Combining ability analysis for yield and maturity traits in elite inbred lines of maize

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Certificate-I

This is to certify that the thesis entitled **“Combining ability analysis for yield and maturity traits in elite inbred lines of maize”** submitted in partial fulfillment of the requirements for the award of the degree **of Master of Science in Agriculture (Plant Breeding and Genetics)**, to the **Faculty of Post-graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Gowhar Sidiq (Registration No. 2003-A-704-M)** under my supervision and guidance. No part of the thesis has been submitted for any degree or diploma.

It is further certified that information received during the course of investigation have been duly acknowledged.

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Certificate-II

We, the members of Advisory Committee of **Mr. Gowhar Sidiq (Registration No. 2003-A-704-M),** a candidate for the degree of **Master of Science in Agriculture (Plant Breeding & Genetics),** have gone through the manuscript of the thesis entitled **"Combining ability analysis for yield and maturity traits in elite inbred lines of maize"** and recommended that it may be submitted by the student in partial fulfillment of the requirements for the award of the degree.

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DEDICATED

TO MY SON

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Title of the Thesis	:	Combining ability analysis for yield and maturity traits in elite inbred lines of maize.

ABSTRACT

The present investigation was carried out to generate information on crossing ability (general and specific), gene action and heterosis. Fifteen S_2 maize lines (used as females) were crossed to three testers (two broad genetic based and one inbred) to generate forty five line x tester progenies. These lines x testers progenies along with 18 parents (15 lines + 3 testers) were evaluated in randomized block design during *Kharif* season of 2005 at K.D. Research Station of SKUAST-K. Data were recorded on competitive plants except for maturity traits where the data were recorded on whole plot basis. The mean/medium values were used for statistical analysis and estimation of genetic parameters.

Analysis of variance and estimates of the components of genetic variance revealed that significant differences existed among the lines and lines x testers progenies for all the traits. The variance due to gca and sca was also significant for all the traits except days taken to 50% anthesis and ear girth in respect of gca. The estimation of variance due to dominance deviations $(\hat{\sigma}^2{}_D)$ was high in magnitude than additive genetic variance $(\hat{\sigma}^2{}_A)$ for all the traits. The average degree of dominance ranged from 1.74 (kernel rows ear^{-1}) to 3.86 (ear height). Narrow sense heritability was very low and ranged from 6.04 (ear height) to 25.93 (100 grain weight). Significant and desirable gca for maturity traits viz., anthesis and silking was recorded in the lines 132C and 139B and for husk browning in the lines 146B and 106B. The lines 132C and 106B revealed significant and desirable gca for shorter plant height and lower ear placement. Among yield component traits the highest significant and desirable gca was recorded in the lines 147C (ear length), 106C (ear girth), 139 B (kernel rows ear^{-1}), 139A (kernels row^{-1}) and 106 C-2 (100 grain weight). For grain yield the maximum significant and desirable gca was recorded in the lines 139A, 151A and 142A. None of the cross combinations revealed significant and desirable sca for all the traits. The most promising crosses that revealed significant and highest sca for grain yield were 139A x 153A, 106C-2

x C_6,106 C-1 x Super-1 and 106 C-1 x 153A. The maximum contribution of different traits towards the performance of crosses came from the lines (35.9%-68.65%) and from lines x testers (31.10% - 60.15%). The contribution from testers was low (0.24% - 24.46%). Significant and desirable heterosis was observed for all the traits. The cross 132C x C_6 was observed to possess earliness. The maximum heterosis for grain yield was observed in the crosses 139A x 153A, 142A x C_6 and 106C-1 x 153A to the extent of 77.08, 39.58 and 35.42 per cent, respectively.

Signature of Student **Signature of Major Advisor**
Dated : ______________ **Dated :__________________**

Chapter-l

INTRODUCTION

Maize *(Zea mays* L) is an important cereal crop, which is grown almost in every part of the world. Maize has wider range of uses than any other cereal crop as animal feed, human food and for many industrial products. Maize in the developing countries is usually a food crop of second choice after wheat or rice, but in several countries in Africa and Latin America it is the food crop of first choice. In the industrialized countries maize is used primarily as animal feed, besides for the production of food and industrial products like starch, sweeteners, and alcohol. Being a C_4 plant, it is physiologically more efficient and has higher grain yield potential and wider adaptation for cultivation (55^{O}N to 55^{O}S) over a range of environmental conditions. The important maize growing countries are U.S.A, China, Brazil, Mexico, India, Philippines, South Africa and Indonesia.

The world production of maize is about 500 million tonnes from about 140 million hectares. India ranks fifth in the total area under maize, 4th in total production and 3rd in the productivity per hectare. Maize in India is grown over a wide range of production environments from the temperate hill zones in North-West Himalayas extending in the west to the semi-arid tropical zones in Karnataka in the South. In 2002-03 the total area in India under maize cultivation was 6.66 million hectares and the production was 11.6 million tonnes with the productivity of 1676 kg ha^{-1} (Dar *et al.*, 2005).

The global scenario of maize indicates that the productivity of developed economies on account of growing hybrid maize, exceeded 8.0 tonnes per hectare where 90% of maize is grown under temperate conditions. About 65% of maize area worldwide is planted to hybrids, which gives an estimated average yield increase of 10%. Therefore, hybrid technology would provide an excellent option to enhance the productivity of maize crop even under Kashmir conditions.

The crop occupies the largest area (321.18 thousand hectares) in Jammu and Kashmir among the cereals with a production of 5381 thousand quintals. However, in Kashmir valley maize occupies an area of only 109.93 thousand hectares with the total production of 870 thousand quintals and the productivity of 11.31 quintals per hectare (Anonymous, 2004). The major cause of low productivity in Kashmir valley is its cultivation under rainfed conditions in most of the area, poor cultural and crop management practices, cultivation of varieties and local cultivars with low yielding ability. In the areas where maize is grown under assured irrigation conditions, the potential for realizing higher productivity through cultivation of high yielding maize varieties under good cultural and crop management exists.

Maize breeding was unconsciously initiated when man recognized the potential of the weedy plant species that were the progenitors of the present day maize spp. Although the ancestral history of maize has not been resolved, yet teosinte *(Zea diploperennis, Zea luxurIance, Zea mexicana* and *Zea perennis)* is generally considered to have a prominent role in the germplasm of the present day maize. Teosinte has a weedy appearance, characterized by several tillers, several small fragile ears with small seeds enclosed in hard glumes and a leafy appearance. The transformation from weed species to the present day maize has gradually evolved for the past 10,000 years to produce the highly productive strains of maize.

Initially open pollinated cultivars were primarily used for cultivation ; but later attempts were made to produce planned crosses between open pollinated cultivars to evaluate their performance relative to the present cultivars. Crosses were made indiscriminately between cultivars and the cross performance was not consistently different from cultivar’s *per se* performance so as to have an impact on the types of cultivars used by growers (Rickey, 1927).

Shull (1908, 1909, 1910) described and outlined the modern methods of maize breeding. In 1908 he conducted experiments to study the genetic variability within maize cultivars and correctly concluded that each population, upon continuous inbreeding, got reduced to a series of pure lines. Subsequently, in 1909 he understood the genesis of pure lines and observed that vigour could be restored if the lines are crossed to make single crosses based on the better combining ability. Accordingly, from the studies reported in 1908, 1909 and 1910 he suggested the procedure to develop high yielding varieties i.e. self within a heterogeneous population to obtain a series of pure lines and produce crosses to determine most productive crosses. Shull (1910) was convinced that the method had the potential for enhancing maize productivity. His suggestions that the inbreeding and hybridization were the feasible methods to be used for the improvement of maize productivity were not generally accepted. The poor productivity of the pure lines was questioned as to whether adequate hybrid seed could be produced at a cost acceptable to growers. Shull (1952) had produced double crosses but he evidently did not recognize the practical implication.

Development of hybrids being a sequential selection process, the judicious choice of parents holds a paramount importance as not all the parents exhibit economically exploitable heterosis in their hybrids. The ability of parents to 'nick well' depends primarily on complex genetic interaction (Allard, 1960).

To emphasize the importance of combining ability analysis, the concept of combining ability played a significant role in crop improvement as it helped in characterizing the nature and magnitude of genetic effects governing yield and yield component traits, besides pinpointing the promising parents to be used in the synthesis of superior hybrids and population.

Among the various mating designs, line x tester mating design proposed by Kempthome (1957) has been found very useful in assessing the general combining ability (gca) of parents and specific combining ability (sca) of the crosses particularly when the number of germplasm lines is large.

The present study was, therefore, planned to evaluate the experimental materials at a single location with the following objectives :

- To estimate the gca effects of parents (lines) and sca effects of crosses.
- To estimate the components of genetic variance for eventual use in selection/breeding programmes.
- To assess the nature and magnitude of standard heterosis.
- To identify the promising lines for exploitation of heterosis through development of hybrids.

Chapter-2

REVIEW OF LITERATURE

Combining ability is one of the powerful tools for identifying the best combiners that could be used for hybridization, to exploit heterosis or to accumulate desirable genes in the resulting homozygous lines. In maize the inbred lines have been used to produce high yielding maize hybrids (involving two or multiple parents) and are presently being grown in different parts of the world.

In India conventional hybrids are more popular in many parts of the country because of their higher productivity. Recently research strategies have been diverted to produce two parent single cross hybrids to achieve quantum jump in the production and the productivity of maize-similar to that achieved in U.S.A and other European countries.

The line x tester method has been extensively used for testing general and specific combining ability in inbred lines. Kempthorne (1957) presented a method analogous to N.C. Design-II of Comstock and Robinson (1952) wherein the covariance of half- sibs (Cov-H.S) and full-sibs (Cov-F.S) are derived to estimate the general combining ability ($\hat{\sigma}^2{}_{gca)}$) and specific combining ability ($\hat{\sigma}^2_{sca)}$). The reports of various workers regarding the combining ability of inbreds derived from composites/synthetics for architecture of yield, yield components and other morphological traits were studied and the important ones published during the past two decades are presented in this chapter briefly under the following sub headings

2.1 Combining ability effects

2.2 Genetic components of variance

2.3 Heritability

2.4 Estimation of standard heterosis

The aim of plant breeding is to identify parents that will combine well and produce productive progenies. The success in identifying such parents mainly depends on the gene action that controls the traits under improvement. Combining ability studies provide the information on the genetic mechanism controlling quantitative traits and enable us to select suitable parents for further improvement or use in hybrid combinations for commercial purpose. General combining ability (gca) is a good estimate of additive gene action, whereas, specific combining ability (sca) is a measure of non-additive gene action (Sprague and Tatum, 1942 ; Rojas and Sprague, 1952).

2.1 Combining ability effects

According to Sprague and Tatum (1942), the term general combining ability refers to the average performance of a line in an array of crosses i.e the mean value of F_1 crosses involving particular parents, and which is represented as deviation from the array mean. The specific combining ability on the other hand refers to the performance of a particular cross taken as deviation from the average general combining ability of two lines Rickey and Mayer (1925) were the first to realize the importance of combining ability of maize hybrids. Davis (1927) suggested the use of the top-cross method for preliminary evaluation of large number of inbred lines, but in this method only a single tester was used which usually is an open pollinated variety. Jenkins and Brunson (1932) suggested that crossing of inbred lines with open pollinated varieties could be used for the rapid screening of new lines.

General combining ability has been explained by Jinks (1954) as the result of additive genetic effects and the specific combining ability as a result of non-additive interactions. Lonnquist and Gardner (1961) compared 66 inter-cross progenies of 12 OPVs of maize and recorded average F_1 values of 108.5 per cent of high yield potential than mid parent and 102.8 per cent than better parent. Hays (1963) defined general combining ability (gca) as the comparative ability of a group of inbreds to combine with a tester or a group of testers. General combining ability (gca), expressed as a statistic, shows the extent of deviation of the mean yield of the single crosses involving each inbreds from the average of all single crosses. General and specific combining abilities have a significant impact on inbred line evaluation and population improvement in maize breeding.

Combining ability analysis for photosynthetic and 11 agronomic characters in 10 F_1 hybrids by Zhang *et al.* (1991) revealed that there were marked differences between gca and sca in inbred lines for the same traits and in the same inbred line for different traits. E.-Hosary *et al.* (1994) observed significant gca effects for 10 yield components in maize except mid silking date and significant sca effect for plant height, ear diameter, number of kernel rows ear^{-1}, number of grains row^{-1}, ear weight plant^{-1} and grain yield plant and observed that most favourable gca effects were observed in the inbred lines. Ilchovska *et al*. (1995) studied gca and sca for yield traits in 16 early generation transformants (M_3) and their hybrids from a complete top cross procedure with two testers of the Lancaster group (XM568-1 and M017). These lines appeared promising for developing synthetic varieties. Studies on combining ability of inbreds derived from source populations collected from the tropical mid altitude maize areas by Everett *et al*. (1995) revealed high significant gca main effects, however, the sca main effects did not attain significance, primarily because of the few degrees of freedom available from the two years.

Studies on sca effects by Dass *et al*. (1997) indicated that most of the superior crosses resulted from high x low, high x high or high x medium combining parents, suggesting that the involvement of one good combiner appears to be essential to get the better specific combiner. Yousif *et al*. (1998) studied gca for 5 yield components of 112 S_1 and 50 S_2 progenies of maize for early generation screening of elite inbred lines. A broad genetic base tester was used for screening of the lines. Significant differences were observed in all the characters except 100 kernel weight. Seventeen progenies were selected for their high gca. Tosquy-valle *et al*. (1998) divided 45 inbred maize lines into three groups and crossed each group to 3 testers. They found that testers had significant effect on plant height, grain yield and days to tassel and silking. Gca was significant for all the characters except for ear height. Line x tester analysis of 12 long eared and 12 thick eared maize lines for grain yield by Vergara *et al*. (1998) revealed that line 4th had highest gca among long eared lines (0.58 t ha^{-1}), where as 19th line had highest gca (0.48 t ha^{-1}) among thick eared lines.

Studies carried out by Paul and Debanth (1999) revealed that both gca and sca effects were significant for all the characters studied viz. days taken to pollen shedding, days taken to silk, plant height, ear height and biomass weight $plant^{-1}$. Combining ability was highly significant for seed yield, days taken to 50% silking, plant height, cob length, number of kernel rows cob^{-1} and silking. Chaudhary *et al*. (2000) reported that mean squares due to crosses were highly significant for all the three traits. Mean squares due to gca were highly significant except for ear length. However, sca effects were significant for days taken to tassel, ear length and grain yield.

Significant difference for gca and sca effects for 10 characters were reported by Desai and Singh (2001). The crosses viz. LB 1073 x LB 143 and LB 1073 x LB 1155 were found to have negative gca effects for days taken to 50% taselling and days taken to 50% silking. However, these crosses exhibited positive sca effects for plant height, number of leaves $plant^{-1}$ and grain yield $plot^{-1}$. Shieh and Thseng *et al*. (2001) conducted a study to determine the combining ability of S_2 inbred lines derived from 6 Tainan-white populations and observed that early generation testing was as effective as that estimated from nearly homozygous lines.

Significant correlation existed between the hybrids derived from the S_2 and S_5 generations for ear dry weight and grain dry weight at maturity indicating that the yield ability of S_5 hybrids could be predicted precisely from that of S_2 hybrids. Combining ability studies viz. days taken to 50% taselling, days taken to 50% silking, plant height and ear traits were studied by Venkatesh *et al*. (2001) using the inbred lines. Diverse combining ability effects of parents reflected the inherent genetic variation for yield and its component traits. They also found that the CML 290 and CM11 were best combiners among the indigenous inbred testers.

Studies on gene action for yield and its attributes in maize by Dodiya and Joshi (2002) revealed that mean squares due to lines, testers and lines x testers were significant for grain yield, ear size, 100 grain weight, stover yield and harvest index, whereas it was non-significant for plant height and days taken to 50% husk browning in the testers. Analysis of variance for combining ability revealed that the mean squares due to lines, testers and lines x testers were significant for most of the characters except for grain yield plant^{-1} and number of rows ear^{-1} in the lines and for grain weight and grain-cob ratio in the testers. Both gca and sca were involved in the genetic expression of these traits (Joshi *et al*., 2002). Srivastava and Singh (2003) studied heterosis and combining ability for yield and maturity traits of maize and observed that significant variation existed for days taken to 50% silking, 100 kernel weight and grain yield. Significant differences were also observed for the lines x testers interaction for all the characters.

Line x tester analysis in maize by Sharma *et al*. (2004) revealed that mean square due to lines were significant for plant height, days taken to 50% silking, days taken to 50% taselling, 100 grain weight, cob girth, cob length and cob weight, indicating thereby that additive genetic variance played significant role in the inheritance of these characters. Variance due to interaction of females and males (lines x testers) were significant for all the characters, which revealed that non additive gene effects governed the inheritance of these traits. Studies on combining ability in varietal crosses of maize by Singh and Jamwal (2004) showed that highest gca effect was observed in the parent C_6 for days taken to silk and days taken to maturity ; in Arun for plant height and ear height ; in Jujote for ear girth, ear length and 100 kernel weight and in Mansar for kernels row^{-1} and grain yield. In general, the *per se* performance of crosses was closely related to the sca effects for grain yield.

2.2 Genetic components of variance and gene effects

Quantitative genetics has undoubtedly made substantial contribution to the genetic improvement of corn (Lamkey and Lee, 1993) and in conjunction with other statistical approaches has been important in the development of systematic progeny testing schemes and breeding methodologies. Ever since the framework for characterization of genetic variance was provided by Fisher in 1918, considerable information on the nature of such components has been investigated in maize.

Evaluation of 8 maize population and their 50 hybrids in 8 x 8 lattice design by Brenner *et al.* (1991) revealed that the additive effects were the most important with reciprocal crosses and sca effects important only in specific crosses. Paul and Duara (1991) carried out combining ability analysis for grain yield and phonological characters in maize. They found that variation was significant for all the characters and both additive and non additive gene action were involved in their inheritance. All the characters except days taken to 50% silking were more influenced by additive gene action. Jha and Khera (1992) reported that non additive gene action was predominant for grain yield and exotic crosses significantly out yielded the best hybrid control. Similar results were also reported by Dhillion and Singh (1977), Sharma *et al*. (1982), Odongo (1983) and Crossa *et al*. (1990). Landi *et al*. (1986) reported importance of both gca and sca components of variance for days to tasselling and plant and ear height. Similar results for plant and ear height were reported by Gupta *et al*. (1994).

Evaluation of 21 hybrids and their reciprocals along with parents for yield and related traits by Scapim *et al*. (1995) revealed that the non- additive gene effects predominated in the control of traits. Sinha and Mishra (1997) reported importance of both additive and non additive gene effects in the expression of days taken to 50% tasselling, and silking, plant and ear^{-1} height, ear length, ear diameter, 100 grain weight and grain yield, however, the non-additive gene effects were of higher magnitude except for days taken to 50% tasselling.

Studies on combining ability for yield in maize by Dass *et al*. (1997) revealed that general and specific combining ability variances were significant for seed weight and grain yield in both summer and winter season. This suggested that both additive and non additive genetic components played important role in brining out heterotic effects in these characters. However, higher magnitude of gca variance in both the seasons indicated the predominance of additive and additive x additive epistatic components. Similar observations were reported by Bhalla and Khera (1977) ; Cross (1977) ; Oyercides – Gracia *et al*. (1985) ;

Pinto *et al.* (1987) ; Dhillion *et al.* (1988); Prasad *et al.* (1988) ; Beck *et al.* (1990) ; Vasal *et al.* (1992a, 1992b) ; Widstorm *et al.* (1992) ; Vasal *et al.* (1993a,1993b) ; Sinobas and Monteagudo (1996) and Sanvicente *et al.* (1988).

Gul *et al.* (1998) observed that mean squares due to gca were highly significant for days taken to 50% tasselling, pollen shedding and ear emergence. Significant gca variance for days to silking, ear length, ear girth, number of rows ear^{-1}, number of grains row^{-1} and grain yield plot^{-1} were reported by Mathur *et al.* (1998) with preponderance of additive gene effects in the expression of all these characters. Similar results for days taken to silking were reported by Bhalla and Khera (1977) ; Dhillion and Singh(1977) ; Sharma *et al.*(1982) ; Beck *et al.* (1990) ; Vasal *et al.*(1992a) ; Vasal *et al.*(1993a) and Spaner *et al.*(1996).

Combining ability studies by Singh and Singh (1998) revealed that general and specific combining ability variances were highly significant for all traits viz days taken to tasselling, silking and husk browning, plant height and ear height. They also found that component of variation due to gca was higher than due to sca, revealing higher importance of additive gene action for all the attributes. Similar results for plant and ear height were reported by Bhalla and Khera (1977); Dhillion and Singh (1977);Beck *et al.*(1990);Ajala (1992); Vasal *et al.*(1992a); Widstorm *et al.*(1992); Sinobas and Monteagudo (1996) and Sughroue and Hallauer,(1997).

Stojakovic *et al.* (1998) reported that partial or complete dominance of dominant allele with additive effects is the main contributor for heterosis in maize, while-as over-dominance is of minor importance in maize heterosis. Significant gca effects for grain yield, days taken to flowering, number of kernels row^{-1}, and 1,000 kernel weight and significant sca effects for grain yield and plant height was reported by Choukan (1999). He also found that both additive and non additive gene effects were important in the genetical control of grain yield, plant height and number of kernels row^{-1}. Similar results were reported by Gupta *et al.*(1994) for plant height, while Singh.(1979); Gamma *et al.*(1984) ; Khalifa and Drolsum (1988) ; Satish and Bhalla (1998); Jha and Sinha (1989) ; Misevic (1989) and Dass *et al.*(1997) reported for grain yield

Choudhary *et al.* (2000) reported predominant role of additive genetic effect for days taken to tassel and non-additive gene effects in the inheritance of ear length and grain yield. This was in good agreement with the comparative estimates of sca and *per se* performance for crosses, as also reported by Prasad *et al.* (1988). Relationship between gca and sca was either partial or practically absent. Combining ability studies using 15 F_1 hybrids and their parents by Zelleke (2000) reported that the ratio between gca : sca was less than unity (0.68), showing that non- additive gene action was more important in controlling grain yield.

Mahto and Ganguli (2001) while studying generation mean analysis for grain yield and its components in maize (*Zea mays* L) reported importance of dominance component (h) in the inheritance of grain yield, days taken to tasselling, days taken to maturity, plant height, ear girth and number of kernels ear^{-1}. Desai and Singh (2001) reported that both additive and non additive components of genetic variance were involved in the inheritance of days taken to 50% tasselling, and silking, plant height, ear height and grain yield plot^{-1}.

Five inbred lines were evaluated for general and specific combining abilities by Aguiar *et al.* (2003). They observed that for grain yield both the additive and non additive gene effects were important. Studies on heterosis and combining ability for yield and maturity of maize by Srivastava and Singh (2003) indicated higher sca variance than gca variance. This higher magnitude of non- additive gene effects resulted in more heterosis for days taken to 50% silking, 1,000 kernel weight and grain yield. Similar results were obtained by Venkatesh *et al.* (2000) and Dubey *et al.*(2001). Barket *et al.* (2003) reported that non- additive genetic variance played an important role in the inheritance of grain yield, plant height and silking date. Similar results have been reported by Souza and De (1981);Vasal *et al.*(1993b); Spaner *et al.*(1996); Vasal *et al.* (1993b); Gupta *et al.*(1994) and Nagda *et al.*(1995) for days to silk.

Combining ability studies for yield and quantitative characters in sweet corn by Dutta *et al.*(2004) revealed predominant role of non additive gene action for grain ear yield, kernel rows ear^{-1} and ear weight, whereas additive gene action was important for plant height, ear height, ear diameter and kernels row^{-1}.

2.3 Heritability

One of the important considerations in the formulation of efficient breeding programme is the knowledge regarding the relative contribution of genes in the expression of a particular trait. Genetic advance i.e, the improvement in genotypic value of the new population as compared with the base population depends on the genotypic values of individuals in the base population. It is an established fact that the selection of plants with desirable phenotype from genotypically variable populations and utilization of these selected plants for creation of new populations to be eventually used as a potential source for the development of a variety are the essential features of most breeding programmes. If all or most of the variability among the individuals in base population is attributable to non heritable agencies, selection of phenotypically superior individuals from the population will not lead to desired improvement. Success of a breeder in changing the characteristics of population, therefore, depends upon the degree of correspondence between phenotypic value and genotypic values. Quantitative measure which provides information about correspondence between genotypic variance and phenotypic variance has been termed as heritability. The concept was originally presented by Lush (1945) to describe the ratio between genotypic and phenotypic variance and is known as broad sense heritability. However, mean genotypic value of the progeny is determined by the average effect of genes transmitted by the parents in question. In other words, it is the breeding value of the parents, which determines the genetic properties of progeny. Hence, it is the proportion of phenotypic variance that is made up of variation attributable to the breeding values (known as additive genetic variance) which is of considerable practical interest to the breeder. The ratio of additive genetic variance to the phenotypic variance has been termed as "narrow sense heritability" and expresses the magnitude of genotypic variance in the population, which is mainly responsible for changing the genetic composition of population through selection.

Singh *et al*. (1995) reported high heritability for days taken to taselling, plant height and 1,000 grain weight. Jha *et al*. (1998) while studying genetic variability and character association in fodder maize revealed high heritability for days taken to 50% silking and ear leaf area, followed by moderate estimates for grain fodder yield. Similar estimates of high heritability were reported for cob yield with husk and baby corn yield by Tiwari and Verma (1999).Genetic analysis of quantitative traits in maize by Vaezi *et al.*(1999) revealed that heritability in narrow sense was low to intermediate for all the traits studied except for ear length, kernel rows ear^{-1} and ear diameter.

Kumar *et al.* (2000) reported that heritability and genetic advance would help the breeders in selection. Heritability estimates aid in deciding selection intensity, whereas, genetic advance predicts the genetic gain likely to be achieved in the selection. Studies on seven parents and their 21 single crosses and two standard controls for estimating the heritability revealed that grain yield had high heritability, however, a large number of characters gave medium to low heritability values with days taken to 50% maturity giving the lowest estimate. A study conducted to estimate the genetic variability and its components by Saikia and Gargi. (2000) indicated high heritability estimates for days taken to 50 % tasselling and silking, ear height and plant height.

Evaluation of inbred lines and their F_1 crosses of maize by Mahto *et al.* (2002) revealed high heritability estimates for days taken to flowering, silking and maturity. Moderate heritability was observed for grain yield, plant height, ear height and 1000 grain weight. High heritability was reported by Viola *et al.*(2003) for cob length, cob yield plant^{-1} and cob weight indicating that additive gene action governed the inheritance of these traits. The number of days taken to 50%, tasselling, silking and harvesting were characterized by high heritability.

Kabdal *et al.* (2003) while studying genetic variability and correlation of yield and its attributing characters in maize reported high heritability estimates for grain yield, ear height, plant height and ear length. Ibrahim (2004) reported that narrow sense heritability estimates were high for plant height, ear height and silking date ; moderate for the number of rows ear^{-1}, kernel weight, ear length and low for the grain yield plant^{-1}, ear diameter and number of kernels row^{-1}.

2.4 Estimation of heterosis

Heterotic effect (h_{ij}) is manifested as a consequence of difference in gene frequencies in two varieties and dominance of more favourable alleles. This heterotic effect is partitioned into three components ($\bar{h}$, h_i and s_{ij}). The average heterosis ($\bar{h}$) contributed by a particular set of parents used in the crosses is the difference between the mean of all crosses and mean of all parents. The variety heterosis (h_i) effect is the heterosis contributed by variety i. The specific heterosis (s_{ij}) effect measures the deviations between the observed performance of the specific cross and its expected performance based on the vj, $\bar{h}$,and hj effects (Sinha and Mishra,1997).

Pavlov (1990) observed that the highest heterosis among the sib crosses was attained by crossing the lines oh 545 and oh 43. Significant heterosis over the better parent was seen in the F_1 for all the traits, but the degree of heterosis was higher at the higher density for almost all traits except for length and height of insertion as reported by Sohu and Kapoor.(1993).

Heterosis and combining ability for grain yield plant^{-1}, days taken to silking and plant height were determined by Altinbas (1995) involving six inbred lines. He found that high parent heterosis ranged from 72 to 140.7% for grain yield and from -2.4 to -18% for days taken to silking. Wonkoo and Bongho (1995) observed that the hybrids involving 'Bosung' cultivar showed the longest ear lengths and the greatest grain weights. Highest grain yield per unit area was obtained by hybrids involving 'Dangjin' parent.

Sinha and Mishra (1997) reported that the average heterosis and variety heterosis effects were not so important for any trait. Navin x popn 26, D765 x kiran and Suwan- 1 x pool 18 showed positive heterotic effects for grain yield. Janick *et al.* (1999) reported that production of F_1 hybrids of seed propagated crops is a successful breeding technique because it exploits heterosis and promotes homogenity in allogamous species. Combining ability analysis by Ipsilandis and Koutsika (2000) observed low heterosis of recombinant lines owing to the additive gene action. Gorgulho and Miranda (2001) observed that the plant height, ear height and ear diameter did not show heterosis effects, however, the average heterosis for ear length was 3.10%.The hybrids showed an average yield of about 7% higher than their parents.

Choudhary and Chaudhary (2002) reported that more crosses showed significant heterosis for ear length than for any

other character, although the proportion of crosses exhibiting positive desirable heterosis were limited. The nine best crosses with high heterosis percentage in grain yield plot^{-1} showed that highest heterosis percentages were usually displayed by intercrosses. It was in consonance with the established fact that heterosis is directly proportional to the relative genetic distance between the parents (within limits) and it increases with the diversity of using gametes. The findings were also in agreement with those of Han *et al.* (1991) and Mukherjee and Ahuja (1991).

Dickert and Tray. (2002) reported that the traits with low heterosis had very high gca: sca ratios, while these ratios were smaller in traits with high heterosis. Mean squares due to crosses vs checks, which is a test of mean standard heterosis (heterosis over the check variety) were highly significant for all characters as reported by Choudhary and Choudhary (2002). Crosses between high x high and high x low gca parents exhibited greater heterosis as reported by Singh *et al.*(2002).Based on gca effects and heterosis, they observed that P_1 x P_7 was best hybrid yielding 14.30% more grain yield. Venugopal *et al.*(2002) observed that 42 out of 45 hybrids exhibited significant positive heterobeltiosis, with a maximum value of 136.97% whereas, for standard heterosis only 8 crosses were significantly positive with a maximum of 18.48%.

Studies carried out by Akhtar *et al.* (2003) found significant differences in the grain yield and 1000 kernel weight. H_{10} recorded the highest grain yield, whereas H_6 recorded the highest kernel weight. Twenty four hybrids were developed by crossing six popcorn lines and four testers in L x T mating design by Reddy *et al.* (2003). The extent of heterosis of Amber corn ranged from 85.69 to 29.14 for popping expansion and from –16.1 to 80.16 for grain yield plot^{-1}.Rezaei *et al.*(2004) from their studies on estimates of heterosis and combining ability in maize, using diallel crossing method, reported high heterosis in more than 50% of the crosses for all studied characteristics. The highest and lowest amounts of heterosis was observed for grain yield and number of rows ear^{-1}, respectively. Number of days taken from planting to tassel emergence and maturity showed negative heterosis. The mid parent heterosis values ranged from 46.10 to 573.12 %, whereas, the useful heterosis values varied between 46.47 to 10.78% for grain yields as reported by Unay and Konak (2004).

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “Combining ability analysis for yield and maturity traits in elite inbred lines of maize (*Zea mays* L.)” was carried out at K.D. Research Station of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Budgam, Kashmir during *Kharif*,2005.

3.1 Experimental materials

The materials comprised fifteen diverse, vigorous and productive maize lines at S_2 stage that were developed at K.D.

Research Station and three testers comprising two well adapted broad genetic base composites and an inbred line having narrow genetic base. The parents (lines and tester) used in the present study were as under :

Lines

1. L_1 : 102A
2. L_2 : 102A-2
3. L_3 : 106B
4. L_4 : 106C-1
5. L_5 : 132C-2
6. L_6 : 132C
7. L_7 : 139A
8. L_8 : 139B
9. L_9 : 140 E-2
10. L_{10} : 141 B-1
11. L_{11} : 142 A
12. L_{12} : 146 B
13. L_{13} : 147 C
14. L_{14} : 150B
15. L_{15} : 151A

Testers

1. T_1 : C_6 (a composite with broad genetic base)
2. T_2 : Super-1 (a composite with broad genetic base)
3. T_3 : 153-A (an inbred line with narrow genetic base)

3.2 Methodology adopted

Each tester (pollen parent) was crossed to every female line (seed parent) in Line x Tester mating design of Kempthorne (1957) at K.D. Research Station during *Kharif*, 2004 and forty-five test cross progenies were generated. The materials were grown in a completely randomized block design using three replications at a single location during *Kharif*, 2005. The 45 F_1s and 18 parents (15 lines + 3 testers) were randomized in each replication. Each experimental plot consisted of three rows of 5 m length. The inter- and intra-row spacing was maintained at 60 and 20 cm, respectively. Two seeds per hill were planted and later thinned to one seedling per hill at 4 leaf stage. One row of non experimental material was planted on either side of each replication to avoid border effect. Recommended agronomic practices were adopted to raise a good crop.

3.2.1 Recording of the data on field experiment

Observations on various quantitative traits were recorded on 10 randomly selected competitive plants from each of the non segregating generations (i.e. parents and F_1's) and 20 plants in case of the two heterozygous composites (C_6 and Super-1) For days taken to 50% anthesis, silking and husk browning the data were recorded on whole plot basis and median values recorded. Detailed description for recording the data for various traits in each experimental plot is presented as under :

3.2.1.1 Days taken to 50% anthesis

The number of days taken from the date of sowing to the pollen shed in 50% plants was recorded.

3.2.1.2 Days taken to 50% silking

The number of days taken from the date of sowing to the appearance of silk in 50% plants was recorded.

3.2.1.3 Days taken to 50% husk browning

The number of days taken from the date of sowing to the browning of husk in 50% plants was recorded.

3.2.1.4 Plant height (cm)

The length from the base of plant at the soil level to base of tassel at dry silk stage was recorded in cm.

3.2.1.5 Ear height (cm)

The length from the base of plant at soil level to the node bearing uppermost ear at dry silk stage was recorded in cm.

3.2.1.6 Ear length (cm)

The length of main ear (the uppermost ear) was measured in cm from the base of the ear to its tip.

3.2.1.7 Ear girth (cm)

The girth of the main ear (the upper most ear) was measured in cm from the middle of ear.

3.2.1.8 Number of kernel rows ear^{-1}

The number of kernel rows in each ear were counted.

3.2.1.9 Kernels row^{-1}

The number of kernels of three randomly selected rows in each ear were counted and averaged to a single row.

3.2.1.10 100 grain weight (g)

Kernels from all the tagged ears in each experimental plot were shelled. A random sample of 100 kernels was weighed in g and the weight adjusted to 15 per cent moisture.

3.2.1.11 Yield (q ha^{-1})

Total grain yield was recorded on plot basis and adjusted to 15 per cent moisture content. Accordingly, the grain yield (q ha^{-1}) was worked out.

3.2.2 Estimation of grain protein content

A sample of the grains used for recording the yield of each experimental plot was crushed, replication wise to a fine powder in order to estimate the per cent crude protein content by Kjeldhal's method as given by Jackson (1973).

3.2.2.1 Reagents used

i) Conc. H_2SO_4

ii) 0.05 N H_2SO_4 (for titration)

iii) Sulphate mixture (10: 1:0.5) consisting of K_2SO_4, $FeSO_4$, and $CuSO_4$.

iv) Selenium powder

v) 4% boric acid with mixed indicator (Bromocresol green and methyl red)

vi) 40% NaoH

3.2.2.2 Procedure adopted

One gram of dried grain sample was taken in 500 ml Kjeldhal's flask to which 25 ml of Conc. H_2SO_4 was added and was allowed to stand subsequently. 10 grams of sulphate mixture and one gram of selenium powder were added to the material in the flask and the flask was heated till the digestion was complete.

The flask was then allowed to cool and volume was made to 100ml.

From this solution 20ml was taken in another Kjeldhal flask and 25ml of NaoH was added and the flask was immediately connected to distillation apparatus. The flask was heated and NH_3 gas evolved was collected in 25ml of 4% boric acid solution to which mixed indicator solution was already added. Distillation was allowed to continue till nearly 50ml distillate was collected in the conical flask. The distillate in the conical flask was titrated against 0.05 N H_2SO_4 solution and crude protein was calculated as :

1 ml of 1 N H_2SO_4 = 14 mg of N

1 ml of 0.05 N H_2SO_4 = 14 x 0.05

Yml of 0.05 N H_2SO_4 = 14 x 0.05 x Y

1000 mg (1 gm) grain sample contains Nitrogen% = $\frac{14 \times 0.05 \times Y}{1000}$

Crude protein % (Z) = % age of nitrogen in grain sample x 6.25

3.3 Statistical Analysis and estimation of components of variance

3.3.1 Analysis of variance

The analysis of variance was based on the following model

$Y_{ijk} = \mu + g_{ij} + bk - e_{ijk}$

Where,

Y_{ijk} is the phenotypic values of genotype ij representing cross of ith and jth parent in kth block, µ is the general mean, gij is the genetic effect of ith genotype, bk is the block effect and e_{ijk} is the environmental effect associated with each observation. The μ, g_{ij} and bk are assumed to be fixed unknown parameters. The e_{ijks} are assumed to be normally and independently distributed around mean with variance ($\hat{\sigma}^2$) equal to zero.

3.3.2 Analysis of Line x Tester mating design

The analysis of variance for the line x tester mating design as proposed by Kempthorne (1957) was used for the analysis of combining ability based on the following model:

$$Y_{ijk} = \mu + g_i + g_j + S_{ij} + r_k + e_{ijk}$$

Where,

Y_{ijk} = observation recorded on i x j^{th} cross grown in k^{th} replication,

μ = general mean,

g_i (g_j) = general combining ability effect of ith (j^{th}) parent (i = 1,2,..........15 lines and j = 1,2, ...3 testers),

S_{ij} = Specific combining ability effect of cross between i^{th} and j^{th} parent,

r_k = the effect of k^{th} replication (k = 1,2,3), and

e_{ijk} = the error associated with [ijk^{th}] observation.

This design leads to the partitioning of the effects of hybrids into general combining ability effects of lines and testers and their specific combining ability effects in cross combinations.

At the same time it is helpful in estimating various types of gene effects. The mating pattern of this design is that 'i' lines are crossed to each of the 'j' testers and thus, i x j fullsib families are produced. On the basis of the above model the data obtained in the present study from line x tester analysis of 45 crosses were subjected to analysis of variance.

The analysis of variance for combining ability in a single environment was as under:

Source	**d.f.**	**S.S.**	**Mean square**	**Expected MS**
Replicates	(r-1)	---	----	---
Line (L)	(l-1)	SS_l	M_l	$\hat{\sigma}_e^2 + \frac{tr}{l-1} \sum_i^l g^2_i$
Tester (T)	(t-1)	SS_t	M_t	$\hat{\sigma}_e^2 + \frac{lr}{t-1} \sum_j^t g^2_j$
Line x Tester (L x T)	(l-1) (t-1)	SS_{lt}	M_{lt}	$\hat{\sigma}_e^2 + \frac{r}{(l-1)\ (t-1)} \sum_i^l \sum_j^t S^2_{ij}$
Error	(lt-1) (r-1)	SS_e	M_e	$\hat{\sigma}_e^2$
Total	**rlt- 1**			

Where,

l,t and r were number of females (lines), males (testers) and replications, respectively.

The different sums of squares thus obtained, were divided by their respective degree of freedom to obtain mean squares which were tested against error mean squares by employing 'F' test.

Fixed model effects were used to estimate the components since the materials used were fixed.

The model of Kempthorne (1957) was used for estimating the gca and sca effects in combining ability analysis of F_1 generation. The model underlying this analysis is :

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

where,

μ = general mean,

g_i = general combining ability effect of the i^{th} line,

g_j = general combining ability effect of the j^{th} tester,

s_{ij} = specific combining ability effect of i^{th} line x j^{th} tester, and

e_{ijk} = error associated with ijk^{th} observation

i = number of lines (i……..1 to 15)

j = number of testers (j………..1 to 3)

k = number of replications (k……….1 to 3)

The individual effects were estimated with the help of following relationship

i) $$\mu = \frac{X\ldots}{}$$

ltr

where, X… = total of all hybrid combination

3.3.3 Estimation of GCA effects

(a) Lines (g_i) $= \dfrac{X_{i..}}{tr} - \dfrac{X_{...}}{ltr}$

Check $\sum_{i=1}^{l} g_i = 0$

b) Testers (g_j) $= \dfrac{X_{.j.}}{lr} - \dfrac{X_{...}}{ltr}$

Check $\sum_{j}^{t} g_j = 0$

Estimation of SCA effect

$$S_{ij} = \frac{X_{ij}}{r} - \frac{X_{i..}}{tr} - \frac{X_{.j.}}{lr} + \frac{X_{...}}{ltr}$$

Check $\sum S_{ij} = \sum S_{ji} = \sum_{i=1}^{l} \sum_{j=1}^{t} s_{ij} = 0$

Where,

l = number of lines

t = number of testers

r = number of replications

X… = sum of all hybrids (line x testers) over all replications

X_{ijk} = sum of ijth hybrid combination over all replications

$X_{i..}$ = sum of i^{th} line over all testers and replications

$X_{.j.}$ = sum of j^{th} testers over all lines and replications

M_l = mean sum of squares due to lines

M_t = Mean sum of squares due to testers

M_e = Mean sum of squares due to error

X_{ij} = ij^{th} cross combination summed over all replications

3.3.4 Standard errors for combining ability effects

i). S.E.(g_i) lines = $(Me/r \times t)^{0.05}$

ii). S.E.(g_i) testers = $(Me/r \times l)^{0.05}$

iii). S.E.(s_{ij}) crosses = $(Me / r)^{0.05}$

iv). S.E. (g_i-g_j) lines = $(2\ Me/r \times t)^{0.05}$

v). S.E. (g_i-g_j) testers = $(2\ Me/\ r \times l)^{0.05}$

vi). S.E. (s_{ij}-s_{kl}) crosses = $(2Me/r)^{0.05}$

Where,

Me = Error mean sum of squares,

r = replication

l = lines

t = testers

Test of significance for general and specific combining ability effects was carried out by comparing with the values obtained by multiplying standard error of the corresponding effect with the table value of 't' at error degree of freedom.

3.3.5 Components of genetic variance

By using appropriate mean squares obtained from the analysis of variance, the estimates of components of genetic variance were computed as given below:

3.3.5.1 Components of genetic variance in a single environment

$$\hat{\sigma}^2_{gca} \text{ (lines)} = \frac{1}{(l-1)} \sum_{i}^{l} g^2_i = \frac{M_l - M_e}{rt}$$

$$\hat{\sigma}^2_{gca} \text{ (testers)} = \frac{1}{(t-1)} \sum_{j}^{t} g^2_j = \frac{M_t - M_e}{rl}$$

$$\hat{\sigma}^2_{sca} = \frac{1}{(l-1)(t-1)} \sum_{i}^{l}\sum_{j}^{t} s^2_{ij} = \frac{M_{lt} - M_e}{r}$$

Variance of general and specific combining ability effects are related to the components of heritable variance as:

$$\hat{\sigma}^2_{gca} \text{ (av.)} = \text{Cov. (H.S)}$$

$$\text{Where, Cov (H.S)} = \left(\frac{1+F}{4}\right)\hat{\sigma}^2_A$$

In the present study the materials (lines) from the reference population were in S_2 stage of selfing that had the inbreeding coefficient (F) equivalent to 0.75. The estimate of covariances were accordingly estimated as under .

$$\hat{\sigma}^2_{gca}\ \text{(av)} = \left[\frac{1.75}{4.0}\right]\hat{\sigma}^2_A$$

$$\hat{\sigma}_A = \left[\frac{4\hat{\sigma}_{gca}}{1.75}\right]$$

The covariance of half-sibs for males as well as females is equal to $\left[\frac{1.75}{4.0}\right]\hat{\sigma}^2_A$

$$\text{Cov. (H.S) females (lines)} = \left[\frac{1.75}{4.00}\right]\hat{\sigma}^2_A = \hat{\sigma}^2{}_{gca(L)}$$

$$\therefore \quad \hat{\sigma}^2_{A\,(lines)} = \left[\frac{4.00}{1.75}\right]\hat{\sigma}^2{}_{gca}\,\text{(lines)}$$

$$\hat{\sigma}^2_{sca} = \left[\frac{1+F}{2}\right]\hat{\sigma}^2{}_D$$

$$F = 0.75$$

$$\hat{\sigma}^2_{sca} = \left[\frac{1.75}{2.00}\right]\hat{\sigma}^2{}_D$$

$$\therefore \quad \hat{\sigma}^2_S = \frac{2\hat{\sigma}^2{}_{sca}}{1.75}$$

3.3.6 Standard error of estimates

Estimates of standard error were calculated following the procedure given by Moll *et al.* (1960).

3.3.6.1 Standard error for single environment estimates

$$\sqrt{\quad}$$

$$\text{S.E. } \hat{\sigma}_e^2 \text{ (error)} = \sqrt{\frac{2(M_e)^2}{\text{d.f. } M_e + 2}}$$

$$\text{S.E. } \hat{\sigma}_e^2 \text{ (Tester)} = \sqrt{\frac{2}{(rl)^2}\left(\frac{(M_t)^2}{\text{d.f.}M_t + 2} + \frac{(M_e)^2}{\text{d.f. } M_e + 2}\right)}$$

$$\text{S.E. } \hat{\sigma}_{gca}^2 \text{ (Line)} = \sqrt{\frac{2}{(rt)^2}\left(\frac{(M_l)^2}{\text{d.f. } M_l + 2} + \frac{(M_e)^2}{\text{d.f. } M_e + 2}\right)}$$

$$\text{S.E. } \hat{\sigma}_{gca}^2 \text{ (Av.)} = \sqrt{\frac{2}{\left(\frac{rl + rt}{2}\right)^2}\left(\frac{(M_l + M_t)^2}{\frac{\text{d.f.}(M_l + M_t) + 2 + 2}{2}} + \frac{(M_e)^2}{\text{d.f. } M_e + 2}\right)}$$

$$\text{S.E. } \hat{\sigma}_{sca}^2 = \sqrt{\frac{2}{(r)^2}\left(\frac{(M_{lt})^2}{\text{d.f. } M_{lt} + 2} + \frac{(M_e)^2}{\text{d.f. } M_e + 2}\right)}$$

Standard error of $\hat{\sigma}_A^2$ (Av) = 2 S.E. of $\hat{\sigma}_{gca}^2$ (Av)

,, ,, ,, ,, ,, $\hat{\sigma}_D^2$ = 2 S.E. of $\hat{\sigma}_{sca}^2$

3.3.6.2 Estimation of heritability

Heritability in narrow sense was calculated following the method of Hallauer and Miranda (1988).

3.3.6.3 Heritability for single environment data

$$h^2 \text{ (n.s)} = \frac{\hat{\sigma}_A^2}{\hat{\sigma}_e^2 + \hat{\sigma}_D^2 + \hat{\sigma}_A^2}$$

3.3.6.4 Per cent contribution of lines, testers and line x tester interaction to the hybrid sum of squares

These were calculated as follows:

i). Per cent contribution of lines =

$$\frac{\text{S.S. due to lines}}{\text{S.S. due to crosses}} \text{ x } 100$$

ii). Per cent contribution of testers =

$$\frac{\text{S.S. due to testers}}{\text{S.S. due to crosses}} \text{ x } 100$$

iii). Per cent contribution of lines x testers =

$$\frac{\text{S.S. due to lines x testers}}{\text{S.S. due to crosses}} \text{ x } 100$$

3.4 Estimation of heterosis

Heterosis was estimated as the per cent deviation of the performance of F_1 from the standard check (composite C_6) as detailed below :

i) Heterosis over standard check (HSC)

$$\textbf{HSC} = \frac{(\overline{F}_1 - \overline{SC})}{\overline{SC}} \times 100$$

To test the significance of extent of heterosis, standard error (S.E) and critical difference (C.D) were calculated as under :

C.D = S.E $(\bar{d})$ x t value at error d.f

Where,

S.E. $(\bar{d})$ = standard error of difference of M_e

S.E $(\bar{d})$ ± for heterosis over $\bar{SC}$

$$= \left(\frac{2\,ME}{r}\right)^{1/2}$$

The level of significance was given to the corresponding values of heterosis by comparing SE values with respective deviations.

Chapter-4

EXPERIMENTAL FINDINGS

The present investigation entitled "Combining ability analysis for yield and maturity traits in elite inbred lines of maize" was carried out to generate information on combining ability effects and gene action together with breeding value heritability for the following traits.

1. Days taken to 50% anthesis
2. Days taken to 50% silking
3. Days taken to 50% husk browning
4. Plant height (cm)
5. Ear height (cm)
6. Ear length (cm)
7. Ear girth (cm)
8. Number of kernel rows ear^{-1}
9. Number of kernels row^{-1}
10. 100 grain weight
11. Grain yield (q ha^{-1})
12. Protein content (%)

The mean/median values recorded for the different traits were subjected to the line x tester analysis as proposed by Kempthrone (1957) and the results so obtained are presented under the following sub heads.

4.1 Analysis of variance.

4.2 Estimation of components of genetic variance, combining ability effects and heritability.

4.3 Estimation of heterosis over standard check.

4.1. Analysis of variance

The analysis of variance (Table 1) revealed significant differences among crosses and female parental lines for all the traits studied except for ear height in case of lines. Testers revealed significant difference only for ear length, ear girth, kernel rows ear^{-1}, 100 grain weight and protein content. The crosses resulting from the line x tester were significantly different for all the traits except for protein content. As such the estimation of combining ability effects (general and specific) and components of genetic variance for this trait (protein content) shall not be presented and discussed hitherto onwards.

The line x tester variance for all the characters was significant that indirectly indicated the diversity among the testers even though the testers did not reveal significant variance for some of the traits. Therefore, the choice of selection of testers was satisfied. Similarly, the single degree of freedom comparison (parent v/s hybrids), which is indicative of magnitude of heterosis, was also significant for all the traits.

4.2 Estimation of components of genetic variance, heritability and combining ability effects

The analysis of variance for the combining ability (Table 2) revealed that crosses possessed significant mean square for all the traits and thus, most of the crosses differed from each other confirming the lines were not related by descent and individual

female lines differed significantly for gene combination for most of the economic traits.

4.2.1 Estimation of components of genetic variance and heritability.

Estimation of genetic components of variance (Table 2) revealed that variance due to lines was significant for all the traits. However, variance due to testers was significant only for ear length and its girth, kernel rows ear^{-1} and grain weight. Translating the variance due to lines and testers into variance due to general combining ability it was observed that all the traits except days taken to 50% anthesis revealed significant variance due to general combining ability. Similarly, the estimates of specific combining ability were significant for all the traits. Variance due to error was non significant indicating that sampling error was reduced to minimum. Translating the variance due to general combining ability and specific combining ability into components of genetic variance i,e. additive genetic variance ($\hat{\sigma}_A^2$) and variance due to dominance deviations ($\hat{\sigma}_D^2$), it was observed that the variance due to dominance deviations was higher in magnitude than additive genetic variance for all the traits. The average degree of dominance ranged from 1.740 (kernel rows ear^{-1}) to 3.863 (ear height) and thus all the traits revealed over-dominance.

Estimation of narrow sense heritability was very low for all the traits and it ranged from 6.045 (ear height) to 25.929 (100 grain weight). This indicated that the crosses had the divergent genes at most of the loci and the level of heterogenity was very high resulting in heterozygosity and over-dominance.

4.2.2 Estimation of combining ability effects

4.2.2.1 General combining ability effects

The general combining ability effects are presented in the Table 3, which revealed that for days taken to 50% anthesis the significant and desirable effect for earliness was present in the lines 132C, 139 B and 102 A-2. The significant effect for later maturity was revealed by the 142 A followed by the lines 140 E-2, 146 B, 147 C and 150 B. Similarly, for days taken to 50% silking the desirable general combining ability for earliness was revealed by the line 132 C followed by the lines 139 B and 106 C-1. Significant general combining ability for delayed silking was revealed by the lines 106 B and 142 A. For days taken to 50% husk browning the desirable and significant general combining ability for earliness was revealed by the line 146 B followed by the lines 106 B, 142 A, 141 B, 102 A-2, 150 B, 151 A and 102 A-1. Significant general combining ability for late husk browning was revealed by the lines 106 C-1 followed by the line 139 A, 147 C, 102 A-2 and 132 C.

In the present study one of the objectives was identification of parents and crosses showing early maturity and medium plant height with lower ear placement. Accordingly, lines showing medium to low plant height and lower ear height would be regarded as desirable. Therefore, significant negative values would be desirable general combining ability effects for plant height and ear placement height. Perusal of the Table 3 revealed that the significant general combining ability for lower plant height was revealed by the line 132 C followed by the lines 106 B, 102 A-2 and 142 A. Similarly, the genotype showing significant and desirable general combining ability effect for lower ear placement height was 132 C followed by the lines 106 B, 102 A-2, 102 A-1 139 B and 150 B.

For yield and yield contributing traits significant positive values were considered to be desirable general combing ability effects. For ear length the significant and desirable general combining ability effect was revealed by the lines 147C and 102A-1 followed by the lines 132 C and 142 A. For ear girth the desirable and significant general combining ability effect was revealed by the line 106 C-1 followed by the lines 102A-1, 139A and 147C. For number of kernel rows ear^{-1} the desirable and significant general combining ability effect was revealed by the lines 139 B and 146B. The desirable and significant general combing ability effect for number of kernels row^{-1} was revealed by the line 139A followed by the lines 102A-1, 147 C, 142A, 141B-1 and 102 A-2. Line possessing desirable and significant general combining ability effect for bolder grains (100 grain weight) were 106C-2, 102A-2, 139 B, 142A and 140 E-2.

The desirable and significant general combing ability effect for the most important trait i.e. grain yield (q ha^{-1}) was revealed by the line 139A followed by the lines 151A, 142A, 147C, 140E0-2 and 139B.

Perusal of the performance of the lines for their gca and *per se* (Table 4) performance for different traits revealed that none of the lines had desirable and significant gca effect for all the traits. However, for the maturity traits the elite lines were 132 C, 139 B and 142 A. possessing significant and desirable gca effect and *per se* performance.

For morphological traits viz. plant and ear height the promising lines possessing shorter plant height and lower ear placement were 132 C and 102 A-1 on the basis of gca effect and *per se* performance, respectively.

Among the yield component traits viz. ear length, ear girth, kernel rows ear^{-1}, kernels row^{-1} and 10 grain weight, the most promising lines possessing desirable and significant gca effect for more than two yield component traits was 102 A-1. Similarly, gca on the basis of *per se* performance the line showing good performance for more than two yield component traits was 147 C.

Among the top ranking five lines for grain yield (q ha^{-1}) showing significant and desirable gca effect, none revealed desirable *per se* performance as well.

4.2.2.2 Specific combining ability effects.

Estimates of specific combining ability effects for maturity, yield and yield contributing traits are presented in the Table 5 and Table 6. Perusal of the results revealed that the crosses showing significant and desirable specific combining ability effects for days taken to 50% anthesis were 106B x Super-1 and 139 A x 153A. For days taken to 50% silking, the desirable and significant specific combining ability effect was revealed by the crosses 139A x 153A, 140 E-2 x 153A and 146 B x 153 A. For days taken to 50% husk browning the desirable and significant specific combining ability effect was revealed by the cross 102 A-2 x 153A followed by the crosses 106 C-1 x C_6, 132C x C_6, 106C-2 x 153A, 106C-2 x Super-1, 139 A x C_6, 139B x Super-1, 139 B x 153A and 106B x 153A.

The desirable and significant specific combining ability effect for shorter to medium plant height was revealed by the cross 106 C-1 x Super-1 followed by the crosses 139 B x 153A, 141 B-1 x Super-1, 139 A x 153 A, 132 C x C_6, 102 A-1 x 153 A, 102 A-1 x C_6, 106 B x 153 A and 142 A x Super-1. Similarly, for lower ear placement the desirable and significant specific combining ability effect was revealed by the cross 102 A-1 x C_6 followed by the crosses 141 B-1 x Super-1, 106 C-1 x Super-1, 106 B x 153 A, 139 A x 153A, 139 B x 153A, 142 A x Super-1, 102 A x 153A, 139 B x C_6, 106 C-2 x 153A and 102A-2 x 153A.

The desirable and significant specific combining ability effect for more longer ear length was revealed by the cross 106B X C_6 followed by the crosses 147C x 153A, 141B-1 x Super-1, 102A-2 x Super-1 and 146B x 153A. For ear girth the significant and desirable specific combining ability effect was revealed by the crosses 132C x 153A and 102A-1 x C_6. Desirable and significant specific combining ability effect for number of kernel rows ear^{-1} was revealed by the cross 1-2 A-1 x super-1 followed by the crosses 132C x 153A, 146B x Super-1 and 106B x 153A. For more number of kernels row^{-1} the desirable and significant specific combining ability effect was revealed by the cross 139B x super-1 followed by the crosses 141B-1 x C_6, 141 B-1 x Super-1, 151A x 153A, 102A-1 x Super-1, 147C x 153 A, 132C x 153A, 140E-2 x Super-1, 132C x C_6, 140E-2 x 153A and 146B x 153A. Desirable and significant specific combining ability effect for 100 grain weight was revealed by the cross 106B x 153A followed by the crosses 106C-1 x Super-1, 151A x C_6, 150B x C_6, 146B x Super-1, 140 E-2 x Super-1 and 106B x Super-1.

The desirable and significant specific combining ability effect for the most important trait i.e. grain yield (q ha^{-1}) was revealed by the cross 139A x 153A followed by the crosses 106C-

2 x C_6, 106C-1 x Super-1, 106C-1 x 153A, 139A x C_6, 102 A-1 x Super-1, 139B x Super-1, 142A x C_6, 132 C X 153A, 140E-2 x Super-1, 141B-1 x 153A, 106C-2 x Super-1, 150 B x C_6 and 147C x Super-1.

Component analysis of the contribution from the lines, testers and lines x testers towards the total performance of the crosses for each trait (Table–7) was observed to be of the following magnitude. For maturity traits i.e. days taken to 50% anthesis, silking and husk browning the contribution of the lines was 57.42%, 68.65% and 52.10% ; from testers 2.83%, 0.24% and 2.18% ; and from lines x testers 39.75%. 31.10 and 45.70%, respectively. For plant height and ear placement the contribution from the lines was 56.35% and 35.92% ; from testers 0.60% and 3.92% ; and from lines x testers 43.05% and 60.15%, respectively.

For yield component traits viz. ear length, ear girth, number of kernel rows ear^{-1}, number of kernels row^{-1} and 100 grain weight, the contribution from the lines was 45.35%, 45.38%, 45.82%, 51.15% and 38.60% ; from testers 12.34%, 12.49%, 15.61%, 2.14% and 24.46%; and from lines x testers it was 42.31%, 42.13%, 38.57%, 46.71% and 36.94%, respectively, For the most important economic trait i.e. grain yield (q ha^{-1}) the contribution from the lines, testers and lines x testers was 48.23%, 6.52% and 45.25%, respectively.

4.3 Estimation of heterosis

The heterosis was calculated as per cent deviation of the crosses from the standard parent (check), for all the traits and the data is presented in the Table 8.

Most of the cross combinations for maturity traits viz. anthesis, silking and husk browning showed that as compared to the standard check, the crosses (F_1 hybrids) were earlier in maturity. The most significant crosses showing earliness for anthesis were 132C x C_6, 132 C x Super-1, 139 B x Super-1, 139 B x C_6, 102A-2 x Super-1, 102 A-1 x Super-1 and 106B x 153 A, revealing an earliness of 4-5 days. Similarly, for days taken to 50% silking the crosses showing earliness as compared to the standard check were 132 C x C_6, 132C x Super-1, 139 B x Super-1 and 139B x C_6, revealing an earliness of 4-5 days. For days taken to 50% husk browning the crosses showing early maturity as compared to standard check were 146B x Super-1, 146B x C_6, 102A-1 x C_6, 150B x C_6, 150B x Super-1 and 151A x 153A, with the earliness of 3-4 days.

Crosses showing desirable heterosis (shorter plants) as compared to the plant height of the standard check were 132C x C_6, 106B x 153A, 102A-2 x C_6, 102A-2 x 153A, 106B x Super-1, 106 C x Super-1, 139 B x 153 A and 132 C x Super-1 revealing a reduction of 12-20% in the plant height of the crosses as compared to the standard check. Lower ear placement as compared to the standard check revealed reduction of 20-28% in the ear placement in the crosses and the best cross combinations were 106B x 153A, 102A-1 x C_6, 141B-1 x Super-1, 102A-1 x 153A and 150B x Super-1.

The cross combinations showing significant desirable performance for yield component traits as compared to standard check were as follows:

Increase in the ear length of the crosses as compared to the standard check was found highest in the cross 102A-1 x Super-1 followed by the crosses 147C x 153A, 106B x C_6,102A-2 x Super-1, 132C x Super-1, 141B-1 x Super-1 and 142A x Super-1, revealing an increase of 23-47%. Increase in the ear girth was observed to be in the cross 102A-1 x C_6 followed by the crosses 106C-1 x Super-1, 139A x C_6, 139A x Super-1, 141B-1 x Super-1, 142A x C_6, 151A x C_6, 151A x Super-1 and 147C x 153A with an increase of 14-22% over the standard check. Increased number of kernel rows ear^{-1}, as compared to the standard check, was revealed by the cross combination 139B x C_6 and 139B x 153A followed by the crosses 102 A-1 x Super-1, 139 B x Super-1, 132 C x 153 A and 146 B x Super-1 revealing an increase of 11-18%. Number of kernels row^{-1} recorded a maximum heterosis of 12.82% in the cross 102A-1 x Super-1 followed by the crosses 147C x 153A and 147C x Super-1, showing an increase of 5-77%. 100 grain weight recorded maximum heterosis in the cross combination 102A-2 x 153A (33.33%) followed by the crosses 106B x 153A and 106C-2 x C_6 (nearly 29.2%) as compared to the standard check. The other significant crosses recording more than 15% heterosis in 100 grain weight as compared to standard check were 102A-2 x C_6, 102A-2 x Super-1, 139B x Super-1, 139B x 153A and 132C x 153A.

The heterosis for the most important trait i.e. grain yield (q ha^{-1}) was recorded by the crosses 139A x 153A (77.08%) ; 142 A x C_6 (41.67%) ; 106 C-1 x 153A (39.58%) ; 106 C-2 x C_6 (35.42%) ; 147C x 153A (35.42%) ; 139B x C_6 (25%) ; 140E-2 x Super-1 (25%) ; 140 E-2 x 153A (20.83%) ; 142A x 153A (20.83%) and 102A-1 x Super-1 (20.83%).

None of the cross combinations revealed significant and desirable sca effect for all or most of the traits. Perusal of the Table 9, where in top ranking crosses on the basis of significant and desirable sca effect and *per se* performance have been identified, revealed that for maturity traits the cross 139 A x 153 A possessed significant and desirable sca effect. On the basis of *per se* performance the cross 139 B x Super-1 revealed earliness.

For the morphological traits (plant and ear height) the cross 106 C-1 x Super-1 revealed desirable and significant sca effect, whereas, the cross 106 B x 153 A possessed good *per se* performance for both the traits.

Among the yield component traits the cross 132 C x 153 A revealed desirable and significant sca effect. On the basis of *per se* performance the cross 102 A-1 x Super-1 was good for ear length and kernel rows ear^{-1}. Among the top five crosses showing significant and desirable sca effect the cross 106 C-1 x 153 A also revealed higher *per se* performance.

Chapter-5

DISCUSSION

In order to keep pace with the population growth, adequate increase in the crop production and productivity needs to be ensured to sustain this growth and have food security in terms of both quantitative and qualitative (nutrition value) aspects. This increase in production and productivity of food crops is obtained through several research and management approaches. Primarily among these approaches is production of crop varieties that have desirable gene complexes and are suited to wide environmental conditions. Among the principle cereal crops, maize occupies most important place because of its food value and industrial uses.

Maize is a cross pollinated crop and production of high yielding varieties involves either development of superior hybrids or recurrent population improvement strategy to synthesize high yielding open pollinated varieties (composites and synthetics). Maize has remained the principle crop for research to generate information on mechanism of heterosis and exploitation of hybrid vigour. High yielding varieties in maize have been synthesized through utilization of allelic resources. However to be a successful breeder it is necessary to have a good knowledge and understanding of nature and magnitude of gene effects. One of the appropriate breeding methodologies involves generation of information on genetic variance, degree of dominance and importance of gene effects that helps in better understanding and adoption of the crop improvement procedures.

Research workers have observed that breeding lines having high combining ability were derived from the populations that had good broad genetic base and also presence of gene complexes of divergent nature. The frequency of favourable alleles was increased in the improved versions through the recurrent selection and these improved versions helped in producing some of the elite maize inbred lines that subsequently were used to develop high yielding commercial single and double cross maize hybrids. The greater importance of maintaining high level of heterozygosity at maximum number of loci that resulted in hybrid vigour was proposed by Hull (1945). He advised exploitation of specific combining ability among the inbreds for developing high yielding hybrids. Exploitation of hybrid vigour in maize has assumed tremendous significance for increasing productivity in maize hybrids and even on date vast areas under maize cultivation in the world use single cross hybrids.

In maize most extensive quantitative genetic studies have been made than in any other crop and most of these fundamental research works have been reviewed by Sprague and Eberhart (1977) and Hallauer and Marinda (1988). In most of the studies contribution from additive genetic variance has been greater than variance arising from dominance deviations. Contribution of epistasis in maize has been of minor significance.

Wide array of biometrical approaches/ mating designs are available to the maize breeders to generate information on the genetic make up of important economic traits and utilization of this information on gene action for the crop improvement. Comstock and Robinson (1948,1952) have laid emphasis to generate the information on the genetic potential of parents and analysed the genetic mechanism involving the reference populations.

The present investigation was carried out to determine the breeding value of advance generation inbred lines and estimate the nature and magnitude of genetic variance governing morphological, maturity and yield component traits. These advance generation lines (S_2) would also help in their early generation testing to identify and screen the most promising lines that could lead to the generations of elite homozygous inbred lines for production of single / double cross hybrids and high yielding synthetic for the climatic conditions of the Kashmir Valley. Line x tester mating design proposed by Kempthorne (1957) was used to generate reliable information on the general and specific combining ability effects of parents and their crosses, besides estimation of the components of genetic variance and standard heterosis for the economic traits. This design has been widely used in maize by several workers to generate information on breeding lines (Joshi *et al.*, 2002 ; Sharma *et al.*, 2004). Combining ability analysis helps to identify most potential lines for generating high yielding crosses. The gca of the parents alongwith their *per se* performance and sca of crosses together with their *per se* performance have helped in identifying the most useful lines that would, by and large, produce high yielding single/double cross hybrids.

The present investigation was undertaken to generate information on nature and magnitude of gene action, combining ability effects (general, specific), heritability and magnitude of standard heterosis for different traits among 15 S_2 lines and 45 F_1 crosses generated through line x tester mating design, as proposed by Kempthorne (1957).

5.1 Analysis of variance.

Analysis of variance revealed highly significant mean squares for all the traits among the crosses. This indicated that the lines used possessed divergent gene complexes which on hybridization with testers produced heterotic crosses. This genetic variability among the lines could be exploited through hybridization and result in creation of latent genetic variability from the heterozygous polygenic blocks in the hybrids. The mean squares due to parents v/s crosses were also significant for most of the traits which also confirmed that the lines used were genetically different from each other and possessed elite gene complexes. Similar results have been reported by Dodiya and Joshi (2002) and Choudry *et al.* (2002).

5.2 Combining ability analysis.

Analysis of variance for line effects revealed significant mean squares for all the traits except ear height. Similarly, tester effects were significant for ear length, ear girth, number of kernel rows ear^{-1} and 100 grain weight. Line x tester effect was significant for all the traits.

The variance due to lines was significant for all the traits where as for testers it was significant for grain yield, ear length and 100 grain weight. Translating this variance into variance due to gca it was observed that all the traits except days taken to 50% anthesis, ear girth and number of kernel rows ear^{-1} had significant gca variance. However, variance due to dominance deviations was significant for all the traits. The variances due to sca were higher in magnitude than their corresponding gca variances revealing greater importance of non additive gene effects in the crosses.

Aim of a plant breeder is to identify parents that would combine well and produce productive hybrids/ progenies. Combining ability helps in estimating the genetic makeup of the lines and in making prediction about the out come when crossed. This approach also helps to evaluate large number of parental lines in initial stages of selfing and predict about their performance in single/ double crosses. This in turn would save the man-power and valuable resources that would otherwise be needed in generating information by making all cross combinations. The combining ability helps in estimating the additive gene action of the parents and also non additive gene action on their crossing (Sprague and Tatum1942; Rojas and Sprague, 1952).

The significant mean squares for the lines and lines x testers indicated importance of both additive and non additive gene action in phenotypic expression of the traits. Similar findings have been reported by Zhang *et al.* (1991), Everett *et al.* (1995), Paul and Debanth (1999), Joshi *et al.* (2002) and Sharma *et al.* (2004).

Significant and desirable general combining ability for early maturity traits was revealed by the lines 132C, 139B and 102 A-2 for days taken to 50% anthesis ; 132C, 139B and 106 C-1 for days taken to 50% silking; and for days taken to 50% husk browning the desirable parents were 146 B, 106B and 142 A. Perusal of the results revealed that the lines 132C and 139B possessed earliness for both anthesis and silking.

For morphological traits the significant and desirable combiners for plant height (medium to short plant height) were 132 C, 106B and 102 A-2 and for lower ear placement height the desirable parents were 132C, 106B and 102A-2. Thus, for both plant height and ear placement the elite lines were 132C and 106B. The line 132C seems to be a good combiner for the maturity and desirable morphological traits as well. Among the yield and yield component traits the desirable and significant general combiners for ear length were 147C, 102A-1 and 132 C; for ear girth the lines were 106 C-1, 102A-1 and 139 A; for number of kernel rows ear^{-1} the lines were 139B and 146B; for number of kernels row^{-1} the lines were 139A, 102A-1 and 147C ; and for 100 grain weight the prominent lines were 106C-2, 102A-2 and 139 B. Overall perusal for yield component traits revealed that the lines 102A-1 possessed good combining ability for these two yield component traits.

Grain yield in maize is the most important economic trait. Lines possessing significant and desirable combining ability for grain yield improvement were identified in 139A, 139B, 151A, 142A, 146C and 140 E-2.

Analysis of the specific combining ability among crosses for different maturity traits revealed that the crosses 106 B x Super-1 and 139 A x 153 A had significant and desirable sca effect for days taken to 50% anthesis, silking the significant and desirable cross on the basis of sca was 139 A x 153 A for days taken to 50% silking and the desirable and significant crosses for 50% husk browning were 102 A-2 x 153 A, 106 C-1 x C_6 and 132 C x C_6.

For morphological traits viz. medium plant height and lower ear placement, height the crosses showing significant and desirable sca effects included106 C-1 x Super I, 139 B x 153 A and 141B-1 x Super I for plant height and 102 A-1 x C_6, 141B-1 x Super I and 106 C-1 x Super I for ear height.

Crosses showing significant and desirable sca effects for yield component traits were 106 B x C_6, 147 C x 153 A and 141B -1 x Super I for ear length; 132C x 153 A and 102 A-1 x C_6; for ear girth ; 102 A-1 x Super I, 132C x 153 A and 146 B x Super I for number of kernel row ear^{-1} ; 139 B x super I, 141 B-1 x C_6, 141B-1 x Super I for kernels row^{-1} and 106 B x 153 A , 106 C-1 x Super I and 151 A x C_6 for 100 grain weight.

For grain yield the crosses showing significant and desirable sca effect were 139 A x 153 A, 106C-2 x C_6, 106C-1x Super I, 106 C-1 x 153 A, 139 A x C_6, 102A-1 x Super I and 139 B x Super I.

Component analysis of the contribution towards the performance of crosses was maximum from the lines and the lines x testers, and the contribution from the lines was to the extent of 57.4, 68.6 and 52.1 per cent and from lines x testers to the extent of 39.7, 31.1 and 45.7 per cent for days taken to anthesis, silking and husk browning, respectively. Similarly for plant height and ear placement the contribution from the lines was 56.35 and 35.9

per cent and from the lines x testers it was 43.1 and 60.1 per cent, respectively. For yield component traits the contribution form the lines was 45.4, 45.4. 45.8, 51.2 and 38.6 per cent and from the lines x testers it was 42.3, 42.1, 38.6, 46.7 and 36.9 per cent for ear length, ear girth, number of kernel rows ear^{-1}, number of kernels row^{-1} and 100 grain weight, respectively. For grain yield the contribution for the performance of the crosses came mainly from the lines (48.1%) and from lines x testers (45.3%). The contribution from the testers was maximum for all the traits and it ranged from 0.24 to 24.46 per cent.

Both general and specific combining ability effects have a significant impact on inbred line evaluation and population improvement in maize breeding. Hays (1963), Dass *et al.* (1997) and Paul and Debanth (1999) observed significant sca for most of the traits particularly ear length and grain yield. Similar results have been reported by Desai and Singh (2001). Srivasthava and Singh (2003) reported significant positive sca effects for plant and ear height in maize. Choudhary *et al.* (2000) also observed significant positive sca effect for ear length and ear diameter.

Identification of best combiner lines on the basis of gca and *per se* performance, and screening of promising crosses on the basis of sca, and their *per se* performance for different maturity, morphological, yield component and grain yield traits (Table-8) revealed that for days taken to 50% anthesis and silking the line 139 B had both significant gca and high *per se* performance and similarly, for days taken to 50% husk browning the line 106 B possessed significant gca and high *per se* performance.

For morphological traits (plant and ear height) the line 106B possessed significant gca and high *per se* performance for plant height, where-as for ear height none of the top lines on the basis of gca had comparatively high *per se* performance.

Among the yield component traits the line 147 C had significant gca and *per se* performance for ear length and number of kernel rows ear^{-1}. The line 139B and 146 B revealed significant gca and high *per se* performance for kernel rows ear^{-1}. Similarly for number of kernels row^{-1} the lines 139 A and 147 C possessed significant gca and high *per se* performance. For grain yield (q ha^{-1}) none of the top five lines showing significant and desirable gca effect were among the top lines on the basis of their *per se* performance.

Similarly none of the crosses showing significant and desirable sca effect had high *per se* performance for days taken to 50% anthesis, silking and husk browning. For plant height none of the cross combinations had both significant and high sca effect and also high *per se* performance. For ear height however, the cross 102A-1 x C_6 revealed both significant sca and high *per se* performance.

Among the yield component traits, the crosses 147 C x 153A and 141B-1 x Super I revealed significant and desirable sca together with high *per se performance* for the ear length and for ear diameter the cross showing both significant and desirable sca and high *per se* performance was 102A-1 x C_6. None of the top three crosses showing significant and desirable sca effects had high *per se* performance for number of kernels row^{-1}. However, for kernel rows ear^{-1} the cross 102 A-1 x Super-1 revealed both significant sca and *per se* performance. For 100 grain weight the cross 106 B x 153 A revealed both significant sca and high *per se* performance.

For grain yield (q ha^{-1}) none of the top 5 crosses showing desirable and significant sca effects were having high *per se* performance except the crosses 106 C -1 x 153 A and 106 C -2 x C_6.

In the study it was observed that the crosses showing significant and desirable sca were the result of the cross between high x low or average x low combiners. This indicated that the high performing crosses resulted from the accumulation of genes form diverse parents. Dass *et al.* (1997) reported that crosses showing significant specific combining ability (sca) effects did not have high *per se* performance. However, Choudhary *et al.* (2000) observed that crosses showing significant and desirable sca effects also revealed high *per se* performance for grain yield, which has also been observed in the present study in some top raking crosses Dass *et al.* (1996) showed that a good cross combination showing high sca and /or *per se* performance resulted from high x high general combiner. Crosses showing involvement of at least one good combiner with good *per se* performance for grain yield would result in the recovery of some transgrassive segregants and good performing inbred lines. Superior crosses involving high x low or average x low combiners as parents are probably the result from the alleles accumulating at loci from two different parents showing higher contrast, which results into desirable level of heterozygosity and over dominance. Dubey (1975) confirmed that positive alleles from good/average combiners and negative alleles from poor combiners on crossing may pledge to a higher level of heterozygosity in the crosses. Such crosses are expected to perform better for exploitation of heterosis and not for generation of high yielding segregants because of preponderance of non-additive gene action. Rehman *et al.* (1981) suggested that superior crosses involving low x low general combiners are the result of over dominance and epistasis.

In the present study some of the crosses revealed better performance for a number of traits. In order to broaden the genetic base in the parent materials and expect high performing segregants, it is advisable to have multiple crossing of the parents showing high performing F_1 crosses on the basis of sca and *per se* performance. This would result in creation of latent-genetic variability from polygenic heterozygous blocks during crossing over and bring together additive genes through recurrent selection. For such a situation selective intermating has been proposed to slow down the rate of inbreeding and enhance chances of recovery of more useful gene constellations in the homozygous condition.

5.3 Estimation of genetic components of variance and heritability

For all breeding studies it is important to characterize nature and magnitude of gene action governing inheritance of yield and other related traits. For this purpose proper mating designs are needed to estimate the gene effect. In the present study the variance components for gca and sca derived from line x tester mating design, were significant for most of the traits with higher magnitude of $\hat{\sigma}^2_{sca}$ as compared to $\hat{\sigma}^2_{gca}$ for all traits. Translating the variances of gca and sca into additive genetic variance ($\hat{\sigma}^2_A$) and variance due to dominance deviations ($\hat{\sigma}^2_D$) it was observed that the later component was predominant for controlling the inheritance of the traits. Estimation of the average degree of dominance revealed that the expression in the overdominance range for all the traits (1.74-3.86). Greater importance of non-additive gene action for maturity, plant height and some of the yield component traits have been reported by Souze and De (1981) ; Gupta *et al*. (1994); Nagda *et al*. (1994) and Spaner *et al*. (1996) for days to silk ; Sinha and Mishra (1997) for grain weight and Matu and Ganguly (2001) for kernels row^{-1} Desai and Singh (2001) observed importance of both additive and non-additive gene effects for most of the traits. Greater importance of non-additive gene effects for yield components and grain yield in maize has been reported by Odongo (1983), Cross *et al*. (1996), Sharma *et al*. (1996), Jhau and Kherra (1997), Zellke (2000) and Srivastava and Singh (2003). However, importance of both additive and non-additive components of genetic variance for grain yield have been reported by Khamis (1983), Gupta *et al*. (1994), Choukan (1999) and Desai and Singh (2001).

Narrow sense heritability provides a measure of the breeding value heritability i.e. fixable component of genetic variance. However, the estimation of heritability is sometimes baised due to interaction resulting from genes showing pseudo-epistasis and overdominance resulting form linkage bias (Comstock and Robinson, 1952). The heritability resulting from high additive genetic variance is expected to result in high genetic gain through recurrent selection. In the present study the heritability (n.s) estimate were low (6.05 – 25.93%) revealing that the genes in the lines were acting in positive and negative directions and on combination at a particular loci might have resulted in higher heterozygosity and over-dominance, giving preponderance of non-additive gene action. Lower estimates of narrow sense heritability have been reported by Vaezi *et al*. (1999) and Viola *et al*. (2003) for yield component traits. Lower estimates of narrow sense heritability for maturity traits have also been reported by Kumar *et al*. (2000). Hallauer and Miranda (1988) reported average narrow sense heritability estimates of 18.7% for grain yield which was based on the results of 39 experiments conducted by different research workers.

5.4 Estimation of heterosis (%)

Exploitation of heterosis in maize could be achieved through identification of homozygous lines possessing significant gca and high *per se* performance and such of the lines on crossing should result in the production of hybrids showing significant sca and high *per se* performance. In the present study the standard heterosis was worked out for all the traits and the heterosis of a cross was measured as per cent deviation from the performance of the standard check (C_6) for each trait. For maturity traits the significant crosses showing earliness for anthesis were 132C x C_6, 132C x Super-1 and 139B x Super-1 with an earliness of 4-5 days. Similarly, for silking the top three crosses were 132C x C_6, 132C x Super-1 and 139B x Super-1 with an earliness of 4-5 days. For husk browning the crosses showing significant standard heterosis were 146B x Super-1, 146B x C_6 and 102A-1 x C_6 with an overall earliness of 3-4 days.

For morphological traits the crosses 132C x C_6, 106B x 153A and 102A-2 x C_6 showed a reduction of nearly 15-20% in plant height. Similarly for ear height the heterotic crosses were 106B x 153A, 102A-1 x C_6 and 141B-1 x Super-1 revealing nearly 25-28% reduction in ear height placement.

For yield component traits the crosses showing heterosis for increase in ear length were 102A x super-1, 147C x 153A and

106B x C_6 with an increase of nearly 35-47%. Heterosis for ear girth was observed in the crosses 102A-1 x C_6, 106C-1 x Subject-1 and 139A x C_6 with an increase of 20 -22%. Heterosis for kernel rows ear^{-1}` was observed in the crosses 139B x C_6, 139B x 153A and 102A-1 x super-1 showing an increase of 11-18%. Kernels row^{-1} revealed an increase of 5-12.8% heterosis in the crosses 102A-1 x Super-1, 147C x 153A and 147C x Super-1. Similarly, for 100 grain weight the maximum heterosis of 33.3% was observed in the cross 102A-2 x 153A followed by 106B x 153A and 106C-2 x C_6, both having an increase of nearly 29%.

The heterosis for the most important economic trait i.e grain yield (q ha^{-1}) was recorded to the extent of 77% in the cross 139A x 153A followed by the crosses 142A x C_6 (41.67%), 106C-1 x 153A (39.58%), 106C-2 x C_6 (35-42%) and 147C x 153A (35-42%).

Desirable negative heterosis for flowering traits have been reported by Srivastava and Singh (2002). Significant heterosis for 100 grain weight has been reported by Srivastava and Singh (2003); for ear length by Dikert and Tracy (2002) and for kernels row^{-1}by Choudhery *et al.* (2002). For grain yield the higher heterosis was observed to result from the crossing of the parents showing diversity for grain yield, the fact also confirmed by Han *et al.* (1991) and Mukherjee and Ahuja (1991).

Chapter-6

SUMMARY AND CONCLUSION

The present investigation entitled “Combining ability analysis for yield and maturity traits in elite inbred lines of maize” was carried out to generate information regarding combining ability and gene action in respect of maturity, morphological and yield component traits together with the overall production potential (grain yield) of some promising S_2 lines of maize and their crosses. The information on combining ability and gene action was generated through the line x tester mating design proposed by Kempthorne (1957).

Fifteen S_2 diverse maize lines were crossed to three testers (2 broad genetic base composites and one inbred line). The 45 progenies along with 18 parents (15 lines + 3 testers) were evaluated in randomized block design during the *Kharif* season of 2005 at K.D. Research Station, SKUAST-K, Budgam, Kashmir. Data on ten competitive plants was recorded for all the traits except maturity traits where data on the whole plot basis were recorded. The mean/median values were subjected to the appropriate statistical analysis to obtain the estimates of combining ability, gene action, heritability and standard heterosis. The salient findings are briefly presented as under :

1) Analysis of variance revealed significant difference among crosses and female parental lines (S_2 lines) except ear height in case of S_2 line. Testers evaluated had significant difference for ear length, ear girth, kernel rows ear^{-1} and 100 grain weight.
2) Estimation of components of variance revealed significant difference for all the traits arising due to lines, however, variance due to testers was significant only for ear length and grain yield (q ha^{-1}).
3) The variance due to gca was significant for all the traits except days taken to 50% anthesis, ear girth and number of

kernels row^{-1} whereas, due to sca it was significant for all the traits.

4) The additive genetic variance was lower in magnitude than the variance due to dominance deviation and the average degree of dominance was in the overdominancne range for all the traits raging from 1.74 (kernel rows ear^{-1}) to 3.86 (ear height).
5) Narrow sense heritability (measuring breeding value heritability) was low for all the crosses and ranged from 6.04 (ear height) to 25.93 per cent (100 grain weight), indicating that crosses had accumulation of divergent genes at most of the loci for each trait.
6) Significant and desirable general combining ability effects for maturity traits was observed in the S_2 lines viz 132C and 139B (anthesis and silking) ; and 146B and 106B (husk browning). Significant and desirable gca effect for shorter to medium plant height and lower ear placement was observed in 132C and 106B. For yield and yield contributing traits significant and desirable gca effect was observed in 147C and 102A-1 (ear length) ; 106C-1 and 102 A-1 (ear girth) ; 139 B and 146B (kernel rows ear^{-1}) ; 139A and 102A-1 (kernels rows^{-1}) and 106C-2 and 102 A-2 (100 grain weight). Desirable and significant gca effect for grain yield (q ha^{-1}) was revealed by the lines 139A, 151A, 142A and 147C.

7) Significant and desirable sca effect for different traits was observed in different crosses and these included 106B x Super-1 and 139A x 153A (anthesis); 139A x 153A and 140 E-1 x 153A (Silking) ; 102A-1x 153A and 106C-1 x C_6 (husk browning) ; 106 C-1 x Super-1 and 139 B x 153 A (Shorter plant height) ; 102A-1 x C_6 and 141 B-1 x Super-1 (lower ear placement) ; 106 B x C_6 and 147C x 153A (ear length) ; 132 C x 153A and 102 A-1 x C_6 (ear girth) ; 102 A-1 x Super-1 and 132C x 153 A (kernel rows ear^{-1}) ; 139 B x Super-1 and 141 B-1 x C_6 (kernels row^{-1}) 106 B x 153 A and 106 C-1 x Super-1 (100 grain weight) ; and 139 A x 153A, 106C-2 x C_6, 106C-1 x Super-1, 106 C-1 x 153A and 139A x C_6 (grain yield q ha^{-1}). The hybrids however, showed inconsistent correspondence with mean *per se* performance.

8) Component analysis of the contribution towards the performance of crosses revealed that the lines contributed to the extent of 57.40, 68.65, 52.10, 56.35, 35.92, 45.35, 45.36, 45.80, 51.15, 38.60 and 48.12 per cent and lines x testers to the extent of 39.75, 31.10, 45.70, 43.05, 60.15, 42.31, 42.13, 38.57, 46.71, 36.39 and 45.25 per cent for the traits viz. days taken to 50% anthesis, days taken to 50% silking, days taken to 50% husk browning, plant height, ear height, ear length, ear girth, kernel rows ear^{-1}, kernels row^{-1}, 100 grain weight and grain yield (q ha^{-1}), respectively.

The contribution from testers was very low ranging from 0.24-24.46 per cent.

9) Significant and maximum standard heterosis as compared to the standard check (C_6) was revealed by the crosses 132C x C_6 (early anthesis) ; 132C x C_6 (early silking) ; 146B x Super-1 (early husk browning), 132C x C_6 (Shorter plant height) ; 106B x 153A (lower ear placement) ; 102 A-1 x Super-1 (ear length) ; 102 A01 x C_6 (ear girth) ; 139B x C_6 (kernel rows ear^{-1}) ; 102A-1 x Super-1 (Kernels rows^{-1}) and 102A-2 x 153A (100 grain weight). For grain yield (q ha^{-1}) the crosses 139 A x 153A, 142A x C_6 and 106 C-1 x 153A revealed the heterosis to the extent of 77.08, 39.58 and 35.42%, respectively.

Conclusions

i) All the lines (S_2 lines) on crossing with testers revealed greater importance of non-additive gene action with high overdomiannce. These lines would be desirable for producing highly productive F_1 single and double cross hybrids.

ii) The promising crosses were the result of high x low or high x medium general combiners revealing that the S_2 lines were having divergent gene complexes for all the traits and under heterozygous conditions resulted in high heterosis due to accumulation of divergent gene complexes at different loci,

iii) Lines showing significant and desirable gca together with higher *per se* performance for economic traits need to be involved in multiple crossing to generate productive synthetic varieties and isolation of promising and elite inbred lines and,

iv) Lines showing cross combinations with significant and desirable sca together with *per se* performance for yield and yield component traits need to be used for developing F_1 hybrids for multi-location testing and release of promising ones for commercial cultivation in Kashmir region.

Table 1: Analysis of variance for maturity, yield and yield contributing traits in maize (*Zea mays* L.)

Source of variation	d.f	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})	Protein content (%)
Replication	2	5.874**	6.466**	13.340**	183.385**	629.429**	1.066	0.496	1.207	1.451	13.540**	8.022	0.729**
Crosses	44	2.928**	2.900**	8.605**	740.800**	429.562**	12.190**	4.206**	5.628**	42.438**	43.037**	371.130**	0.602**
Line effect	14	5.283**	6.257**	14.093*	1312.118*	484.959	17.377*	5.997*	8.102*	68.235*	52.213*	562.457*	0.922**
Tester effect	2	1.829	0.155	4.140	96.007	370.585	33.066*	11.562*	19.340*	19.874	231.607**	532.466	6.778**
Line x Tester effect	28	1.829**	1.417**	6.180**	501.197**	406.077**	8.106**	2.785**	3.412**	31.151**	24.980**	263.942**	0.001
Error	88	0.608	0.413	0.181	10.332	12.376	1.172	0.958	0.957	2.254	1.555	13.135	0.058
Total	134	1.449	1.320	3.144	252.770	157.572	4.789	2.018	2.494	15.437	15.355	130.609	0.246

*,** significant at 5 and 1 per cent levels, respectively

Table 2: Estimates of combining ability variance, degree of dominance and heritability for maturity, yield and yield contributing traits in maize (*Zea mays* L.)

Source of variation	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
$\hat{\sigma}^2_{Line}$	0.519** (±0.144)	0.649** (±0.245)	1.545* (±0.552)	144.642** (±51.544)	52.509* (±19.031)	1.800* (±0.712)	0.559* (±0.235)	0.793* (±0.318)	7.331* (±2.675)	5.628* (±2.047)	61.035* (±22.055)
$\hat{\sigma}^2_{Tester}$	0.027 (±0.039)	-0.005 (±0.002)	0.088 (±0.062)	1.903 (±1.508)	7.960 (±5.823)	0.708* (±1.636)	0.235 (±0.214)	0.408 (±0.303)	0.391 (±0.312)	5.112* (±3.638)	11.540** (±3.054)
$\hat{\sigma}^2_{gca}$	0.109 (±0.060)	0.103* (±0.039)	0.330* (±0.159)	25.693* (±12.289)	15.385* (±7.466)	0.890** (±0.440)	0.289* (±0.153)	0.472* (±0.239)	1.548* (±0.768)	5.198* (±2.477)	19.789* (±9.555)
$\hat{\sigma}^2_{sca}$	0.406** (±0.160)	0.334** (±0.123)	1.999* (±0.531)	163.621* (±43.137)	131.233** (±234.954)	2.311** (±0.700)	0.608** (±0.244)	0.818** (±0.297)	9.632** (±2.683)	7.808** (±2.151)	83.602** (±22.719)
$\hat{\sigma}^2_{e}$	0.203	0.137	0.060	3.444	4.125	0.390	0.319	0.319	0.751	0.518	4.378
$\hat{\sigma}^2_{A}$ (F = 0.75)	0.047 (±0.120)	0.045 (±0.078)	0.144 (±0.318)	11.240 (±24.578)	6.730 (±14.932)	0.389 (±0.880)	0.126 (± 0.306)	0.206 (±0.478)	0.677 (±1.536)	2.274 (±4.954)	8.658 (±19.110)
$\hat{\sigma}^2_{D}$ (F=0.75)	0.311 (±0.330)	0.253 (±0.246)	1.530 (±1.062)	125.268 (±86.274)	100.472 (±47.908)	1.769 (±1.400)	0.466 (±0.488)	0.626 (±0.594)	7.374 (±5.366)	5.977 (±4.302)	64.005 (±45.438)
Degree of dominance	2.555	2.369	3.252	3.338	3.863	2.131	1.918	1.740	3.299	2.628	2.718
$\hat{\sigma}^2_{P}$	0.562	0.436	1.736	139.953	111.328	2.549	0.912	1.152	8.803	8.770	77.042
Heritabiilty (N.S) %	8.484	10.590	8.335	8.031	6.045	18.281	13.887	17.946	7.693	25.929	11.237

*,** significant at 5 and 1 per cent levels, respectively

Table 3: Estimates of general combining ability effects for maturity, yield and yield contributing traits in maize (*Zea mays* L.)

Parent lines (S_2 lines used as females)		Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
102 A-1	L_1	-0.504	0.200	-0.719**	0.970	-5.341**	2.178**	1.096**	0.193	2.615**	-2.526**	-0.156
102 A-2	L_2	-0.948**	0.422	0.615**	-16.363**	-6.007**	-0.156	0.430	-0.130	1.504**	4.030**	-12.378**
106 B	L_3	-0.059	1.533**	-1.163**	-16.474**	-8.785**	0.178	-1.459**	-0.807 *	1.281*	-1.193*	-10.378**
106 C-1	L_4	-0.504	-0.800**	2.948**	2.081	6.659**	0.178	1.430**	-1.474**	-0.941	-3.415**	0.178
106 C-2	L_5	0.052	-0.244	-0.385*	6.304**	9.659**	-3.489**	-0.570	0.193	-1.607**	4.141**	-0.489
132 C	L_6	-1.393**	-1.689**	0.615**	-19.141**	-9.230**	1.178**	-0.570	0.193	-0.385	0.585	-14.489**
139 A	L_7	0.274	-0.022	2.170**	4.193**	7.770**	0.511	0.874*	-0.474	2.948**	-2.526**	14.178**
139 B	L_8	-1.281**	-1.578**	-0.496**	-0.030	-4.007**	-1.267**	-0.570	2.526**	-5.052**	2.807**	2.178
140 E-2	L_9	0.719*	0.422	-0.163	1.748	-1.119	-0.378	-0.237	-0.141	1.615**	1.141*	3.844**
141 B-1	L_{10}	0.496	0.200	-0.941**	0.748	-2.007	-0.489	-0237	-0.807*	-1.052*	-1.193*	0.289
142 A	L_{11}	1.052**	0.756**	-1.052**	-8.807**	-5.230**	0.844*	0.096	-0.141	2.281**	1.252**	6.511**
146 B	L_{12}	0.719*	0.422	-1.274**	2.5256*	1.993	-0.822*	-0.904*	1.193**	-0.385	-2.748**	-3.489*
147 C	L_{13}	0.607*	0.311	1.059**	15.859**	2.326	2.178**	0.763*	-0.141	2.615**	0.141	5.511**
150 B	L_{14}	0.607*	0.200	-0.607**	-0.696	-2.896*	-0.489	-0.571	0.526	0.948	0.696	-1.156
151 A	L_{15}	0.163	-0.133	-0.607**	27.081**	16.215**	-0.156	0.430	-0.807*	-6.385**	-1.193*	9.844**
Standard error												
gca (Line)	±	0.260	0.214	0.142	1.071	1.172	0.361	0.326	0.326	0.500	0.415	1.208
gi - gj (Line)	±	0.367	0.303	0.200	1.515	1.658	0.510	0.461	0.461	0.707	0.588	1.708

*,** significant at 5 and 1 per cent levels, respectively

Table 5: Estimates of specific combining ability effects for maturity, yield and yield contributing traits in maize (*Zea mays* L.)

Crosses	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_1 x T_1	0.593	-0.533	-0.393	-11.948**	-15.681**	-1.044	1.215*	0.007	0.207	0.074	3.756
L_1 x T_2	-0.674	0.156	-0.281	124.141**	22.252**	2.356**	-0.430	2.319**	3.741**	0.341	10.556**
L_1 x T_3	0.081	0.378	0.674*	-12.193**	-6.570**	-1.311*	-0.758	-2.326**	-3.948**	-0.415	-14.311**
L_2 x T_1	0.370	-0.089	1.607**	-3.615	-1.681	0.289	-0.119	-0.770	0.319	-0.630	-3.022
L_2 x T_2	-0.230	-0.067	0.719*	5.474**	6.919**	1.689*	0.237	-0.126	-0.148	0.770	-1.778
L_2 x T_3	-0.141	0.156	-2.326**	-1.859	-5.237*	-1.978*	-0.119	0.896	-0.170	-0.141	-1.224
L_3 x T_1	1.148*	0.133	0.052	10.163**	9.430**	2.956**	1.104	1.007	-0.459	-2.407*	-1.022
L_3 x T_2	-1.119*	0.156	0.496*	-3.415	3.363	-3.644**	0.126	0.319	0.074	1.674*	1.222
L_3 x T_3	-0.030	-0.589	-0.548*	-6.748**	-12.793**	0.689	-1.230*	1.326*	0.385	4.081**	2.244
L_4 x T_1	0.593	0.800*	-1.726**	10.941**	14.319**	-0.044	0.881	-0.326	-0.237	0.815	-0.422
L_4 x T_2	-0.007	-0.178	0.719*	-21.637**	-13.081**	0.356	0.237	0.985	1.296	3.452**	12.778**
L_4 x T_3	-0.585	-0.622	1.007**	10.696**	-1.237	-0.311	-1.119	0.659	1.059	2.637**	12.356**
L_5 x T_1	0.370	0.578	1.941**	2.385	4.985*	1.622	0.881	0.007	0.430	2.259**	14.089**
L_5 x T_2	-0.230	-0.400	-0.948**	-0.859	1.252	1.022	0.237	-0.681	-0.704	-3.007*	-7.111**
L_5 x T_3	-0.141	-0.178	-0.993**	-1.526	-6.237**	-2.644**	-1.119	0.674	0.274	0.748	6.978**

Continued…..

Table : 5

Crosses	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_6 x T_1	-0.852	-0.644	-1.393**	-12.504**	1.207	-0.044	-1.119	0.007	2.207*	0.815**	1.911
L_6 x T_2	-0.452	-0.622	1.719**	1.252	0.474	0.356	-0.763	-1.681*	-0.741	-0.119	-8.111**
L_6 x T_3	1.304*	1.267*	-0.326	11.252**	-1.681	-0.311	1.881*	1.674*	2.948**	0.696**	10.022**
L_7 x T_1	0.481	0.689	-0.948**	9.496**	10.207**	0.622	0.437	0.674	0.126	0.074	10.578**
L_7 x T_2	0.548	0.378	-0.170	3.919	2.141	-0.978	-0.207	-0.015	-0.593	-0.341**	-5.778*
L_7 x T_3	-1.030*	-1.067*	1.119**	-13.415**	-12.348**	0.356	-0.230	0.659	0.719	0.415**	16.355**
L_8 x T_1	-0.630	-0.422	1.385**	-0.615	-6.348**	-0.600	-1.119	-0.326	-0.459	-0.407**	-1.422
L_8 x T_2	-0.563	-0.733	-0.837**	20.474**	16.252**	0.467	0.237	0.015	6.259**	3.326**	10.222**
L_8 x T_3	1.193*	1.156**	-0.548*	-19.859**	-9.904**	0.133	0.881	0.341	-6.719**	-2.919**	-11.644**
L_9 x T_1	0.704	0.911*	0.385	-3.726*	-0.237	-0.489	-0.452	-0.659	-0.207	-0.741**	-8.244**
L_9 x T_2	0.104	-0.067	0.496*	-1.637	-5.970**	-0.756	-0.096	-0.348	2.259*	1.993**	8.556**
L_9 x T_3	-0.807	-0.844*	0.881**	5.363**	6.207**	1.244	0.548	1.007	2.052*	1.252**	0.311
L_{10} x T_1	-0.741	-0.533	0.163	5.941**	0.985	-2.378**	-1.452*	0.007	6.126**	1.407**	3.311
L_{10} x T_2	0.659	0.489	-0.059	-16.637**	-15.415**	2.022**	0.904	0.681	4.407**	2.326**	5.111*
L_{10} x T_3	0.081	0.044	-0.104	10.696**	14.430**	0.356	0.548	0.674	1.719	0.919**	8.422**
L_{11} x T_1	-0.630	-0.422	-0.059	6.163**	0.541	0.289	0.215	0.341	0.541	5.481**	10.089**

L_{11} x T_2	0.104	-0.067	0.052	-6.081**	-9.526**	-0.311	-0.430	-0.348	0.074	-0.911**	-7.111**
L_{11} x T_3	0.526	0.489	0.007	-0.081	8.985**	0.022	0.215	0.007	-0.615	5.363**	-2.978

Continued…..

Table : 5

Crosses		Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_{12} x T_1		0.370	0.578	-1.504**	4.830*	2.652	0.044	0.215	-0.993	-3.207**	2.148**	-7.911**
L_{12} x T_2		0.437	0.267	-2.059**	0.919	0.919	-0.644	0.570	1.319*	-1.259	2.119**	2.889
L_{12} x T_3		-0.807	-0.844*	3.563**	-5.748**	-3.570	0.689	-0.785	0.326	1.948*	0.030	5.022**
L_{13} x T_1		-0.852	-0.644	1.163**	-12.170**	-8.681**	-1.044	0.548	0.341	-3.793**	-4.741**	-1.911
L_{13} x T_2		0.548	0.378	-0.393	5.252*	-0.748	-1.644*	-1.096	0.348	0.741	1.993**	3.111
L_{13} x T_3		0.304	0.267	-0.770**	6.919**	9.430**	2.689**	0.548	0.007	3.052**	2.748**	5.022*
L_{14} x T_1		-0.852	-0.533	-0.504**	8.719**	3.207	-0.378	-1.119	0.674	1.126	2.370**	5.756*
L_{14} x T_2		0.548	0.156	-0.726**	-15.526**	-14.193**	0.022	0.237	-0.015	1.407	0.437**	1.556
L_{14} x T_3		0.304	0.378	1.230**	6.807**	10.985**	0.356	0.881	-0.659	-2.281	-2.807**	-7.311**
L_{15} x T_1		-0.074	0.133	-0.170	-14.059**	-14.904**	0.289	-0.119	0.007	-5.207**	3.407**	-4.244*
L_{15} x T_2		0.326	0.156	1.274**	4.363*	5.363*	-0.311	0.237	-0.681	1.259	0.326*	-0.311
L_{15} x T_3		-0.252	-0.289	-1.104**	9.696**	9.541**	0.022	-0.119	0.674	3.948**	3.081**	4.556*
Standard error												
Sca (S_{ij})	±	0.450	0.371	0.246	1.855	2.031	0.625	0.565	0.564	0.867	0.139	2.092
S_{ij} - S_{kjl}	±	0.637	0.525	0.348	2.624	2.872	0.884	0.799	0.798	1.226	0.197	2.959
S_{ij} - S_{ik}	±	1.471	1.212	0.803	6.061	6.633	2.042	1.846	1.845	2.831	0.445	6.834

*,** significant at 5 and 1 per cent levels, respectively

Where,

L_1 = 102A-1 L_2 = 102A-2 L_3 = 106 B L_4 = 106 C-1 L_5 = 106 C-2 L_6 = 132 C L_7 = 139 B L_8 = 139 B L_9 = 140 E-2
L_{10} = 141 B-1 L_{11} = 142 A L_{12} = 146 B L_{13} = 147 C L_{14} = 150 B L_{15} = 151 A

T_1 = C_6 (Broad genetic base) T_2 = Super-1 (Broad genetic base) T_3 = 153 A (inbred)

Table 8 : Estimates of standard heterosis(%) for maturity, yield and yield contributing traits in maize (*Zea mays* L.).

Crosses	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_1 x T_1	-2.255	-2.546	-3.218	-10.248	-27.500	17.647	22.222	4.653	2.564	-8.333	14.583
L_1 x T_2	-4.135	-1.818	-2.970	9.090	8.333	47.058	11.111	11.630	12.820	-12.500	20.833
L_1 x T_3	-3.007	-1.455	-1.980	-9.752	-20.000	17.647	5.555	-16.277	-10.256	8.333	-16.666
L_2 x T_1	-3.007	-1.818	-0.742	-14.710	-16.110	11.764	11.111	-2.323	0.000	16.666	-25.000
L_2 x T_2	-4.135	-1.818	-1.237	-8.760	-5.000	29.411	11.111	-9.300	0.000	16.666	-22.916
L_2 x T_3	-3.760	1.455	-3.218	-13.223	-19.444	0.000	5.555	4.653	-5.128	33.333	-10.416
L_3 x T_1	-1.127	-0.364	-3.218	-7.933	-9.166	29.411	5.555	4.653	-2.564	-12.500	-16.666
L_3 x T_2	-4.135	-0.364	-2.723	-13.223	-10.277	0.000	0.000	-9.300	0.000	-12.500	-25.000
L_3 x T_3	-2.632	-0.727	-3.218	-15.702	-28.055	17.647	-11.111	-16.277	-2.564	29.166	-4.166
L_4 x T_1	-2.255	-2.181	-1.485	1.652	7.777	11.764	22.222	-9.300	-7.692	-8.333	8.333
L_4 x T_2	-3.383	-3.272	0.494	-13.058	-11.110	23.529	16.666	-9.300	-2.564	-29.166	-27.083
L_4 x T_3	-3.760	-3.637	0.989	2.148	-5.555	11.764	5.555	-16.277	-12.820	12.500	39.583
L_5 x T_1	-1.880	-1.818	-1.237	-0.495	2.500	0.000	11.111	4.653	-7.692	29.166	35.416

L_5 x T_2	-3.007	-2.909	-3.218	-0.661	3.333	5.882	5.555	-9.300	-10.256	4.166	-16.666
L_5 x T_3	-2.632	-2.546	-2.970	**-1.818**	-7.222	-23.529	-5.555	4.653	-10.256	4.166	-2.083

Continued…..

Table : 8

Crosses	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_6 x T_1	-4.887	-4.727	-2.970	-20.496	-16.389	17.647	0.000	4.653	0.000	8.333	-27.083
L_6 x T_2	-4.887	-4.727	-0.495	-12.231	-13.055	29.411	0.000	-16.277	-2.564	0.000	-47.916
L_6 x T_3	-2.632	-2.546	-1.733	-8.099	-19.166	17.647	11.111	11.630	-15.384	16.666	11.166
L_7 x T_1	-1.504	-1.455	-1.485	1.983	5.277	17.647	21.428	4.653	2.564	-8.333	14.583
L_7 x T_2	-1.880	-1.818	-0.742	0.660	2.500	17.647	14.285	-9.300	2.564	-12.500	16.666
L_7 x T_3	-3.383	-3.272	0.494	-8.760	-13.889	17.647	7.142	-9.300	2.564	8.333	77.083
L_8 x T_1	-4.511	-4.363	-1.733	-5.124	-18.333	0.000	0.000	18.607	-18.802	12.500	14.583
L_8 x T_2	-4.887	-4.727	-3.218	6.776	4.166	15.688	7.142	11.630	-32.479	25.000	25.000
L_8 x T_3	-2.632	-2.546	-2.723	-14.049	-21.666	5.882	7.142	18.607	-2.564	16.666	-6.250
L_9 x T_1	-0.751	-0.729	-2.227	-5.785	-10.833	5.882	7.142	-2.323	0.000	4.166	-2.083
L_9 x T_2	-1.880	-1.818	-1.980	-3.305	-11.666	11.764	7.142	-9.300	-5.128	8.333	25.000
L_9 x T_3	2.632	-2.546	-2.723	-0.826	-5.833	17.647	7.142	4.653	2.564	12.500	20.833
L_{10} x T_1	-2.632	-2.546	-2.970	-1.487	-10.555	-5.882	0.000	-2.323	-23.076	-8.333	14.583

L_{10} x T_2	-1.504	-1.455	-2.970	-11.239	-20.277	29.411	14.285	-16.277	5.128	4.166	10.416
L_{10} x T_3	-1.880	-1.818	-2.723	1.487	0.277	11.764	7.142	-2.653	-5.128	8.333	-4.166
L_{11} x T_1	-1.880	-1.818	-3.218	-6.116	-13.610	17.647	14.285	4.653	2.564	29.166	41.666
L_{11} x T_2	-1.504	-1.455	-2.970	-10.743	-18.055	23.529	7.142	-9.300	2.564	4.166	-2.083
L_{11} x T_3	-0.751	-0.729	-2.723	-8.760	-6.944	17.647	7.142	-2.323	-2.564	0.000	20.833

Continued…..

Table : 8

Crosses	Days taken to 50% anthesis	Days taken to 50% silking	Days taken to 50% husk browning	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	No. of Kernel rows ear^{-1}	No. of Kernels row^{-1}	100 grain weight (g)	Grain yield (q ha^{-1})
L_{12} x T_1	-0.370	-0.578	-1.504	-1.157	-5.833	5.882	7.142	4.653	2.564	0.000	-16.666
L_{12} x T_2	-1.504	-1.455	-4.703	-1.653	-3.333	11.764	7.142	11.630	-7.692	-20.833	-2.083
L_{12} x T_3	-2.632	-2.546	-0.248	-5.785	-11.389	11.764	-7.142	4.653	-12.820	5.554	16.666
L_{13} x T_1	-2.632	-2.546	-0.742	-2.975	-15.000	17.647	21.428	4.653	-7.692	-16.666	14.583
L_{13} x T_2	-1.504	-1.455	-1.733	7.107	-4.444	23.529	7.142	-9.300	5.128	8.333	4.166
L_{13} x T_3	-1.504	-1.455	-1.733	7.107	-0.277	41.176	14.285	-2.323	7.692	29.166	35.416
L_{14} x T_1	-2.632	-2.546	-3.218	-0.826	-9.444	5.882	0.000	11.630	-5.128	12.500	16.666
L_{14} x T_2	-1.504	-1.818	-3.218	-11.404	-20.000	17.647	7.142	-2.323	2.564	4.166	0.000
L_{14} x T_3	-1.504	-1.455	-1.485	-1.157	-3.333	11.764	7.142	-2.323	-5.128	8.333	-4.166
L_{15} x T_1	-2.255	-2.181	-2.970	-1.652	-8.610	11.764	14.285	-2.323	-7.692	-16.666	18.750
L_{15} x T_2	-2.255	-2.181	-1.733	12.231	12.225	17.647	14.285	-16.277	-23.076	-4.1666	19.160

L_{15} x T_3	-2.632	-2.546	-3.218	14.049	11.389	11.764	7.142	-2.323	-33.333	25.000	3.330

Where,

L_1 = 102A-1 L_2 = 102A-2 L_3 = 106 B L_4 = 106 C-1 L_5 = 106 C-2 L_6 = 132 C L_7 = 139 B L_8 = 139 B L_9 = 140 E-2
L_{10} = 141 B-1 L_{11} = 142 A L_{12} = 146 B L_{13} = 147 C L_{14} = 150 B L_{15} = 151 A

T_1 = C_6 (Broad genetic base) T_2 = Super-1 (Broad genetic base) T_3 = 153 A (inbred)

Table 4: Best lines with respect to their gca and *per se* performance for maturity, yield and yield contributing traits in maize (*Zea mays* L.).

Traits	**Lines**	**(gca)**	***Per se* performance**
Days taken to 50% anthesis	132 C	(-1.393)**	(88.330)
	139B	(-1.281)**	(87.667)
	102A-2	(-0.948)**	(87.000)
Days taken to 50% silking	132 C	(1.689)**	(91.333)
	139 B	(-1.578)**	(90.667)
	106 C-1	(-0.800)**	(92.333)
Days taken to 50% husk browning	146 B	(-1.274)**	(135.667)
	142 A	(-1.052)**	(133.000)
	141 B-1	(-0.941)**	(134.333)

	102 A-1	(-0.719)**	(134.000)
	106 C-2	(-0.385)*	(135.000)
Plant height (cm)	106 B	(-16.474)**	(166.000)
	102 A-2	(-16.363)**	(226.000)
	142 A	(-8.807)**	(200.000)
Ear height (cm)	132 C	(-9.230)**	(116.000)
	106 B	(-8.785)**	(103.000)
	102 A-2	(-6.000)**	(136.000)
Ear length (cm)	147 C	(2.178)**	(20.000)
	102A-1	(2.178)**	(18.000)
	132-C	(1.178)**	(18.000)

Continued…..

Table 4 :

Traits	**Lines**	**(gca)**	***Per se* performance**
Ear girth (cm)	106 C-1	(1.430)**	(14.000)
	102 A-1	(1.096)**	(14.000)
	147 C	(0.763)*	(15.000)
No. of kernel rows ear^{-1}	139 B	(2.526)**	(16.000)
	146 B	(1.193)*	(15.000)
No. of kernels row^{-1}	139 A	(2.948)**	(37.000)
	142 A	(2.281)**	(37.000)
	102A-1	(2.615)**	(36.000)
Grain yield (q ha^{-1})	139 A	(14.178)**	(30.000)
	151 A	(9.844)**	(36.000)
	142 A	(6.511)**	(30.000)
	147 C	(5.511)**	(40.000)
100 grian weight (g)	106 C-2	(4.141)**	(22.000)
	102 A-2	(4.030)**	(21.000)
	139 B	(2.807)**	(28.000)

	142 A	(1.252)**	(19.000)
Protein content (%)	106 C-2	(0.375)**	(7.250)
	142 A	(0.335)*	(7.160)
	151 A	(0.292)**	(7.070)

*,** significant at 5 and 1 per cent levels, respectively

Table 6 : Best cross combinations with respect to their sca for maturity, yield and yield contributing traits in maize (*Zea mays* L.).

Traits	Crosses	Sca
Days taken to 50% anthesis	L_3 x T_2	(-1.119)*
	L_7 x T_3	(-1.030)*
Days taken to 50% silking	L_7 x T_3	(-1.067)*
	L_9 x T_3	(-0.844)*
	L_{12} x T_3	(-0.844)*

Days taken to 50% husk browning	L_2 x T_3	(-2.326)**
	L_2 x T_2	(-2.059)**
	L_4 x T_1	(-1.726)**
	L_6 x T_1	(-1.393)**
	L_5 x T_3	(-0.993)**
Plant height (cm)	L_4 x T_2	(-21.637)**
	L_{10} x T_2	(-16.081)**
	L_{14} x T_2	(-15.526)**
	L_7 x T_3	(-13.415)**
	L_1 x T_3	(-12.193)**
Ear height (cm)	L_1 x T_1	(-15.681)**
	L_{14} x T_2	(-15.526)**
	L_{15} x T_1	(-14.904)**
	L_{14} x T_2	(-14.193)**

	L_7 x T_3	(-12.348)***

Continued…..

Table 6:

Traits	**Crosses**	**Sca**
Ear length (cm)	L_{13} x T_3	(2.689)**
	L_{10} x T_2	(2.022)**
	L_{12} x T_3	(0.689)**
Ear girth (cm)	L_6 x T_3	(1.881)**
	L_1 x T_1	(1.215)*
No. of kernel rows ear^{-1}	L_1 x T_2	(2.319)**
	L_6 x T_3	(1.674)**
	L_{12} x T_2	(1.319)*
No. of kernels row^{-1}	L_{10} x T_1	(6.126)**
	L_{15} x T_3	(3.948)**
	L_{13} x T_3	(3.052)**

	L_6 x T_3	(2.948)**
Grain yield (q ha^{-1})	L_7 x T_3	(16.355)**
	L_5 x T_1	(14.089)**
	L_4 x T_2	(12.778)**
	L_4 x T_3	(12.356)**
	L_7 x T_1	(10.578)**
	L_1 x T_2	(10.556)**
100 grain weight (g)	L_4 x T_2	(3.452)**
	L_8 x T_2	(3.326)**
	L_{15} x T_3	(3.081)**
	L_{10} x T_2	(2.326)**
	L_{12} x T_2	(2.119)**

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*,** significant at 5 and 1 per cent levels, respectively

Table 9 : Identification of the good general combiners and best cross combination with respect to their combining ability and *per se* performance for different traits

Traits	Best lines		Best cross	
	gca basis	*Per se* performance	Sca basis	*Per se* performance
Days taken to 50% anthesis	132-C	102-A-2	106-B x Super-1	139-B x Super-1
	139-B	106-B	139-A x 153-A	139-A x C_6
	102 A-2	139-B		102A-1 x Super-1
Days taken to 50% silking	132-C	139-A	139-A x 153-A	132-C x C_6
	139-B	147-C	140-E-2 x 153-A	132-C x Super-1
	106 C-1	102-A-1	146-B x 153-A	139-B x Super-1
Days taken to 50% husk browning	146-B	140-E2	102-A-2 x 153-A	146-B x Super-1
	106-B	142-A	106-C-1 x C_0	146-B x C_6
	142-A	106-B	132-C x C_6	102-A-1 x C_6
Plant height (cm)	132-C	102-A-1	106-C x Super-1	132-C x C_6
	106-B	106-B	139-B x 153-A	106-B x 153-A
	102 A-2	146-B	141-B-1 x Super-1	102-A-2 x C_6

Ear height	132-C	102-A-1	102A-1 x C_6	106-B x 153-A
	106-B	106-C-2	141 B-1 x Super-1	102 A-1 x C_6
	102A-2	106-C-1	106 C-1 x Super-1	139-B x 153-A
Ear length	147-C	147-C	106-B x C_6	102 A-1 x Super-1
	102 A-1	142-A	147-E x 153-A	147-C x 153-A
	132-C	141 B-1	141 B-1 x Super-1	1-B x Super-1

Continued……

Table : 9

Ear diameter	106-C-1	102 A-2	132-C x 153-A	1-2-A-1 x C_6
	102-A-1	147-C	102 A-1 x C_6	106-C x Super-1
	139-A	151-A		
Kernel rows ear^{-1}	139-B	139-B	102 A-1 x Super-1	139-B x C_6
	146-B	106 C-2	132-C x 153-A	139-B x 153-A
		146-B	146-B x Super-1	102 A-1 x Super-1
Kernels row^{-1}	139-A	147-C	139-B x Super-1	102 A-1 x C_6
	102 A-1	106-B	141-B-1 x C_6	147-C x C_6
	147-C	139-A	14 B-1 x Super-1	141-B x Super-1
100-grain weight	106 C-2	141 B-1	106 B x 153 A	106 C-2 x 153 A
	102 A-2	147 C	106 C-1 x Super-1	102 A-2 x 153 A
	139 B	106 C-1	151 A x C_6	106 B x 153 A
Grain yield (q ha^{-1})	139 A	150 B	106 C-2 x C_6	139 A x 153 A
	151 A	106 C-1	106 C-1 x Super-1	142 A x C_6
	142 C	141 B-1	106 C-1 x 153 A	106 C-1 x 153 A
	147 C	146 B	139 A x C_6	106 C-2 x C_6
	140 E-2	139 B	102 A-1 x Super-1	151 A x 153 A

Table 7 : Per cent contribution of lines testers and lines x testers towards the overall performance of crosses

	Per cent contribution		
Traits	Lines	Testers	Lines x testers
Days taken to 50% anthesis	57.42	2.83	39.75

Days taken to 50% silking	68.65	0.24	31.11
Days taken to 50% husk browning	52.10	2.18	45.70
Plant height (cm)	56.35	0.60	43.05
Ear height (cm)	35.92	3.93	60.15
Ear length (cm)	45.35	12.34	42.31
Ear girth (cm)	45.38	12.49	42.13
Number of kernel rows ear^{-1}	45.82	15.61	38.57
Number of kernels row^{-1}	51.15	2.14	46.71
100-grain weight (g)	38.60	24.46	36.94
Grain yield (q ha^{-1})	48.23	6.52	45.25

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*** Original not seen**