Research Article

Study of Heterosis and Inbreeding Depression under Natural and Water Stress Conditions in Diverse Maize Hybrids

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Abstract | The present study was conducted to evaluate 108 inbred lines of maize planted in two separate trials under normal irrigation and water stress conditions. Parental selection for further study was done with regards to grain yield and its related traits. Inbred lines explained a broad range of genetic variability and displayed different levels of drought tolerance. Four inbred lines were selected i.e. VDR-51, DR3-126, DR-37 and 5CDR-53. Crosses were done among the selected inbred lines. Six generations as P1, P2, F1, F2, BC1 and BC2 were prepared for both the crosses to calculate heterosis and inbreeding depression for Randomized Complete Block Design under split plot arrangement. Highly significant inbreeding depression was recorded for all traits indicating a dominant type of gene action. Heterosis was high for both crosses along with high inbreeding depression. All these results exhibit that the hybrid breeding is the best option for inbreds to exploit their potential.

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Introduction

Maize production increases in 2016 at record high of 6.130 million tonnes showing a major increase of 16.3 percent over the previous year's production of 5.271 million tonnes (Anonymous, 2017).

Abiotic factors for example drought are one of the biggest limitations in increasing maize production. Water deficit is an unavoidable and revenant phenomenon in global agriculture. Approximately 1/3 of the global cultivated area is affected by moisture stress. Water is a vital component of plants and contribute to initiating growth, in maintaining process of development during the life of plant and eventually the economy of a country. Severe yield losses are observed when maize is exposed to drought during the crucial stage of life cycle from tasseling to start of grain filling (Saddozai et al., 2015).

Sometimes patterns of cropping are altered due to water deficit. Under these conditions development of drought tolerant, high yielding maize cultivar is a right choice to cater the problem of drought (Jayne et al., 2010). Simple and rapidly measurable physiological parameters that must be heritable, selection responsive and associated to growth and yield.

Numerous breeding techniques are developed to enhance the grain yield in maize and the hybrids obtained from them. Numerous elite inbred lines are hybridized to among themselves to choose best hybrid

(Unay et al., 2004). Prior to the formulation of highly productive corn varieties or hybrids, it's imperative to assess genetic architecture of yield related traits. The assessment of gene action or genetic analysis of these metric characters is most necessary before initiating an effective breeding program. Principal contributing traits to total genetic variation should be assessed to anticipate genetic regulation of different metric traits in following generations. Several bio metrical procedures related to genetic analysis of key parameters are established in the past, which have significantly facilitated the scientists in development of superior cultivars for varied environments and cropping systems. Rawalakot is a mountainous area and maize crop is cultivated under rainfed conditions. Rainfall in the region particularly in Rawalakot has become erratic due to the incidence of climatic changes which frequently affects the Maize crop by decreasing yields. To increase yield farmers, rely on cultivation of hybrids. Hybrid seed is mostly introduced from the major growing areas of Punjab which is tried and tested under their climatic conditions. This seed is not acclimatized to mountainous region resulting in poor yields. Hence a drought tolerant maize hybrid adapted to mountainous region of Azad Kashmir was required to boost the production of this area. Development of hybrid adapted to this area has not been reported yet hence the aim of this study is to assessed the genetic diversity among different inbred lines and also to study the heterosis and inbreeding depression for yield and its components under natural and drought conditions.

Materials and Methods

The current studies were carried out at the Department of Plant Breeding and Molecular Genetics, Faculty of Agriculture, University of The Poonch, Rawalakot, Azad Jammu and Kashmir. Based on screening under drought and normal conditions for two sets of inbred lines (four inbred lines) were selected as parents viz., drought tolerant and susceptible to drought. The two crosses between diverse parents were as cross 1, VDR-51 x 5CDR-53 and cross 2, DR3-126 x DR-37. Selfing of the parents was also done. All six generations i.e., F_1, F_2, back crosses along with parents were planted at Faculty of Agriculture, University of The Poonch Rawalakot, Azad Jammu and Kashmir during Kharif, during 2015. The trial was planted in a Randomized Complete Block Design with three replications under drought conditions. Trial was conducted in tunnel and drought treatments were covered with plastic sheet four weeks prior to flowering to impose drought stress one week before flowering and remained covered up to two weeks after flowering. For good stand, two seeds were planted per site. The spacing was kept 25 cm and 75 cm in plant-to-plant and row-to-row respectively. Standard dose of fertilizer was applied to each of the experimental unit. The treatments under natural conditions were not covered by plastic sheet i.e., they were kept under rain fed conditions. The quantitative data that were recorded during the present study includes, plant height, ear height, flag leaf area, ear leaf area, days to 50% silking, days to 50 % pollen shed, anthesis-silking interval (ASI) number of kernel rows per ear, number of kernels per row, 100-kernel weight, grain yield per plant and shelling percentage.

Statistical analysis

For estimates of heterosis in F1 (HF1), computations were worked out deploying formula by Singh (2003).

$$HF1 = [(mF1-mMP) \div mMP] \times 100$$

Where;
mMP1=Mid parent value

While inbreeding depression (ID) was computed following Singh (2003) as follows,

$$ID = [(mF1 - mF2) \div F1] \times 100$$

Heterosis and inbreeding depression significance was checked according to method given by Singh and Narayanan (2009) as under:

$$CD = S.E \times t \text{ at } 5\% \text{ or } 1\%$$

Where;
S.E is standard error and is equal to (2MSe/r) 1/2

Results and Discussion

Mid and better parent heterosis is important in cross pollinated crops like maize. Plant Breeders goal is acquisition of high heterosis for the desired trait especially in quantitative traits. Heterosis remained the subject matter for the past century however the basic mechanism involved in expressing the heterosis remained unclear. Irrespective of the genetic control of the heterosis remained unclear, breeders however have exploited heterosis for breeding of high cultivars in the domesticated crop specie and significant achievements have been recorded (Springer and Sutpar, 2007). Heterosis have boosted the yield of different cross pollinated species especially in case of maize a boost of 15% has been observed in the yield. In past decade heterosis was exploited for maize with respect to different morphological, biochemical, physiological and molecular traits (Springer and Sutpar, 2007). Hence the heterosis was estimated for different phenological traits of crosses i.e. VDR-51 × 5CDR-53 and DR3-126 × DR-37 under natural and water deficit conditions to exploit heterotic pattern of given crosses.

Inbreeding depression can be described as the lowest vigour of inbred lines with respect to its non-inbred counterpart. The continuous selfing of an inbred line causes the inbreeding depression. The continuous selfing leads to homozygosity at different loci in inbred lines which leads to loss of vigour. The inbreeding depression is more linked with dominance rather than heterosis. It is mainly because of non-additive gene action (Saxena and Sharma, 1990). It is most commonly determined in cross pollinated crops rather than self-pollinated species. As maize is a cross pollinated species hence estimation of inbreeding depression will help to devise the future breeding strategy in a given set of inbred lines. Inbreeding depression in a given set of inbred lines related to different morphological and phonological traits (Table 2).

To identify the significant heterosis effects, t-test was applied which indicated significant to highly significant heterotic effects for all characters except anthesis-silking interval. These results indicated dominance gene effects for all traits except anthesis-silking interval. Negative non-significant heterosis for anthesis-silking interval showed a reduced gap between anthesis and silking under natural and drought conditions which favors the pollen availability to silk and seed setting directing to higher yield especially under water deficit.

While estimates of inbreeding depression was highly significant expect for ear height of cross VDR-51×5CDR-53 under drought conditions. Highly significant inbreeding depression for all characters in both the crosses showed fixation of unfavorable recessive alleles in F_2 generations for both crosses (Singh and Nanayanam, 2009).

Plant height

Mid and better parent heterosis for both crosses under natural as well drought stress conditions for plant height were mentioned in Table 2. Results showed that mid parent heterosis ranged from 24.71 to 49.59 %. Maximum magnitude of the mid parent heterosis was found in VDR-51×5CDR-53 under water deficit and minimum mid parent heterosis was found in the same cross under natural conditions. In both the crosses mid parent was always found low as compared to the better parent heterosis under controlled as well as drought stress conditions. Similar trend was observed with the better parent heterosis as maximum (68.5%) was observed in VDR-51 × 5CDR-53 under drought stress conditions while minimum better parent heterosis (28.66%) was also recorded in same cross under natural conditions.

Both the crosses showed negative inbreeding depression for plant height under controlled conditions i.e. in cross VDR-51 × 5CDR-53. (-14.75) and in cross DR3-126 × DR-37 (-14.75). Whereas, under drought stress conditions the inbreeding depression was positive in both crosses 7.43 and 5.86 in cross VDR-51 × 5CDR-53 and DR3-126 × DR-37 respectively. The negative value of the inbreeding depression showed that magnitude of the plant height increased in F_2 as compared to the F_1. Whereas, positive values of the inbreeding depression showed that value of plant height decreased in the F_2 as compared to the F_1. The magnitude of the negative inbreeding depression from the F_2 to F_1 showed preponderance of the additive genes and magnitude of the positive inbreeding depression showed preponderance of the dominance gene action (Table 2).

Ear height

Positive mid and better parent heterosis was calculated with both crosses i.e. VDR-51 × 5CDR-53 and DR3-126 × DR-37 under natural and water stress conditions as shown in Table 1. Highest mid parent heterosis for ear height (100%) was observed with Cross DR3-126 × DR-37 under drought conditions however minimum mid parent heterosis (58.20%) was found with cross VDR-51 × 5CDR-53 under natural conditions. Maximum better parent heterosis was recorded for Cross DR3-126 × DR-37 (120.67%) under drought conditions and minimum better parent heterosis was observed with VDR-51 × 5CDR-53 (60.57%) under natural conditions. It was observed that in both crosses that the mid parent was always lower as compared to the better parent heterosis under controlled as well as drought stress conditions.

First cross VDR-51 × 5CDR-53(-5.03 and -0.80 respectively under natural and drought stress conditions) showed negative inbreeding depression for the ear height. Whereas, the inbreeding depression magnitude was high in the second cross DR3-126 × DR-37 and varied from 6.37 to 7.21 under natural and drought stress conditions (Table 2).

Ear leaf area

Maximum mid parent heterosis was determined for ear leaf area in the cross DR3-126 × DR-37(74.84%) under natural conditions flowed by the in cross VDR-51 × 5CDR-53 (71.63%) under drought conditions whereas minimum mid parent heterosis was showed for ear leaf area was observed in DR3-126 × DR-37 (58.10%) under drought conditions as given in Table 1. However, in better parent heterosis it was found that highest better parent heterosis was recorded in cross DR3-126 × DR-37 (76.16 %) under natural conditions. Whereas minimum better parent heterosis was observed in Cross DR3-126 × DR-37 (59.39%) under drought stress conditions. However mid parent heterosis was always lower than better parent heterosis.

The magnitude of the inbreeding depression was positive in both crosses under natural as well as control conditions which indicated that the ear leaf area was being governed by the non-additive genes. Highest inbreeding depression was observed in Cross DR3-126 × DR-37 (28.7) under natural conditions whereas lowest inbreeding depression (23.2) was also indicated in the same cross under water deficit conditions (Table 2).

Flag leaf area

Mid parent heterosis for both crosses under natural and water deficit conditions along with better parent heterosis for flag leaf area was found positive (Table 1). Results showed that mid parent heterosis changed from lowest 113.15% (for cross VDR-51 × 5CDR-53 under natural conditions) to highest 153.4 % (for Cross DR3-126 × DR-37 under drought stress conditions). Whereas, better parent heterosis ranged from 142.76% to 164.20%. Among these highest better parent heterosis was recorded for Cross DR3-126 × DR-37 under drought stress and lowest better parent heterosis was observe in VDR-51 × 5CDR-53 under natural conditions. The better parent heterosis was higher in both crosses under natural as well drought stress conditions. It was also observed that magnitude of mid and better parent heterosis was almost higher in drought stress conditions as compared to the natural condition for flag leaf area.

Magnitude of inbreeding depression for flag leaf area was mentioned in (Table 2). Results revealed that highest inbreeding depression was observed in Cross DR3-126 × DR-37 (48.90) under drought stress and minimum inbreeding depression for flag leaf area was indicated in VDR-51 × 5CDR-53(42.29) under natural conditions.

Anthesis-silking interval

The results for mid and better parent heterosis for anthesis-silking interval are given in (Table 1). The results showed that highest mid (-0.96) and better parent heterosis (-0.76) was showed in VDR-51 × 5CDR-53 cross under natural conditions. However lowest mid and better parent heterosis was recorded in DR3-126 × DR-37 under drought conditions. It was observed that the better parent heterosis was low in both crosses under drought as well natural conditions.

Both crosses indicated positive magnitude for the inbreeding depression for anthesis- silking interval (Table 2). Highest magnitude of the inbreeding depression was showed in cross VDR-51 × 5CDR-53 (16.76) under drought conditions and lowest magnitude of the inbreeding depression was recorded in Cross DR3-126 × DR-37 (4.96) under drought stress conditions.

Shelling percent

Maximum mid parent heterosis for shelling% was observed in VDR-51 × 5CDR-53(8.32%) cross under drought conditions and minimum better parent heterosis was observed in Cross DR3-126 × DR-37 (3.65%) under drought conditions (Table 1). However, highest better parent heterosis was observed VDR-51 × 5CDR-53 (7.12%) cross under natural conditions and lowest better parent heterosis was showed Cross DR3-126 × DR-37 (3.05%) under drought conditions. Further the magnitude of the better parent heterosis was high in both crosses under natural and water deficit conditions.

Table 1: *Mid and better parent heterosis for 02 maize crosses evaluated under drought as well as natural conditions.*

Parameters	Cross 1 (N)		Cross 1 (D)		Cross 2 (N)		Cross 2 (D)	
	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH
Plant Height	24.71	28.66	49.59	68.24	30.53	35.59	36.59	39.04
Ear Height	58.20	60.75	76.75	88.47	91.62	108.51	100.56	120.37
Number of leaves per plant	26.76	29.71	30.72	35.67	26.15	29.81	39.42	40.22
Ear Leaf Area	71.21	72.02	71.63	72.07	74.87	76.16	58.10	59.39
Flag Leaf Area	113.15	142.76	113.15	142.76	156.18	168.50	153.40	164.20
Days to pollen Shed	-8.49	-3.27	-7.65	-2.21	-8.58	-5.94	-6.31	-3.45
Days to Silk Emergence	-8.73	-2.65	-6.92	-1.02	-8.32	-5.67	-6.05	-5.09
Anthesis Silking Interval	-0.96	-0.76	-0.51	-0.43	-0.72	-0.69	-0.39	-0.29
Shelling %	7.12	8.32	3.94	4.79	5.16	7.98	3.05	3.65
Kernel Per Rows	26.74	28.99	58.10	59.18	21.02	25.29	48.63	50.69
Rows Per Ear	104.92	104.92	57.60	57.60	112.61	117.72	31.76	37.15
100-Grain Weight	46.20	49.03	58.40	59.072	40.52	55.46	56.75	58.64
Grain Yield	70.08	110.73	200.60	210.52	175.55	185.30	195.54	208.50
Biological Yield	120.91	182.39	91.98	99.78	46.56	93.21	73.01	87.86
Harvest Index	1.83	8.71	3.92	7.23	1.91	2.81	7.54	10.52

Table 2: *Inbreeding depression estimates for two maize crosses under natural and drought stress conditions.*

Parameters	Cross 1 (N)	Cross 1 (D)	Cross 2 (N)	Cross 2 (D)
Plant height	-14.75**	7.43**	-14.75**	5.86**
Ear height	-5.03**	-0.80	6.37**	7.21**
Number of leaves per plant	16.79**	17.31**	13.96**	14.30**
Ear leaf area	27.37**	27.56**	28.27**	23.32**
Flag leaf area	42.29**	42.32**	45.12**	48.90**
Days to pollen shed	12.13**	15.84**	7.89**	15.67**
Days to silk emergence	13.73**	9.43**	12.74**	17.54**
Anthesis-silking interval	11.65**	16.76**	8.74**	4.96**
Shelling %	8.34**	9.65**	6.93**	4.54**
Number of kernels per row	10.61**	23.71**	8.59**	18.77**
Number of kernel row/ear	19.41**	18.57**	20.84**	13.81**
100-Grain weight	8.60**	17.39**	21.79**	21.25**
Grain yield tons/ha	39.03**	35.01**	57.12**	39.70**
Biological yield tons/ha	12.34**	18.91**	19.34**	15.45**
Harvest index	20.91**	39.32**	17.14**	15.34**

Where, N: Natural conditions; D: Drought conditions.

Inbreeding depression for both the crosses under drought as well natural conditions was positive for shelling percentage. Highest inbreeding depression was observed in VDR-51 × 5CDR-53(9.65) under drought conditions whereas lowest inbreeding depression was observed in Cross DR3-126 × DR-37 (4.54) under drought conditions (Table 2).

Number of kernels row^{-1}

Mid parent heterosis for both crosses under natural as well as drought stress condition along with better parent heterosis for number of kernels per row was found positive (Table 1). Results showed that mid parent heterosis ranged from lowest 21.02% (for cross DR3-126 × DR-37 under natural conditions) to highest 58.10 % (for VDR-51 × 5CDR-53 cross under natural conditions). Whereas, better parent heterosis ranged from 25.29% to 59.18%. Among these highest better parent heterosis was determined for VDR-51 × 5CDR-53 (59.18%) cross under drought stress and lowest better parent heterosis was determined in the cross DR3-126 × DR-37 (25.29) under natural conditions.

Magnitude of the inbreeding depression for number of kernels per row was mentioned in the Table 2. Results revealed that highest inbreeding depression was observed in VDR-51 × 5CDR-53 (23.71) under drought conditions and minimum inbreeding depression for this character was observed in Cross DR3-126 × DR-37 (8.59) under natural conditions.

Number of kernel rows ear^{-1}

The results showed that the highest magnitude of mid (112.61%) and better parent heterosis (117.72%) for number of kernel rows/ear were noticed in DR3-126 × DR-37 cross under natural conditions. Similar lowest magnitude of the mid (31.76 %) and better parent heterosis (37.15%) were found in DR3-126 × DR-37 under drought stress conditions. Further it was observed that in both crosses under natural and drought stress conditions better parent heterosis was higher as compared to mid parent heterosis (Table 1).

High heterotic levels for kernel rows per ear were observed for both crosses under natural as well as drought stress conditions. Better parent heterosis recorded in this study for kernel rows per ear from moderate to higher levels in both the crosses.

Inbreeding depression magnitude varied from 13.84 to 20.81 (for cross DR3-126 × DR-37 under natural and drought conditions for number of kernel rows/ear (Table 2). Results indicated that inbreeding depression values were also high indicating that trait might be improved by hybrid breeding.

100-kernel weight

Positive mid and better parent heterosis was found with both crosses i.e. VDR-51 × 5CDR-53 and DR3-126 × DR-37 under natural and water deficit for hundred grain weight (Table 1). Results showed that highest mid parent heterosis for hundred grain weight was recorded with VDR-51 × 5CDR-53 (58.4%) cross under drought conditions however minimum mid parent heterosis was determined with Cross DR3-126 × DR-37 (40.2%) under natural conditions. Maximum better parent heterosis was calculated for VDR-51 × 5CDR-53(59.07%) cross under drought conditions and minimum better parent heterosis was observed with VDR-51 × 5CDR-53(49.03%) under natural conditions. It was observed that in both crosses the mid parent was always lower than better parent heterosis under control and water deficit conditions.

Mid-parent heterosis of moderate to high levels was found for 100-grain weight in both the crosses. Both the crosses VDR-51 × 5CDR-53 and DR3-126 × DR-37 showed positive inbreeding depression for the hundred grain weight. The magnitude of the inbreeding depression varied from 8.60 (for VDR-51 × 5CDR-53 under natural conditions) to 21.79 (for cross DR3-126 × DR-37 under natural conditions (Table 2). The results showed that the inbreeding depression values were high indicating that the trait might be improved by hybrid breeding.

Grain yield

VDR-51 × 5CDR-53 (210.52%) cross showed maximum better parent heterosis for grain yield under drought conditions then by the cross DR3-126×DR-37 (195.54%) under drought conditions whereas, minimum mid parent heterosis for grain yield in cross VDR-51× 5CDR-53(70.8%) under natural conditions (Table 1). However, in case of better parent heterosis it was observed that highest better parent heterosis showed by cross DR3-126 × DR-37 (208.50) under drought conditions. Whereas minimum better parent heterosis was observed in VDR-51 × 5CDR-53(110.73%) under natural conditions.

The expression of larger magnitudes of heterosis for grain yield in our study was not unexpected since grain yield in maize is concomitant product of various components including ear length, kernel rows per ear, number of kernel per row and hundred grain weight, all of which were seen to have heterosis of varying magnitudes in different crosses.

The magnitude of the inbreeding depression was positive in both the crosses under natural as well as control conditions which showed that the grain yield was being governed by non-additive genes. Highest inbreeding depression was observed in the cross DR3-126 × DR-37 (57.12) under natural conditions whereas lowest inbreeding depression was observed in cross VDR-51 × 5CDR-53(35.01) under water stress (Table 2).

Biological yield

Positive heterosis was recorded for both crosses under natural and water deficit conditions for biological yield (Table 1). Highest mid parent heterosis was observed in VDR-51 × 5CDR-53(182.39%) cross under natural conditions. Whereas lowest mid parent heterosis was determined in Cross DR3-126 × DR-37 (87.8%) under drought stress conditions. With respect to better parent heterosis for biological yield cross VDR-51 × 5CDR-53 was important as it express maximum better parent heterosis of 120.91% whereas lowest better parent heterosis was recorded in Cross DR3-126 × DR-37 (73.01%) under drought stress.

Moderate to high levels of both mid and better parent heterosis estimates were seen for biological yield among both crosses. Expression of greater heterotic response is associated with greater genetic diversification among its parental inbred lines. The status of the inbreeding depression for both maize crosses i.e. VDR-51 × 5CDR-53 and DR3-126 × DR-37 under drought as well as natural conditions for biological yield tons per/ha was summarized (Table 2). The results showed that the highest magnitude of the inbreeding depression was determined in Cross DR3-126 × DR-37 (19.43) under natural conditions whereas lowest magnitude of the inbreeding depression was recorded in VDR-51 × 5CDR-53 (12.34) cross under natural conditions.

Harvest index

The results for mid and better parent heterosis for harvest index are mentioned in (Table 1). Results indicated that highest mid and better parent heterosis was found in Cross DR3-126 × DR-37 (10.52% and 7.54%) under drought conditions. However, lowest mid parent heterosis (2.81%) and better parent heterosis (1.83%) were recorded in DR3-126 × DR-37 under natural conditions and VDR-51 × 5CDR-53 under natural conditions respectively.

Mid-parent heterotic levels were considerably low in magnitude than better parent heterosis for both crosses. Better parent heterosis of lower level was recorded in both crosses for the harvest index percentage indicating positive magnitude under drought as well as natural conditions.

Both the crosses depicted positive magnitude for inbreeding depression for harvest index as was shown in the Table 2. Highest magnitude of the inbreeding depression was recorded in VDR-51 × 5CDR-53(39.32) under drought conditions and lowest magnitude of the inbreeding depression was observed in Cross DR3-126 × DR-37 (15.34) under drought stress conditions.

Decline in the fitness and vigour due to selfing is called inbreeding depression. Inbreeding and heterosis are differentiated on the basis of assumptions. Inbreeding results due to mating of closely related species. Decreased heterozygosity reveals inbreeding depression, while heterosis come due to increase fitness and vigour with increased heterozygosity. If high heterosis is followed by the high inbreeding depression indicated that character is controlled by the non-additive gene action. If performance of a character remains same in the F_1 and F_2 it indictes that trait is governed by the additive gene affects. If heterosis is negative in the F_1 and it increased in the F_2 it also indicates that trait is being governed by the additive genes.

Plant height exhibited low to moderate levels of heterosis of mid and better parent in both maize crosses, representing the existence of some dominant and complementary gene actions. The study suggested that these inbred lines can utilize as parents in maize breeding program for the development of short stature, maize hybrids. Moderate levels of mid-parent heterosis for plant height was also observed in their studies (Dickert and Tracy, 2002; Saleh et al., 2002). Better parent heterosis for plant height in maize was also reported (Benjamin, 2001). Low levels of heterosis exhibited for plant height were also in conformity by (Springer and Stupar, 2007).

Moderate to high heterosis both as mid-parent and better parent were exhibited in present study for ear height in both crosses. Higher magnitude of heterosis was presumably due to the existence of dominance or dominance × dominance type allele interaction for ear height. These findings of high magnitude of better parent heterosis for ear height were atpar with those investigated earlier (Benjamin, 2001). Mid-parents heterosis of moderate level for ear height in present study was in agreement with findings (Malik et al., 2004; Abuali et al., 2012).

High mid parent heterosis was recorded in flag leaf area for both crosses under water deficit and natural conditions. This heterosis may be attributed to the dominance of the alleles present in early and late maturing inbred parents were also at par with (Malik et al., 2004; Springer and Stupar, 2007).

Flag leaf area, shelling percentage, no. of kernels per row showed similar levels of mid-parent heterosis (Saleh et al., 2002; Springer and Stupar, 2007; Abuali et al., 2012). High level of heterosis for 100-grain weight in maize were also described by (Malik et al., 2004; Abuali et al., 2012).

Moderate level of mid parent Heterosis for grain yield, Biological yield and harvest index percentage was observed, depicting the dominance and over dominance gene effect (Tollenaar et al., 2004; Ali et al., 2013).

Conclusions and Recommendations

Significant heterosis estimates the dominance type of gene action for all traits indicated the plant material is good for exploitation of heterosis. Highly significant inbreeding depression for all characters in both the crosses under natural and drought conditions indicates for further selection from advanced generations. The results obtained from heterosis and inbreeding depression of the said material might be perfect for heterosis breeding for the drought prone semi-arid areas.

Novelty Statement

This research will be helpful in making hybrid cultivars for future breeding programmes.

Author's Contribution

MI performd the experiments and wrote the paper. SAK supervised the PhD research. SIA (member of PhD supervisory committee) helped in planning of experiments. SR assisted in data collection. MRK contributed in data analysis. SH modified the paper.

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