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Genetic analysis in maize (*Zea mays* L.) under moisture stress conditions

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Abstract

The present study was undertaken to assess combining ability, heterosis and association among morpho-physiological traits of maize under stress and optimum conditions. Elite maize inbred lines with known performance under drought were crossed in half diallel fashion. The resulting hybrids and their parents were evaluated under managed drought and optimum conditions. CI 4, Hyd Sel 4 and KDMI 15 recorded high mean grain yield and significant positive gca effects under stress where as CML 446 and NEI 9208B recorded high mean grain yield with significant positive gca effects under optimum conditions. CI 4 and NEI 9202B were identified as good combiners for grain yield. Among the 66 hybrids, 15 under optimum conditions and 21 under stress recorded significant positive heterosis over mid parent. Three hybrids *viz.,* KDMI 15 x NEI 9202B, Hyd Sel 4 x NEI 9202B and NEI 9208B x Hyd Sel 15 were identified as high grain yielding under stress and optimum conditions. The hybrids *viz.,* Hyd Sel 15 x Hyd Sel 17 (4.18 t ha^{-1}), KDMI 15 x NEI 9202B (4.01 t ha^{-1}), NEI 9208B x Hyd Sel 15 (3.96 t ha^{-1}), CM 111 x CI 4 (3.96.5 t ha^{-1}) and KDMI 15 x Hyd Sel 15 (3.88 t ha^{-1}) recorded good grain yield under stress.

Key words: Maize, moisture stress, heterosis, combining ability, association of traits.

Introduction

Drought is the most pervasive limitation to the realization of grain yield potential in maize [1]. Average annual global losses due to drought in maize range from 15% in temperate zone to 17% in tropical zone [2]. It is now accepted that the global climatic changes may cause disturbances which may adversely affect distribution pattern of rainfall, that will result in poor and scanty rainfall in one area causing severe water deficit and heavy and concentrated rainfall in other, causing water logging coupled with heavy nutrient leaching in light soils [3]. Breeding maize for drought tolerance is important to close the grain yield gap between rainfed and well watered conditions. Water-conserving growing practices with limited or complete irrigation play a critical part, but are limited in many parts of the world due to water availability or economic reasons for non-adoption. Genetic solutions although not complete can be more easily packaged, promoted and adopted than agronomic and other input dependent practices.

Occurrence of drought is unpredictable; it can occur at any stage of the crop. Maize is very sensitive to water stress in the period one week before flowering to two weeks after flowering [4]. Drought during this period results in an easily measured increase in the anthesis- silking interval (ASI) as the silk emergence is delayed [3] and in grain abortion [5]. When the drought occurs at 75 per cent silking, grain yield loss to the extent of 53 per cent is noticed [6].

Based on the consideration of heritability and correlation with grain yield under stress, Banziger *et al.* [7] proposed secondary traits such as barrenness, ASI, leaf senescence and leaf rolling were useful for improving maize in drought-prone environments. An effective breeding strategy for developing drought tolerant cultivars primarily depends on a sound knowledge and understanding of the inheritance

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mechanism of stress tolerance. Besides this, the information on combining ability and gene action for different agronomic characters is also important to decide upon choice of parents for hybridization and exploitation of heterosis in maize. Hence, it is desirable to generate information on combining ability of popularly used inbred lines. In the present study, an attempt was made to estimate heterosis, combining ability, variances and effects and correlation for drought related traits under water stress (here after stress / drought) and optimum conditions separately.

Materials and methods

Twelve inbred lines varying for drought tolerance were used to generate diallel crosses (Table 1). Among the inbred lines, CI 4 and CML 446 were from CIMMYT maintained at All India Coordinated maize Improvement Project (AICMIP), Agriculture Research Station (ARS), Arabhavi and ARS, Nagenahalli, respectively. Hyd Sel lines were received by AICMIP, ARS, Arabhavi from Directorate of Maize Research, Winter Nursery, Amberpet, Hyderabad; KDMI 15 was developed at AICMIP, ARS, Arabhavi and NEI 9202B and NEI 9208B were introduced through Directorate of Maize Research (DMR), New Delhi as turcicum leaf blight resistant lines from Thailand. These inbred lines were selected from among 82 inbred lines evaluated during post rainy season 2007-08 under stress and under optimum conditions at Agriculture College Farm, Bheemarayanagudi (16^{o} 44' N, 76^{o} 47' E, 458 m msl), Karnataka, India [8]. A total of 66 hybrids were produced during rainy season 2008-09. Sixty six single cross hybrids along with their parents and seven commercial checks *viz.,* All-Rounder, Arjun, Bio 9681, NAH 2049, NK 6240, Rajkumar and 900M were evaluated in the field following randomized block design with two replications each under stress and optimum conditions. However, the best check (Rajkumar) was considered for computing the standard heterosis. The field experiments were conducted during post rainy seasons of 2008-09 and 2009-10 to avoid rains during the study.

The weather data during the crop growth period till physiological maturity indicated that during 2008-09, there were virtually no rains before and after flowering of the crop and thus facilitating a good evaluation for stress. During 2009-10, the rains in the month of November were received after the crop was sown and well before inducing the moisture stress for stress experiment. However, 30 days after withholding water for the stress experiment, one rainy event (16.5 mm) occurred in the month of January (at 68 DAS). Another rainy event (6.5 mm) that occurred in the month of February was at the time of physiological maturity. Over all, the experiment under stress was subjected to water stress as compared to the experiment conducted under optimum conditions.

The mean maximum temperatures- during the crop growth ranged from 30.8 to 34.8^{o}C during 2008-09 and 28.7 to 33.0^{o}C during 2009-10, respectively. The mean maximum relative humidity ranged from

Table 1. Details of maize inbred lines used in diallel study

Inbred line	Pedigree	Source	Reaction to drought
CM 111	-	Coordinated maize	S
CI 4	Pop 27-C5-HS-29-1-1	CIMMYT	T
CML 446	CML 446-#-NA-R-2006	CIMMYT	S
Hyd Sel 2	-	DMR Winter nursery, Amberpet, Hyderabad	MT
Hyd Sel 4	-	-do-	T
Hyd Sel 7	-	-do-	S
Hyd Sel 10	-	-do-	S
Hyd Sel 15	-	-do-	MS
Hyd Sel 17	-	-do-	MT
KDMI 15	1108-13-2-2-x#	Developed at AICMIP, Arabhavai, Karnataka	T
NEI 9202B	-	Introduced through, DMR from Thailand	MT
NEI 9208 B	-	-do-	MT

Note: S =Susceptible; T = Tolerant; MS = Moderately susceptible; MT = Moderately tolerant; DMR- Directorate of Maize Research, New Delhi; AICMIP – All India Coordinated Maize Improvement Project

Table 2. Estimates of gca effects and mean *per se* performance of parents for selected traits under optimum and stress conditions

Parents	Anthesis to silking interval		Ears per plant		Grain yield (t ha^{-1})		RWC at 90 DAS		Chlorophyll content at 90DAS		DSI
	Optimum	Stress	Optimum	Stress	Optimum	Stress	Optimum	Stress	Optimum	Stress	
CM 111	0.55** (3.25)	0.42** (3.50)	–0.046** (0.81)	–0.031 (0.69)	–0.76** (3.61)	–0.03 (2.02)	–0.01 (0.88)	–0.003 (0.66)	0.41 (46.07)	1.119* (24.41)	0.026 (1.19)
Hyd Sel 2	0.41** (3.00)	0.35* (3.00)	0.001 (1.00)	0.040* (0.89)	–0.22 (5.86)	–0.19** (2.26)	–0.007 (0.89)	–0.040** (0.52)	1.61** (50.89)	–0.403 (26.33)	–0.007 (1.03)
Hyd Sel 7	0.93** (4.50)	1.11** (5.00)	–0.033** (0.85)	–0.041* (0.64)	–0.62** (4.60)	–0.20** (1.650	–0.015* (0.87)	–0.028** (0.59)	–0.41 (47.77)	–0.259 (23.35)	–0.066* (0.98)
Hyd Sel 10	0.52** (2.75)	0.81** (4.25)	–0.009 (0.92)	–0.042** (0.76)	–0.01 (5.66)	–0.34** (1.88)	–0.020** (0.89)	0.004 (0.67)	–1.04* (47.57)	–0.556 (23.60)	0.109** (1.18)
KDMI 15	0.12 (1.75)	–0.37* (2.25)	0.012 (1.07)	0.021 (0.86)	–0.07 (6.67)	0.18** (2.78)	–0.021** (0.86)	–0.012 (0.77)	0.99* (48.99)	–0.184 (27.300)	–0.025 (1.11)
NEI 9208 B	–0.44** (1.75)	–0.22 (4.00)	0.037** (1.12)	0.001 (0.83)	0.39** (6.81)	0.12 (3.14)	0.014* (0.89)	0.01 (0.69)	0.08 (47.75)	0.011 (25.38)	–0.012 (0.92)
CI 4	–0.27** (1.50)	–0.31** (2.00)	–0.012 (0.92)	0.013 (0.82)	0.40** (6.53)	0.24** (2.96)	0.004 (0.90)	0.016 (0.63)	–0.21 (46.35)	0.184 (27.30)	–0.005 (1.01)
CML 446	–0.45** (1.50)	–0.04 (3.75)	0.029* (1.11)	–0.049** (0.61)	0.49** (7.53)	–0.23** (1.81)	0.017* (0.90)	0.022* (0.73)	–1.10* (47.67)	0.41 (26.36)	0.073** (1.20)
Hyd Sel 4	–0.01 (2.25)	–0.37* (2.50)	0.001 (1.05)	0.043** (0.92)	–0.04 (6.65)	0.15* (2.80)	–0.003 (0.85)	–0.01 (0.66)	1.73** (50.49)	0.836 (27.42)	–0.018 (1.10)
Hyd Sel 15	–0.11 (2.50)	–0.15 (3.50)	–0.007 (0.99)	0.038* (0.83)	0.32** (6.41)	0.22** (1.96)	0.006 (0.88)	0.012 (0.79)	1.12* (50.72)	0.088 (23.74)	0.007 (1.15)
Hyd Sel 17	–0.42* (1.50)	–0.37* (2.00)	–0.009 (0.93)	–0.009 (0.79)	–0.46** (5.86)	–0.05 (2.270	0.019** (0.93)	0.022* (0.70)	–0.45 (46.52)	–0.771 (26.24)	–0.038 (1.08)
NEI 9202B	–0.81** (1.50)	–0.89** (3.00)	0.037** (1.02)	0.016 (0.84)	0.58** (5.17)	0.13* (1.88)	0.016* (0.90)	0.007 (0.72)	–2.71** (41.09)	–0.474 (27.82)	–0.043 (0.98)
Mean	2.31	3.23	0.98	0.790	5.95	2.28	0.886	0.680	47.65	25.74	1.07
CD (gi) @5%	0.18	0.28	0.021	0.032	0.24	0.13	0.012	0.020	0.86	1.04	0.055
CD (gi-gj) @5%	0.27	0.41	0.034	0.046	0.35	0.19	0.022	0.025	1.28	1.54	0.080
CD @ 5%	0.77	1.54	0.18	018	1.40	0.73	0.07	0.13	4.56	ns	ns

Figures in the parentheses indicate mean *per se* performance; * and ** - Significant at 0.05 and 0.01 level of probability, respectively; ns= nonsignificant

52.4 to 66.7% during 2008-09 and 70.3 to 84% during 2009-10, respectively The dates of sowing of experiments were 14.11.2008 and 06.11.2009, respectively.

The experiments were conducted in deep black soils having a pH of 7.92 and electrical conductivity of 0.25 dS/m. The soils are poor in available nitrogen, medium in phosphorous and rich in potassium. Each entry was grown at a spacing of 75 cm x 20 cm in a plot size of one row of 4 m length. Two seeds were dibbled per hill and later thinned to retain one seedling per hill. The genotypes under optimum conditions received recommended cultural practices besides regular furrow irrigation at an interval of 10-12 days to avoid water-stress. The same genotypes under stress condition received recommended cultural practices but irrigation up to 40 days after sowing and no irrigation there after till harvest so that they experienced moisture stress during flowering and grain filling period. The irrigated and managed stress experiments were separated from each other by a four metre buffer zone of maize crop, which was sown along with these experiments.

The traits *viz.,* days to 50 per cent tasseling, days to 50 per cent silking, cobs per plant and grain yield per plot (later expressed as grain yield t ha^{-1}), were recorded on plot basis. The other traits were recorded on five randomly selected competitive plants per replication per genotype. Anthesis to silking interval was computed as the difference between silking and anthesis dates. Drought susceptibility index (DSI) was computed as per standard procedure [9] using mean values of each genotype under both the conditions. Relative water content (RWC) expresses the water in the original sample as a percentage of the water in the fully hydrated tissue. It was estimated by the prescribed method [10] at 60 and 90 days after sowing (DAS). Leaf discs of the third leaf from the top were used for the estimation of RWC. The chlorophyll content of the third leaf from the top was measured at 60 and 90 DAS on five random plants using chlorophyll meter (SPAD-502, Konica Minolta make). The SPAD readings were recorded as the average value of chlorophyll at lower, upper and middle portion of the leaf of sample plant. SPAD reading is equivalent to chlorophyll content mg cm^{-2} [11, 12]. However, the results of RWC and chlorophyll recorded at 90 days were presented and discussed as the differentiation of genotypes was easy at 90 days.

Analysis of variance for individual characters was carried out on the basis of mean value of the genotype per replication [13] for randomized block design (RBD). The pooled analysis over environments for combining ability was carried out separately for optimum conditions and stress as per the method suggested by Singh [14] based on model 1, method 2 of Griffing [15] with the help of WINDOSTAT 8.0 software.

Results and discussion

The inbred lines selected for the present study showed highly significant genotypic variability for anthesis to silking interval ($P<0.01$), cobs per plant ($P<0.01$) and grain grain yield ($P<0.01$) under both the conditions indicating differences among the genotypes (data not shown). They also showed significant genotypic variability for relative water content at 90 DAS ($P<0.05$) under stress and chlorophyll content at 90 DAS ($P<0.01$) under optimum conditions, respectively. Hybrids recorded significant genotypic variability for all the traits under both the conditions except number of cobs per plant under optimum conditions. The mean sum of squares due to interaction of parents versus hybrids were significant for most of the traits indicating the presence of average heterosis.

The ANOVA for combining ability revealed that variances due to GCA and SCA were significant for most the traits in both conditions indicating both additive and nonadditive gene actions in controlling the traits. The magnitude of GCA variance was greater than SCA variance for all the traits under both the conditions (except chlorophyll content at 90 DAS under stress) indicating the predominance of additive variance in controlling the expression of these traits.

Under drought, additive effects were more important and the importance of additive effects increased with intensity of drought suggesting the need for drought tolerance in both parental lines to achieve acceptable hybrid performance under severe drought [16].Whereas, the additive genetic effects were more important for grain yield under drought stress and well watered conditions but not under low N stress, suggesting different gene action in control of grain yield [17]. The variances of specific combining ability (SCA) were about double that of the general combining ability (GCA) for ASI and grain yield per plant [18].

The mean *per se* performance of parents indicated that the parents, namely, NEI 9208 B and CI 4 recorded high grain yield under both stress and optimum conditions (Table 2) and recorded 54 % less grain yield under stress. Hyd Sel 4 also recorded good grain yield under both the conditions with 58% less grain yield under stress. Inbreds CI 4, Hyd Sel 17, KDMI 15 and Hyd Sel 4 recorded poor anthesis to silking interval, whereas Hyd Sel 4 (0.92), Hyd Sel 2 (0.89), KDMI 15 (0.86) and NEI 9202 B (0.84) recorded more number of cobs per plant under stress. They also produced good number of cobs per plant under optimum conditions. Floral development and flowering stages are very sensitive to moisture stress. Stress period of drought/water shortages cause delay in anthesis, silking and anthesis to silking interval in maize [4]. Drought at flowering causes severe barrenness and destabilizes the grain yield. Ability of a genotype to produce an ear under such adverse conditions is an important characteristic of drought tolerance in maize. Ears per plant showed high heritability and strong relationship with grain yield and hence it has been used as a trait in selection for water limited environment. It received high importance, next to grain yield, in terms of weight in selection index [7].

Plant growth is directly controlled by plant water status and indirectly by soil water status. The relative water content (RWC) gives an idea of water retention capacity of a tissue. The relative water content of

Table 3. Mean *per se* performance, heterosis and sca effects for grain yield (t ha^{-1}) of selected hybrids under optimum and stress conditions

Hybrids	Grain yield (t ha^{-1})						% reduction in grain yield under stress	sca effects for grain yield (t ha^{-1})	
	Optimum			Stress					
	Mean	Hmp	Hcc	Mean	Hmp	Hcc		Optimum	Stress
CM 111 x CI 4	7.56	49.17**	–7.00	3.96	58.88**	–3.39	47.7	1.18*	0.88**
CM 111 x Hyd Sel 15	7.80	55.54**	–4.10	2.86	43.03	–30.35*	63.4	1.50**	–0.20
CM 111 x NEI 9202B	8.90	102.08**	9.17	3.25	65.71**	–20.97	63.5	2.30**	0.28
Hyd Sel 2 x KDMI 15	7.46	19.04	–8.29	2.99	18.58	–27.02*	59.9	0.99*	0.14
Hyd Sel 2 x Hyd Sel 17	7.82	33.23*	–3.93	2.03	–10.08	–50.31**	73.9	1.75**	–0.58*
Hyd Sel 2 x NEI 9202B	7.30	31.71*	–10.62	3.76	81.85**	–8.08	48.2	0.15	0.96*
Hyd Sel 7 x Hyd Sel 15	7.43	34.86*	–8.69	3.18	76.24**	–22.3	57.1	0.97*	0.29
Hyd Sel 10 x NEI 9208B	8.15	30.35*	–0.01	2.53	1.08	–38.11**	68.8	0.99*	–0.10
Hyd Sel 10 x Hyd Sel 15	8.12	34.43*	–0.21	3.00	56.35*	–26.66*	63.0	1.04*	0.26
Hyd Sel 10 x NEI 9202B	8.25	52.32**	1.45	2.98	58.52*	–27.23*	63.9	0.91*	0.33
KDMI 15 x NEI 9208B	8.21	21.74	0.94	2.65	–10.25	–35.13**	67.6	1.14*	–0.50*
KDMI 15 x Hyd Sel 15	5.85	–10.66	–28.14*	3.87	63.38**	–5.31	33.6	–1.16*	0.61*
KDMI 15 x NEI 9202B	8.86	49.64**	8.95	4.01	72.00**	–2.04	54.7	1.60**	0.84**
NEI 9208B x CI 4	7.93	18.78	–2.54	3.37	10.79	–17.59	57.4	0.38	0.15
NEI 9208B x CML 446	7.80	8.52	–4.23	2.35	–5.02	–42.61**	69.8	0.15	–0.40
NEI 9208B x Hyd Sel 4	7.50	11.21	–7.87	2.60	–12.65	–36.75**	65.4	0.40	–0.53*
NEI 9208B x Hyd Sel 15	8.10	22.32	–0.48	3.96	55.27**	–3.31	51.0	0.62	0.75**
CI 4 x CML 446	8.63	22.72	6.10	3.54	48.73*	–13.41	58.9	0.98*	0.68*
Hyd Sel 4 x NEI 9202B	8.63	45.85**	6.09	3.74	59.92**	–8.69	56.6	1.33**	0.59*
CML 446 x NEI 9202B	8.65	36.08**	6.33	2.68	45.38	–34.43**	68.9	0.81	–0.71
Hyd Sel 15 x Hyd Sel 17	6.16	0.33	–24.25*	4.17	97.43**	2.00	32.1	–0.45	1.14**
Hyd Sel 15 x NEI 9202B	7.75	33.72*	–4.72	3.33	73.61**	–18.49	56.9	0.08	0.12
Rajkumar (check)	8.14			4.09			49.6		
Mean	6.90	17.08	–15.18	2.96	31.76	–27.65		6.90	2.96
Range	–4.17 –8.88	–18.30 –102.08	–48.61 –9.17	1.76 –4.17	–16.71 –97.43	–56.96 –2.00			
CD at 5%	1.88			1.03			CD (Sij) @5%	0.87	0.48
CD at 1%	2.48			1.36			CD (Sij-Skl) @5%	1.23	0.67

Hmp = Heterosis over mid-parent, Hcc = Heterosis over commercial check.* & ** - Significant at 0.05 and 0.01 level of probability, respectively.

leaves decreased under stress compared to optimum condition. Hyd Sel 15 maintained relatively good (90 % of the normal conditions) at 90 days after sowing. With increasing stress, the RWC decreased, while free proline content increased [19]. Chlorophyll concentration is a measure of functional stay green [20]. The chlorophyll content decreased under stress and it also decreased with age (data not shown) but it was drastic under stress. Inbred lines, NEI 9208B, NEI 9202B, Hyd Sel 7 and CI 4 recorded lower DSI values indicating their drought tolerance ability.

General combining ability of parents is reckoned as a factor in predicting the performance of cross combinations. Generally, parents with high mean values are preferred in hybridization programme as they are predicted to produce desirable segregants. The parents with good mean performance would result in better genotypes. But this need not be the case all the times, in such situation, the combining ability effects will have to be considered [21]. General combining ability (gca) effects of lines for selected traits revealed that CI 4 and NEI 9202B were good general combiners for ASI and grain yield under both the conditions by recording desirable (significantly negative for ASI and significantly positive for grain yield) gca effects. While CM 111, Hyd Sel 2, Hyd Sel 7 and Hyd Sel 10 were poor general combiners for the same traits (Table 4). Hyd Sel 4 recorded desirable gca effects for ASI, ears per plant and grain yield under stress and for chlorophyll content at 90DAS under optimum conditions. Whereas NEI 9208B recorded desirable gca effects for ASI, ears per plant, grain yield and RWC at 90 DAS under optimum conditions. Hyd Sel 17 recorded desirable gca effects for ASI and RWC at 90 DAS under both the conditions. While KDMI 15 showed desirable gca effects for ASI and grain yield under stress and for chlorophyll content under optimum conditions. Hyd Sel 2 recorded desirable gca effects for DSI.

Among the parental lines used in the study, three inbred lines, namely, CI 4, Hyd Sel 4 and KDMI 15 recorded high mean grain yield and significant positive gca effects for grain yield under stress and hence, they could be used as parents for production of new hybrids tolerant to stress. Similarly, CML 446 and NEI 9208B recorded high mean grain yield with significant positive gca effects for grain yield under optimum conditions. NEI 9202B and NEI 9208B were good combiner for ears per plant with high *per se* performance for the trait under optimum conditions.

Among the 66 hybrids tested for two seasons, CM 111 x Hyd Sel 7 (4.18 t ha^{-1}) and CM 111 x NEI 9202B (8.87 t ha^{-1}) recorded the lowest and highest grain yield, respectively with an overall mean of 6.89 t ha^{-1} under optimum conditions (Table 3). Under moisture stress, Hyd Sel 7 x Hyd Sel 10 (1.76 t ha^{-1}) and Hyd Sel 15 x Hyd Sel 17 (4.17 t ha^{-1}) recorded lowest and highest grain yield. The overall mean of hybrids was 2.96 t ha^{-1} (about 57% less grain yield under stress).

The average heterosis over midparent and check was 17.08 and –15.18% under optimum conditions and 31.76 and –27.65% under stress, respectively. None of the hybrids showed significant positive standard heterosis for grain yield in either of the environments over the best check. However, 15 hybrids under optimum conditions and 21 hybrids under moisture stress recorded significant positive heterosis over mid parent. Eight hybrids, namely, CM 111 x CI 4, CM 111 x NEI 9202B, Hyd Sel 10 x Hyd Sel 15, Hyd Sel 10 x NEI 9202B, KDMI 15 x NEI 9202B, Hyd Sel 4 x NEI 9202B and Hyd Sel 15 x NEI 9202B expressed significant positive heterosis over mid

Table 4. Genotypic and phenotypic correlation of grain yield with physiological traits of maize under optimum and stress conditions

S.No.	Trait	r value	
		Stress	Optimum
1	Plant heightG	–0.175	0.379**
	P	–0.117	0.285*
2	Ear height	0.006	0.407**
		–0.079	0.166
3	Days to 50% tasseling	–0.214	0.570**
		–0.182	0.174
4	Days to 50% silking	–0.399**	0.486**
		–0.313	0.091
5	ASI	–0.457**	–0.738**
		–0.231	–0.227
6	Days to maturity	–0.219	0.258*
		–0.220	–0.017
7	Cob length	0.894**	0.962**
		0.413**	0.232
8	Cob girth	0.608**	0.381**
		0.437**	0.285*
9	Number of grain rows per cob	0.219	0.172
		0.217	0.095
10	Grains per row	0.326**	0.253*
		0.249*	0.271*
11	Ears per plant	0.769**	0.272*
		0.549**	0.224
12	Shelling per cent	–0.079	0.751**
		–0.107	0.218
13	100 grain weight	0.304**	0.144
		0.293*	0.225
14	RWC at 90 DAS	–0.358**	0.528**
		–0.102	0.127
15	CHL at 90 DAS	–0.194	–0.138
		–0.030	0.017
16	DSI	–0.533**	-
		–0.336	

*,**-Significant at 0.05 and 0.01 level of probability, respectively. G and P indicate genotypic and phenotypic correlation coefficients, repectively.

parent under both the conditions indicating their drought tolerance as well as ability to respond to high input management under stress free environment.

The minimum grain yield loss under stress was recorded by Hyd Sel 15 x Hyd Sel 17 (32.1 %). The other top ranking hybrids under stress were: Hyd Sel 15 x Hyd Sel 17 (4.17 t ha^{-1}), KDMI 15 x NEI 9202B (4.01 t ha^{-1}), NEI 9208B x Hyd Sel 15 (3.96), CM 111 x CI 4 (3.95 t ha^{-1}) and KDMI 15 x Hyd Sel 15 (3.87 t ha^{-1}). All the top ranking hybrids were derived from either tolerant x tolerant or tolerant x susceptible parents. The hybrids namely, CM 111 x CI 4, KDMI 15 x NEI 9202B, CI 4 x CML 446 and Hyd Sel 4 x NEI 9202B showed good specific combining ability for grain yield (t ha^{-1}) under both the conditions by recording significant positive sca effects. Whereas, CM 111 x Hyd Sel 15, CM 111 x NEI 9202B, Hyd Sel 2 x KDMI 15, Hyd Sel 2 x Hyd Sel 17, Hyd Sel 10 x NEI 9208B, Hyd Sel 10 x Hyd Sel 15, Hyd Sel 10 x NEI 9202B and KDMI 15 x NEI 9208B under optimum conditions recorded significant positive sca effects. The hybrids, CM 111 x NEI 9208B and Hyd Sel 15 x Hyd Sel 17 were good specific combiner for grain yield under stress as revealed by their significant positive sca effects.

In any breeding programme, grain yield is the ultimate goal. Occurrence and intensity of drought cannot be predicted in advance. Hence, genotypes selected or developed should be able to withstand drought and give fairly good grain yield under moisture stress/drought, but at the same time they should also be able to utilize the resources better under stress free conditions and give much better grain yields under stress free environment. This is very true because moisture stress/drought may occur in one year and may not occur next year; under such conditions, there should not be any grain yield penalty to the growers planting drought tolerant hybrids/genotypes.

It is well known that drought tolerance/resistance is a very complex phenomenon. Grain yield of plant is the net result of several genetic factors and their individual or combined interplay with environmental factors. Therefore, character association among themselves or with grain yield is of great importance. Here, only the association of grain yield with other traits under moisture stress and optimum conditions is presented and discussed. The grain yield under moisture stress (drought) showed significantly negative association with days to 50% silking, anthesis to silking interval, RWC at 90 DAS and DSI at genotypic and/or phenotypic levels (Table 4). Whereas it was positively associated with cob length, cob girth, number of grains per row, number of ears per plant and 100 grain weight. Under optimum conditions, grain yield exhibited significantly positive association with most of the characters except ASI at genotypic level. Bolanos and Edmeades [22] observed significant positive genetic correlations between grain yield and kernels per plant (0.86 to 0.88) under severe drought stress at flowering. Monneveux *et al.* [23] reported in two drought tolerant populations *viz*., DTP 1 and DTP 2 that significant grain yield gains in the populations were associated with a significant increase in number of cobs per plant and grains per ear and significant reductions in anthesis to silking interval, ovule number and abortion rate during grain filling. Abortion rate was positively correlated with the number of ovules at silking and anthesis-silking interval.

Inbred lines namely, CI 4, Hyd Sel 4 and KDMI 15 were identified as drought tolerant and good general combiners for grain yield under moisture stress. CI 4 and NEI 9202B were identified as good general combiners for ASI and grain yield under both stress and optimum conditions. Three hybrids *viz.,* KDMI 15 x NEI 9202B, Hyd Sel 4 x NEI 9202B and NEI 9208B x Hyd Sel 15 were identified as high grain yielding hybrids under stress and optimum conditions. Whereas, Hyd Sel 15 x Hyd Sel 17 (4.17 t ha^{-1}), KDMI 15 x NEI 9202B (4.01 t ha^{-1}), NEI 9208B x Hyd Sel 15 (3.96 t ha^{-1}), CM 111 x CI 4 (3.95 t ha^{-1}) and KDMI 15 x Hyd Sel 15 (3.87 t ha^{-1}) were identified high grain yielding hybrids under moisture stress (drought) conditions. These hybrids could be further tested under rainfed conditions and released for commercial cultivation.

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