Indian J. Genet., **63**(2): 119-123 (2003)

Genetic studies under different levels of moisture stress in maize (*Zea mays* L.)

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(Received: July 2002; Revised: March 2003; Accepted: April 2003)

Abstract

The genetic analysis carried out according to variety cross diallel model involving eight diverse maize composites possessing various levels of tolerance to moisture stress under optimum moisture and rainfed conditions revealed that the variance due to dominance effect was significant for days to 50% silking and tasseling, leaf area, plant height, cob width under both moisture situations. Variance due to additive effect, dominance effect GCA and SCA were significant for grain yield and test weight under both irrigated and rainfed conditions. The average heterosis x mating interaction was significant for grain yield under irrigated condition and for test weight for both the conditions. In our study, A-68 was one of the parents in crosses, which recorded highest heterobeltiosis under rainfed conditions for grain yield, plant height, and Cob width and cob length. The heritability values estimated on individual diallel sets revealed that test weight, plant height and cob width are highly heritable under both irrigated and rainfed conditions. While, heritability for yield was very low. The estimates of heritability also changed with mating systems. Thus, for breeding for moisture stress tolerance, indirect selection using highly heritable and highly correlated traits with yield will be an effective strategy. The correlation studies revealed that the grain yield was positively and significantly correlated with test weight, cob length, cob width, number of rows per cob and number of grains per cob under optimum moisture (I_4), limited moisture (I_2) and rainfed (I_0) situations. The results revealed that cob width, number of grains per row and test weight were the common yield components across different moisture regimes. The multiple regression equation fitted to predict grain yield explained 47%, 37% and 26% of the variation in yield under I_4, I_2, I_0, respectively. Thus, low leaf area in conjugation with more test weight, cob width and grains per row form effective indirect selection criteria for grain yield under water stress situation.

Key words: Maize, character association, yield prediction, heterosis, genetic studies, heritability

Introduction

Drought is a major factor responsible for limiting maize production and productivity in developing world. Global estimate about annual losses of maize production due to problem of drought in early 1990s was about 15 per cent [1]. Therefore there is a need to enhance breeding effort for drought tolerance in maize. The inbred-hybrid approach has been dominating and important at present, yet in many cases, non-conventional (non-inbred hybrids) hybrids have been developed for commercial cultivation particularly in developing countries. Maize in the developing countries is grown generally under unpredictable environments inherent with one or the other stress. In such situations and in those countries where new hybrid breeding programme is being initiated and scientific expertise and seed industry are in their infancy, beginning should be made with non-conventional hybrids and gradually shift towards conventional hybrids [2].

The selection for grain yield under the stress condition is the most practical way to select for water stress tolerance [3]. However, one major problem with this is of high G × E interaction leading to low heritability of the yield. Therefore, it becomes important to select for highly heritable and strongly correlated secondary traits under stress conditions. Keeping these points in view an experiment involving eight maize composites was planned to study genetic components, extent of heterosis, heritability, correlation and regression analysis in varietal crosses under irrigated and moisture deficit conditions.

Material and methods

The experimental material consisted of eight genetically diverse maize composites possessing different levels of tolerance to moisture stress. The composites included were Comp.8551 (highly tolerant), Comp 8527, Comp 85134, Comp 85164 (tolerant), Comp 8557, DRC 8601, Ageti 76 (moderately tolerant) and Ageti 68 (susceptible). Diallel mating design was adopted to generate 28 F_1s and 28 F_1's random mated $[C^r_{jj}]$ and 28 F_1s selfs $[C^s_{jj}{}']$ populations were derived from F_1s. Twenty-five plants were sampled randomly covering whole plot either to cross or to self as the case may be. For generating F_1s random mated population, the pollens were bulked and pollination was done. In all, five different populations, *viz.*, eight composites as parents, eight parental Selfs, 28 F_1s, 28 F_1s random mated and 28 F_1 selfs were evaluated at IARI, New Delhi, under irrigated and moisture stress conditions (rainfed) in Kharif season of 1989. The experimental material was sown in complete randomized block design with three replications. Each experimental population was raised in to rows each of five-metre length consisting of 20 plants each. The experimental material was sown in July third week following the monsoon rains. A distance of five metres was kept between the experimental fields with irrigation and rainfed conditions to avoid seepage effects on the results. Data on various morpho- physiological traits were recorded in both the experiments and analysis was done according to the analysis-II of the variety cross diallel [4]. The ANOVA Table was modified to include GCA × matings, h_j (variety heterosis) × matings, S_{ij} (specific heterosis) × matings, additive effects (A_j), dominance effect (D_k), GCA (V_j) and SCA (h_{ij}). For correlation analysis data on eight parental composites and 28 F_1s evaluated under optimum moisture [I_4-four irrigations], limited moisture (I_2-with only two irrigations) and moisture stress (I_0-rainfed) conditions at IARI were used. A distance of three metre was kept between the materials with four irrigations (I_4) and with two irrigations [I_2], and the rainfed experiment (I_0) was sown in a different field five metre apart from the irrigated field so as to avoid seepage effects on the results. In limited irrigation treatment, two irrigations at critical stages, that is, at knee-high stage (40 DAS) and at flowering stage (65-70 DAS), were applied. In the rainfed treatment, no irrigation was given throughout the crop period

Results and discussion

The distribution of rainfall during the crop season of 1989 was as follows; July 52 mm, August 55 mm, September 70 mm, October 6.2 mm and November 9.2 mm. The crop was sown in third week of July. Though August and September received above 50 mm rainfall, this was well short of optimum and in addition, most of the rainfall during September was during first and second week while, third and fourth week together received only 10 mm rainfall. In all, The rainfall during the crop season (July-November, 1989) was 192.8 mm, which can be considered as a moisture deficient season and a good condition to test material under moisture stress (rainfed) conditions as water requirements of maize during the kharif season has been reported to be about 500 mm [5]. The flowering and post flowering periods of rainfed crop experienced moisture stress due to very low rainfall during that period. Thus, it provided an opportunity to carry out correlation and regression analysis under sufficient moisture (I_4), limited moisture (I_2) and moisture deficit (I_0) conditions, and genetic and heterosis components, extent of heterosis and heritability under sufficient moisture (irrigated) and moisture stress (rainfed) conditions. The results and discussion of experiments are presented below.

Genetic components: The total heterotic effect h_{ij}' was partitioned into effect due to average heterosis (h^-), effect due to varietal effect (h_j') and due to specific effects (Table 1). The average heterosis contributed by the particular set of varieties used in crosses was significant for grain yield under both the moisture regimes. But significance of h^- × matings interaction was observed for grain yield under irrigated condition and for test weight under both conditions. It was also observed that parental varieties differ in the contribution to heterosis for grain characters as heterosis due to varietal effect (hj) was highly significant under irrigated and rainfed conditions. The variance due to specific heterosis (S_{ij}') in hybrids was not altered due to change in matings under irrigated conditions. However, S_{ij}' × matings was significant for grain yield and test weight under rainfed conditions. Further partitioning of h_{jj}' into variance due to average heterosis (h^-), varietal heterosis (h_j) and specific heterosis revealed that average heterosis was significant for days to 50% silking under both moisture situations and under rainfed conditions only for days to 50% tasseling. And also hj was significant for leaf area, days to 50% silking and tasseling under both the conditions. While, S_{ij}' was significant for leaf area under irrigation only. Similarly, h^- × matings, h_j × matings and S_{ij}' × matings interactions were significant for various characters, which can be seen from, the Table 1.

The differences among matings were significant for morpho-physiological traits indicating that morphological traits differed from one mating to another [9]. The present statistical model (analysis-II) of Gardner and Eberhart (1966) has been extended to compute the interaction of *GCA* and *SCA* variances with matings so that genetic information for the effect of mating on *GCA* and *SCA* variances in crosses can be derived. The differences among matings were significant under both moisture regimes for grain yield. Both *gca* and *sca* effects significantly interacted with matings for grain yield and test weight under both irrigated and rainfed conditions indicating that *SCA* and *GCA* estimates differed significantly in different matings.

The *GCA* variance (V_j) contributed by variety j in its crosses as its deviation from average heterosis, irrespective of mating design which has been defined as general combining ability of parental lines in crosses was significant for grain yield and test weight. Thus, parents do possess significant differences among themselves in their ability to contribute to heterosis in their crosses due to additive genes which was expressed under both irrigated and rainfed conditions. The variance due to additive effects ((a_j), due to heterozygous loci and dominance effects (d_k) due to heterozygous loci in parents were significant for grain yield and test weight [10]. The variance due to dominance effects (d_k) were significant for leaf area, days to 50% tasseling, days to 50% silking, plant height and cob width under both irrigated and rainfed conditions. Thus, there was a significant variation among parental composites for additive and dominance effects.

Heritability: The different hybrid sets i.e., F_1 hybrid (C_{jj}), F_1 hybrid selfed ($C^s_{jj}{}'$) and F_1 random mated (C^r_{jj})′ form distinct bases for development of hybrids, inbreds and composites. The heritability of various characters has been estimated using ANOVA method on individual diallel sets (Table 1). The highly heritable traits under irrigated as well as rainfed situations are test weight, plant height and cob width. These characters showed consistency in heritability over different moisture regimes and also exhibited significant correlation with yield. Thus, these traits form a set of secondary traits to select for higher yield both under stress and non-stress conditions. These secondary traits are important in selection as heritability for yield is very low. The heritability estimates changed with mating system. The implication of this was that direct selection for yield made under stress would not be effective even by changing the mating system. Therefore, it is suggested to select for grain yield under no stress situation and to select for correlated secondary traits of yield with high heritability under stress or rainfed situations for improving yield under moisture stress.

Studies on Heterosis: The wider adaptation and better performance of hybrids than their inbreds is a known phenomenon even under drought [8]. The present study also brings out the fact that F_1 hybrids were better than parental composites for grain yield under both irrigated and rainfed conditions. This was confirmed by the average heterosis values over better parental composites under irrigated (16%) and rainfed conditions (11.7%). The hybrid Comp 8527 × Comp DRC-8601 deserves special mention as it performed exceedingly well under irrigated as well as rainfed conditions (Table 2).

The heterosis estimates showed that for grain yield, out of 10 top heterotic crosses (data not shown) five involved A-76 and the rest five involved DRC-8601 as one of the parents in both irrigated and rainfed conditions and the cross A-76 × A-68 topped in heterobeltiosis for grain yield, test weight, plant height, leaf area, cob length and cob width. These composites can further be utilized for development of high yielding

Table 1. ANOVA for heterosis and genetic components and heritability estimates under two levels of water stress

Source of Variation	df	VARIANCE															
		Days to 50% tasseling		Days to 50% silking		Plant height (cm)		Leaf area (cm^2)		Test weight (g)		Cob length		Cob width		Grain yield/ plant (g)	
		IR	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF
h^-	1	2.2	19.4	2.8**	14.2**	12.3**	211.6	0.7	15.8	21.2**	0.9**	0.7	0.3	0.5	4.9	413.2**	287.5**
H_j	7	9.3**	8.2	2.7**	39.9**	7.6**	405.7**	829.9**	1168.4**	14.3**	9.2**	5.9**	4.3	7.7**	16.8**	1065.2**	405.4**
S_{ij}'	20	1.4**	2.3**	2.4**	6.7**	0.9	8.0	66.2	468.2**	1.6**	1.3**	0.2	0.6	1.0	0.7	36.5	26.6**
A_j	70	4.8**	5.3**	5.2**	14.0**	7.8**	62.5	334.1**	502.9**	5.8**	6.3**	1.1	1.1	7.2**	4.5	148.9**	38.7**
D_k	8	5.0**	3.3**	5.3**	11.4**	1.9**	67.1**	540.7**	446.7**	8.5**	11.1**	1.8	4.0	5.7**	8.2*	255.5**	130.0**
GCA(v_j)	7	4.7**	8.2**	3.7**	14.0**	23.1**	201.0**	816.2**	603.4**	13.7**	16.7**	2.5*	4.3	25.0**	18.0**	414.2**	90.7**
SCA(h_{ij}')	28	3.4**	4.3**	4.2**	15.3**	2.9**	114.7**	254.8**	627.4**	5.4**	3.2**	1.6*	1.5	2.7	4.9	307.2**	130.6**
matings	2	129.1**	143.3**	146.2**	279.9**	0.8	379.4**	2128.5**	2203.7	4.4**	19.6**	24.5**	19.6	146.2**	78.2**	9206.5**	1618.3**
GCA× matings	14	2.3**	1.9**	3.3**	8.6**	5.0**	134.7*	239.1**	523.1**	5.1**	2.6**	1.6*	1.6	2.7	3.6	187.0**	80.3**
SCA× matings	56	3.9**	2.7**	3.6**	8.1**	3.0**	98.9	282.6**	20.3**	3.8**	3.4**	1.2	1.3	3.1*	3.7	167.1**	92.2**
h^- × matings	1	14.7**	24.1**	14.5**	27.8**	2.1	274.4	1797.8**	643.5**	5.8**	26.0**	1.5	3.8	7.8**	8.6	751.1**	5.6
H_j× matings	7	15.2	14.6**	17.6**	54.1**	17.8**	560.8**	1577.9**	2051.3**	25.2**	14.0**	8.3**	7.8	16.1**	25.3**	1024.0**	617.7**
S_{ij}'× matings	40	2.4**	0.6**	1.6**	1.3**	1.1**	33.4	74.6	73.3	0.8	1.6**	0.2	0.3	1.3	0.5	35.9	20.9**
Error	210	0.8	0.6	0.8	0.6	0.6	74.8	64.4	80.6	0.8	0.4	1.0	0.6	2.2	2.5	51.2	9.4
Heritability																	
C_{jj}'	-	18.3	8.6	15.0	7.7	29.6	29	17.5	15.6	32.7	36.4	34.5	1.2	30.3	31.4	22.9	6.5
$C^s_{jj}{}'$	-	13.8	3.8	20.8	60.6	43.8	9.2	52.6	15	35.4	13.8	47.6	1.6	67.0	7.0	14.8	15.8
$C^r_{jj}{}'$	-	21.2	22.3	16.9	19.1	23.3	18.6	16.6	36.5	22.9	44.9	9.8	22.0	44.5	21.3	16.6	20.1

h^- - average heterosis; H_j - variety heterosis; S_{ij} - specific heterosis; A_j - additive effect; D_k - dominance effect

Table 2. Character-wise top crosses exhibiting significant heterosis in different matings under irrigated and rainfed conditions in maize

Character	F_1's (C_{jj}')		F_1's self (C^s_{jj}')		F_1's random mated (C^r_{jj}')	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Plant height	A-76 × A-68 (12.2)	DRC8601 × A-68 (15.2)	Comp8527 × 8551 (12.5)	Comp.8557 × DRC 8601 (12.5)	Comp85134 × 8527 (10.8)	Comp.8527 × A-68 (16.4)
Leaf area	Comp85134 × 8551 (30.0)	Comp8527 × DRC 8601 (–27.5)	Comp.85134 × A-76 (37.6)	Comp.8551 × A-68 (–26.6)	No hybrid recorded positive heterosis	Comp.8527 × DRC 8601 (–34.1)
DFT	Comp8527 × 8551 (–7.5)	Comp85164 × 8551 (–11.2)	Comp85134 × 85164 (–15.0)	Comp85134 × DRC8601 (–9.8)	Comp8557 × 8557 (–5.1)	Comp8527 × DRC 8601 (–10.1)
DFS	Comp8527 × A-76 (–9.5)	Comp8527 × 8557 (–16.8)	Comp 85134 × 8557 (–10.7)	Comp85134 × 8557 (–13.0)	Comp85134 × 8527 (–6.8)	Comp 85134 × DRC8601 (–14.5)
Cob length	DRC8601 × A-68 (20.9)	Comp8527 × DRC8601 (20.8)	Comp8527 × 8551 (13.0)	Comp8557 × DRC 8601 (69.8)	DRC8601 × A-68 (18.9)	Comp8527 × 8551 (21.8)
Cob width	A-76 × A-68 (10.2)	Comp85164 × DRC8601 (19.8)	No significant positive heterosis	Comp85134 × 8527 (40.9)	Comp8527 × A-76 (7.3)	Comp8527 × 8557 (13.7)
Test weight	A-76 × A-68 (32.8)	All hybrids showed negative values	A-76 × Comp.8551 (27.8)	Comp.8557 × A-76 (46.2)	Comp.8527 × A-76 (31.9)	No significant positive heterosis
Grain yield	A-76 × A-68 (54.8)	Comp8527 × DRC8601 (104.5)	Comp.85134 × A-76 (40.0)	Comp.8551 × A-68 (166.6)	DRC8601 × A-68 (44.9)	Comp.8527 × DRC 8601 (81.8)

better combining inbreds for hybrid breeding for irrigated as well as for moisture stress conditions.

Correlation Studies: The correlation coefficients among different characters under optimum moisture (I_4) limited moisture (I_2) and moisture stress (I_0) condition are given in Table 3. Grain yield was positively and significantly correlated with test weight, plant height, cob length, cob width, number of rows per cob and number of grains per cob consistently under I_4, I_2 and I_0 conditions. Thus, increase in any of these traits would enhance the grain yield. Early growth vigor and good grain filling have been reported to be associated with stable yields under water stress situations [6]. In case of water deficit (I_0) situation correlation of grain yield with days to 50% silk emergence and 50% tasseling were non-significant and hence earliness could not confer advantage under moisture stress. Therefore, under water stress grain yield will be determined by test weight, cob components and plant height. Another important point is that the leaf characteristics could not exhibit significant influence on grain yield. However, days to 50% silking under I_2 and I_4 was significantly and negatively correlated with yield. Therefore early maturity confers the advantage under moderate moisture stress possibly due to avoidance mechanism [3].

It is also interesting to note that test weight which showed positive correlation with plant height, cob length and cob width, did not show significant relationship with other grain characters (data not shown). Number of grains/row showed negative correlation with silking and tasseling revealing that selection for earliness will enhance number of grains per row under moisture stress situations. This could be due to the synchronization between tasseling and silking characters ensuring better seed setting. Though there was a positive correlation between days to silking and tasseling under all the three moisture conditions, anthesis silking interval increased under stress. The delay in silking under moisture stress is undesirable, as seed set would be affected due to both non-availability of pollen and possible decline in pollen fertility.

Regression analysis: The multiple regression equations fitted through stepwise regression technique are presented below along with coefficient of determination (R^2).

In I_4, $\mathbf{Y} = -70.36 + 0.79\ X_1 + 0.16\ X_2 + 1.02\ X_3 + 1.48X_4 + 1.73\ X_5;\ R^2 = 0.47$

In I_2, $\mathbf{Y} = -69.43 + 0.85\ X_1 + 0.19\ X_2 + 3.02\ X_4 + 1.71\ X_5;\ R^2 = 0.37$

In 10, $Y = -9.98 + 0.46\ X_1 + 0.56\ X_3 + 0.66\ X_5 + -0.004\ X_6;\ R^2 = 0.26$

Where,

X_1 = cob width X_2 = plant height X_3 = grains/row

X_4 = cob length X_5 = test weight X_6 = leaf area

From the above equations it is seen that the grain yield in I_4 can be predicted by a combination of characters such as cob width, plant height, grains per row, cob length and test weight. All these characters possessed positive regression coefficients. Thus, increase in their magnitude would enhance the grain yield. The R^2 =0.47 indicates that present equation accounts for 47 per cent variation. Similarly, characters that were important under I_2 and I_0, can be known by

Table 3. Correlation of yield with yield components and morpo-physiological traits under different levels of moisture stress in maize

Moisture regime	Test wt.	Cob length	Cob width	NR	NG	Pl. height	Leaf area	Leaf wt.	DFT	DFS
I_4	0.42**	0.56**	0.55**	0.29**	0.55**	0.44**	0.25**	0.09	–0.16	–0.27**
I_2	0.40**	0.53**	0.45**	0.27**	0.38**	0.43**	0.15	0.07	–0.24*	–0.26**
I_0	0.26**	0.44**	0.41**	0.27**	0.42**	0.27**	0.01	0.02	–0.19	–0.16

*,** - Significant at 5% and 1% level of probability, respectively;
DFT - Days to 50% tasseling; DFS - days to 50% silking; NR - Number of rows per cob; NG - Number of grains per row

seeing the prediction equation given above and also the variation accounted by the equations. It is interesting to note that X_1 (Cob width) and X_5 (Test weight) are there in all three-regression equations.

The preferred method of selections should involve a combination of direct and indirect selection using a selection index of desirable secondary traits and grain yield under stressed and unstressed conditions. However, in breeding where enhanced yield potential is a major breeding goal, the breeder might consider making 75% traditional breeding efforts (direct selection for yield) and 25% traits oriented [7]. From this statement it appears that one should select for yield as well as secondary traits. Contribution of some characters changed under water stress situation as plant height did not make significant contribution and leaf area was negatively correlated with yield under water stress. Correlation and regression analysis suggested that low leaf area in conjugation with selection for higher cob width; more number of grains per rows and bigger seed size would form effective selection criteria under water stress situations.

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