ABSTRACT - Heterosis for morphological traits was examined in maize crosses between inbred lines of contrasting maturities and plant heights in a field study over two years at CCRI, Pirsabak, Nowshera, Pakistan. The parameters included days to silking, leaf area, plant height and days to maturity. Except for one cross, mid-parent heterosis was significant for all traits in all crosses. Significant better parent heterosis was only found in one of the 4 crosses. Magnitudes of heterosis, both mid-parent and better parent, were positive and higher for leaf area and plant height traits compared to those for days to flowering and maturity. Mid-parent heterosis ranged from 24.57%-71.28%, 29.30%-37.85%, -6.03% to -9.74% and 0.82% to -9.53% for leaf area, plant height, days to silking and days to maturity, respectively. Based on the consideration of the level of heterosis, the study suggested Pop 9804xFRW4 as the best hybrid combination for early maturity and high fodder yield.

KEY WORDS: Mid-parent and better parent heterosis; Maize hybrids, Morphological traits.

INTRODUCTION

Heterosis or hybrid vigor referred to as the superiority of a hybrid over the mean of its two homozygous parents (SHULL, 1908) has been the subject of intense research and speculation for well over a century; however, the basic mechanisms that cause or contribute to heterosis remain unclear (COORS and PANDEY, 1999). Despite this lack of understanding, breeders have quite successfully manipulated heterosis to increase the vigor of many domesticated species (SPRINGER and STUPAR, 2007). Heterosis has been used in the breeding and production of many crop and animal species (MELCHINGER and GUMBER, 1988; JANICK, 1998). In maize, it is estimated that the use of hybrids and heterosis increases yields by 15% per annum (DUVICK, 1999). Maize breeders have been looking for the possibility of predicting heterosis in crosses between inbred lines of maize based on the morphological, pedigree, physiological, biochemical and molecular marker data during the past decades (SMITH and SMITH, 1989; SMITH et al., 1990; RAMESH et al., 1995). Heterosis could also be estimated from generation means and variances. Estimation of heterosis is helpful in checking the performance of parents in hybrid combinations. According to SPRINGER and STUPAR (2007) heterosis refers to the phenomenon in which the hybrid F1 offspring exhibit phenotypic characteristics that are superior to the better of the two parents (best parent heterosis).

The genetic explanation for heterosis has been made on the basis of three main hypotheses. The dominance hypothesis explains heterosis due to cumulative effect of favorable alleles with partial to complete dominance (DAVENPORT, 1908; BRUCE, 1910; JONES, 1917). However, pseudo-overdominance may occur due to repulsion phase linkages of such genes. The overdominance hypothesis attributes heterosis due to superiority of heterozygous genotypes over both parental homozygous genotypes (HULL, 1945; CROW, 1948). The hypothesis of epistasis explains heterosis on the basis of interactions among genes at different loci (POWERS, 1944; JINNS and JONES, 1958; WILLIAMS, 1959). Results of large number of investigations in the twentieth century supported the hypothesis that heterosis is attributable to the cumulative effect of a large number of fa-
Vorable dominant genes (Hallauer and Miranda, 1981).

Positive interactions between alleles from two opposite heterotic pools has been indicated the very likely explanation for the superior performance of a heterotic pattern for grain yield in maize (Schon et al., 2009). Dominance effects of heterotic loci at the single locus level as well as additive x additive interactions have been found to play an important role in the genetic basis of heterosis for grain yield and its components (Tang et al., 2009). The importance of dominance effects in the manifestation of heterosis for grain yield was confirmed and the pleiotropic effects on the overall vigor has been suggested in a study of heterosis in maize by procedures of classical genetics and quantitative trait loci (QTL) analyses (Frascaroli et al., 2007). In a system-oriented approach, new genetic effects denoted as augmented dominance effects have been defined to distinguish between dominance and overdominance in the manifestation of heterosis (Melchinger et al., 2009).

Heterosis for grain yield and yield component traits in maize has been addressed in many research studies in the past with little emphasis on the physiological traits such leaf area and plant height and flowering and maturity traits which are of primary concern in many breeding programs for high fodder yield and/or early maturity. Dehghanpour et al. (1996) observed high mid parent heterosis estimates for grain yield in maize. Scapim et al. (1998) observed positive heterosis estimates for dry matter and negative estimates for protein content. In crosses between broad base maize populations by Rezende and Souza (2000), a much lower expression of heterosis (6.05%, 7.38%, 8.50% and 8.80%) was indicated for grain yield. Sheoran et al. (2000) observed positive and significant heterobeltiosis for all traits except days to flowering in Pearl millet. High better parent heterosis was reported for yield and yield components in 90 maize hybrids and the highest value of heterosis over better parent (97.45%) was recorded for grain yield plant-1. Iqbal et al. (2001) in their study on single cross maize hybrids found heterosis in grain yield varying from 19 - 40% over the best check and were of the opinion that top yielding hybrids had desirable plant height of 132-166 cm range and similar in maturity with local check (97-100 days). Mohammedi et al. (2002) reported that the amount of heterosis for yield was higher than its components and revealed the importance of overdominance gene action in the expression of heterosis for these traits in maize. High estimates of heterosis for grain yield and some yield components while moderate levels of heterosis for plant height have been reported by Saleh et al. (2002). A better-parent heterosis of 101.7% for seed weight per ear, 64.7% for grain yield and 2.9% for days to silk have been documented in hybrid combinations between B73 and Mo17 (Springer and Stupar, 2007).

Heterosis in maize hybrids has been the subject of many previous investigations but information on heterosis for physiological traits in crosses between contrasting groups of inbred lines i.e., inbred lines of early maturity with short stature and tall with late maturity is too limited. Therefore, the present study was undertaken with the objectives 1) to determine the nature and levels of heterosis for plant height, leaf area, days to flowering and days to maturity in crosses between inbred lines of contrasting maturities and plant stature and 2) to identify the best hybrid combination(s) relating to these traits for their probable use in future breeding programs for hybrid development.

MATERIALS AND METHODS

Genetic material

The breeding material used in this experiment comprised a set of four white kernel flint maize inbred lines, each developed by manual self pollination for 6-8 generations, having distinct genetic make-up as shown in Table 1. Two out of the 4 inbreds were tall in stature with late maturity (100-120 days) and the oth-

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name</th>
<th>Pedigree</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pop. 9804</td>
<td>CHSW x Sahard White</td>
<td>Late (110-120 days)</td>
</tr>
<tr>
<td>2.</td>
<td>Pop. 9805</td>
<td>Sarhad White x Azam</td>
<td>Late (100-110 days)</td>
</tr>
<tr>
<td>3.</td>
<td>Pop. 9801</td>
<td>Pahari x Swabi White</td>
<td>Early (90-95 days)</td>
</tr>
<tr>
<td>4.</td>
<td>FRW-4</td>
<td>Shaheen x Peshawer White</td>
<td>Early (95-100 days)</td>
</tr>
</tbody>
</table>
er two were dwarf having early maturity (90-100 days). These lines were grown at the Cereal Crops Research Institute (CCRI) Pirsaab, Nowshera NWFP (Pakistan) which is located about 1540 km north of Indian Ocean at 34°N latitude, 72°E longitude and an altitude of 288 meters above sea level, thus representing a continental climate. Four hybrids were developed by crossing contrast groups using manual pollination procedures for crossing and selfing described by RUSSELL and HALLAUER (1980).

During the crop season of spring 2005, all the 4 parental lines were crossed with each other to produce four F1 hybrids using the crossing pattern given below. Similarly, seed of parental inbred lines was also increased in the same breeding season to produce appropriate quantity of seed for evaluation in the succeeding seasons.

### Field evaluation

The material for field evaluation comprised 8 entries, generated from crossing and selfing of parental inbred lines i.e., 4 parents and 4 F1 hybrids. These entries were planted in the field in triplicate, using randomized complete block (RCB) design, for evaluation at Cereal Crops Research Institute (CCRI) Pirsaab, Nowshera for two consecutive years in the summer growing season (July-October) of the year 2006 and 2007. The plot size comprised two rows each 5 m long with row spacing of 75 cm and 25 cm between plants within each row. Two seeds were planted in each hill and were later thinned to maintain one plant hill-1. A uniform dose of fertilizer, 200 kg N, 90 kg P2O5 and 90 kg K2SO4 per plot by taking their averages.

**Parameters as follow:**

- **DS** = Days to 50% silking (no)
- **LA** = Leaf area (cm²)
- **PH** = Plant height (cm)
- **DM** = Days to maturity (no)

**TABLE 2 - Means for 4 morphological traits in 4 maize crosses, combined over years, evaluated during 2006 and 2007 at CCRI, Pirsaab (Nowshera), NWFP, Pakistan.**

<table>
<thead>
<tr>
<th>Trait</th>
<th>Crosses</th>
<th>P1</th>
<th>P2</th>
<th>F1</th>
<th>P1</th>
<th>P2</th>
<th>F1</th>
<th>P1</th>
<th>P2</th>
<th>F1</th>
<th>P1</th>
<th>P2</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS</td>
<td>Pop.9804 × FRW-4</td>
<td>62.2</td>
<td>54.8</td>
<td>52.8</td>
<td>62.2</td>
<td>54.8</td>
<td>54.2</td>
<td>54.8</td>
<td>58.0</td>
<td>51.2</td>
<td>54.8</td>
<td>58.0</td>
<td>53.0</td>
</tr>
<tr>
<td>LA</td>
<td>Pop.9804 × Pop. 9801</td>
<td>125376</td>
<td>84504</td>
<td>179739</td>
<td>125376</td>
<td>139857</td>
<td>181543</td>
<td>84504</td>
<td>137002</td>
<td>169720</td>
<td>139857</td>
<td>137002</td>
<td>172444</td>
</tr>
<tr>
<td>PH</td>
<td>Pop.9804 × Pop. 9801</td>
<td>118.8</td>
<td>140.7</td>
<td>177.4</td>
<td>118.8</td>
<td>121.1</td>
<td>155.1</td>
<td>140.7</td>
<td>115.1</td>
<td>175.4</td>
<td>121.1</td>
<td>115.1</td>
<td>162.8</td>
</tr>
<tr>
<td>DM</td>
<td>Pop.9804 × FRW-4</td>
<td>119.8</td>
<td>97.5</td>
<td>98.3</td>
<td>119.8</td>
<td>94.2</td>
<td>96.0</td>
<td>97.5</td>
<td>108.5</td>
<td>95.5</td>
<td>108.5</td>
<td>97.8</td>
<td></td>
</tr>
</tbody>
</table>

**Estimation of heterosis**

The estimates of heterosis over the mid parent and better with the application of Furadon granules (3%) one month after planting by applying in leaf whirl. Hand weeding and earthing-up operations were practiced for weed control in later stages i.e., four weeks after emergence. The crop was irrigated, as and when required, till one week before maturity. Mean minimum and mean maximum temperatures ranged from 22.68°C to 35.3°C during crop growing season of 2006 (CCRI, 2006) and 14.68°C to 34.83°C in 2007 (CCRI, 2007). A total precipitation of 143.25 mm during the crop growth period of 2006 (CCRI, 2007) and 180 mm during 2007 (CCRI, 2008) was recorded. Ten plants each were selected at random in each plot for recording data on the 4 plant parameters as follow:

**Days to silking** - Silking date was recorded when the silk became visible on the topmost ear of at least 50% of plants in a plot (TOLLENAAR et al., 2004; LEE et al., 2005). The number of days from planting to silking was then expressed as days to silking (HINZ and LAMKEY, 2003).

**Leaf area (cm²)** - Length of 8th leaf from the top was measured in centimeters just after completion of pollination and fertilization processes. At the same time width of the same leaf was also measured at the widest point in centimeters. Leaf area was then determined using the following formula suggested by FRANCIS et al. (1969).

\[
\text{Leaf Area} = (\text{Leaf Length} \times \text{Leaf Width}) \times 0.75
\]

**Plant height (cm)** - Height of each plant was measured with the help of a measuring rod as the distance from ground level to the auricle of the flag leaf (GUZMAN and LAMKEY, 2000) on 10 randomly selected plants from each plot and was then converted to per plot by taking their averages.

**Days to maturity** - Date of maturity was recorded when grains in ears of at least 50% of plants in a plot attained black layer (TOLLENAAR et al., 2004; LEE et al., 2005). The number of days from planting to maturity were then calculated and recorded as days to maturity.
parent (heterobeltiosis) were calculated on the two years average data using the procedures adopted by Hallauer and Miranda (1981) and Fehr (1993) as under:

\[
\text{Mid Parent Heterosis (MPH)} = \frac{(F_1 - MP) \times 100}{MP}
\]

\[
\text{Better Parent Heterosis (BPH)} = \frac{(F_1 - BP) \times 100}{BP}
\]

Where,

- \(MP\) = mid parent value of the particular \(F_1\) cross \([(P_1 + P_2)/2]\).
- \(BP\) = better parent value in the particular \(F_1\) cross \((P_1\) or \(P_2\)).

### Statistical methods

Analysis of variance procedure for Randomized Complete Block (RCB) design for two years average data was used to estimate error mean squares (EMS) and degrees of freedom (DF), following Cochran and Cox (1960) and Singh and Chaudhary (1985). The ‘t’ test was then manifested to determine whether \(F_1\) hybrid means were statistically different from mid-parent and better parent means according to the following relationship of Wynne et al. (1970).

‘t’ for mid-parent Heterosis

\[
t = \frac{F_1 - MP}{\sqrt{2/5} \times \text{EMS}}
\]

‘t’ for better parent Heterosis

\[
t = \frac{F_1 - BP}{\sqrt{2/5} \times \text{EMS}}
\]

Where,

- \(F_1\) = Mean of \(F_1\) cross
- \(MP\) = mid parent value of the particular \(F_1\) cross \([(P_1 + P_2)/2]\).
- \(BP\) = better parent value in the particular \(F_1\) cross \((P_1\) or \(P_2\)).
- EMS = Error Mean square

### RESULTS

Mean values for days to silking, leaf area, plant height and days to maturity from the combined two years data on 4 maize crosses are presented in Table 2. These values were used in the estimation of percentage of heterosis. Estimated values of heterosis percentage, mid-parent and the best parent, for days to silking, leaf area, plant height and days to maturity in 4 maize crosses are given in Table 3. The estimates of genetic effects for these traits observed in the same four maize crosses are given in Table 4 (unpublished data).

Significant mid-parent heterosis estimates (Table 3) were observed for all traits in all 4 crosses except Cross-IV (Pop.9805 x Pop.9801) where a non significant heterosis estimate of -3.5% was found for days to maturity. However, estimates of heterosis for the better parent were not significant except Cross-1 (Pop.9804 x RRW.4) where these estimates of heterosis were significant for all traits under investigation.

The heterosis estimates in case of mid-parent as well as better parent for leaf area and plant height were positive and also much higher in magnitudes in all crosses compared to those for days to silking and days to maturity where these estimates were found negative and much lower in their magnitudes except Cross-1 (Pop.9804 x RRW.4), having a significant positive but still a lower better-parent heterosis estimate of 0.82% for days to maturity. Mid-parent heterosis estimates, in percentage, were found in the range of 24.57 to 71.28 for leaf area, 29.30 to 37.85 for plant height, -6.03 to -9.74 for days to silking and 0.82 to -9.53 for days to maturity.

### DISCUSSION

A significant mid-parent heterosis appeared for all traits (days to silking, days to maturity, leaf area and plant height) in all crosses except days to maturity in Cross IV (Pop.9805 x Pop.9801) with a non

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cross-I MPH</th>
<th>Cross-I BPH</th>
<th>Cross-II MPH</th>
<th>Cross-II BPH</th>
<th>Cross-III MPH</th>
<th>Cross-III BPH</th>
<th>Cross-IV MPH</th>
<th>Cross-IV BPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to Silking</td>
<td>-9.74**</td>
<td>-3.65**</td>
<td>-7.35**</td>
<td>-1.09 NS</td>
<td>-9.22**</td>
<td>-6.57 NS</td>
<td>-6.03**</td>
<td>-3.28 NS</td>
</tr>
<tr>
<td>Leaf Area</td>
<td>71.28**</td>
<td>43.36**</td>
<td>36.89**</td>
<td>29.81 NS</td>
<td>53.24*</td>
<td>23.88 NS</td>
<td>24.57**</td>
<td>25.30 NS</td>
</tr>
<tr>
<td>Plant Height</td>
<td>36.72**</td>
<td>26.08**</td>
<td>29.30**</td>
<td>28.08 NS</td>
<td>37.14**</td>
<td>24.66 NS</td>
<td>37.85**</td>
<td>34.43 NS</td>
</tr>
<tr>
<td>Days to Maturity</td>
<td>-9.53**</td>
<td>0.82**</td>
<td>-10.28**</td>
<td>1.91 NS</td>
<td>-7.28*</td>
<td>-2.05 NS</td>
<td>-3.50 NS</td>
<td>3.82 NS</td>
</tr>
</tbody>
</table>

MPH = Mid-Parent Heterosis, BPH = Better-Parent Heterosis

Cross-I = Pop.9804 x FRW-4, Cross-II = Pop.9804 X Pop.9801, Cross-III = Pop.9805 X FRW-4, Cross-IV = Pop.9805 X Pop.9801.
significant heterosis of -3.50% where as the presence of better-parent heterosis was evident in one
(Pop.9804 x FRW.4) of the 4 crosses. These results could be attributed to dominance or dominance type
of epistasis for these traits resulting from differences in allelic frequencies of dominant alleles present in
the parental lines of these hybrid combinations.

SCHON et al. (2009) compared quantitative trait loci
(QTL) mapping results for grain yield, grain moisture
and plant height from three populations derived
from crosses of the heterotic pattern Iowa Stiff Stalk
Synthetic x Lancaster Sure Crop. They concluded
that the high mid-parent heterosis for grain yield in
their study was due to combination of different alle-
les which were fixed in each opposite heterotic
pool. They further added that the positive interac-
tions of these alleles very likely formed the base line
for the superior performance of the heterotic pattern
being studied. Moreover, the manifestation of a sig-
nificant better-parent heterosis in Cross-1 could be
due to the presence of higher frequencies of some
dominant alleles with epistatic effects for the 4 traits
in one of the two parents involved in this cross com-
pared to other 3 crosses included in this investiga-
tion. Similar results of mid-parent heterosis and bet-
ter-parent heterosis in hybrids have been document-
ed in other studies. BENJAMIN (2001) conducted an
experiment on 13 reciprocal full-sib selection cycles
in two maize populations and reported a mid-parent
heterosis (MPH) of 7.58% and 7.05% for the two
populations in cycle 7. He further reported estimates
of -1.64% for mid-parent heterosis and -4.39% for
days to silking in cycle 9.

MOHAMMADI et al. (2002) in their study on yield and
yield components of F 1s from 8 maize inbred lines
revealed the importance of over dominance gene ac-
tion in maize for the expression of heterosis for
yield and its components. The estimates of mid-parent heterosis for leaf
area and plant height were all significant and posi-
tive and much higher in their magnitudes across all
4 hybrids compared to those for flowering and ma-
turity traits with significant and negative estimates
and of lower magnitudes in most cases. This again
indicates that higher frequencies of alleles with
dominance and dominance type of interaction ef-
fects could have been operative in the manifestation
of such increased vigor for leaf area and plant
height compared to lower frequencies of alleles re-
sponsible for enhancing flowering and maturity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cross</th>
<th>M</th>
<th>d</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>l</th>
<th>Type of non-allelic interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to Silking</td>
<td>Pop.9804 X FRW-4</td>
<td>53.23</td>
<td>0.43</td>
<td>-6.12</td>
<td>-1.45</td>
<td>-3.62</td>
<td>10.52</td>
<td>Duplicate</td>
</tr>
<tr>
<td></td>
<td>Pop.9804 X Pop.9801</td>
<td>55.06</td>
<td>0.29</td>
<td>-4.70</td>
<td>0.29</td>
<td>-4.32</td>
<td>-3.15</td>
<td>——</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X FRW-4</td>
<td>54.61</td>
<td>1.54</td>
<td>-10.15</td>
<td>-5.69</td>
<td>-0.55</td>
<td>6.46</td>
<td>Duplicate</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X Pop.9801</td>
<td>53.49</td>
<td>0.72</td>
<td>-3.12</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
</tr>
<tr>
<td>Leaf Area</td>
<td>Pop.9804 X FRW-4</td>
<td>3614.52</td>
<td>149.97</td>
<td>4398.61</td>
<td>2406.38</td>
<td>-567.40</td>
<td>-1004.23</td>
<td>309.65**</td>
</tr>
<tr>
<td></td>
<td>Pop.9804 X Pop.9801</td>
<td>4223.70</td>
<td>318.21</td>
<td>1896.45</td>
<td>457.43</td>
<td>-230.57</td>
<td>104.59</td>
<td>47.32**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X FRW-4</td>
<td>4445.03</td>
<td>-154.28</td>
<td>1754.71</td>
<td>-435.12</td>
<td>-901.50</td>
<td>1871.32</td>
<td>109.19**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X Pop.9801</td>
<td>4824.51</td>
<td>351.45</td>
<td>1402.92</td>
<td>-482.70</td>
<td>-227.19</td>
<td>514.53</td>
<td>8.34**</td>
</tr>
<tr>
<td>Plant Height</td>
<td>Pop.9804 X FRW-4</td>
<td>142.86</td>
<td>-1.63</td>
<td>78.11</td>
<td>50.46</td>
<td>9.28</td>
<td>-18.01</td>
<td>52.88**</td>
</tr>
<tr>
<td></td>
<td>Pop.9804 X Pop.9801</td>
<td>134.64</td>
<td>-3.33</td>
<td>52.36</td>
<td>17.26</td>
<td>-2.23</td>
<td>-23.09</td>
<td>9.28**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X FRW-4</td>
<td>146.69</td>
<td>-5.08</td>
<td>56.70</td>
<td>9.21</td>
<td>7.75</td>
<td>1.23</td>
<td>34.85**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X Pop.9801</td>
<td>140.42</td>
<td>14.50</td>
<td>56.92</td>
<td>12.17</td>
<td>17.50</td>
<td>-24.30</td>
<td>115.03**</td>
</tr>
<tr>
<td>Days to Maturity</td>
<td>Pop.9804 X FRW-4</td>
<td>110.30</td>
<td>-1.52</td>
<td>-14.00</td>
<td>-29.47</td>
<td>-12.90</td>
<td>29.33</td>
<td>169.10**</td>
</tr>
<tr>
<td></td>
<td>Pop.9804 X Pop.9801</td>
<td>103.14</td>
<td>0.97</td>
<td>-9.09</td>
<td>-1.58</td>
<td>-13.71</td>
<td>-2.94</td>
<td>66.00**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X FRW-4</td>
<td>98.73</td>
<td>-0.63</td>
<td>2.59</td>
<td>5.93</td>
<td>-2.76</td>
<td>-15.85</td>
<td>50.50**</td>
</tr>
<tr>
<td></td>
<td>Pop.9805 X Pop.9801</td>
<td>95.41</td>
<td>-2.79</td>
<td>31.61</td>
<td>27.14</td>
<td>-8.21</td>
<td>-42.52</td>
<td>101.32**</td>
</tr>
</tbody>
</table>

m = mean, d = additive, h = dominance, i = additive x additive, j = additive x dominance, l = dominance x dominance.
(heterosis with negative estimates) in these crosses. The present results of mid-parent heterosis and best parent heterosis in our study are not surprising since the preponderance of dominance and dominance type of inter-allelic interactions was evident from the estimates of genetic effects for these traits (Table 4). The findings of the present study closely correspond with those observed in the previous such investigations on heterosis in maize. Tang et al. (2009) from his investigation on the dissection of the genetic basis of heterosis in an elite maize hybrid by QTL (quantitative Trait Loci) mapping in an immortalized F2 concluded that dominance effects of heterotic loci at the single-locus level as well as additive x additive interactions played an important role in the genetic basis of heterosis for grain yield and its components in the hybrid. Uzarowska et al. (2007) in their study on evaluation of F1 crosses derived from 4 genetically diverse inbred maize lines observed substantial mid-parent heterosis of 56.4% under field environment and 39.5% under controlled green house condition for plant height. Maximum heterosis of 101.7% for seed weight and a minimum of 2.9% for days to silk have been reported in a study by Springer and Stuper (2007) on the performance of hybrid combinations between two prominent maize inbred lines (B-73 and Mo-17) of the USA Tollenaar et al. (2004) examined 12 maize hybrids and their parental lines and observed positive mid-parent heterosis of high levels (85%-167%) for dry matter accumulation and negative with low levels of such heterosis for days to silking and days to maturity. Mid-parent heterosis of 9.0% for plant height and very low levels for days to silking have been reported by Dicker and Tracy (2002) in their evaluation of crosses among 6 open pollinated varieties of sweet corn.

The range of mid-parent heterosis estimates among crosses, varying from 24.57% to 71.28% for leaf area, 29.30% to 37.85% for plant height, -6.03% to 9.74% for days to flowering and 0.82% to -9.53% for days to maturity, observed in the present investigation was not unexpected since parental inbred lines greatly varied in their genetic background. The ranges of variation for the estimates of mid-parent heterosis observed in the present study closely corroborated with many other such previous studies. Uzarowska et al. (2007) observed substantial mid-parent heterosis for plant height ranging from 37.9% to 56.4% in the field and 11.1% to 39.55 under controlled green house conditions during evaluation of F1 crosses derived from genetically diverse maize inbred lines where as Benjamin (2001) in his study on reciprocal full-sib recurrent in two maize populations reported a mid-parent heterosis of 7.58% to 7.05% for this trait. High levels of mid-parent heterosis as high as 85% for dry matter accumulation have been observed by Tollenaar et al. (2004) in their experiment with 12 maize hybrids and their parental inbred lines. Mid-parent heterosis of -1.37% and -1.64% for days to mid-silk was indicated in cycle 7 and cycle 9, respectively, in the experiment conducted on reciprocal recurrent selection cycles in maize populations by Benjamin (2001) while Springer and Stuper (2007) recorded a minimum of 2.9% mid-parent heterosis for flowering in their investigation on the performance hybrid combinations resulting from two prominent maize inbred lines, B-73 and Mo-17, of USA. The manifestation of negative estimates of heterosis both for flowering and maturity traits (i.e., enhanced flowering and maturity) in these crosses could be either due to dominance at the same locus or different dominant genes which are closely linked and /or pleiotropic in their action. Frascaroli et al. (2007) in his study on the heterosis in the material arising from the single cross B73 x H99 has confirmed the importance of dominance effects for grain yield and suggested the pleiotropic effects on overall plant vigor from the over lapping of over dominant QTL, for four plant traits, found in some chromosome regions.

**CONCLUSIONS**

Based on results of the present study, it is concluded that 1) heterosis for leaf area and plant height traits is positive and much higher in magnitude compared to that for flowering and maturity traits which had negative and lower levels of heterosis and that the dominance and dominance type of epistatic effects played greater role compared to additive or additive x additive interaction effects in these crosses and 2) the cross between Pop.9804 x FRW.4 appeared as the best hybrid combination with respect to early maturity and high fodder yield for use in the future breeding programs.

**REFERENCES**

SINGH R.K., B.D. CHAUDHARY, 1985  Biometrical methods in quan-

SMITH J.S.C., O.S. SMITH, 1989  Comparison of heterosis among
hybrids as a measure of relatedness with that to be expected
on the basis of pedigree. Maize Genet. Coop. Newsletter 63:
86-87.

SMITH O.S., J.S.C. SMITH, S.L. BROWN, 1990  Similarities among a
group of elite maize inbreds as measured by pedigree, F1
grain yield, grain yield, heterosis and RFLPs. Theor. Appl.
Genet. 80: 833-840.

SPRINGER N.M., R.M. STUPAR, 2007  Allelic variation and heterosis
in maize: How do two halves make more than a whole?
Genome Res. 17: 264-275.

MECHINGER, J. LI, 2010  Dissection of genetic basis of hetero-
sis in an elite maize hybrid by QTL mapping in an immortal-

TOLLENAAR M., A. AHRAMI-ZADEH, E.A. LEE, 2004  Physiological ba-
sis of heterosis for grain yield in maize. Crop Sci. 44: 2086-
2094.

UZAROWSKA A., B. KELLER, H.P. PIEPHO, G. SCHWARZ, C. INGVARDSEN,
G. WENZEL, T. LUBBERSTEDT, 2007  Comparative expression
profiling in meristems of inbred-hybrid triplets of maize
based on morphological investigations of heterosis for plant

WILLIAMS W., 1959  Heterosis and the genetics of complex char-

WYNNE J.C., D.A. EMBRY, P.H. RICE, 1970  Combining ability esti-
mation in Arachis hypogaea L. II. Field performance of F1