybrids were predicted in maize by many maize breeders. The work done by them are being reviewed below:

Arnold and Jenkins (1932) reported that single crosses were most uniform and the double crosses and the top crosses were approximately mid way in variability.

Dhawan and Mukherjee (1964) evaluated predicted vs. actual performance of double cross hybrids developed from early generation inbred lines and from combinations of early and advance generation lines. Jenkins method B utilized for making the predictions. Results from correlation coefficient studies and from a test of significance on the difference between predicted and actual values, revealed that the characters like grain yield and plant height predicted with a high degree of accuracy.

Malhi *et al.* (1993) studied 10 single and 18 double hybrids out of a possible 25 single and 100 double hybrids between 10 promising lines belonging to two gene pools. The single hybrids had significantly higher ranking than the double ones for yield on average over all crosses and over the five best crosses. Out of ten sets of related single and double crosses, five sets showed significant differences between the grain yield of the single and double hybrids. Comparison of results

from two test sites indicated that the single hybrids were more stable than the double ones in performance. With the available germplasm, it is expected that single hybrids would out yield double ones by 7-9%.

Sujiprihati *et al.* (2003a) evaluated single cross hybrids among selected inbred lines for the performance of the hybrids and to determine phenotypic correlations among traits. Grain yield of the hybrids most highly correlated with grain weight and grain weight ear⁻¹. Grain yield correlations with grain weight gave *r* values of 0.87, 0.90 and 0.91 while its correlation coefficients with grain weight ear⁻¹ were 0.87, 0.81 and 0.90 respectively. Flowering and maturity characters negatively correlated with most other characters, indicating that early flowering and maturing hybrids more favourable for grain yield and the other characters measured. Among the yield components themselves, highest correlation shown between ear weight and grain weight ear⁻¹, with *r* values 0.99, 0.96 and 0.98 respectively.

Sujiprihati *et al.* (2003b) suggested the use of double cross hybrids in maize to overcome the problem of seed production related to single cross resulting from low vigor and yield associated with the inbred parents. These single crosses were used to produce some double cross hybrids. The performance of ten selected double cross hybrids were evaluated at two environments. The predicted performance of these double cross hybrids was also compared with the actual, using the method based on the mean values of non parental single crosses. The best performing double cross hybrids, DC-26 and DC-34 were found to have high yields at both environments as well as in the combined analysis. DC-26 and DC-34 gave mean grain yields of 6125.0 and 5917.8 kg ha⁻¹ respectively, at Field 2, 5648.9 and 5676.2 kg per ha respectively and 5887.0 and 5797.0 kg ha⁻¹ respectively, in the combined analysis. From the correlation analysis, the actual and the predicted performances of the double cross hybrids were found to be in good agreement at each location and locations combined

($r = 0.38, 0.46$ and 0.27 , respectively, at field 2, implying that the method used for yield predictions in the crosses was appropriate.

Castellanos *et al.* (2004) predicted the genotypic mean of synthetic variety (SVs) derived from n double crosses (DCs) in which two sets of predictors, each containing three unbiased prediction formulae. In the first set each formula expressed in terms of two means, from the population formed by all direct crosses between parents and the population formed by randomly mating in isolation each parent. Besides the $4n$ lines, parents of the SV can be the elements of any set of n DCs or $2n$ single crosses (SCs) formed with all $4n$ lines (Ls). In the second set of predictors each involves three means since each random mating population decomposed into two groups of individuals obtained by selfing and crossing. These predictors showed superiority from 8 to 40% in efficiency relative to comparable predictors in the first set.

Kumar and Satyanarayana (2006) predicted superior double cross hybrids for grain yields. Twenty four F_1 hybrids obtained from ten inbreds AKH-102, APN-36, APN-105, GK-814, DMV-11, CMP-910, CM-119, CM-120, CM-211 and CM-131. These crosses along with their parents and a standard double cross check, DHM-105 were evaluated in a randomized block design with three replications. The predicted double cross hybrid yields were 10.3 to 12.3 per cent higher than the standard double cross check DHM-105. The double cross hybrids, $(P6 \times P2) \times (P9 \times P10)$, $(P1 \times P6) \times (P8 \times P10)$ and $(P6 \times P3) \times (P8 \times P10)$ appeared more potential combinations for further evaluation.

Shakoor *et al.* (2007) studied thirty maize double crosses along with two controls (Hicorn984 and Hicorn 11+) for ears plant⁻¹, plant height, ear height, days to 50% tasseling, days to 50% silking and grain yield plant⁻¹. Significant differences were found among the crosses for ears plant⁻¹, plant height, ear height and highly significant differences for days to 50% tasseling, days to 50% silking and grain yield. Grain

yield plant⁻¹, followed by days to 50% silking and days to 50% tasseling, were found high heritable traits for grain yield improvement. Plant height followed by ear height, days to 50% tasseling and days to 50% silking, had strong genotypic and phenotypic associations with each other and significantly positive genotypic correlation with grain yield. Plant height, followed by days to 50% tasseling, also exerted positive direct effect on grain yield.

Kumar (2010) studied prediction of double cross hybrid performance in maize (*Zea mays* L.). A total of ten inbred lines of maize were used to predict the performance of double cross hybrids. The performance of predicted 630 double crosses was estimated on the basis of performance of their constituent single crosses. The predicted mean performance for grain yield plant⁻¹ of 630 double crosses varied from 91.52 g [(CML83) x (CML141)] x [(CML3) x (CML117)] to 142.88 g [(CML601S423) x (CML107)] x [(CML83) x (Pop 34C5HC8621 (x) 5b)]. The expected yield performance of these crosses was 142.83, 142.15, 140.00, 130.00 and 138.67 g plant⁻¹ respectively, whereas the grain yield plant⁻¹ of the best check variety, Suwan was only 120.26 g. The double cross [(CM 601S423) x (CML107)] x [(CML83) x (Pop 34C5HC8621 (x) 5b)] predicted better for most of the characters viz., earliness in 50% silking and maturity, short plant and ear height, longer and thicker ears, average 500 kernel weight and number of kernel rows, short vegetative growth, medium grain filling and average grain moisture content. Similarly the second top ranking double cross [(M9 x CM601) (x) S41) x (Pop 30C3P583)] x [(CML3) x (CML117)] was also expected to perform better for most of the desirable traits.

Pavan *et al.* (2011) developed eighty seven single cross hybrids of maize by crossing twenty nine newly developed inbred lines in a randomized complete block design with two replications to assess the direct and indirect effects of grain yield. Plant height, ear length, ear

circumference, 100 grain weight and grain yield plant⁻¹ recorded significantly positive genetic correlation with grain yield.

Sanchez (2011) calculated equations for inbreeding coefficient and mean prediction for a synthetic made with a mixture of single, three way, and double cross hybrids. As inbreeding and mean predictions for the three types of hybrids was already known, corresponding results for inbreeding and mean prediction for the hybrid mixture obtained with relative ease.

Kanagarasu *et al.* (2012) developed seventy two single cross maize hybrids along with their parental lines assessed for genetic correlation among quantitative traits. Plant height, cob diameter, cob length, and 100 grain weight, exhibited a positive and significant correlations with grain yield plant⁻¹ except days to tasselling, silking and days to maturity. A strong positive inter correlation was observed among the plant height, cob length, cob diameter. Grain yield indicating that the selection for these characters help to improve the grain yield in maize indirectly.

Ertiro *et al.* (2013) studied sixteen inbred lines and sixty single cross hybrids for grain and stover yield. Hybrids had higher grain and stover yields and lower stover fodder quality traits than the inbred lines. Significant positive relationships observed between inbred lines *per se* and hybrid performances for these fodder quality traits suggest the feasibility of predicting hybrid performance from the performance of the inbred lines.

Kanagarasu *et al.* (2013) carried out 72 single cross hybrids and along with its parents evaluated in randomized block design with two replications. Association studied revealed significant and positive correlation coefficients between grain yield and cob diameter (0.902), cob length (0.880), plant height (0.809) and 100 grain weight (0.575). Genotypic correlation coefficients and path analysis revealed that

grains row⁻¹, grain rows cob⁻¹, 100 grain weight and plant height had positively significant correlation and highest direct effect on grain yield.

Kote *et al.* (2014) studied 45 hybrids along with their 15 inbred lines, 3 testers and 3 checks evaluated in a randomized block design with three replications. Plant height, ear length, ear girth and test weight found to possess significant association in desirable direction with seed yield plant⁻¹ at both genotypic and phenotypic levels. Days to 50% tasseling, days to 50% silking and days to maturity showed significant negative association with seed yield plant⁻¹ and with other yield attributing characters like cob length and cob girth.

From the review of work done by various scientists on heterosis and Prediction of hybrid performance in maize the following observations were drawn:

- 1) Maize being a highly cross pollinated crop, offers good scope for heterosis exploitation.
- 2) Exploitation of hybrid vigour depends on the direction and magnitude of heterosis and the type of gene action involved.
- 3) The identification of superior single and double cross hybrids is the major objective in hybrid maize breeding.
- 4) Prediction methods for the performance of single and double crosses greatly improve the efficiency of commercial breeding programs.
- 5) Heterosis estimation, prediction of hybrid performance and the *per se* performance together plays an important criteria for hybrid development technology.

MATERIAL AND METHODS

The research work entitled "Evaluation of single and double cross hybrids in maize" was conducted during *rabi* 2013 and *kharif* 2014 at the experimental farm of Agricultural Botany Section, College of Agriculture, Nagpur. The material used and methodologies followed in this research work are described below:

3.1 Material required

The experimental material comprised of six inbreds, nine single crosses and one check (single cross hybrid Rajarshi) as listed below

| Inbreds | Source |
|--------------|--|
| 1. NM 32-1-1 | These NM (Nagpur Maize) Inbred lines are developed from EC and IC germplasm supplied by DMR to Botany Section, College of Agriculture, Nagpur. |
| 2. NM 44-3-1 | |
| 3. NM 2-1 | |
| 4. NM 60-4 | |
| 5. NM 44-5 | |
| 6. NM 62-4-1 | |

| Single crosses |
|---------------------------------|
| 1. NM 32-1-1 x NM 60-4 (SC-1) |
| 2. NM 32-1-1 x NM 44-5 (SC-2) |
| 3. NM 32-1-1 x NM 62-4-1 (SC-3) |
| 4. NM 44-3-1 x NM 60-4 (SC-4) |
| 5. NM 44-3-1 x NM 60-5 (SC-5) |
| 6. NM 44-3-1 x NM 62-4-1 (SC-6) |
| 7. NM 2-1 x NM 60-4 (SC-7) |
| 8. NM 2-1 x NM 44-5 (SC-8) |
| 9. NM 2-1 x NM 62-4-1 (SC-9) |

| Check |
|---------------------|
| Rajarshi [KMH22168] |

3.2 Methods adopted

During *rabi* 2013, nine single crosses were raised. Crossing were followed to produce thirty six double crosses from these nine single crosses in *rabi* 2013. Crossed seeds of these thirty six double crosses along with nine single crosses, six inbreds and one check (Rajarshi) were grown in Randomized Complete Block Design with three replications with the spacing of 60 cm x 20 cm accommodating 15 plants in each row for evaluation in *kharif* 2014. Recommended package of practices were followed to raise a good crop. The data were recorded on five randomly selected plants from each genotype on following seven characters except days to 50 % tasseling, days to 50% silking and days to maturity which were recorded on plot basis.

3.2.1 Recording of experimental data

1. Days to 50 % tasseling

The number of days taken by 50% of plants to initiate tasseling in each genotype from the date of sowing were counted and presented as days to 50 % tasseling.

2. Days to 50 % silking

The number of days taken by 50 % of plants to initiate silking in each genotype from the date of sowing were counted and presented as days to 50 % silking.

3. Days to maturity

The number of days taken by all the plants in each genotype to attain physiological maturity from the date of sowing were counted and presented as days to maturity.

4. Plant height (cm)

The plant height was measured in centimetre from bottom to flag leaf of shoot with the help of meter scale on five randomly selected

plants at the time of maturity. The average height of five plants were recorded as plant height in centimetre.

5. Cob length (cm)

Five cobs from each line were selected randomly and husk (covering) were removed at the time of harvesting and their length were measured with meter scale and average length was calculated in centimetre.

6. Cob girth (cm)

Girth of five cobs whose length were already recorded were measured with meter scale in centimetre and average girth was calculated.

7. Number of grains cob⁻¹

Five cobs from each observational plant were picked up, threshed separately and the grains cob⁻¹ was counted. The average grains over five plants were recorded as grains cob⁻¹.

8. 100 grain weight (g)

100 grains were counted from five randomly selected plants and weighed in gram separately on precision weighing balance and mean 100 grain weight was recorded.

9. Grain yield plant⁻¹ (g)

The grains obtained from five randomly selected plants were weighed in gram separately on precision electronic weighing balance and mean grain yield was calculated and recorded as grain yield plant⁻¹ (g).

10. Grain yield plot⁻¹ (Kg)

The grains obtained from all the non selected and selected plants in the plot were weighed in gram together on precision electronic weighing balance and mean grain yield was calculated and recorded as grain yield plot⁻¹ (Kg).

3.3 Statistical analysis

The data were subjected to the following statistical and biometrical analysis

1. Analysis of variance for the experimental design (Panse and Sukhatme, 1954).
2. Estimation of heterosis and useful heterosis.
3. Prediction of single cross and double cross performance (Jenkins, 1934).
4. Pearson's simple correlation coefficient was calculated between expected and actual hybrid phenotypes.
5. The regression analysis of expected hybrid yield on observed hybrid yield (Rao and Richard, 2008).

3.3.1 Analysis of variance for the experimental design

The analysis of variance was performed to test the significance of differences between the genotypes (parents, crosses and check) for all the ten characters as per the methodology suggested by Panse and Sukhatme (1954).

The statistical model used for the design was,

$$Y_{ij} = \mu + g_i + b_j + e_{ij}$$

Where,

- Y_{ij} = Phenotypic performance of i^{th} genotype over j^{th} replication
- μ = general mean
- g_i = the effect of the i^{th} genotype
- b_j = Effect of j^{th} block
- e_{ij} = environmental effect



The analysis of variance based on this model is given below

| Sources of variation | Degrees of freedom (d.f.) | Mean Squares | |
|----------------------|---------------------------|-----------------|--------------------------|
| | | Observed | Expected |
| Replications | (r-1) | MS _r | $\sigma_e^2 + g\sigma^2$ |
| Genotypes | (g-1) | MS _g | $\sigma_e^2 + r\sigma^2$ |
| Error | (g-1)(r-1) | MS _e | σ_e^2 |
| Total | (gr-1) | | |

Where,

r = Number of replications

g = Number of genotypes

e = error

σ^2 = Variance

The significance of mean squares was tested against error variance by using F test. The standard error of difference for comparing any two progeny means was computed by using error variance of respective characters as follows

$$\text{S.E. (Diff.)} = \sqrt{\frac{2\sigma_e^2}{r}}$$

The critical difference was computed by multiplying the standard error of difference with 't' values at error degrees of freedom at P=0.05 (5%) and P=0.01(1%).

3.3.2 Estimation of heterosis and useful heterosis

I. Heterosis of single cross

Heterosis was calculated as the deviation of the F₁ hybrid over the average of the two parents and expressed in percentage by following formula,

$$\text{Heterosis of single crosses (\%)} = \frac{\overline{F_1(\text{sc})} - \overline{MP}}{\overline{MP}} \times 100$$

Where,

$\overline{F_1}$ = mean performance of F_1 of single crosses

\overline{MP} = mean performance of parent

$$\overline{MP} = \frac{\overline{P_1} + \overline{P_2}}{2}$$

Where,

$\overline{P_1}$ = mean performance of parent 1

$\overline{P_2}$ = mean performance of parent 2

Standard error of difference for heterotic effects were calculated using the formula,

$$SE(\text{Diff.}) = \sqrt{\frac{3\sigma^2 e}{2r}}$$

The critical difference was computed by multiplying the standard error with 't' value for error degrees of freedom at 5 and 1 per cent level of significance.

Useful heterosis for single cross

Useful heterosis was calculated as the deviation of F_1 over check variety and was expressed as percentage increase over it.

$$\text{Useful heterosis of single crosses (\%)} = \frac{\overline{F_1(\text{sc})} - \overline{\text{Check}}}{\overline{\text{Check}}} \times 100$$

Where,

$\overline{F_1(\text{sc})}$ = mean performance of F_1 of single crosses

$\overline{\text{Check}}$ = mean performance of check

The standard error of difference for comparing the values of useful heterosis was calculated as follows,

$$SE(\text{Diff.}) = \sqrt{\frac{2\sigma^2 e}{r}}$$

The critical difference was computed as given above for error degrees of freedom at 5 and 1 per cent level of significance.

II. Heterosis of double cross

$$\text{Heterosis of double crosses (\%)} = \frac{\overline{F_1(Dc)} - \overline{MP(Sc)}}{\overline{MP(Sc)}} \times 100$$

Where,

$\overline{F_1(Dc)}$ = Mean performance of F_1 of double crosses

\overline{MP} = Mean performance of single crosses

$$\overline{MP} = \frac{\overline{SC_1} + \overline{SC_2}}{2}$$

Where,

$\overline{SC_1}$ = mean performance of single cross 1

$\overline{SC_2}$ = mean performance of single cross 2

Standard error of difference for heterotic effects were calculated using the formula,

$$SE(\text{Diff.}) = \sqrt{\frac{3\sigma^2 e}{2r}}$$

The critical difference was computed by multiplying the standard error with 't' value for error degrees of freedom at 5 and 1 per cent level of significance.

Useful heterosis for double cross

Useful heterosis was calculated as the deviation of F_1 over check variety and was expressed as percentage increase over it.

$$\text{Useful heterosis of double crosses (\%)} = \frac{\overline{F_1(Dc)} - \overline{\text{Check}}}{\overline{\text{Check}}} \times 100$$

Where,

$\overline{F_1(Dc)}$ = mean performance of double crosses

$\overline{\text{Check}}$ = mean performance of check

The standard error of difference for comparing the values of useful heterosis was calculated as follows,

$$SE(\text{Diff.}) = \sqrt{\frac{2\sigma^2 e}{r}}$$

The critical difference was computed as given above for error degrees of freedom at 5 and 1 per cent level of significance.

3.3.3 Prediction of single cross and double cross performance

Expected performance of single cross and double cross were estimated using a prediction method based on *per se* performance of inbreds given by Jenkins (1934) is as follows.

I. Expected performance of single cross

Expected performance of single cross was estimated by using the following formula,

$$H_{AB} = \frac{P_A + P_B}{2}$$

Where,

H_{AB} is the expected performance of single cross progenies from parents A and B with respective phenotypic values of P_A and P_B .

II. Expected performance of double cross

Expected performance of double cross was calculated by using the following formula,

$$H_{(AB) \times (CD)} = \frac{P_A + P_B + P_C + P_D}{4}$$

Where,

$H_{(AB) \times (CD)}$ is expected performance of double cross progeny from single cross (A x B) and (C x D).

P_A , P_B , P_C and P_D are the phenotypic values of parents involved in the single crosses.

3.3.4 Pearson's simple correlation coefficient

Pearson's simple correlation coefficient was calculated between expected and actual hybrid phenotypes by using the following formula,

$$r_{(AE)} = \frac{\text{Cov}_{(AE)}}{\sqrt{\text{Var}_{(A)} \cdot \text{Var}_{(E)}}}$$

Where,

$r_{(AE)}$ is correlation between actual (A) and expected (E) hybrid phenotype

$\text{Cov}_{(AE)}$ is the covariance between A and E

$V_{(A)}$ is the variance of A

$V_{(E)}$ is the variance of E

The statistical significance of the correlation coefficient is found by referring to table r value at (n-2) degrees of freedom. Where 'n' is the number of genotypes / treatments used in the study.

Coefficient of determination (r^2) is calculated by taking the square of correlation coefficient.+

$$\text{Coefficient of determination } (r^2) = (r_{AE})^2$$

3.3.5 Regression analysis

The regression analysis of expected hybrid yield on observed hybrid yield was calculated as per the method given by Rao and Richard (2008).

The linear equation for estimating regression line and line of slope is,

$$Y = a + bx$$

Where,

Y = actual performance

a = constant computed from data or the point on Y axis at which this regression line intercepts

x = expected performance

b = regression coefficient of y on x

Regression coefficient 'b' was calculated by the formula,

$$b = \frac{(1/n) \sum (X - \bar{X})(Y - \bar{Y})}{(\text{S.D of } X)^2}$$

S.E. for regression coefficient b was calculated by,

$$\text{S.E (b)} = \sqrt{\frac{1}{n-2} \left(\frac{\sum (Y - \bar{Y})^2}{\sum (X - \bar{X})^2} b^2 \right)}$$

The significance of b is tested by 't' test where,

$$t_{(\text{cal})} = \frac{b}{\text{S.E } b}$$

and comparing $t_{(\text{cal})}$ with table 't' value at error degrees of freedom.

3.4 Place / Duration / Season of experiment

This work was conducted in the Research farm of Agricultural Botany Section, College of Agriculture, Nagpur during the year 2013-2014 and 2014-15.

RESULTS AND DISCUSSION

Maize is an important cereal food crop of the world with the highest production and productivity as compared to rice and wheat. It is the most versatile crop with wider genetic variability and which is being grown successfully in more than 166 countries across the globe including tropical, sub tropical and temperate regions from sea level to 3000 m amsl. In addition to being an economically important crop, maize has genetic characteristics that allowed this species to be widely studied. Thus contributing for an understanding of many questions of genetic nature has given the great economic importance of maize. Genetic breeding in this crop is very intense and mostly targeted at increasing grain yield. Yield in maize crop has been increased dramatically over the years as the crop breeders are successful in harnessing the heterosis and hybrid vigour in maize than in any other crop species.

Maize has the various utilization, the main goal of maize breeding is to obtain new hybrids that will outperform the existing hybrids with respect to a number of traits. In working towards this goal, particular attention is paid to grain yield as it is the most important agronomic trait. A frequent method used in maize breeding is to develop genetically diverse inbred lines that are latter crossed to develop different types of hybrids, which exhibit high heterosis when the inbred lines are complementary and also have high uniformity.

Single cross hybrid technology has been widely adopted because of its high yield, uniformity, early production, ability to withstand biotic and abiotic stresses, food and nutritional security. In India a coordinated emphasis has been laid on various aspects of maize breeding activities viz. development of genetically diverse, productive inbred lines with good *per se* performance and resistance or tolerance to biotic and abiotic stress. After shifting to single cross hybrid technology, India witnessed 30 per cent increase in production

and 2.7 per cent increase in productivity within two years with the coverage of 20 per cent area under single cross hybrid (Dass *et al.*, 2010). There was also 15 per cent annual increase in production and more than 12 per cent increase in productivity. This is the visible impact of single cross hybrid technology. Therefore the development of single cross hybrid and their adoption in farmer's field should become the main strategy to ensure food and feed security of the developing world.

The regions where the use of single cross hybrids are too expensive or even does not exist, the crosses like double cross, open pollinated varieties, synthetics or three way crosses are most frequently used. Among these, double cross hybrids showed the broadest adaptation and alternative for the environmental conditions, where the single crosses might not be recommendable (Weatherspoon, 1970). Double cross hybrid results from the cross between two single crosses and can be considered as the first commercial maize hybrid cultivar available to the farmers. This fact was possible only due to the work developed by Jones in the early part of the 20th century and also reported that double cross hybrids are genetically more variable, stable and consistent in the performance than the single crosses (Troyer, 2009). For the successful double cross hybrid development, heterotic effects have to be maximized and the best results are expected when the four unrelated or diverse inbred lines are used.

The evaluation of a large number of single and double cross hybrids obtained from the large set of inbred lines on the actual field trial is not possible mainly because of limited land and financial resources. Thus it is of great importance to the breeder to identify the most promising single and double cross hybrids for the field evaluation. Therefore with the ability to predict the performance of single and double cross hybrids from the parental inbreds *per se* performance, only promising single and double cross hybrids need to be developed and the yield performance confirmed in actual yield test. Several

methods to predict the performance of single and double cross hybrid were given by Jenkins (1934), one of the method is based on the *per se* performance of inbreds.

Considering all the above points, the present research work entitled "Evaluation of single and double cross hybrids in maize (*Zea mays* L.)" was planned and carried out with the objectives, to estimate the heterosis of single and double cross hybrids, to predict the performance of single and double crosses and assess the reliability of prediction methods. Details of parentages of single crosses (SC) and double crosses (DC) are given in Appendix-1. The results obtained from this research work are presented and discussed under the following sub-headings:

4.1 Analysis of variance for various characters in maize

4.2 Mean performance of parents and their crosses

4.3 Heterosis

4.4 Prediction of single and double cross hybrids performance

4.1 Analysis of variance for various characters in maize

The analysis of variance for all the ten characters studied are presented in Table 1. The mean squares due to genotypes were highly significant for all the ten characters studied i.e. days to 50% tasseling, days to 50% silking, days to maturity, plant height, cob length, cob girth, number of grains cob⁻¹, 100 grain weight, grain yield plant⁻¹ and grain yield plot⁻¹. This indicates the presence of wide genetic variation among the genotypes (parents, crosses and check) for all the ten characters.

The analysis of variance for the experimental design thus indicated the presence of substantial genetic variability among the genotypes which allows the further estimation in the experimental material. The wide variability for yield plant⁻¹ and yield contributing characters in maize were also observed by Dadheech and Joshi

Table 1. Analysis of variance for various characters in maize

| Sources of variation | Degrees of freedom | Mean squares | | | | | | | | | |
|----------------------|--------------------|------------------------|----------------------|------------------|-------------------|-----------------|----------------|------------------------------------|----------------------|-------------------------------------|-------------------------------------|
| | | Days to 50 % tasseling | Days to 50 % silking | Days to maturity | Plant height (cm) | Cob length (cm) | Cob girth (cm) | Number of grains cob ⁻¹ | 100 grain weight (g) | Grain yield plant ⁻¹ (g) | Grain yield plot ⁻¹ (Kg) |
| Replications | 2 | 14.94 | 10.06 | 8.48 | 125.43 | 4.06 | 3.03 | 1905.20 | 2.44 | 194.91 | 0.06 |
| Genotypes | 51 | 14.74** | 12.03** | 5.67** | 203.80** | 5.57** | 2.15** | 4246.73** | 1.71** | 217.61** | 0.05** |
| Error | 102 | 5.69 | 6.04 | 2.98 | 47.22 | 2.42 | 1.04 | 708.39 | 0.95 | 63.86 | 0.02 |

*, ** = significant at 5% and 1% level respectively.

(2007), Shakoor *et al.* (2007), Dubey *et al.* (2009), Iqbal *et al.* (2010), Singh and Gupta (2009), Amanullah *et al.* (2011) and Avinash *et al.* (2013).

4.2 Mean performance of parents and their crosses

The *per se* performance of parents, single crosses, their respective double crosses and check for ten characters recorded in maize are presented in Table 2.

A. Days to 50% tasseling

Among the six parents under study, the mean performance of the parent NM 2-1 (54 days) was the earliest followed by NM 32-1-1 (54.67 days) and NM 44-5 (55.67 days) for days to 50% tasseling. Among the nine single crosses, SC-2 (51 days) was the earliest for days to 50% tasseling followed by SC-5 and SC-6 (51.67 days).

Among thirty six double crosses, the double cross DC-1X6 (51.33 days) was the earliest for days to 50% tasseling followed by 51.67 days each for the double crosses, DC-6X2, DC-6X7, DC-7X6 and DC-6X8 (52 days). All of the above single and double crosses were found to be significantly superior over the check Rajarshi (56 days) for earliness in days to 50% tasseling.

B. Days to 50% silking

Among the six parents under study, the parents NM 32-1-1 and NM 2-1 (60.33 days) were earliest followed by NM 44-5 (60.67 days) and NM 60-4 (62 days) for days to 50% silking. Among the nine single crosses, the single crosses SC-2, SC-4, SC-6 (57.33 days) were earliest for days to 50% silking followed by SC-5 (57.67 days).

Among thirty six double crosses, the double cross DC-6X8 (56.67 days) was the earliest for days to 50% silking followed by 57.33 days each for the double crosses, DC-1X6, DC-6X2, DC-7X6 and 57.67 days each for the double cross DC-6X7 and DC-8X4. All of the above single and double crosses were found to be significantly

Table 2. Mean performance of parents and their single and double crosses for different characters

| Sr. No. | Genotypes | Days to 50% tasseling | Days to 50% silking | Days to maturity | Plant height (cm) | Cob length (cm) | Cob girth (cm) | No. of grains cob ⁻¹ | 100 grain weight (g) | Grain yield plant ⁻¹ (g) | Grain yield plot ⁻¹ (Kg) |
|-----------------------|-----------|-----------------------|---------------------|------------------|-------------------|-----------------|----------------|---------------------------------|----------------------|-------------------------------------|-------------------------------------|
| Inbreds | | | | | | | | | | | |
| 1 | NM 32-1-1 | 54.67 | 60.33 | 92.33 | 173.47 | 12.17 | 11.63 | 233.20 | 19.23 | 45.33 | 0.68 |
| 2 | NM 44-3-1 | 56.33 | 62.67 | 92.33 | 172.80 | 11.37 | 13.41 | 255.73 | 22.43 | 57.70 | 0.87 |
| 3 | NM 2-1 | 54.00 | 60.33 | 95.00 | 171.60 | 13.29 | 12.61 | 260.67 | 21.65 | 60.48 | 0.91 |
| 4 | NM 60-4 | 57.00 | 62.00 | 93.00 | 181.13 | 11.09 | 13.49 | 256.87 | 22.59 | 58.51 | 0.88 |
| 5 | NM 44-5 | 55.67 | 60.67 | 92.33 | 180.20 | 14.29 | 12.29 | 322.53 | 21.69 | 72.05 | 1.08 |
| 6 | NM 62-4-1 | 59.00 | 63.67 | 93.00 | 175.53 | 13.64 | 12.62 | 330.07 | 21.78 | 72.90 | 1.09 |
| Single crosses | | | | | | | | | | | |
| 1 | SC-1 | 53.67 | 58.67 | 93.67 | 193.97 | 14.19 | 12.68 | 346.27 | 20.41 | 71.40 | 1.07 |
| 2 | SC-2 | 51.00 | 57.33 | 94.00 | 192.00 | 14.33 | 14.06 | 339.20 | 22.85 | 78.39 | 1.18 |
| 3 | SC-3 | 54.67 | 60.67 | 91.67 | 195.93 | 13.51 | 12.95 | 298.27 | 20.57 | 62.11 | 0.93 |
| 4 | SC-4 | 52.33 | 57.33 | 90.33 | 191.20 | 14.62 | 13.33 | 346.27 | 22.39 | 78.23 | 1.17 |
| 5 | SC-5 | 51.67 | 57.67 | 92.33 | 196.00 | 13.53 | 13.57 | 333.87 | 21.81 | 73.66 | 1.10 |
| 6 | SC-6 | 51.67 | 57.33 | 93.00 | 190.13 | 14.15 | 14.42 | 345.47 | 21.90 | 75.71 | 1.14 |
| 7 | SC-7 | 53.00 | 59.67 | 93.33 | 182.40 | 15.15 | 13.43 | 345.07 | 21.51 | 73.65 | 1.10 |
| 8 | SC-8 | 54.67 | 61.00 | 93.67 | 186.33 | 13.49 | 11.48 | 291.27 | 22.87 | 66.76 | 1.00 |
| 9 | SC-9 | 56.33 | 61.33 | 94.33 | 194.13 | 14.46 | 12.33 | 339.47 | 23.28 | 79.58 | 1.19 |
| Double crosses | | | | | | | | | | | |
| 1 | DC 1X5 | 57.67 | 63.33 | 94.00 | 175.07 | 16.48 | 12.23 | 352.93 | 21.29 | 76.50 | 1.15 |
| 2 | DC 1X6 | 51.33 | 57.33 | 91.67 | 171.40 | 11.98 | 12.19 | 285.00 | 21.23 | 62.55 | 0.94 |
| 3 | DC 1X8 | 55.33 | 60.33 | 92.67 | 167.40 | 14.37 | 12.51 | 371.93 | 21.61 | 81.89 | 1.23 |
| 4 | DC 1X9 | 57.67 | 63.00 | 93.67 | 176.67 | 15.66 | 13.41 | 351.13 | 22.25 | 79.00 | 1.18 |
| 5 | DC 2X4 | 52.67 | 58.00 | 92.67 | 182.60 | 14.91 | 12.51 | 326.33 | 22.12 | 72.23 | 1.08 |

Continued...

Table 2. Continued...

| Sr. No. | Genotypes | Days to 50% tasseling | Days to 50% silking | Days to maturity | Plant height (cm) | Cob length (cm) | Cob girth (cm) | No. of grains cob ⁻¹ | 100 grain weight (g) | Grain yield plant ⁻¹ (g) | Grain yield plot ⁻¹ (Kg) |
|---------|-----------|-----------------------|---------------------|------------------|-------------------|-----------------|----------------|---------------------------------|----------------------|-------------------------------------|-------------------------------------|
| 6 | DC 2X6 | 56.67 | 60.67 | 94.67 | 171.87 | 13.26 | 14.17 | 339.60 | 21.67 | 74.53 | 1.12 |
| 7 | DC 2X7 | 54.33 | 59.00 | 92.33 | 180.53 | 12.83 | 12.78 | 291.80 | 22.42 | 66.73 | 1.00 |
| 8 | DC 2X9 | 58.00 | 62.33 | 95.33 | 186.93 | 15.50 | 12.69 | 336.33 | 21.33 | 72.12 | 1.08 |
| 9 | DC 3X4 | 53.67 | 59.00 | 92.00 | 189.13 | 15.07 | 14.47 | 375.60 | 21.31 | 80.84 | 1.21 |
| 10 | DC 3X5 | 53.67 | 58.67 | 95.33 | 185.93 | 14.13 | 13.41 | 333.00 | 23.21 | 78.57 | 1.18 |
| 11 | DC 3X7 | 57.33 | 62.00 | 93.00 | 188.33 | 14.94 | 12.95 | 363.07 | 21.17 | 78.14 | 1.17 |
| 12 | DC 3X8 | 56.33 | 60.00 | 93.00 | 190.73 | 14.99 | 13.93 | 355.07 | 21.45 | 77.02 | 1.15 |
| 13 | DC 4X2 | 55.33 | 61.00 | 92.00 | 187.93 | 17.84 | 13.45 | 426.27 | 21.25 | 91.32 | 1.37 |
| 14 | DC 4X3 | 53.00 | 58.33 | 92.00 | 182.73 | 17.60 | 13.43 | 389.00 | 22.27 | 86.83 | 1.30 |
| 15 | DC 4X8 | 54.67 | 60.33 | 91.67 | 186.47 | 15.26 | 12.83 | 371.93 | 21.93 | 82.29 | 1.23 |
| 16 | DC 4X9 | 55.67 | 61.33 | 91.67 | 178.53 | 14.72 | 13.55 | 343.20 | 20.85 | 72.50 | 1.09 |
| 17 | DC 5X1 | 58.00 | 63.00 | 91.33 | 184.67 | 16.63 | 13.05 | 370.53 | 22.37 | 83.54 | 1.25 |
| 18 | DC 5X3 | 53.33 | 59.00 | 91.00 | 180.87 | 14.29 | 14.17 | 311.93 | 21.96 | 69.22 | 1.04 |
| 19 | DC 5X7 | 54.67 | 62.33 | 90.33 | 191.53 | 14.54 | 13.23 | 346.13 | 21.29 | 74.40 | 1.12 |
| 20 | DC 5X9 | 54.00 | 60.00 | 94.00 | 196.07 | 13.73 | 14.62 | 351.87 | 23.44 | 82.73 | 1.24 |
| 21 | DC 6X1 | 55.00 | 60.67 | 91.00 | 176.20 | 15.13 | 14.13 | 388.60 | 22.38 | 87.25 | 1.31 |
| 22 | DC 6X2 | 51.67 | 57.33 | 94.00 | 188.33 | 13.07 | 14.13 | 289.47 | 22.14 | 64.22 | 0.96 |
| 23 | DC 6X7 | 51.67 | 57.67 | 91.00 | 180.87 | 15.49 | 14.48 | 382.07 | 21.57 | 83.79 | 1.26 |
| 24 | DC 6X8 | 52.00 | 56.67 | 91.33 | 171.33 | 13.65 | 13.35 | 351.13 | 22.61 | 79.98 | 1.20 |
| 25 | DC 7X2 | 57.00 | 62.33 | 92.33 | 172.07 | 14.77 | 12.43 | 330.27 | 21.77 | 71.97 | 1.08 |
| 26 | DC 7X3 | 58.67 | 62.33 | 94.33 | 180.27 | 13.89 | 11.45 | 323.40 | 22.12 | 71.85 | 1.08 |
| 27 | DC 7X5 | 54.33 | 59.67 | 90.67 | 176.87 | 14.67 | 12.33 | 360.93 | 22.23 | 80.06 | 1.20 |
| 28 | DC 7X6 | 51.67 | 57.33 | 92.67 | 171.73 | 14.01 | 14.65 | 336.13 | 21.56 | 73.05 | 1.10 |
| 29 | DC 8X1 | 53.33 | 59.00 | 93.67 | 187.60 | 15.19 | 13.79 | 376.73 | 20.91 | 78.74 | 1.18 |
| 30 | DC 8X3 | 56.00 | 61.67 | 95.00 | 186.53 | 15.01 | 14.26 | 356.53 | 21.89 | 79.78 | 1.20 |

Continued...

Table 2. Continued...

| Sr. No. | Genotypes | Days to 50% tasseling | Days to 50% silking | Days to maturity | Plant height (cm) | Cob length (cm) | Cob girth (cm) | No. of grains cob ⁻¹ | 100 grain weight (g) | Grain yield plant ⁻¹ (g) | Grain yield plot ⁻¹ (Kg) |
|-----------------------|---------------------|-----------------------|---------------------|------------------|-------------------|-----------------|----------------|---------------------------------|----------------------|-------------------------------------|-------------------------------------|
| 31 | DC 8X4 | 53.00 | 57.67 | 92.67 | 189.93 | 15.85 | 13.63 | 326.87 | 21.82 | 73.73 | 1.11 |
| 32 | DC 8X6 | 55.00 | 61.33 | 93.33 | 196.47 | 15.99 | 13.77 | 373.93 | 21.89 | 81.94 | 1.23 |
| 33 | DC 9X1 | 54.00 | 60.33 | 93.00 | 196.00 | 13.25 | 12.33 | 324.67 | 21.83 | 71.64 | 1.07 |
| 34 | DC 9X2 | 60.67 | 65.00 | 95.67 | 184.80 | 12.27 | 13.61 | 279.47 | 22.07 | 61.53 | 0.92 |
| 35 | DC 9X4 | 54.00 | 58.67 | 95.00 | 194.93 | 14.14 | 14.43 | 348.33 | 22.79 | 80.61 | 1.21 |
| 36 | DC 9X5 | 55.00 | 60.00 | 94.00 | 195.27 | 13.11 | 14.25 | 316.20 | 22.27 | 70.62 | 1.06 |
| Standard Check | | | | | | | | | | | |
| 1 | Rajarshi [KMH22168] | 56.00 | 61.67 | 94.67 | 179.00 | 13.93 | 12.29 | 326.13 | 20.99 | 69.16 | 1.04 |
| | S.E.(m) ± | 1.38 | 1.42 | 1.00 | 3.97 | 0.90 | 0.59 | 15.37 | 0.56 | 4.61 | 0.09 |
| | C.D. 5% | 3.86 | 3.98 | 2.80 | 11.13 | 2.52 | 1.65 | 43.12 | 1.58 | 12.95 | 0.25 |

superior over the check Rajarshi (61.67 days) for early days to 50% silking.

C. Days to maturity

Out of the six parents studied, the parents NM 32-1-1, NM 44-3-1 and NM 44-5 were earliest to attain maturity within 92.33 days followed by NM 60-4, NM 62-4-1 (93 days) and NM 2-1(95 days). The single cross SC-4 (90.33 days) was the earliest to attain maturity followed by SC-3 (91.67days). The double cross DC-5X7 (90.33 days) was the earliest to attain maturity followed by DC-7X5 (90.67days) and 91 days each for the double crosses DC-5X3, DC-6X1 and DC-6X7.

Two single crosses SC-4 (90.33 days) and SC-3 (91.67days) and ten double crosses viz. DC-1X6, DC-4X8, DC-4X9 (91.67 days), DC-5X1, DC-6X8 (91.33 days), DC-5X3 (91 days), DC-5X7 (90.33 days), DC-6X1, DC-6X7 (91 days) and DC-7X5 (90.67 days) showed significant superiority over the check Rajarshi (94.67 days).

D. Plant height (cm)

Plant height of the parents ranged from 171.60 cm (NM 2-1) to 181.13 cm (NM 60-4). The tallest parent was found to be NM 60-4 (181.13 cm) followed by NM 44-5 (180.20 cm) and NM 62-4-1 (175.53 cm). Plant height of single crosses ranged from 182.40 cm (SC-7) to 196.00 cm (SC-5). The tallest single cross was SC-5 (196.00 cm) followed by SC-3 (195.93 cm) and SC-9 (194.13 cm). The plant height of double crosses ranged from 167.40 cm (DC-1X8) to 196.47 cm (DC-8X6). The tallest double cross was DC-8X6 (196.47 cm) followed by DC-5X9 (196.07 cm) and DC-9X1 (196.00 cm).

Among the nine single crosses studied, seven single crosses viz. SC-1 (193.97 cm), SC-2 (192.00 cm), SC-3 (195.93 cm), SC-4 (191.20 cm), SC-5 (196.00 cm), SC-6 (190.13 cm) and SC-9 (194.13 cm) were found to be significantly superior over the check Rajarshi (179.00 cm). Among the thirty six double crosses, seven

double crosses viz. DC-3X8 (190.73 cm), DC-5X7 (191.53 cm), DC-5X9 (196.07 cm), DC-8X6 (196.47 cm), DC-9X1 (196.00 cm), DC-9X4 (194.93 cm) and DC-9X5 (195.27 cm) were also found to be significantly superior over the check Rajarshi (179.00 cm).

E. Cob length (cm)

Cob length of the parents ranged from 11.09 cm (NM 60-4) to 14.29 cm (NM 44-5) and the maximum cob length among the parents was recorded in NM 44-5 (14.29 cm) followed by NM 62-4-1 (13.64 cm) and NM 2-1 (13.29 cm). The range of cob length in single crosses was from 13.49 cm (SC-8) to 15.15cm (SC-7) and the maximum cob length was observed in the single cross SC-7 (15.15 cm) followed by SC-4 (14.62 cm) and SC-9 (14.46 cm). While the double crosses ranged from 11.98 cm (DC-1X6) to 17.84 cm (DC-4X2) and among them, the maximum cob length was observed in the double cross DC-4X2 (17.84 cm) followed by DC-4X3 (17.60 cm) and DC-5X1 (16.63 cm).

None of the single cross was found to be significantly superior over the check and four double crosses viz. DC-4X2 (17.84 cm), DC-4X3 (17.60 cm), DC-5X1 (16.63 cm) and DC-1X5 (16.48 cm) were found to be significantly superior over the check Rajarshi (13.93 cm) for cob length.

F. Cob girth (cm)

Cob girth ranged from, 11.63 cm to 13.49 cm, 11.48 cm to 14.42 cm and 11.45 cm to 14.65 cm for the six parents, nine single crosses and thirty six double crosses respectively. Among the parents, NM 60-4 (13.49 cm) showed the highest cob girth followed by NM 44-3-1 (13.41 cm) and NM 62-4-1 (12.62 cm). Out of nine single crosses studied, the highest cob girth was recorded in the single cross SC-6 (14.42 cm) followed by SC-2 (14.06 cm). Similarly among the thirty six double crosses, the highest cob girth was recorded in the double cross DC-7X6 (14.65 cm) followed by DC-5X9 (14.62 cm) and DC-6X7 (14.48 cm).

The above two single crosses SC-6 (14.42 cm) and SC-2 (14.06 cm) and eleven double crosses viz. DC-7X6 (14.65 cm), DC-5X9 (14.62 cm), DC-6X7 (14.48 cm), DC-3X4 (14.47 cm), DC-9X4 (14.43 cm), DC-8X3 (14.26 cm), DC-9X5 (14.25 cm), DC-2X6 (14.17 cm), DC-5X3 (14.17 cm), DC-6X1 (14.13 cm) and DC-6X2 (14.13 cm) exhibited significantly superior performance over the check Rajarshi (12.29 cm) for cob girth.

G. Number of grains cob⁻¹

Number of grains cob⁻¹ of the parents ranged from 233.20 (NM 32-1-1) to 330.07 (NM 62-4-1). Among the nine single crosses, number of grains cob⁻¹ ranged from 291.27 (SC-8) to 346.27 (SC-4), whereas among the thirty six double crosses it ranged from 279.47 (DC-9X2) to 426.27 (DC-4X2). The parent NM 62-4-1 (330.07) had highest number of grains cob⁻¹ followed by NM 44-5 (322.53) and NM 2-1 (260.57). The single cross SC-1 and SC-4 (346.27) produced highest number of grains cob⁻¹ followed by SC-6 (345.47) and SC-7 (345.07). While the double cross DC-4X2 (426.27) also produced highest number of grains cob⁻¹ followed by DC-4X3 (389.00) and DC-6X1 (388.60).

None of the single cross was found to be significantly superior over the check Rajarshi (326.13). While ten double crosses viz. DC-4X2 (426.27), DC-4X3 (389.00), DC-6X1 (388.60), DC-6X7 (382.07), DC-8X1 (376.73), DC-3X4 (375.60), DC-8X6 (373.93), 371.93 for both the double crosses DC-1X8, DC-4X8 and DC-5X1 (370.53) showed significant superiority over the check Rajarshi (326.13) for number of grains cob⁻¹.

H. 100 grain weight (g)

The data recorded for 100 grain weight was ranged from, 19.23 g to 22.59 g, 20.41 g to 23.28 g and 20.85 g to 23.44 g for six parents, nine single crosses and thirty six double crosses respectively. The maximum 100 grain weight was recorded by the parent NM 60-4

(22.59 g) followed by NM 44-3-1 (22.43 g) and NM 62-4-1 (21.78 g). The maximum 100 grain weight was recorded by the single cross SC-9 (23.28 g) followed by SC-8 (22.87 g) and SC-2 (22.85 g). For the double crosses, the maximum 100 grain weight was recorded by the double cross DC-5X9 (23.44 g), DC-3X5 (23.21 g), DC-9X4 (22.79 g) and DC-6X8 (22.61 g).

All of the above single and double crosses were found to be significantly superior over the check Rajarshi (20.99) for 100 grain weight. The parent NM 60-4 (22.59 g) also exhibited superior performance over the check Rajarshi (20.99 g) for 100 grain weight.

I. Grain yield plant⁻¹ (g)

The grain yield plant⁻¹ among parents ranged from, 45.33 g (NM 32-1-1) to 72.90 g (NM 62-4-1). Among the single crosses grain yield plant⁻¹ ranged from 62.11 g (SC-3) to 79.58 g (SC-9), whereas among the double crosses it ranged from 61.53 g (DC-9X2) to 91.32 g (DC-4X2). The highest grain yield plant⁻¹ among the parents was observed in NM 62-4-1 (72.90 g) followed by NM 44-5 (72.05 g) and NM 2-1 (60.48 g). Among the single crosses, the highest grain yield plant⁻¹ was recorded in the single cross SC-9 (79.58 g) followed by SC-2 (78.39 g) and SC-4 (78.23 g). Among the double crosses, the highest grain yield plant⁻¹ was recorded in the double cross DC-4X2 (91.32 g) followed by DC-6X1 (87.25 g) and DC-4X3 (86.83 g).

None of the single cross was found to be significantly superior over the check Rajarshi (69.16 g). While seven double crosses viz. DC-4X2 (91.32 g), DC-6X1 (87.25 g), DC-4X3 (86.83 g), DC-6X7 (83.79 g), DC-5X1 (83.54 g), DC-5X9 (82.73 g) and DC-4X8 (82.29 g) were observed to be significantly superior over the check Rajarshi (69.16 g) for grain yield plant⁻¹.

J. Grain yield plot⁻¹ (Kg)

Among the six parents, the parent NM 62-4-1 (1.09 Kg) showed highest grain yield plot⁻¹ followed by NM 44-5 (1.08 Kg) and NM 2-1

(0.91 Kg). Out of the nine single crosses studied, the highest grain yield plot⁻¹ was recorded in the single cross SC-9 (1.19 Kg) followed by SC-2 (1.18 Kg) and SC-4 (1.17 Kg). Similarly among the thirty six double crosses, the highest grain yield plot⁻¹ was recorded in the double cross DC-4X2 (1.37 Kg) followed by DC-6X1 (1.31 Kg) and DC-4X3 (1.30 Kg).

None of the single cross was found to be significantly superior over the check while all of the above three double crosses viz. DC-4X2 (1.37 Kg), DC-6X1 (1.31 Kg) and DC-4X3 (1.30 Kg) were found to be significantly superior performance over check Rajarshi (1.04 Kg) for grain yield plot⁻¹.

On the basis of *per se* performance studied for the yield and yield contributing characters among the nine single crosses and thirty six double crosses with the check Rajarshi, the single cross SC-2 was found to be significantly superior over the check Rajarshi for 100 grain weight (g), cob girth (cm), plant height (cm), days to 50% silking and days to 50% tasseling. The single cross SC-6 was also found to be significantly superior over the check Rajarshi for plant height (cm), cob girth (cm), days to 50% silking and days to 50% tasseling. Another single cross SC-4 performed significantly superior over the check for plant height (cm), days to maturity and days to 50% silking. The single cross SC-5 was significantly superior over the check for plant height (cm), days to 50% silking and days to 50% tasseling. The single cross SC-9 also showed significant superiority over the check Rajarshi for plant height (cm) and 100 grain weight (g). Similar to this results Patil *et al.* (2012) reported significant high mean performance for days to 50% tasseling, days to 50% silking, days to maturity, plant height and 100 grain weight. Avinash *et al.* (2012) also reported the same results for days to 50% tasseling, days to 50% silking and plant height.

Similarly the double cross DC-6X7 recorded significant superiority over the check Rajarshi for grain yield plot⁻¹, number of grains cob⁻¹, cob girth (cm), days to maturity, days to 50% silking and

days to 50% tasseling. The double cross DC-6X1 was found to be significantly superior over the check for grain yield plant⁻¹, grain yield plot⁻¹ (Kg), number of grains cob⁻¹, cob girth (cm) and days to maturity. The double crosses DC-4X2 and DC-4X3 were recorded significant superiority over the check Rajarshi for grain yield plant⁻¹, grain yield plot⁻¹ (Kg), number of grains cob⁻¹ and cob length (cm). The double cross DC-5X1 was found to be significantly superior over the check for grain yield plant⁻¹, number of grains cob⁻¹, cob length (cm) and days to maturity. The another double cross DC-4X8 also performed significantly superior over the check Rajarshi for grain yield plant⁻¹, number of grains cob⁻¹ and days to maturity. The same results was also reported by Souza *et al.* (2002) for yield and yield contributing characters.

The mean performance of nine single crosses and thirty six double crosses when compared with the check Rajarshi, only the double crosses DC-4X2, DC-4X3, DC-4X8, DC-5X1, DC-6X1 and DC-6X7 identified as superior crosses for yield and most of the yield contributing characters like number of grains cob⁻¹. Hence, these six double crosses were identified as potential crosses on the basis of *per se* performance.

4.3 Heterosis

The degree of heterosis depends on the relative performance of inbred parents and their corresponding hybrids. Maize has great potential for heterotic manifestation and its exploitation. The encouraging results have been achieved for increasing maize yield through the successful exploitation of heterosis. Heterosis breeding has been extensively explored and utilized for increasing yield in number of crops particularly in cross pollinated crops. Heterosis is the most effective tool for the use in estimating performance of various quantitative traits in hybrid combination. In hybrid and varietal improvement programme a first hand knowledge regarding the performance of selected parents in cross combinations i.e. expression

Table 3. Heterosis percent (H_1) and Useful Heterosis percent over Rajarshi (H_2) of single and double crosses for different characters

| Sr. No. | Crosses | Days to 50% tasseling | | Days to 50% silking | | Days to 50% maturity | | Plant height (cm) | | Cob length (cm) | |
|---------|-----------------------|-----------------------|--------|---------------------|--------|----------------------|---------|-------------------|--------|-----------------|--------|
| | | H_1 | H_2 | H_1 | H_2 | H_1 | H_2 | H_1 | H_2 | H_1 | H_2 |
| | Single crosses | | | | | | | | | | |
| 1 | SC-1 | -3.88 | -4.17 | -4.09 | -4.86 | 1.08 | -1.06 | 9.40** | 8.36** | 22.02* | 1.87 |
| 2 | SC-2 | -7.55* | -8.93* | -5.23 | -7.03* | 1.81 | -0.70 | 8.58** | 7.26* | 8.29 | 2.87 |
| 3 | SC-3 | -3.81 | -2.38 | -2.15 | -1.62 | -1.08 | -3.17* | 12.28** | 9.46** | 4.68 | -3.02 |
| 4 | SC-4 | -7.65* | -6.55 | -8.02** | -7.03* | -2.52 | -4.58** | 8.04** | 6.82* | 30.23** | 4.98 |
| 5 | SC-5 | -7.74* | -7.74* | -6.49* | -6.49* | 0.00 | -2.46 | 11.05** | 9.50** | 5.43 | -2.87 |
| 6 | SC-6 | -10.40** | -7.74* | -9.23** | -7.03* | 0.36 | -1.76 | 9.17** | 6.22 | 13.20 | 1.63 |
| 7 | SC-7 | -4.50 | -5.36 | -2.45 | -3.24 | -0.71 | -1.41 | 3.42 | 1.90 | 24.29** | 8.76 |
| 8 | SC-8 | -0.30 | -2.38 | 0.83 | -1.08 | 0.00 | -1.06 | 5.93* | 4.10 | -2.15 | -3.11 |
| 9 | SC-9 | -0.29 | 0.60 | -1.08 | -0.54 | 0.35 | -0.35 | 11.85** | 8.45** | 7.40 | 3.83 |
| | Double crosses | | | | | | | | | | |
| 1 | DC 1X5 | 9.49** | 2.98 | 8.88** | 2.70 | 1.08 | -0.70 | -10.21** | -2.20 | 18.93* | 18.33* |
| 2 | DC 1X6 | -2.53 | -8.33* | -1.15 | -7.03* | -1.79 | -3.17* | -10.75** | -4.25 | -15.46* | -13.98 |
| 3 | DC 1X8 | 2.15 | -1.19 | 0.84 | -2.16 | -1.07 | -2.11 | -11.96** | -6.48* | 3.81 | 3.16 |
| 4 | DC 1X9 | 4.85 | 2.98 | 5.00 | 2.16 | -0.35 | -1.06 | -8.96** | -1.30 | 9.33 | 12.45 |
| 5 | DC 2X4 | 1.94 | -5.95 | 1.16 | -5.95 | 0.54 | -2.11 | -4.70 | 2.01 | 3.04 | 7.08 |
| 6 | DC 2X6 | 10.39** | 1.19 | 5.81 | -1.62 | 1.25 | 0.00 | -10.05** | -3.99 | -6.88 | -4.79 |
| 7 | DC 2X7 | 4.49 | -2.98 | 0.85 | -4.32 | -1.42 | -2.46 | -3.56 | 0.86 | -12.96 | -7.90 |
| 8 | DC 2X9 | 8.07* | 3.57 | 5.06 | 1.08 | 1.24 | 0.70 | -3.18 | 4.43 | 7.69 | 11.30 |
| 9 | DC 3X4 | 0.31 | -4.17 | 0.00 | -4.32 | 1.10 | -2.82 | -2.29 | 5.66 | 7.18 | 8.23 |
| 10 | DC 3X5 | 0.94 | -4.17 | -0.85 | -4.86 | 3.62** | 0.70 | -5.12* | 3.87 | 4.56 | 1.48 |
| 11 | DC 3X7 | 6.50* | 2.38 | 3.05 | 0.54 | 0.54 | -1.76 | -0.44 | 5.21 | 4.28 | 7.28 |
| 12 | DC 3X8 | 3.05 | 0.60 | -1.37 | -2.70 | 0.36 | -1.76 | -0.21 | 6.55* | 11.06 | 7.66 |

*, **= Significant at 5% and 1% level respectively.

Continued...

Table 3. Continued...

| Sr. No. | Crosses | Days to 50% tasseling | | Days to 50% silking | | Days to 50% maturity | | Plant height (cm) | | Cob length (cm) | |
|---------|-------------|-----------------------|----------------|---------------------|----------------|----------------------|----------------|-------------------|----------------|-----------------|----------------|
| | | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ |
| 13 | DC 4X2 | 7.10* | -1.19 | 6.40* | -1.08 | -0.18 | -2.82 | -1.91 | 4.99 | 23.26** | 28.10** |
| 14 | DC 4X3 | -0.93 | -5.36 | -1.13 | -5.41 | 1.10 | -2.82 | -5.60* | 2.09 | 25.15** | 26.38** |
| 15 | DC 4X8 | 2.18 | -2.38 | 1.97 | -2.16 | -0.36 | -3.17* | -1.22 | 4.17 | 8.56 | 9.57 |
| 16 | DC 4X9 | 2.45 | -0.60 | 3.37 | -0.54 | -0.72 | -3.17* | -7.34** | -0.26 | 1.24 | 5.70 |
| 17 | DC 5X1 | 10.13** | 3.57 | 8.31** | 2.16 | -1.79 | -3.52* | -5.29* | 3.17 | 20.04* | 19.44* |
| 18 | DC 5X3 | 1.27 | -4.76 | 1.43 | -4.32 | -2.15 | -3.87* | -7.24** | 1.04 | 3.10 | 2.58 |
| 19 | DC 5X7 | 4.46 | -2.38 | 6.25* | 1.08 | -2.69* | -4.58** | 1.23 | 7.00* | 1.42 | 4.40 |
| 20 | DC 5X9 | 0.00 | -3.57 | 0.84 | -2.70 | 0.71 | -0.70 | 0.51 | 9.53** | -1.86 | -1.39 |
| 21 | DC 6X1 | 4.43 | -1.79 | 4.60 | -1.62 | -2.50 | -3.87* | -8.25** | -1.56 | 6.80 | 8.66 |
| 22 | DC 6X2 | 0.65 | -7.74* | 0.00 | -7.03* | 0.53 | -0.70 | -1.43 | 5.21 | -8.24 | -6.18 |
| 23 | DC 6X7 | -1.27 | -7.74* | -1.42 | -6.49* | -2.33 | -3.87* | -2.90 | 1.04 | 5.76 | 11.25 |
| 24 | DC 6X8 | -2.19 | -7.14* | -4.23 | -8.11* | -2.14 | -3.52* | -8.98** | -4.28 | -1.23 | -1.96 |
| 25 | DC 7X2 | 9.62** | 1.79 | 6.55* | 1.08 | -1.42 | -2.46 | -8.08** | -3.87 | 0.20 | 6.03 |
| 26 | DC 7X3 | 8.98** | 4.76 | 3.60 | 1.08 | 1.98 | -0.35 | -4.70 | 0.71 | -3.02 | -0.24 |
| 27 | DC 7X5 | 3.82 | -2.98 | 1.70 | -3.24 | -2.33 | -4.23** | -6.52* | -1.19 | 2.30 | 5.31 |
| 28 | DC 7X6 | -1.27 | -7.74* | -1.99 | -7.03* | -0.54 | -2.11 | -7.80** | -4.06 | -4.35 | 0.62 |
| 29 | DC 8X1 | -1.54 | -4.76 | -1.39 | -4.32 | 0.00 | -1.06 | -1.34 | 4.80 | 9.78 | 9.10 |
| 30 | DC 8X3 | 2.44 | 0.00 | 1.37 | 0.00 | 2.52 | 0.35 | -2.41 | 4.21 | 11.21 | 7.80 |
| 31 | DC 8X4 | -0.93 | -5.36 | -2.54 | -6.49* | 0.72 | -2.11 | 0.62 | 6.11 | 12.78 | 13.83 |
| 32 | DC 8X6 | 3.45 | -1.79 | 3.66 | -0.54 | 0.00 | -1.41 | 4.37 | 9.76** | 15.65 | 14.79 |
| 33 | DC 9X1 | -1.82 | -3.57 | 0.56 | -2.16 | -1.06 | -1.76 | 1.00 | 9.50** | -7.52 | -4.88 |
| 34 | DC 9X2 | 13.04** | 8.33* | 9.55** | 5.41 | 1.59 | 1.06 | -4.28 | 3.24 | -14.78 | -11.92 |
| 35 | DC 9X4 | -0.61 | -3.57 | -1.12 | -4.86 | 2.89* | 0.35 | 1.18 | 8.90** | -2.75 | 1.53 |
| 36 | DC 9X5 | 1.85 | -1.79 | 0.84 | -2.70 | 0.71 | -0.70 | 0.10 | 9.09** | -6.34 | -5.89 |
| | S.E. | 1.69 | 1.95 | 1.74 | 2.01 | 1.22 | 1.41 | 4.86 | 5.61 | 1.10 | 1.27 |

*, **= Significant at 5% and 1% level respectively.

Continued...

Table 3. Continued...

| Sr. No. | Crosses | Cob girth (cm) | | No. of grains cob ⁻¹ | | 100 grain weight (g) | | Grain yield plant ⁻¹ (g) | | Grain yield plot ⁻¹ (Kg) | |
|---------|-----------------------|----------------|----------------|---------------------------------|----------------|----------------------|----------------|-------------------------------------|----------------|-------------------------------------|----------------|
| | | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ |
| | Single crosses | | | | | | | | | | |
| 1 | SC-1 | 0.93 | 3.15 | 41.31** | 6.17 | -2.38 | -2.75 | 37.53** | 3.24 | 37.56** | 2.95 |
| 2 | SC-2 | 17.56** | 14.37* | 22.07** | 4.01 | 11.70** | 8.88* | 33.57** | 13.34 | 33.59** | 13.01 |
| 3 | SC-3 | 6.82 | 5.37 | 5.91 | -8.54 | 0.34 | -1.99 | 5.07 | -10.19 | 5.10 | -10.45 |
| 4 | SC-4 | -0.92 | 8.41 | 35.10** | 6.17 | -0.55 | 6.65 | 34.63** | 13.11 | 34.65** | 12.79 |
| 5 | SC-5 | 5.66 | 10.41 | 15.47* | 2.37 | -1.12 | 3.92 | 13.54 | 6.50 | 13.54 | 6.19 |
| 6 | SC-6 | 10.81 | 17.30* | 17.95** | 5.93 | -0.92 | 4.34 | 15.94 | 9.47 | 15.93 | 9.13 |
| 7 | SC-7 | 2.91 | 9.27 | 33.35** | 5.81 | -2.76 | 2.49 | 23.79* | 6.49 | 23.78* | 6.19 |
| 8 | SC-8 | -7.79 | -6.62 | -0.11 | -10.69 | 5.51 | 8.94* | 0.74 | -3.48 | 0.74 | -3.75 |
| 9 | SC-9 | -2.30 | 0.27 | 14.93* | 4.09 | 7.20* | 10.91** | 19.33* | 15.07 | 19.30 | 14.71 |
| | Double crosses | | | | | | | | | | |
| 1 | DC 1X5 | -6.81 | -0.49 | 3.78 | 8.22 | 0.85 | 1.45 | 5.48 | 10.62 | 5.47 | 10.29 |
| 2 | DC 1X6 | -10.04 | -0.84 | -17.60** | -12.61 | 0.33 | 1.13 | -14.97 | -9.56 | -14.98 | -9.84 |
| 3 | DC 1X8 | 3.59 | 1.79 | 16.68** | 14.04* | -0.15 | 2.94 | 18.54* | 18.41 | 18.55 | 18.08 |
| 4 | DC 1X9 | 7.22 | 9.06 | 2.41 | 7.67 | 1.83 | 5.99 | 4.65 | 14.23 | 4.64 | 13.88 |
| 5 | DC 2X4 | -8.62 | 1.79 | -4.79 | 0.06 | -2.21 | 5.38 | -7.76 | 4.44 | -7.76 | 4.13 |
| 6 | DC 2X6 | -0.47 | 15.29* | -0.80 | 4.13 | -3.17 | 3.22 | -3.26 | 7.77 | -3.28 | 7.44 |
| 7 | DC 2X7 | -7.03 | 3.96 | -14.71** | -10.53 | 1.07 | 6.81 | -12.21 | -3.51 | -12.21 | -3.78 |
| 8 | DC 2X9 | -3.79 | 3.25 | -0.88 | 3.13 | -7.54* | 1.60 | -8.69 | 4.28 | -8.71 | 3.94 |
| 9 | DC 3X4 | 10.15 | 17.73* | 16.55** | 15.17* | -0.78 | 1.54 | 15.21 | 16.89 | 15.22 | 16.57 |
| 10 | DC 3X5 | 1.08 | 9.06 | 5.36 | 2.11 | 9.50** | 10.56** | 15.74 | 13.61 | 15.74** | 13.27 |
| 11 | DC 3X7 | -1.82 | 5.37 | 12.87* | 11.33 | 0.59 | 0.84 | 15.11 | 12.98 | 15.11 | 12.66 |
| 12 | DC 3X8 | 14.05* | 13.34 | 20.46** | 8.87 | -1.23 | 2.21 | 19.54* | 11.37 | 19.51 | 11.03 |
| 13 | DC 4X2 | -1.75 | 9.44 | 24.37** | 30.70** | -6.07* | 1.22 | 16.61* | 32.04** | 16.68 | 31.73** |
| 14 | DC 4X3 | 2.23 | 9.27 | 20.71** | 19.28** | 3.69 | 6.11 | 23.75** | 25.55** | 23.78* | 25.22* |

*, **= Significant at 5% and 1% level respectively.

Continued...

Table 3. Continued...

| Sr. No. | Crosses | Cob girth (cm) | | No. of grains cob ⁻¹ | | 100 grain weight (g) | | Grain yield plant ⁻¹ (g) | | Grain yield plot ⁻¹ (Kg) | |
|---------|-------------|----------------|----------------|---------------------------------|----------------|----------------------|----------------|-------------------------------------|----------------|-------------------------------------|----------------|
| | | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ | H ₁ | H ₂ |
| 15 | DC 4X8 | 3.47 | 4.39 | 16.68** | 14.04* | -3.06 | 4.49 | 13.51 | 18.98* | 13.49 | 18.62 |
| 16 | DC 4X9 | 5.61 | 10.20 | 0.10 | 5.23 | -8.70** | -0.68 | -8.11 | 4.83 | -8.09 | 4.55 |
| 17 | DC 5X1 | -0.61 | 6.13 | 8.96 | 13.62* | 5.97 | 6.59 | 15.18 | 20.80* | 15.16 | 20.42 |
| 18 | DC 5X3 | 7.97 | 15.29* | -8.27 | -4.35 | 4.01 | 4.62 | -4.56 | 0.09 | -4.58 | -0.22 |
| 19 | DC 5X7 | -2.05 | 7.59 | 1.96 | 6.13 | -1.71 | 1.45 | 1.01 | 7.58 | 1.00 | 7.24 |
| 20 | DC 5X9 | 12.90* | 18.93** | 4.51 | 7.89 | 3.96 | 11.67** | 7.98 | 19.63* | 7.84 | 19.10 |
| 21 | DC 6X1 | 4.26 | 14.91* | 12.36* | 19.15** | 5.78 | 6.62 | 18.62* | 26.16** | 18.63* | 25.80* |
| 22 | DC 6X2 | -0.75 | 14.97* | -15.44** | -11.24 | -1.06 | 5.48 | -16.65* | -7.14 | -16.64 | -7.40 |
| 23 | DC 6X7 | 3.97 | 17.79* | 10.66 | 17.15* | -0.61 | 2.78 | 12.19 | 21.15* | 12.21 | 20.80 |
| 24 | DC 6X8 | 3.11 | 8.62 | 10.29 | 7.67 | 1.00 | 7.70* | 12.28 | 15.65 | 12.30 | 15.32 |
| 25 | DC 7X2 | -9.55 | 1.14 | -3.47 | 1.27 | -1.85 | 3.73 | -5.33 | 4.06 | -5.34 | 3.75 |
| 26 | DC 7X3 | -13.24* | -6.89 | 0.54 | -0.84 | 5.12 | 5.38 | 5.84 | 3.88 | 5.81 | 3.56 |
| 27 | DC 7X5 | -8.66 | 0.33 | 6.32 | 10.67 | 2.63 | 5.92 | 8.70 | 15.76 | 8.69 | 15.42 |
| 28 | DC 7X6 | 5.17 | 19.14** | -2.65 | 3.07 | -0.68 | 2.72 | -2.18 | 5.62 | -2.17 | 5.32 |
| 29 | DC 8X1 | 14.13* | 12.15 | 18.18** | 15.52* | -3.39 | -0.40 | 13.99 | 13.86 | 14.37 | 13.91 |
| 30 | DC 8X3 | 16.73** | 16.00* | 20.95** | 9.32 | 0.77 | 4.27 | 23.81** | 15.36 | 23.82* | 15.03 |
| 31 | DC 8X4 | 9.89 | 10.87 | 2.54 | 0.23 | -3.57 | 3.95 | 1.71 | 6.61 | 1.69 | 6.28 |
| 32 | DC 8X6 | 6.31 | 11.98 | 17.45** | 14.66* | -2.19 | 4.30 | 15.03 | 18.47 | 15.04 | 18.14 |
| 33 | DC 9X1 | -1.41 | 0.27 | -5.31 | -0.45 | -0.09 | 3.99 | -5.11 | 3.58 | -5.14 | 3.24 |
| 34 | DC 9X2 | 3.13 | 10.68 | -17.64** | -14.31* | -4.31 | 5.16 | -22.09** | -11.03 | -22.11* | -11.31 |
| 35 | DC 9X4 | 12.53* | 17.41* | 1.59 | 6.81 | -0.20 | 8.56* | 2.16 | 16.56 | 2.20 | 16.25 |
| 36 | DC 9X5 | 10.01 | 15.89* | -6.08 | -3.04 | -1.24 | 6.08 | -7.84 | 2.11 | -7.84 | 1.79 |
| | S.E. | 0.72 | 0.83 | 18.82 | 21.73 | 0.69 | 0.80 | 5.65 | 6.52 | 0.10 | 0.12 |

*, **= Significant at 5% and 1% level respectively.

of heterosis is necessary. The magnitude of heterosis provides a basis for genetic diversity and guide for choice of desirable parents for developing superior F₁ hybrids, so as to exploit hybrid vigour and for building gene pools to be used in breeding programme by helping in eliminating a large number of poor performing crosses in very first generation. With this aim the magnitude of heterosis and useful heterosis (over check Rajarshi) were estimated and the results are presented in table 3 and discussed below.

1. Days to 50% tasseling

For days to 50% tasseling, four single crosses showed significant heterosis in the desirable negative direction ranged from -7.55 per cent (SC-2) to -10.40 per cent (SC-6). The maximum negative heterosis was shown by the single cross SC-6 (-10.40 per cent) followed by SC-5 (-7.74 per cent), SC-4 (-7.65 per cent) and SC-2 (-7.55 per cent). None of the double cross showed significant heterosis in the desirable direction.

The significant useful heterosis recorded by three single crosses ranged from -7.74 per cent (SC-5 and SC-6) to -8.93 per cent (SC-2). The maximum negative useful heterosis was exhibited by the single cross SC-2 (-8.93 per cent) followed by SC-5 and SC-6 (-7.74 per cent). In case of the double crosses, the significant useful heterosis ranged from -7.14 per cent (DC-6X8) to -8.33 per cent (DC-1X6). The maximum negative useful heterosis was exhibited by the double crosses, DC-1X6 (-8.33 per cent) and (-7.74 per cent) each for the double crosses DC-6X2, DC-6X7, DC-7X6 and (-7.14 per cent) for the double cross DC-6X8.

2. Days to 50% silking

For days to 50% silking, three single crosses out of nine exhibited significant heterosis in the desirable negative direction ranged from -6.49 per cent (SC-5) to -9.23 per cent (SC-6). Highest negative significant heterosis was exhibited by the single cross SC-6

(-9.23 per cent) followed by SC-4 (-8.02 per cent) and SC-5 (-6.49 per cent). Like days to 50% tasseling, none of the double cross showed significant heterosis in the desirable negative direction.

The significant useful heterosis in the negative direction was recorded by four single crosses and the maximum significant useful heterosis over the check Rajarshi was observed (-7.03 per cent) each for the single cross SC-2, SC-4 and SC-6 followed by SC-5 (-6.49 per cent). The significant useful heterosis for the six double crosses recorded over the check Rajarshi and the maximum significant useful heterosis was observed in the double cross DC-6X8 (-8.11 per cent) followed by (-7.03 per cent) each of the double crosses DC-1X6, DC-6X2, DC-7X6 and (-6.49 per cent) each for the double crosses DC-6X7 and DC-8X4.

3. Days to maturity

None of the single cross and only the double cross DC-5X7 (-2.69 per cent) showed significant heterosis in the desirable negative direction for days to maturity.

The significant useful heterosis shown by two single crosses SC-4 (-4.58 per cent) and SC-3 (-3.17 per cent). The significant useful heterosis in the desirable negative direction ranged from -3.17 per cent (DC-1X6) to -4.58 per cent (DC-5X7) for the double crosses. The maximum negative useful heterosis over the check Rajarshi was exhibited by the double crosses DC-5X7 (-4.58 per cent) followed by DC-7X5 (-4.23 per cent) and (-3.87 per cent) each for the double crosses DC-5X3, DC-6X1 and DC-6X7 for days to maturity.

4. Plant height

The significant heterosis ranged from 5.93 per cent (SC-8) to 12.28 per cent (SC-3) for the single crosses. The highest significant heterosis for plant height was shown by the single cross SC-3 (12.28 per cent) followed by SC-9 (11.85 per cent) and SC-5

(11.05 per cent). While none of the double cross showed significant heterosis.

In case of useful heterosis, six single crosses showed significant useful heterosis which ranged from 6.82 per cent (SC-4) to 9.50 per cent (SC-5). The maximum useful heterosis showed by the single cross SC-5 (9.50 per cent) followed by SC-3 (9.46 per cent) and SC-9 (8.45 per cent). Seven double crosses showed significant useful heterosis which ranged from 6.55 per cent (DC-3X8) to 9.76 per cent (DC-8X6). Whereas the double cross DC-8X6 (9.76 per cent) recorded the highest useful heterosis followed by DC-5X9 (9.53 per cent) and DC-9X1 (9.50 per cent).

5. Cob length

The single cross SC-4 (30.23 per cent) recorded the highest significant heterosis followed by SC-7 (24.29 per cent) and SC-1 (22.02 per cent). Four double crosses showed the significant heterosis in which the double cross DC-4X3 (25.15 per cent) showed the highest significant heterosis followed by DC-4X2 (23.26 per cent), DC-5X1 (20.04 per cent) and DC-1X5 (18.93 per cent).

None of the single cross showed significant useful heterosis while four double crosses viz. DC-4X2 (28.10 per cent), DC-4X3 (26.38 per cent), DC-5X1 (19.44 percent) and DC-1X5 (18.33 per cent) showed significant useful heterosis for cob length.

6. Cob girth

Out of nine only the single cross SC-2 (17.56 per cent) exhibited the significant heterosis in the desirable direction and two single crosses SC-6 (17.30 per cent) and SC-2 (14.37 per cent) showed significant useful heterosis.

Five double crosses showed significant heterosis ranged from 12.53 per cent (DC-9X4) to 16.73 per cent (DC-8X3). The highest



value of significant heterosis was recorded by the double cross DC-8X3 (16.73 per cent) followed by DC-8X1 (14.13 per cent) and DC-3X8 (14.05 per cent).

Eleven double crosses showed significant useful heterosis which ranged from 14.91 per cent (DC-6X1) to 19.14 per cent (DC-7X6). The highest value of significant useful heterosis obtained by the double cross DC-7X6 (19.14 per cent) followed by DC-5X9 (18.93 per cent) and DC-6X7 (17.79 per cent) for cob girth.

7. Number of grains cob⁻¹

The significant heterosis for number of grains cob⁻¹ was observed in seven single crosses ranged from 14.93 per cent (SC-9) to 41.31 per cent (SC-1). The maximum significant heterosis for this trait was noticed in the single cross SC-1 (41.31 per cent) followed by SC-4 (35.10 per cent) and SC-7 (33.35 per cent). Eleven double crosses showed significant heterosis were ranged from 12.36 per cent (DC-6X1) to 24.37 per cent (DC-4X2). The maximum significant heterosis was noticed in the double cross DC-4X2 (24.37 per cent) followed by DC-8X3 (20.95 per cent) and DC-4X3 (20.71 per cent).

None of the single cross showed significant useful heterosis for number of grains cob⁻¹. While ten double crosses showed significant useful heterosis ranged from 13.62 per cent (DC-5X1) to 30.70 per cent (DC-4X2). And the maximum significant useful heterosis over the check Rajarshi was observed in the double cross DC-4X2 (30.70 per cent) followed by DC-4X3 (19.28 per cent) and DC-6X1 (19.15 per cent) for number of grains cob⁻¹.

8. 100 grain weight

Two single crosses SC-2 (11.70 per cent) and SC-9 (7.20 per cent) and only one double cross DC-3X5 (9.50 per cent) showed the significant heterosis.

The highest significant useful heterosis was found in the single cross SC-9 (10.91 per cent) followed by SC-8 (8.94 per cent) and SC-2 (8.88 per cent). While four double crosses showed significant useful heterosis ranged from 7.70 per cent (DC-6X8) to 11.67 per cent (DC-5X9). The highest value of significant useful heterosis over the check Rajarshi recorded in the double cross DC-5X9 (11.67 per cent) followed by DC-3X5 (10.56 per cent), DC-9X4 (8.56 per cent) and DC-6X8 (7.70 per cent) for 100 grain weight.

9. Grain yield plant⁻¹

The significant heterosis for the single crosses ranged from 19.33 per cent (SC-9) to 37.53 per cent (SC-1). The maximum significant heterosis was recorded by the single cross SC-1 (37.53 per cent) followed by SC-4 (34.63 per cent) and SC-2 (33.57 per cent). In case of the double crosses, the significant heterosis ranged from 16.61 per cent (DC-4X2) to 23.81 per cent (DC-8X3). The maximum significant heterosis was recorded by the double cross DC-8X3 (23.81 per cent) followed by DC-4X3 (23.75 per cent) and DC-3X8 (19.54 per cent).

None of the single cross showed significant useful heterosis over the check Rajarshi. While Seven double crosses showed significant useful heterosis ranged from 18.98 per cent (DC-4X8) to 32.04 per cent (DC-4X2). The maximum significant useful heterosis over the check Rajarshi was recorded by the double cross DC-4X2 (32.04 per cent) followed by DC-6X1 (26.16 per cent) and DC-4X3 (25.55 per cent) for Grain yield plant⁻¹.

10. Grain yield plot⁻¹

The significant heterosis for Grain yield plot⁻¹ was recorded in the four single crosses which ranged from 23.78 per cent (SC-7) to 37.56 per cent (SC-1). The highest significant heterosis for this trait was recorded by the single cross SC-1 (37.56 per cent) followed by SC-4 (34.65 per cent), SC-2 (33.59 per cent) and SC-7

(23.78 per cent). In case of the double cross, the four double crosses showed significant heterosis ranged from 15.74 per cent (DC-3X5) to 23.82 per cent (DC-8X3). And the highest significant heterosis was recorded by the double cross DC-8X3 (23.82 per cent) followed by DC-4X3 (23.78 per cent), DC-6X1 (18.63 per cent) and DC-3X5 (15.74 per cent).

None of the single cross showed significant useful heterosis over the check Rajarshi. While the double cross DC-4X2 (31.73 per cent) showed the highest significant useful heterosis followed by the double crosses DC-6X1 (25.80 per cent) and DC-4X3 (25.22 per cent) for Grain yield plot⁻¹.

The estimation of heterosis and useful heterosis over the check Rajarshi, revealed the response of heterosis for all the ten characters studied. The useful heterosis over the check Rajarshi was found among the single crosses for the six characters viz. 100 grain weight, cob girth, plant height, days to maturity, days to 50 per cent silking and days to 50 per cent tasseling studied in the desirable direction. The useful heterosis among the double crosses was found for all the ten characters studied in the desirable direction over the check Rajarshi. The highest magnitude of heterosis was observed for number of grains cob⁻¹ in the single cross SC-1 (41.31 per cent) followed by grain yield plot⁻¹ (37.56 per cent) and grain yield plant⁻¹ (37.53 per cent) in the same single cross. The magnitude of heterosis for the single crosses obtained for cob length, cob girth, 100 grain weight and plant height were low as compared to number of grains cob⁻¹, grain yield plant⁻¹ and grain yield plot⁻¹. In case of the double cross, the highest magnitude of heterosis was observed for cob length in the double cross DC-4X3 (25.15 per cent) followed by number of grains cob⁻¹ in the double cross DC-4X2 (24.37 per cent) and grain yield plot⁻¹ in the double cross DC-8X3 (23.82 per cent). The magnitude of heterosis for the double cross obtained for cob girth, 100 grain weight, grain yield plant⁻¹ and plant height were low as compared to cob length, number of grains

cob⁻¹ and grain yield plot⁻¹. The results of similar nature on heterosis were also reported for various characters in maize by Saleh *et al.* (2002), Srivastava and Singh (2003), Bajaj *et al.* (2007), Iqbal *et al.* (2010), Amanullah *et al.* (2011), Patil *et al.* (2012) and Singh *et al.* (2013).

The extent of heterosis gives an idea of the genetic control of the character. Mid-parent heterosis and better-parent heterosis are important parameters as they provide information about the presence of dominance and over dominance type of gene action in the expression of various traits. But can not predict much about the superiority of hybrid over the check which is of practical value for the plant breeding, therefore more emphasis is given by useful heterosis.

The highest estimate for useful heterosis over the check Rajarshi was observed for cob girth in the single cross SC-6 (17.30 per cent) followed by cob girth in the single cross SC-2 (14.37 per cent) and 100 grain weight in the single cross SC-9 (10.91 per cent). The highest estimate for useful heterosis over the check Rajarshi was observed for the grain yield plant⁻¹ in the double cross DC-4X2 (32.04 per cent) followed by grain yield plot⁻¹ (31.73 per cent) and number of grains cob⁻¹ (30.70 per cent) in the same double cross.

The single cross SC-2 was found to exhibit significant useful heterosis over the check Rajarshi for five characters *viz.* 100 grain weight, cob girth, plant height, days to 50% silking and days to 50% tasseling in the desirable direction. The single cross SC-6 exhibited significant useful heterosis over the check Rajarshi for the four characters *viz.* cob girth, plant height, days to 50% silking and days to 50% tasseling in the desirable direction. The single cross SC-4 was found to exhibit significant useful heterosis for the three characters *viz.* plant height, days to maturity and days to 50% silking in the desirable direction. The single cross SC-5 was observed to exhibit significant useful heterosis over the check Rajarshi for the characters like plant

height, days to 50% silking and days to 50% tasseling. And the single cross SC-9 was also found to exhibit significant useful heterosis for 100 grain weight and plant height. However, none of the single cross was found to exhibit significant useful heterosis for yield and yield contributing characters like number of grains cob⁻¹.

The double cross DC-6X7 was identified to exhibit significant useful heterosis over the check Rajarshi for six characters viz. grain yield plant⁻¹, number of grains cob⁻¹, cob girth, days to maturity, days to 50% silking and days to 50% tasseling in the desirable direction. The double cross DC-6X1 was found to exhibit significant useful heterosis for the five characters viz. grain yield plot⁻¹, grain yield plant⁻¹, number of grains cob⁻¹, cob girth and days to maturity. The double cross DC-4X2 and DC-4X3 was identified to exhibit significant useful heterosis over the check Rajarshi for four characters viz. grain yield plot⁻¹, grain yield plant⁻¹, number of grains cob⁻¹ and cob length. The double cross DC-5X1 exhibited significant useful heterosis over the check Rajarshi for the four characters viz. grain yield plant⁻¹, number of grains cob⁻¹, cob length and days to maturity. The double cross DC-4X8 also exhibited significant useful heterosis over the check Rajarshi for the three characters viz. grain yield plant⁻¹, number of grains cob⁻¹ and days to maturity in the desirable direction.

All of the above mentioned six double crosses recorded significant *per se* performance for grain yield plant⁻¹ and number of grains cob⁻¹ along with or without other traits like cob girth and cob length. The level of heterosis observed in these six double crosses gives us the opportunity for the development of commercial hybrids in maize. Such potential of maize crosses for commercial exploitation of heterosis were also reported by many maize breeders like Wani *et al.* (2007), Singh and Gupta (2009), Dubey *et al.* (2009), Iqbal *et al.* (2010), Wali *et al.* (2010) and Patil (2012). This study on heterosis has clearly indicated that heterotic response for yield and its components

results only in selected cross combinations indicating the pre-dominant role of non-fixable inter-allelic interactions.

The above six double crosses viz. DC-6X7, DC-6X1, DC-4X2, DC-4X3, DC-5X1 and DC-4X8 hold promise for further evaluation and commercial exploitation of heterosis. These hybrids by chain crossing may be composited to make a gene pool. This pool may be advanced for further generations to devise and isolate lines with gene combinations for high grain yield (Saidaiah *et al.*, 2008).

4.4 Prediction of single cross and double cross hybrids performance

Choice of parents to produce the single and double cross hybrids which results in extensive testing of a number of combinations of potential parents. In commercial hybrid breeding programmes, the identification of pairs of parental lines with superior yield performance in single and double cross combinations are costly and time consuming. So one of the major problem faced by the breeder is to reduce the number of possible single and double cross hybrids to the reasonable number which are to be tested. In cross pollinated crops like maize, the method of predicting the single and double cross hybrids performance has been widely used to identify combinations of the inbred lines that are worth evaluating in field trials.

The predicted means of nine single and thirty six double crosses based on *per se* performance of inbreds along with actual mean for ten characters are presented in Table 4.

Coefficients of simple determination (r^2) were used to assess the effectiveness of the predicted performance of the single and double cross hybrids. The results on simple correlation coefficient between actual and predicted means of all the nine single and thirty six double cross hybrids revealed non significant correlation for all the ten characters studied. The regression coefficient of predicted means on actual mean of all the nine single and thirty six double cross hybrids

Table 4. Actual (1) and predicted means (2) of single and double crosses for different characters

| Sr. No. | Crosses | Days to 50% tasseling | | Days to 50% silking | | Days to 50% maturity | | Plant height (cm) | | Cob length (cm) | |
|---------|-----------------------|-----------------------|-------|---------------------|-------|----------------------|-------|-------------------|--------|-----------------|-------|
| | | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| | Single crosses | | | | | | | | | | |
| 1 | SC-1 | 53.67 | 55.83 | 58.67 | 61.17 | 93.67 | 92.67 | 193.97 | 177.30 | 14.19 | 11.63 |
| 2 | SC-2 | 51.00 | 55.17 | 57.33 | 60.50 | 94.00 | 92.33 | 192.00 | 176.83 | 14.33 | 13.23 |
| 3 | SC-3 | 54.67 | 56.83 | 60.67 | 62.00 | 91.67 | 92.67 | 195.93 | 174.50 | 13.51 | 12.90 |
| 4 | SC-4 | 52.33 | 56.67 | 57.33 | 62.33 | 90.33 | 92.67 | 191.20 | 176.97 | 14.62 | 11.23 |
| 5 | SC-5 | 51.67 | 56.00 | 57.67 | 61.67 | 92.33 | 92.33 | 196.00 | 176.50 | 13.53 | 12.83 |
| 6 | SC-6 | 51.67 | 57.67 | 57.33 | 63.17 | 93.00 | 92.67 | 190.13 | 174.17 | 14.15 | 12.50 |
| 7 | SC-7 | 53.00 | 55.50 | 59.67 | 61.17 | 93.33 | 94.00 | 182.40 | 176.37 | 15.15 | 12.19 |
| 8 | SC-8 | 54.67 | 54.83 | 61.00 | 60.50 | 93.67 | 93.67 | 186.33 | 175.90 | 13.49 | 13.79 |
| 9 | SC-9 | 56.33 | 56.50 | 61.33 | 62.00 | 94.33 | 94.00 | 194.13 | 173.57 | 14.46 | 13.46 |
| | Double crosses | | | | | | | | | | |
| 1 | DC 1X5 | 57.67 | 55.92 | 63.33 | 61.42 | 94.00 | 92.50 | 175.07 | 176.90 | 16.48 | 12.23 |
| 2 | DC 1X6 | 51.33 | 56.75 | 57.33 | 62.17 | 91.67 | 92.67 | 171.40 | 175.73 | 11.98 | 12.07 |
| 3 | DC 1X8 | 55.33 | 55.33 | 60.33 | 60.83 | 92.67 | 93.17 | 167.40 | 176.60 | 14.37 | 12.71 |
| 4 | DC 1X9 | 57.67 | 56.17 | 63.00 | 61.58 | 93.67 | 93.33 | 176.67 | 175.43 | 15.66 | 12.55 |
| 5 | DC 2X4 | 52.67 | 55.92 | 58.00 | 61.42 | 92.67 | 92.50 | 182.60 | 176.90 | 14.91 | 12.23 |
| 6 | DC 2X6 | 56.67 | 56.42 | 60.67 | 61.83 | 94.67 | 92.50 | 171.87 | 175.50 | 13.26 | 12.87 |
| 7 | DC 2X7 | 54.33 | 55.33 | 59.00 | 60.83 | 92.33 | 93.17 | 180.53 | 176.60 | 12.83 | 12.71 |
| 8 | DC 2X9 | 58.00 | 55.83 | 62.33 | 61.25 | 95.33 | 93.17 | 186.93 | 175.20 | 15.50 | 13.35 |
| 9 | DC 3X4 | 53.67 | 56.75 | 59.00 | 62.17 | 92.00 | 92.67 | 189.13 | 175.73 | 15.07 | 12.07 |
| 10 | DC 3X5 | 53.67 | 56.42 | 58.67 | 61.83 | 95.33 | 92.50 | 185.93 | 175.50 | 14.13 | 12.87 |
| 11 | DC 3X7 | 57.33 | 56.17 | 62.00 | 61.58 | 93.00 | 93.33 | 188.33 | 175.43 | 14.94 | 12.55 |
| 12 | DC 3X8 | 56.33 | 55.83 | 60.00 | 61.25 | 93.00 | 93.17 | 190.73 | 175.20 | 14.99 | 13.35 |
| 13 | DC 4X2 | 55.33 | 55.92 | 61.00 | 61.42 | 92.00 | 92.50 | 187.93 | 176.90 | 17.84 | 12.23 |
| 14 | DC 4X3 | 53.00 | 56.75 | 58.33 | 62.17 | 92.00 | 92.67 | 182.73 | 175.73 | 17.60 | 12.07 |

Continued...

Table 4. Continued...

| Sr. No. | Crosses | Days to 50% tasseling | | Days to 50% silking | | Days to 50% maturity | | Plant height (cm) | | Cob length (cm) | |
|---------|---|---------------------------|-------|---------------------------|-------|---------------------------|-------|--------------------------|--------|---------------------------|-------|
| | | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| | Double crosses | | | | | | | | | | |
| 15 | DC 4X8 | 54.67 | 55.75 | 60.33 | 61.42 | 91.67 | 93.17 | 186.47 | 176.43 | 15.26 | 12.51 |
| 16 | DC 4X9 | 55.67 | 56.58 | 61.33 | 62.17 | 91.67 | 93.33 | 178.53 | 175.27 | 14.72 | 12.35 |
| 17 | DC 5X1 | 58.00 | 55.92 | 63.00 | 61.42 | 91.33 | 92.50 | 184.67 | 176.90 | 16.63 | 12.23 |
| 18 | DC 5X3 | 53.33 | 56.42 | 59.00 | 61.83 | 91.00 | 92.50 | 180.87 | 175.50 | 14.29 | 12.87 |
| 19 | DC 5X7 | 54.67 | 55.75 | 62.33 | 61.42 | 90.33 | 93.17 | 191.53 | 176.43 | 14.54 | 12.51 |
| 20 | DC 5X9 | 54.00 | 56.25 | 60.00 | 61.83 | 94.00 | 93.17 | 196.07 | 175.03 | 13.73 | 13.15 |
| 21 | DC 6X1 | 55.00 | 56.75 | 60.67 | 62.17 | 91.00 | 92.67 | 176.20 | 175.73 | 15.13 | 12.07 |
| 22 | DC 6X2 | 51.67 | 56.42 | 57.33 | 61.83 | 94.00 | 92.50 | 188.33 | 175.50 | 13.07 | 12.87 |
| 23 | DC 6X7 | 51.67 | 56.58 | 57.67 | 62.17 | 91.00 | 93.33 | 180.87 | 175.27 | 15.49 | 12.35 |
| 24 | DC 6X8 | 52.00 | 56.25 | 56.67 | 61.83 | 91.33 | 93.17 | 171.33 | 175.03 | 13.65 | 13.15 |
| 25 | DC 7X2 | 57.00 | 55.33 | 62.33 | 60.83 | 92.33 | 93.17 | 172.07 | 176.60 | 14.77 | 12.71 |
| 26 | DC 7X3 | 58.67 | 56.17 | 62.33 | 61.58 | 94.33 | 93.33 | 180.27 | 175.43 | 13.89 | 12.55 |
| 27 | DC 7X5 | 54.33 | 55.75 | 59.67 | 61.42 | 90.67 | 93.17 | 176.87 | 176.43 | 14.67 | 12.51 |
| 28 | DC 7X6 | 51.67 | 56.58 | 57.33 | 62.17 | 92.67 | 93.33 | 171.73 | 175.27 | 14.01 | 12.35 |
| 29 | DC 8X1 | 53.33 | 55.33 | 59.00 | 60.83 | 93.67 | 93.17 | 187.60 | 176.60 | 15.19 | 12.71 |
| 30 | DC 8X3 | 56.00 | 55.83 | 61.67 | 61.25 | 95.00 | 93.17 | 186.53 | 175.20 | 15.01 | 13.35 |
| 31 | DC 8X4 | 53.00 | 55.75 | 57.67 | 61.42 | 92.67 | 93.17 | 189.93 | 176.43 | 15.85 | 12.51 |
| 32 | DC 8X6 | 55.00 | 56.25 | 61.33 | 61.83 | 93.33 | 93.17 | 196.47 | 175.03 | 15.99 | 13.15 |
| 33 | DC 9X1 | 54.00 | 56.17 | 60.33 | 61.58 | 93.00 | 93.33 | 196.00 | 175.43 | 13.25 | 12.55 |
| 34 | DC 9X2 | 60.67 | 55.83 | 65.00 | 61.25 | 95.67 | 93.17 | 184.80 | 175.20 | 12.27 | 13.35 |
| 35 | DC 9X4 | 54.00 | 56.58 | 58.67 | 62.17 | 95.00 | 93.33 | 194.93 | 175.27 | 14.14 | 12.35 |
| 36 | DC 9X5 | 55.00 | 56.25 | 60.00 | 61.83 | 94.00 | 93.17 | 195.27 | 175.03 | 13.11 | 13.15 |
| | Simple correlation coefficient (r) | -0.18^{NS} | | -0.19^{NS} | | -0.11^{NS} | | 0.08^{NS} | | -0.04^{NS} | |
| | Coefficient of determination (r²) | 0.032 | | 0.036 | | 0.012 | | 0.006 | | 0.002 | |
| | Regression equation | Y=64.61-0.05X | | Y=97.48-0.08X | | Y=58.81+0.05X | | Y=15.82-0.02X | | Y=0 | |
| | Regression coefficient | ^{NS} | | * | | ^{NS} | | ^{NS} | | ^{NS} | |

Continued...

Table 4. Continued...

| Sr. No. | Crosses | Cob girth (cm) | | No. of grains cob ⁻¹ | | 100 grain weight (g) | | Grain yield plant ⁻¹ (g) | | Grain yield plot ⁻¹ (Kg) | |
|---------|-----------------------|----------------|-------|---------------------------------|--------|----------------------|-------|-------------------------------------|-------|-------------------------------------|------|
| | | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| | Single crosses | | | | | | | | | | |
| 1 | SC-1 | 12.68 | 12.56 | 346.27 | 245.03 | 20.41 | 20.91 | 71.40 | 51.92 | 1.07 | 0.78 |
| 2 | SC-2 | 14.06 | 11.96 | 339.20 | 277.87 | 22.85 | 20.46 | 78.39 | 58.69 | 1.18 | 0.88 |
| 3 | SC-3 | 12.95 | 12.13 | 298.27 | 281.63 | 20.57 | 20.50 | 62.11 | 59.11 | 0.93 | 0.89 |
| 4 | SC-4 | 13.33 | 13.45 | 346.27 | 256.30 | 22.39 | 22.51 | 78.23 | 58.11 | 1.17 | 0.87 |
| 5 | SC-5 | 13.57 | 12.85 | 333.87 | 289.13 | 21.81 | 22.06 | 73.66 | 64.88 | 1.10 | 0.97 |
| 6 | SC-6 | 14.42 | 13.01 | 345.47 | 292.90 | 21.90 | 22.10 | 75.71 | 65.30 | 1.14 | 0.98 |
| 7 | SC-7 | 13.43 | 13.05 | 345.07 | 258.77 | 21.51 | 22.12 | 73.65 | 59.50 | 1.10 | 0.89 |
| 8 | SC-8 | 11.48 | 12.45 | 291.27 | 291.60 | 22.87 | 21.67 | 66.76 | 66.27 | 1.00 | 0.99 |
| 9 | SC-9 | 12.33 | 12.62 | 339.47 | 295.37 | 23.28 | 21.72 | 79.58 | 66.69 | 1.19 | 1.00 |
| | Double crosses | | | | | | | | | | |
| 1 | DC 1X5 | 12.23 | 12.71 | 352.93 | 267.08 | 21.29 | 21.49 | 76.50 | 58.40 | 1.15 | 0.88 |
| 2 | DC 1X6 | 12.19 | 12.79 | 285.00 | 268.97 | 21.23 | 21.51 | 62.55 | 58.61 | 0.94 | 0.88 |
| 3 | DC 1X8 | 12.51 | 12.51 | 371.93 | 268.32 | 21.61 | 21.29 | 81.89 | 59.09 | 1.23 | 0.89 |
| 4 | DC 1X9 | 13.41 | 12.59 | 351.13 | 270.20 | 22.25 | 21.31 | 79.00 | 59.30 | 1.18 | 0.89 |
| 5 | DC 2X4 | 12.51 | 12.71 | 326.33 | 267.08 | 22.12 | 21.49 | 72.23 | 58.40 | 1.08 | 0.88 |
| 6 | DC 2X6 | 14.17 | 12.49 | 339.60 | 285.38 | 21.67 | 21.28 | 74.53 | 61.99 | 1.12 | 0.93 |
| 7 | DC 2X7 | 12.78 | 12.51 | 291.80 | 268.32 | 22.42 | 21.29 | 66.73 | 59.09 | 1.00 | 0.89 |
| 8 | DC 2X9 | 12.69 | 12.29 | 336.33 | 286.62 | 21.33 | 21.09 | 72.12 | 62.69 | 1.08 | 0.94 |
| 9 | DC 3X4 | 14.47 | 12.79 | 375.60 | 268.97 | 21.31 | 21.51 | 80.84 | 58.61 | 1.21 | 0.88 |
| 10 | DC 3X5 | 13.41 | 12.49 | 333.00 | 285.38 | 23.21 | 21.28 | 78.57 | 61.99 | 1.18 | 0.93 |
| 11 | DC 3X7 | 12.95 | 12.59 | 363.07 | 270.20 | 21.17 | 21.31 | 78.14 | 59.30 | 1.17 | 0.89 |
| 12 | DC 3X8 | 13.93 | 12.29 | 355.07 | 286.62 | 21.45 | 21.09 | 77.02 | 62.69 | 1.15 | 0.94 |
| 13 | DC 4X2 | 13.45 | 12.71 | 426.27 | 267.08 | 21.25 | 21.49 | 91.32 | 58.40 | 1.37 | 0.88 |
| 14 | DC 4X3 | 13.43 | 12.79 | 389.00 | 268.97 | 22.27 | 21.51 | 86.83 | 58.61 | 1.30 | 0.88 |

Continued...

Table 4. Continued...

| Sr. No. | Crosses | Cob girth (cm) | | No. of grains cob ⁻¹ | | 100 grain weight (g) | | Grain yield plant ⁻¹ (g) | | Grain yield plot ⁻¹ (Kg) | |
|---------|---|--------------------------|-------|---------------------------------|--------|--------------------------|-------|-------------------------------------|-------|-------------------------------------|------|
| | | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| | Double crosses | | | | | | | | | | |
| 15 | DC 4X8 | 12.83 | 12.95 | 371.93 | 273.95 | 21.93 | 22.09 | 82.29 | 62.19 | 1.23 | 0.93 |
| 16 | DC 4X9 | 13.55 | 13.03 | 343.20 | 275.83 | 20.85 | 22.11 | 72.50 | 62.40 | 1.09 | 0.94 |
| 17 | DC 5X1 | 13.05 | 12.71 | 370.53 | 267.08 | 22.37 | 21.49 | 83.54 | 58.40 | 1.25 | 0.88 |
| 18 | DC 5X3 | 14.17 | 12.49 | 311.93 | 285.38 | 21.96 | 21.28 | 69.22 | 61.99 | 1.04 | 0.93 |
| 19 | DC 5X7 | 13.23 | 12.95 | 346.13 | 273.95 | 21.29 | 22.09 | 74.40 | 62.19 | 1.12 | 0.93 |
| 20 | DC 5X9 | 14.62 | 12.73 | 351.87 | 292.25 | 23.44 | 21.89 | 82.73 | 65.78 | 1.24 | 0.99 |
| 21 | DC 6X1 | 14.13 | 12.79 | 388.60 | 268.97 | 22.38 | 21.51 | 87.25 | 58.61 | 1.31 | 0.88 |
| 22 | DC 6X2 | 14.13 | 12.49 | 289.47 | 285.38 | 22.14 | 21.28 | 64.22 | 61.99 | 0.96 | 0.93 |
| 23 | DC 6X7 | 14.48 | 13.03 | 382.07 | 275.83 | 21.57 | 22.11 | 83.79 | 62.40 | 1.26 | 0.94 |
| 24 | DC 6X8 | 13.35 | 12.73 | 351.13 | 292.25 | 22.61 | 21.89 | 79.98 | 65.78 | 1.20 | 0.99 |
| 25 | DC 7X2 | 12.43 | 12.51 | 330.27 | 268.32 | 21.77 | 21.29 | 71.97 | 59.09 | 1.08 | 0.89 |
| 26 | DC 7X3 | 11.45 | 12.59 | 323.40 | 270.20 | 22.12 | 21.31 | 71.85 | 59.30 | 1.08 | 0.89 |
| 27 | DC 7X5 | 12.33 | 12.95 | 360.93 | 273.95 | 22.23 | 22.09 | 80.06 | 62.19 | 1.20 | 0.93 |
| 28 | DC 7X6 | 14.65 | 13.03 | 336.13 | 275.83 | 21.56 | 22.11 | 73.05 | 62.40 | 1.10 | 0.94 |
| 29 | DC 8X1 | 13.79 | 12.51 | 376.73 | 268.32 | 20.91 | 21.29 | 78.74 | 59.09 | 1.18 | 0.89 |
| 30 | DC 8X3 | 14.26 | 12.29 | 356.53 | 286.62 | 21.89 | 21.09 | 79.78 | 62.69 | 1.20 | 0.94 |
| 31 | DC 8X4 | 13.63 | 12.95 | 326.87 | 273.95 | 21.82 | 22.09 | 73.73 | 62.19 | 1.11 | 0.93 |
| 32 | DC 8X6 | 13.77 | 12.73 | 373.93 | 292.25 | 21.89 | 21.89 | 81.94 | 65.78 | 1.23 | 0.99 |
| 33 | DC 9X1 | 12.33 | 12.59 | 324.67 | 270.20 | 21.83 | 21.31 | 71.64 | 59.30 | 1.07 | 0.89 |
| 34 | DC 9X2 | 13.61 | 12.29 | 279.47 | 286.62 | 22.07 | 21.09 | 61.53 | 62.69 | 0.92 | 0.94 |
| 35 | DC 9X4 | 14.43 | 13.03 | 348.33 | 275.83 | 22.79 | 22.11 | 80.61 | 62.40 | 1.21 | 0.94 |
| 36 | DC 9X5 | 14.25 | 12.73 | 316.20 | 292.25 | 22.27 | 21.89 | 70.62 | 65.78 | 1.06 | 0.99 |
| | Simple correlation coefficient (r) | 0.11^{NS} | | -0.07^{NS} | | 0.13^{NS} | | 0.07^{NS} | | -0.03^{NS} | |
| | Coefficient of determination (r²) | 0.012 | | 0.005 | | 0.017 | | 0.005 | | 0.001 | |
| | Regression equation | Y=275.86+0.05X | | Y=22.83-0.10X | | Y=274.99+0.12X | | Y=1.55-0.01X | | Y=-0.0001X | |
| | Regression coefficient | NS | | NS | | NS | | NS | | NS | |

also showed non significant regression for all the characters studied except for days to 50 per cent silking.

Therefore, this study indicates that the single cross and double cross hybrids performance can not be predicted on the basis of Jenkins (1934) parental inbreds *per se* performance prediction method. Smith (1986) and Hallaur (1990) also stated that predicting the performance of hybrids from *per se* performance of their parental inbred lines failed due to the masking dominance or non-additive effects. Thus, it is necessary to cross the parental inbreds and evaluate their respective single and double cross hybrids themselves or adopt some other Jenkins (1934) A, B or C prediction models or methods.

Selection of single and double cross hybrids

Maize is a highly cross pollinated crop and hence the exploitation of hybrid vigour has gained much significance. In view of its tremendous yield increase, there is a continuous need to evolve the new hybrid which should exceed the existing hybrids in yield and quality. Maize being a monoecious crop can be exploited to the maximum for commercial hybrid production. The scope for the exploitation of hybrid vigour depends on the direction and magnitude of heterosis, biological feasibility and type of gene action involved. Heterosis has been well utilized in maize improvement programme. The success in commercial production of hybrid maize depends on extensive assessment of inbred lines.

For exploiting hybrid vigour, *per se* performance and the extent of heterosis of hybrid are important.

None of the single cross was found high *per se* performance, significant heterosis and useful heterosis for yield and yield contributing characters like number of grains cob^{-1} and therefore, no any single cross was selected as potential cross for hybrid production in maize.

Table 5. Promising double crosses and their performance for economically important characters

| Sr. no. | Double Crosses | Characters | Mean performance | Heterosis | Useful heterosis |
|---------|---|---------------------------------|------------------|-----------|------------------|
| 1. | DC-4X2 i.e. [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 44-5] | Grain yield plant ⁻¹ | 91.32 | 16.61* | 32.04** |
| | | No. of grains cob ⁻¹ | 426.27 | 24.37** | 30.70** |
| | | Cob length (cm) | 17.84 | 23.26** | 28.10** |
| 2. | DC-4X3 i.e. [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 62-4-1] | Grain yield plant ⁻¹ | 86.83 | 23.75** | 25.55** |
| | | No. of grains cob ⁻¹ | 389.00 | 20.71** | 19.28** |
| | | Cob length (cm) | 17.60 | 25.15** | 26.38** |
| 3. | DC-6X1 i.e. [NM 44-3-1 X NM 62-4-1] X [NM 32-1-1 X NM 60-4] | Grain yield plant ⁻¹ | 87.25 | 18.62* | 26.16* |
| | | No. of grains cob ⁻¹ | 388.60 | 12.36* | 19.15** |
| | | Cob girth (cm) | 14.13 | 4.26 | 14.91* |

Among thirty six double cross hybrids, the double cross DC-4X2 (Table 5) was also identified as best double cross hybrid since they possessed high *per se* performance, significant heterosis and useful heterosis for grain yield plant⁻¹ and other yield contributing characters like number of grains cob⁻¹, cob length (cm) and cob girth(cm). The other two double crosses, DC-4X3 and DC-6X1 also recorded high mean, significant heterosis and useful heterosis in desirable direction for yield and yield contributing characters like number of grains cob⁻¹, cob length (cm) and cob girth (cm). All of the above three double crosses also showed the high *per se* performance, significant heterosis and useful heterosis for grain yield plot⁻¹. Therefore it is suggested that, all of the above three double crosses can be used directly for heterosis breeding programme in maize. Souza *et al.* (2002) also reported that the grain yield of double cross hybrids were higher than single cross hybrids.

From the results of this study discussed above the following inferences are drawn.

1. Significant variability was observed among the material studied.
2. There was a good correspondence between the *per se* performance and the heterosis.
3. Double cross hybrids are yielded more than the single cross hybrids.
4. High *per se* performance and high heterosis were considered as the criteria for selecting the superior crosses and based on which the double crosses DC-4X2, DC-4X3 and DC-6X1 were identified as superior double crosses for their use in heterosis breeding.
5. The single cross and double cross hybrids performance can not be predicted from the Jenkins prediction method based on the parental inbreds *per se* performance.

Chapter V

SUMMARY AND CONCLUSIONS

The present study entitled "Evaluation of single and double cross hybrids in maize (*zea mays* L.)" was undertaken to assess the performance of single and double cross hybrids, to estimate the heterosis of single and double cross hybrids, to identify superior hybrids, to predict the performance of single and double crosses for yield and yield components and to assess the reliability of prediction methods. To achieve these objectives, nine single crosses were crossed to produce thirty six double crosses. These thirty six double crosses along with nine single crosses, six inbreds and one check (Rajarshi) were raised in Randomised Complete Block Design with three replications. The spacing of 60 cm x 20 cm was maintained to accommodate 15 plants in each row. The data were recorded on days to 50 % tasseling, days to 50 % silking, days to maturity, plant height (cm), cob length (cm), cob girth (cm), number of grains cob⁻¹, 100 grain weight (g), grain yield plant⁻¹ (g) and grain yield plot⁻¹ (Kg).

Considerable variability existed among the genotypes for all the characters studied as observed from the significant mean squares due to genotypes. Among the single crosses, SC-1, SC-2, SC-4, SC-6, SC-9 and from the double crosses, DC-4X2, DC-4X3 and DC-6X1 had high mean performance for grain yield plant⁻¹ and other yield contributing trait i.e. number of grains cob⁻¹.

Among the single cross, SC-1 has the highest magnitude of heterosis for number of grains cob⁻¹ followed by grain yield plot⁻¹ and grain yield plant⁻¹ in the same single cross. In case of the double cross, the highest magnitude of heterosis was observed for cob length in the double cross DC-4x3 followed by number of grains cob⁻¹ in the double cross DC-4x2 and grain yield plot⁻¹ in the double cross DC-8X3.

The useful heterosis over the check Rajarshi was found among the single crosses for the six characters viz. 100 grain weight, cob girth, plant height, days to maturity, days to 50% silking and days to

50% tasseling in the desirable direction. And the highest useful heterosis over the check was found in SC-6 for cob girth followed by SC-2 for cob girth and SC-9 for 100 grain weight. The useful heterosis among the double crosses was found for all the ten characters studied in the desirable direction over the check Rajarshi. And the highest useful heterosis over the check was found in the double cross DC-4X2 for the grain yield plant⁻¹ and number of grains cob⁻¹.

The single crosses viz. SC-2, SC-4, SC-5, SC-6 and SC-9 were also exhibited significant useful heterosis for the characters like plant height, days to 50% silking and days to 50% tasseling. Similarly the double crosses viz. DC-4X2, DC-4X3, DC-4X8, DC-5X1, DC-6X1 and DC-6X7 were also exhibited significant useful heterosis for yield and most of the yield contributing characters like number of grains cob⁻¹. These crosses also had significant *per se* performance for these respective characters.

Out of nine single crosses none of the single cross was found high *per se* performance, significant heterosis and useful heterosis for yield and yield contributing characters like number of grain cob⁻¹. Therefore, no any single cross was selected as potential cross for hybrid production. On the other hand, from thirty six double crosses, only three double crosses viz. DC-4X2, DC-4X3 and DC-6X1 identified as the most potential crosses for hybrid production based on high *per se* performance, high significant heterosis and useful heterosis. Hence it is suggested that, these three double crosses can be used directly for heterosis breeding in maize.

Single cross and double cross hybrids were exhibited non significant correlation and regression coefficient between the actual and predicted means of all the studied characters except days to 50 % silking for regression coefficient. From that it revealed, the single cross and double cross hybrids performance can not be predicted on the basis of Jenkins (1934) parental inbreds *per se* performance prediction methods.

Chapter VI

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Signature of student

APPENDIX-I

Details of parentages of single crosses (SC) and double crosses (DC).

| Sr. no. | Cross Details | Cross no. |
|-----------------------|---|-----------|
| Single crosses | | |
| 1. | NM 32-1-1 X NM 60-4 | SC-1 |
| 2. | NM 32-1-1 X NM 44-5 | SC-2 |
| 3. | NM 32-1-1 X NM 62-4-1 | SC-3 |
| 4. | NM 44-3-1 X NM 60-4 | SC-4 |
| 5. | NM 44-3-1 X NM 44-5 | SC-5 |
| 6. | NM 44-3-1 X NM 62-4-1 | SC-6 |
| 7. | NM 2-1 X NM 60-4 | SC-7 |
| 8. | NM 2-1 X NM 44-5 | SC-8 |
| 9. | NM 2-1 X NM 62-4-1 | SC-9 |
| Double crosses | | |
| 1. | [NM 32-1-1 X NM 60-4] X [NM 44-3-1 X NM 44-5] | DC-1X5 |
| 2. | [NM 32-1-1 X NM 60-4] X [NM 44-3-1 X NM 62-4-1] | DC-1X6 |
| 3. | [NM 32-1-1 X NM 60-4] X [NM 2-1 X NM 44-5] | DC-1X8 |
| 4. | [NM 32-1-1 X NM 60-4] X [NM 2-1 X NM 62-4-1] | DC-1X9 |
| 5. | [NM 32-1-1 X NM 445] X [NM 44-3-1 X NM 60-4] | DC-2X4 |
| 6. | [NM 32-1-1 X NM 44-5] X [NM 44-3-1 X NM 62-4-1] | DC-2X6 |
| 7. | [NM 32-1-1 X NM 44-5] X [NM 2-1 X NM 60-4] | DC-2X7 |
| 8. | [NM 32-1-1 X NM 44-5] X [NM 2-1 X NM 62-4-1] | DC-2X9 |
| 9. | [NM 32-1-1 X NM 62-4-1] X [NM 44-3-1 X NM 60-4] | DC-3X4 |
| 10. | [NM 32-1-1 X NM 62-4-1] X [NM 44-3-1 X NM 44-5] | DC-3X5 |
| 11. | [NM 32-1-1 X NM 62-4-1] X [NM 2-1 X NM 60-4] | DC-3X7 |
| 12. | [NM 32-1-1 X NM 62-4-1] X [NM 2-1 X NM 44-5] | DC-3X8 |
| 13. | [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 44-5] | DC-4X2 |
| 14. | [NM 44-3-1 X NM 60-4] X [NM 32-1-1 X NM 62-4-1] | DC-4X3 |
| 15. | [NM 44-3-1 X NM 60-4] X [NM 2-1 X NM 44-5] | DC-4X8 |
| 16. | [NM 44-3-1 X NM 60-4] X [NM 2-1 X NM 62-4-1] | DC-4X9 |
| 17. | [NM 44-3-1 X NM 44-5] X [NM 32-1-1 X NM 60-4] | DC-5X1 |
| 18. | [NM 44-3-1 X NM 44-5] X [NM 32-1-1 X NM 62-4-1] | DC-5X3 |
| 19. | [NM 44-3-1 X NM 44-5] X [NM 2-1 X NM 60-4] | DC-5X7 |
| 20. | [NM 44-3-1 X NM 44-5] X [NM 2-1 X NM 62-4-1] | DC-5X9 |
| 21. | [NM 44-3-1 X NM 62-4-1] X [NM 32-1-1 X NM 60-4] | DC-6X1 |
| 22. | [NM 44-3-1 X NM 62-4-1] X [NM 32-1-1 X NM 44-5] | DC-6X2 |
| 23. | [NM 44-3-1 X NM 62-4-1] X [NM 2-1 X NM 60-4] | DC-6X7 |
| 24. | [NM 44-3-1 X NM 62-4-1] X [NM 2-1 X NM 44-5] | DC-6X8 |
| 25. | [NM 2-1 X NM 60-4] X [NM 32-1-1 X NM 44-5] | DC-7X2 |
| 26. | [NM 2-1 X NM 60-4] X [NM 32-1-1 X NM 62-4-1] | DC-7X3 |
| 27. | [NM 2-1 X NM 60-4] X [NM 44-3-1 X NM 44-5] | DC-7X5 |
| 28. | [NM 2-1 X NM 60-4] X [NM 44-3-1 X NM 62-4-1] | DC-7X6 |
| 29. | [NM 2-1 X NM 44-5] X [NM 32-1-1 X NM 60-4] | DC-8X1 |
| 30. | [NM 2-1 X NM 44-5] X [NM 32-1-1 X NM 62-4-1] | DC-8X3 |
| 31. | [NM 2-1 X NM 44-5] X [NM 44-3-1 X NM 60-4] | DC-8X4 |
| 32. | [NM 2-1 X NM 44-5] X [NM 44-3-1 X NM 62-4-1] | DC-8X6 |
| 33. | [NM 2-1 X NM 62-4-1] X [NM 32-1-1 X NM 60-4] | DC-9X1 |
| 34. | [NM 2-1 X NM 62-4-1] X [NM 32-1-1 X NM 44-5] | DC-9X2 |
| 35. | [NM 2-1 X NM 62-4-1] X [NM 44-3-1 X NM 60-4] | DC-9X4 |
| 36. | [NM 2-1 X NM 62-4-1] X [NM 44-3-1 X NM 44-5] | DC-9X5 |

No. 157955
 AKOLA