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Estimation of general combining ability effects on phenological, physiological and yield component under non-stress and stress conditions in maize

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Abstract
Maize is one of the most important crops of world agricultural economy and ranks third next to rice and wheat in production. By origin, maize is native to South America and has adapted significantly to temperate condition with much higher productivity. Performance of inbred lines in top crosses with divergent half Diallyl crosses known origin can be used as a practical tool to determine the heterotic patterns among the lines under drought and non-stressed conditions. Ten corn inbred lines (DMIL 230, DMIL 438, DMIL 447, DMIL 516, DMIL 553, DMIL 607, DMIL 692, DMIL 715, CML 425 and NC 468) were used as female and male parents. GCA is the relative ability of an individual to transmit genetic superiority to its offspring when crossed with other individuals, although the GCA of a parent signifies the average performance of its progenies in various crosses, compared with progenies of other parents in the same test and the breeding value of a parent is twice its GCA, while SCA is the degree to which the average performance of a specific family (usually full sibs) departs from the average of its parental breeding values. DMIL 447 (-0.86), DMIL 516 (-0.62) under stress recorded significant negative gca effects indicating that they were good combiners for days to 50 per cent anthesis. The DMIL 553 (22.18) and NC 468 (26.65) parents were recorded significant positive gca effects under stress for good combining ability CML 425 (0.01) recorded non-significant positive gca effects proved to be a good combiner for DSI.

Keywords: Estimation, general combining, phenological, maize

Introduction

Maize is one of the most important crops of world agricultural economy and ranks third next to rice and wheat in production. Globally, maize is known as ‘Queen of Cereals’ because of its highest genetic yield potential among cereals. By origin, maize is native to South America and has adapted significantly to temperate condition with much higher productivity. Being a C_4 plant, it is physiologically more efficient and has higher harvest index and wider adaptability to a range of environmental conditions. Maize is one of the important cereal crops occupying 144 m ha with a production of 695 million tonnes in the world. In India, maize occupies an area of 9.20 million hectares with the production of 24.70 million tonnes and the average productivity is 2,566 kg ha^{-1} (Anon., 2016) [2]. The productivity of maize in India is low (2,566 kg/ha) as compared the world average (4,815 kg ha^{-1}). Maize is used as food grains for human and animals. Therefore, corn breeders make great and continuous efforts to improve the yielding ability of this crop. Performance of inbred lines in top crosses with divergent half Diallyl crosses known origin can be used as a practical tool to determine the heterotic patterns among the lines under drought and non-stressed conditions. Previous report in maize under drought condition elucidate the nature of performance in yield and its components (Najeeb *et al.* 2009: Khalily *et al.* 2010) [20, 11]. A selection index (SI) for standardized variables across environments across water regimes. SI, illustrated by Smith (1936) [27], gives proper weight to each of two or more characters to be considered for selecting better genotypes. When the economic importance of a plant type is considered, the entry with the highest yield may not get the highest score resulting from use of the SI (Robinson *et al*. 1951). A number of studies in maize have been conducted to elucidate the SI which identify traits like ear length, ear diameter, number of kernels/row, number of ears/plant, 100-kernel weight, and number of rows/ear as potential selection criteria in breeding programs aiming at higher yield (Tollenaar *et al.* 2004; Awadalla *et al.* 2007; Najeeb *et al.* 2009; Khalily *et al.* 2010) [30, 20, 11].

The half Diallel method proved to be efficient in testing inbred lines for general combining ability (GCA) and identifying the more promising inbred lines by making fewer crosses than the possible single cross combinations among the same number of lines (Kempthorne, 1957) [10].

After selecting the more promising high general combiner lines, it is necessary to identify the particular combination that will produce the highest yield through specific combining ability (SCA). GCA is the relative ability of an individual to transmit genetic superiority to its offspring when crossed with other individuals, although the GCA of a parent signifies the average performance of its progenies in various crosses, compared with progenies of other parents in the same test and the breeding value of a parent is twice its GCA, while SCA is the degree to which the average performance of a specific family (usually full sibs) departs from the average of its parental breeding values (Dictionary of Forestry, 2011) [7]. The importance of a half diallel hybridization technique in maize breeding has already been emphasized (Menkir *et al.* 2003; Tassawar *et al.* 2007; Rahman *et al.* 2010) [19, 29, 23]. The present study was planned to identify maize inbred lines for their GCA and SCA by half diallel method: without reciprocal of their parents DMIL 447, DMIL 516, NC 468, DMIL 607, DMIL 438, CML 425 and DMIL 715 in desired direction under non-stress and stress situations.

Material and Methods

Ten corn inbred lines (DMIL 230, DMIL 438, DMIL 447, DMIL 516, DMIL 553, DMIL 607, DMIL 692, DMIL 715, CML 425 and NC 468) were used as female and male parents (Table 1). These lines were derived from 100 inbred lines during an inbreeding program by the Genetics and Plant Breeding Group, During the June 2015 Kharif crop season. the above 10 elite lines were crossed with the half diallel fashion at The Main Agriculture Research Station (MARS) Dharwad. During the December -May 2015-16 summer crop season, the 45 top crosses (10 × 9) and their parents were evaluated at Main Agricultural Research Station Dharwad under normal irrigation (irrigation every 15 days, Experiment 1) and drought stress conditions (irrigation at 30 days intervals, Experiment 2) in a replicated trial using a randomized complete block design (RCBD), with two replications. Each row was 4 m in length and 60 cm wide and plants was spaced at 30 cm with one plant/well. 10 plants were selected at random from each row for studying the following characters: plant height (cm), ear height (cm), number of leaves, leaf area (cm^2), grain yield (g), ear length (cm), ear diameter (cm), number of rows/ear, ear weight (g) and 100-kernel weight (g). Data for each trait was separately analyzed in each experiment and combined analysis was performed across environments according to Steel and Torrie (1980). SI was performed as illustrated by Smith (1936) [27]. The estimates of combining ability effects (GCA and SCA) under normal conditions and drought stress were detected based on the method described by Singh and Chaudhary (1985) [25].

Table 1: set of Half diallel crosses in Maize

Female parents	Male parents									
	DMIL 230	**DMIL 438**	**DMIL 447**	**DMIL 516**	**DMIL 553**	**DMIL 607**	**DMIL 692**	**DMIL 715**	**CML 425**	**NC 468**
DMIL 230										
DMIL 438	DMIL438 × DMIL 230									
DMIL 447	DMIL 447 × DMIL 230	DMIL 447 × DMIL 438								
DMIL 516	DMIL 516 × DMIL230	DMIL 516 × DMIL 438	DMIL 516 × DMIL 447							
DMIL 553	DMIL553 × DMIL 230	DMIL 553 × DMIL 438	DMIL 553 × DMIL 447	DMIL 553 × DMIL 516						
DMIL 607	DMIL 607 × DMIL 230	DMIL 607 × DMIL 438	DMIL 607 × DMIL 447	DMIL 607 × DMIL 516	DMIL 607 × DMIL 553					
DMIL 692	DMIL 692 × DMIL 230	DMIL 692 × DMIL 438	DMIL 692 × DMIL 447	DMIL 692 × DMIL 516	DMIL 692 × DMIL 553	DMIL 692 × DMIL 607				
DMIL 715	DMIL 715 × DMIL 230	DMIL 715 × DMIL 438	DMIL 715 × DMIL 447	DMIL 715 × DMIL 516	DMIL 715 × DMIL 553	DMIL 715 × DMIL 607	DMIL 715 × DMIL 692			
CML 425	CML 425 × DMIL 230	CML 425 × DMIL 438	CML 425 × DMIL 447	CML 425 × DMIL 516	CML 425 × DMIL 553	CML 425 × DMIL 607	CML 425 × DMIL 692	CML 468 × DMIL 715		
NC 468	NC 468 × DMIL 230	NC 468 × DMIL 438	NC 468 × DMIL 447	NC 468 × DMIL 516	NC 468 × DMIL 553	NC 468 × DMIL 607	NC 468 × DMIL 692	NC 468 × DMIL 715	NC 468 × CML 425	
Hybrids	9	8	7	6	5	4	3	2	1	45

Results and Discussion

Days to 50 per cent anthesis

Days from planting to pollen shedding are one of the important maturity characters. The study on gca suggested that DMIL 715, DMIL 447 and DMIL 516 are good general combiner which exhibited earliness in developing tassel under both non-stress and stress conditions. This result indicated that these parents possess high frequency of favorable genes for the trait and expected to exhibit earliness in flowering.

Williams *et al.* (1969) [32] reported that inbred lines which exhibit high GCA for drought tolerance produce greater number of drought tolerant hybrids. Suneetha *et al.* (2000) [28] noticed significant variances for GCA and SCA for days to 50 per cent anthesis. Among the 10 parents, DMIL 438 (1.08 and 0.60), recorded significant positive gca effects under non-stress and stress situations and DMIL 607 (0.28) under non-stress and NC 468 (1.20) under stress indicating that they were good combiners for days to 50 per cent anthesis and DMIL 715 (-1.08) under non-stress and DMIL 447 (-0.86), DMIL 516 (-0.62) under stress recorded significant negative gca effects indicating that they were good combiners for days to 50 per cent anthesis (Table 3.).

Days to 50 per cent silking

Days to 50 per cent silking are another maturity character often used and more reliable to predict maturity. The study on gca effects revealed that parents, DMIL 447, DMIL 516 and DMIL 715 recorded significant negative gca effects in desired direction under non-stress and stress situations. This reveals that these parents which showed negative *gca* effects may possess high frequency of favorable genes for the trait and thus can be used as donor parents for the accumulation of favorable genes. Muchena (1978) [21] reported the importance of GCA effects for days to 75 per cent silking under drought. Two parents *viz.*, DMIL 438 (1.01 and 0.99), DMIL 607 (1.16 and 0.77) under non-stress and stress and NC 468 (1.11) under stress recorded significant positive gca effects. Respectively, the DMIL 447 (-0.82 and -0.96) both non-stress and stress and DMIL 516 (-1.08) under stress and the DMIL 715 (-1.15) under non-stress recorded significant negative gca effects indicating that they were good combiners for days to 50 per cent silking.

Anthesis to silking interval

Magorokosho *et al.* (2003) [13] noticed that value of ASI as an indirect selection criterion for improving grain yield under drought stressed conditions. In the present study parents DMIL 516 under stress alone and DMIL 447 under non-stress and stress recorded significant negative gca effects indicating their good combining ability for shorter ASI. For anthesis to silking interval, DMIL 516 (-0.45) under stress and DMIL 447 (-0.32 and -0.09) under non-stress and stress significant negative gca effects indicating their good combining ability and DMIL 607 (0.47) under stress recorded significant positive gca effects indicating their good combining ability. The ten and eight parents are showed numerically non-significant positive and negative gca effect under both non-stress and stress condition. Kuchanur *et al.* (2013) [12] reported the magnitude of GCA variance was greater than SCA variance for anthesis to silking interval.

Plant height

Plant height is of major concern to plant breeder since yield has positive correlation with plant height (Rupak *et al.,* 1979) [24]. Among the 10 parents, two parents DMIL 230 and DMIL 447 exhibit good general combiner for this trait under non-stress. Under stress alone DMIL 447 recorded significant positive gca effects. The GCA was more important than SCA for plant height as reported by Dhillon and Singh (1976) [6]. The parental lines with positive and highly significant *gca* effects for plant were reported by Mohamad *et al.* (2007) [17] indicating good combiners for tall plants. Contrastingly in the studies conducted by Amiruzzaman *et al.* (2013) [1] observed negative and highly significant *gca* effects for the parents used in their studies, indicating good combiner for short plant. Among the 10 parents, two parents *viz.*, DMIL 230 (9.46) and DMIL 447 (14.98) recorded significant positive gca effects for the trait under non-stress indicating for their good combining ability. Similarly, among the ten parents under stress situations none of the parents showed significantly positive gca effects except one parent *viz*, DMIL 447 (9.34) recorded positive gca effects under stress for good combiners. Under non-stress CML 425 and NC 468 (-9.51 and -10.04), respectively under stress condition DMIL 553 (-17.94), recorded significant negative gca effects for plant height indicating their good combining ability for this trait.

Cob height

Based on the *gca* effects, among the parents DMIL 230, DMIL 438, DMIL 447 and and DMIL 516 under non-stress and stress negative gca effect proved to be good combiners. The significant GCA effects for ear height were reported by Zamberi *et al.* (1986) [33], Hemalatha Devi (1989) [9]. Muchena (1978) [21] reported the importance of GCA effects ear height under drought. The parents NC 468 (8.40 and 3.80) recorded significant positive gca effects for the trait under non-stress and stress conditions indicating for their good combining ability. Whereas, The parents *viz*, DMIL 230 (-7.12 and -5.27), DMIL 438 (-9.72 and -4.92), DMIL 447 (-3.42 and -3.15), and DMIL 516 (-6.22 and -6.76) recorded significant negative gca effects for the trait under non-stress and stress conditions indicating for their good combining ability. The DMIL 553 (5.37) under stress recorded significantly positive gca effects, respectively the DMIL 692 (-4.52) and CML425 (-4.76) recorded significantly positive gca effects for this trait indicating good combining ability under stress.

Leaf area

Two parents *viz.,* DMIL 230 (-27.65 and -0.49) and DMIL 438 (-63.76 and -127.94) recorded significant negative gca effects under non-stress and stress situations for good combining ability. The parent's *viz*., DMIL 447 (38.06) DMIL 553 (30.39) and NC 468 (37.09) proved to be good general combiners for leaf area under stress as indicated by their significant positive gca effects. None of the parents recorded significant positive gca effects under non-stress situation. Three parents DMIL 447, DMIL 553 and NC 468 proved to be good general combiners for leaf area under stress condition.

Relative chlorophyll content (SPAD value)

One parent *viz.,* DMIL 607 under non-stress and stress were proved general good combiners for this trait. Kuchanur *et al.* (2013) reported the magnitude of GCA variance was greater than SCA for chlorophyll content. Three parents *viz.,* DMIL 230 (-0.72 and -1.69) and DMIL 553 (-0.42 and -1.76) recorded significant negative gca effects under non-stress and stress for good combining ability of the trait. and DMIL 607 (1.63 and 0.46) recorded were significant positive gca effects under non-stress and stress for good combining ability, the DMIL 692 and DMIL 715 were positive non-significant under non-stress as it is similarly, five parents were good combiners under stress as revealed by their non-significant positive gca effects. This revealed the predominance of non-additive gene action for this trait.

Canopy temperature

The parents DMIL 438, DMIL 692 and NC 468 under non-stress and stress proved good general combiners for canopy temperature. The parent DMIL 438 (-0.64 and -0.23), the DMIL 692 (-0.04 and -0.40) and NC 468 (-0.03 and -0.02) recorded significant negative gca effects under non-stress and stress for good combing ability of the canopy temperature at flowering stage. The four parents were recorded non-significant positive gca effects under stress for good combiners. This revealed the predominance of non-additive gene action under non-stress and stress situation.

Relative water content

Among the 10 parents, DMIL 516 (3.86 and 0.31), DMIL 553 (2.93 and 3.87) and DMIL 447 (1.36 and 4.14) recorded significant positive gca effects under both the situations. Respectively, the DMIL 230 (-2.79 and -3.90), DMIL 607 (-1.54 and -2.65), DMIL 438 (-0.28 and -2.94) and CML 425 (-1.82 and -0.42) recorded significant negative gca effects under both the situations. The DMIL 692 (1.23) under stress recorded positive non-significant positive gca effects, and DMIL 715 (-0.39 and -0.46) under both the situations, recorded non-significant negative gca effects indicating their good combining ability for the trait (Table 4). Among the 10 parents, DMIL 516, DMIL 553 and DMIL 447 proved good general combiner under both the situations. DMIL 230, DMIL 607 and NC 468 showed negative significant gca effects under non-stress and DMIL 692 under stress exhibited non-significant positive gca effect. The magnitude of sca variance was greater than gca variance. This revealed the predominance of additive gene action for this trait under non-stress and stress situations.

Photosynthetic rate

The parents CML 425 and NC 468 under non-stress and stress proved good general combiners for photosynthetic rate. DMIL 230 (-0.05 and -0.15), the DMIL 553 (-0.09 and -0.37), DMIL 692 (-0.01 and -0.39) and DMIL 715 (-0.12 and -.042) recorded significant negative gca effects under non-stress and stress for good combing ability of the photosynthetic rate at flowering stage. Respectively, the CML 425 (0.58 and 0.11) and NC 468 (0.24 and 0.62) recorded significant positive gca effects under non-stress and stress for good combing ability for the trait.

Leaf area duration

The parents, DMIL 447 and DMIL 516 under non-stress and stress proved good general combiners for leaf area duration. Among the 10 parents, DMIL 438 (-15.58 and -8.39) and DMIL 607 (-1.04 and -0.06) recorded significant negative gca effects under non-stress and stress. Respectively, the DMIL 447 (4.43 and 2.94) and DMIL 516 (3.47 and 1.08), recorded significant positive gca effects under both the situations indicating their good combining ability for the trait. The DMIL 553 and DMIL 692 were recorded non-significant positive gca effects under non-stress and stress for good combing ability of the leaf area duration at flowering to maturity. This revealed the predominance of non-additive gene action under non-stress and stress situation.

Specific leaf weight

The DMIL 715 under non-stress and stress proved good general combiners for specific leaf weight. Among the 10 parents, DMIL 715 (0.10 and 0.07) recorded significant positive gca effects under both the situations. Respectively, the CML 425 (-0.04 and -0.38) and NC 468 (-0.39 and -0.62), recorded significant negative gca effects under both the situations indicating their good combining ability for the trait. The DMIL 438 and DMIL 447 were recorded non-significant positive gca effects under stress for good combing ability of the trait. Whereas, under non-stress four parents recorded non-significant gca effects for the trait. This revealed the predominance of non-additive gene action under non-stress and stress situation.

Yield and yield components

The data on yield components *viz,* cob length (cm), cob girth (cm), cob weight (g per plant), number of seed rows per cob, number of seeds per cob as influenced by varied water stress situation in different maize F_1 hybrids is presented in Table 20 and data pertaining to hundred grain weight, shelling percent, harvest index, yield per plant, yield per hectare and drought susceptibility index is presented in Table 5.

Cob length

For cob length, positive general combining ability is desirable because increase in ear length is of utmost importance in improvement of maize yield. Among parental lines, DMIL 516 and DMIL 607 recorded significant positive gca effects under stress. Alika (1994) [3] and Debnath and Sarkar (1990) [5] indicated the significant GCA estimates for ear length. For cob length, DMIL 516 (0.91) and DMIL 607 (0.54) recorded significant positive gca effects under stress. Wereas, DMIL 438 (-0.71) and DMIL 715 (-1.19) recorded significant negative gca effects under stress indicating their good combining ability only in specific environment. Respectively, under non-stress five parents recorded non-significant positive gca effects for the trait (Table 5).

Cob girth

Combining ability analysis revealed that GCA variance were significant for this trait. Similar findings were reported by Turgut *et al.* (1995) [31]. The parent DMIL 438 (-0.66 and -0.88) were good combiners for the trait under non-stress and stress and parent DMIL 692 (-0.62) under stress environments as indicated by their significant negative gca effects. The parent DMIL 447 (0.77) under non-stress and the parent DMIL 516 (1.15) under stress environment were, recorded significant positive gca effects indicating their good combining ability for the trait. The parent DMIL 447 under non-stress and DMIL 516 under stress exhibited good combining ability for cob girth. Alika (1994) [3] and Pal and Prodhan (1994) [22] indicated the significant GCA estimates for ear diameter.

Cob weight

Malik *et al.* (2004) [15] reported that temperate material gave *gca* effects for striking characters contributing towards high grain yield *i.e.,* ear weight and seeds per cob. Among the 10 parents, DMIL 230 (3.35) under non-stress and DMIL 447 (4.75 and 3.92) under both the environments, the DMIL 516 (2.52) and CML 425 (1.24) under stress environment recorded significant positive gca effects indicating their good combining ability for cob weight per plant under both the situations. Wereas, DMIL 607 (-8.49) under non-stress significant negative gca effects for the trait of good combining ability. The DMIL 438 (-2.61), DMIL 692 (-3.91) and DMIL 715 (-2.39) parent recorded significant negative gca effects for their good combining ability under stress environment. The DMIL 447 recorded significant positive gca effects and proved to be good general combiner under non-stress and stress environments. DMIL 230 under non-stress and DMIL 516 and CML 425 under stress were good combiners as revealed by their significant positive gca effects. The results were in line with Alika (1994) [3] indicated the significant GCA estimates ear weight per plant.

Number of seeds per cob

The results were in accordance with Mohammad *et al.* (2012) [15] who reported the significant of *GCA* for number of seeds in ear row. Among 10 parents, DMIL 447 (50 97) under non-stress and the parent DMIL 516 (44.38 and 17.38), the NC 468 (52.23 and 8.51) recorded significant positive gca effects under both the environments indicating their good combining ability for this trait under both the situations. Three parents *viz.,* DMIL 438 (-66.58) under non-stress and DMIL 230 (-8.39) and DMIL 692 (-14.14) under stress were considered to be good general combiners as they recorded significant negative gca effects. The general combining ability studies revealed that parent DMIL 516 and NC 468 showed good general combiner for this trait under both the environments. Four parents *viz.,* DMIL 447 under non-stress were considered to be good general combiners

Grain yield

Among the 10 parents, parent DMIL 516 (1.67 and 1.17) and NC 468 (0.21 and 0.47) recorded significant positive gca effects under non-stress and stress environments indicating their good combining ability for grain yield per plant. The three parents *viz.*, DMIL 607 (-3.26 and -0.32), DMIL 692 (-2.56 and -0.84) and CML 425 (-0.12 and -0.32) were recorded negative gca effects of the trait under non-stress and stress for good combining ability for grain yield g per plant, wereas DMIL 230 (2.16), DMIL 447 (1.51) and the DMIL 715 (3.31), recorded significant positive gca effect under non-stress for good combiner. The DMIL 438 (0.14) and DMIL 553 (0.39) parents were exhibited non-significant positive gca effects under stress for good combining ability. Among 10 parents DMIL 516 and NC 468 showed good general combiner for grain yield under non-stress and stress environments. DMIL 230, DMIL 447 and DMIL 715 under non-stress, whereas DMIL 438 and DMIL 553 under stress showed significant positive *gca* effect and were found to be good general combiners for seed yield per plant and proved as an useful index for combining ability as shown in Fig. 9. Similarly Beck *et al.* (1991) [4] and Mathur and Bhatnagar (1995) [16] reported highly significant GCA effects for grain yield. Makumbi *et al* (2011) [14] reported that, GCA effects were highly significant for grain yield across stresses and well-watered environments. Kuchanur *et al.* (2013) [12] reported the magnitude of GCA variance was greater than SCA variance for grian yield under non-stress and stress conditions.

Seed yield

Among the 10 parents, parent DMIL 516 (94.53 and 66.13) recorded significant positive gca effects under non-stress and stress environments indicating their good combining ability for seed yield kg per ha. The two parents *viz.*, DMIL 607 (-184.50 and -18.11), DMIL 692 (-145.19 and -47.76) were recorded negative significant gca effects of the trait under both the environment conditions for good combiners for grain yield kg per ha, wereas DMIL 230 (122.58), the DMIL 447 (85.50) NC 468 (11.89) and recorded non-significant positive gca effect under non-stress for good combiner. The DMIL 553 (22.18) and NC 468 (26.65) parents were recorded significant positive gca effects under stress for good combining ability.

Hundred seed weight

Five parent's *viz.*, DMIL 516 (2.24), DMIL 553 (0.81), DMIL 692 (1.07), DMIL 715 (1.36) and CML 425 (1.39) parent recorded significant positive gca effect for the trait good combining ability under stress. Whereas, the four parents *viz.*, DMIL 230 (-2.51), DMIL 438 (-0.69), DMIL 607 (-2.17) and NC 468 (-1.80) parent were recorded significantly negative gca effects under stress. The five parents were recorded non-significant positive gca effects under non-stress for good combiners for hundred Seed weight (Table 6). Ultimate grain yield of a plant depends mainly on hundred grain weight through various other component characters. The study of hundred grain weight deserves much attention because grain yield is product of interaction of various grain components so improvement will be quite easier and study will help in understanding the complex trait and grain yield. Five parents' *viz.*, DMIL 516, DMIL 553, DMIL 692, DMIL 715 and NC 468 proved to be good general combiners. Similarly, Alika (1994) [3], Pal and Prodhan (1994) [22], Mathur and Bhatnagar (1995) [16] indicated the significant GCA estimates for hundred grain weight.

Total dry matter at harvest

Among the 10 parents, DMIL 447 (8.53 and 10.56) under both the conditions recorded significant positive gca effects indicating their good combining ability for total dry matter at harvest. Wereas, DMIL 516 (11.70) and under non-stress environment recorded significant positive gca effects. Wereas, DMIL 607 (-10.68 and -3.32) recorded significant negative gca effects under non-stress and stress for the trait of good combining ability. One parent DMIL 447 is showed good general combiner for total dry matter at harvest under non-stress and stress environments. DMIL 516 under non-stress, were showed significant positive *gca* effect and were found to be good general combiners for total dry matter at harvest and proved as an useful index for combining ability.

Harvest index

Among the 10 parents, NC 468 (0.51 and 0.47) under non-stress and stress environment recorded significant positive gca effects indicating their good combining ability for trait. Wereas, DMIL 692 (-1.22 and -0.26) recorded significant negative gca effects under non-stress and stress for the trait of good combining ability. The DMIL 516 (0.61) recorded positive significant gca effects under stress. The two parents were recorded non-significant positive gca effect under stress for good combining ability. The parent DMIL 230 is showed good general combiner for harvest index under non-stress and stress environments. DMIL 516 under stress, were showed significant positive *gca* effect and were found to be good general combiners for harvest index and proved as an useful index for combining ability

Drought susceptibility index

Three parents DMIL 553 (-0.03) recorded significant negative gca effects and proved to be a good general combiner for DSI. DMIL 230 (0.03), DMIL 447 (0.02), DMIL 715 (0.03), Recorded significant positive gca effects and proved to be a good general combiner for DSI. Wereas the parents DMIL 438 (-0.01), DMIL 516 (-0.02), DMIL 607 (-0.01) and NC 468 (-0.01) recorded non-significant negative gca effects and proved to be a good general combiner for DSI. CML 425 (0.01) recorded non-significant positive gca effects proved to be a good combiner for DSI. The parent DMIL 553 is good general combiner. Kuchanur *et al.* (2013) [12] reported the magnitude of GCA variance was greater than SCA variance for drought susceptibility index.

Table 2: ANOVA of combining ability for different morpho-physiological traits in 10 × 10 half diallel set of crosses under non-stress and stress situations

Characters	GCA		SCA		Error		GCA/SCA ratio	
	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
Days to 50 per cent anthesis	5.64**	4.52**	3.29**	7.90**	1.66	0.99	0.20	0.04
Days to 50 per cent silking	6.32**	7.18**	3.17*	7.86**	1.81	1.45	0.27	0.07
Anthesis to silking Interval (ASI)	0.52	1.178*	0.88*	1.74**	0.48	0.57	0.01	0.04
Plant height (cm)	785.58**	843.77	267.22	424.73	216.50	431.96	0.94	-4.74
Cob length (cm)	0.95	3.60**	2.52**	2.73**	1.26	0.89	-0.01	-0.03
Cob girth (cm)	3.83**	4.73**	1.95*	4.22**	1.09	0.65	0.27	0.12

Number of seeds per cob	21183.04**	1019.02**	7491.98	3309.79*	4722.24	163.22	0.52	0.02
Grain yield (g per plant)	56.65**	3.91**	84.06**	11.94**	16.01	0.39	0.05	0.02
Grain yield (kg/ha)	181913.90**	12530.91**	269954.00**	38349.39**	51411.81	1248.11	0.05	0.02
TDM at harvest (g per plant)	696.78*	417.18**	452.66**	300.44**	176.61	245.89	0.16	0.26
Harvest index (%)	7.08**	2.21**	10.94**	2.95**	2.27	0.64	0.04	0.05
Hundred grain weight (g)	9.43	33.93**	10.65	28.17**	8.29	0.44	0.04	0.10
Cob height (cm)	376.59**	260.78**	129.87**	137.95**	38.27	25.65	0.31	0.17
Cob weight (g per plant)	180.49**	69.13**	108.56**	64.53**	30.72	2.60	0.16	0.19
Reltive water content (%)	53.24**	86.74**	65.15**	75.23**	0.98	7.52	0.06	0..09
Canopy temperature (^{0}C)	1.13	0.99	0.46	1.29*	0.56	0.68	-0.48	0.04
Relative chlorophyll (SPAD)	16.50*	34.46**	7.36	13.01*	7.54	7.88	-0.20	0.43
Leaf area (cm^2 per plant)	28756.50**	1103.44**	6644.73**	220.82**	3048.69	75.74	0.59	0.14
Photosynthetic rate (μ mole CO_2 m^{-2} s^{-1})	0.98	1.65	3.43	2.85	2.51	2.11	-0.15	-0.05
Specific leaf weight (g per dm^2)	0.34	2.98	0.63	0.93	0.89	0.45	0.23	0.44
Leaf area duration (days)	519.03**	116.46**	102.19**	37.02*	34.25	19.60	0.56	0.46
Drought susceptibility index (DSI)	0.00**		0.01**		0.00		0.07	
Digrees of freedom	9		45		54			

Table 3: Estimation of general combining ability in parents for phenological traits and leaf area in non-stress and stress

S. No	Parent lines	Days to 50 % anthesis		Days to 50 % silking		Anthesis to silking interval		Plant height at 90 DAS		Cob height		Leaf area at 90 DAS	
		Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
1	DMIL 230	0.41	-0.37	0.05	-0.08	-0.36	0.29	9.46*	-3.24	-7.12**	-5.27**	-27.647*	-0.49*
2	DMIL 438	1.08**	0.60*	1.01**	0.99**	-0.07	0.39	-0.09	-7.67	-9.72**	-4.92**	-63.76**	-127.94**
3	DMIL 447	-0.50	-0.86**	-0.82*	-0.96**	-0.32*	-0.09*	14.98**	9.34*	-3.42*	-3.15*	-3.23	38.06*
4	DMIL 516	-0.17	-0.62*	-0.08	-1.08**	0.08	-0.45*	5.70	-3.45	-6.22**	-6.76**	-18.74	26.75
5	DMIL 553	0.14	-0.05	0.31	-0.46	0.17	-0.41	-1.60	-17.94**	1.31	5.37**	22.33	30.39*
6	DMIL 607	0.28**	0.30	1.16**	0.77*	0.17	0.47*	-6.82	1.35	0.06	-0.66	28.88	-16.27
7	DMIL 692	-0.39	-0.24	-0.13	-0.18	0.26	0.06	-0.72	2.89	-2.69	-4.52**	8.22	-7.48
8	DMIL 715	-1.08**	-0.24	-1.15**	-0.38	-0.06	-0.14	-1.38	4.94	-1.81	1.05	30.27	-0.47
9	CML 425	-0.50	0.29	-0.47	0.27	0.03	-0.02	-9.51*	9.43*	1.94	-4.76**	-0.31	20.35
10	NC 468	0.01	1.20**	0.12	1.11**	0.11	-0.09	-10.04*	4.34	8.40*	3.80**	23.99	37.09*
	C. D. @ 95 %	0.79**	0.62**	0.83**	0.74**	0.43**	0.47**	9.12**	12.87**	3.83**	3.14**	39.35**	34.21**
	G_i--G_j at 95 %	1.19**	0.92**	1.24**	1.11**	0.64**	0.69**	13.59**	19.19**	5.70**	4.68**	58.68**	50.99**

Table 4: Estimation of general combining ability in parents for different biophysical traits and growth parameters in non-stress and stress.

Sl. No.	Parent lines	RWC at 70 DAS		Photosynthetic rate at 70 DAS		Canopy temperature at 70 DAS		Relative chlorophyll content (SPAD) at 70 DAS		Specific leaf weight at 90 DAS		Leaf area duration 70-90 DAS	
		Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
1	DMIL 230	-2.79**	-3.90**	-0.05*	-0.15*	-0.11	0.23	-0.72**	-1.69*	0.08	-0.09	-6.79**	0.75
2	DMIL 438	-0.28	-2.94**	0.06	-0.27	-0.64**	-0.23*	-1.40	2.84	-0.07	1.20	-15.58**	-8.39**
3	DMIL 447	1.36**	4.14**	-0.13	0.24	-0.01	0.23	-0.30	1.03	-0.07	-0.27	4.43**	2.94*
4	DMIL 516	3.86**	0.31*	-0.02	0.26	0.37	-0.16	-1.04	1.37	0.18	0.01	3.47*	1.08*
5	DMIL 553	2.93**	3.87**	-0.09*	-0.37*	0.33	-0.26	-0.42*	-1.76*	0.20	-0.24	2.85	0.07
6	DMIL 607	-1.54**	-2.65**	-0.46	0.37	0.36	-0.16	1.63*	0.46*	-0.04	0.32	-1.04*	-0.06*
7	DMIL 692	-0.47	1.23	-0.01*	-0.39*	-0.04*	-0.40*	1.45	-1.54	0.04	0.00	2.69	0.44
8	DMIL 715	-0.39	-0.46	-0.12*	-0.42*	-0.17	0.43	1.36	-3.16*	0.10*	0.07*	0.15	1.56
9	CML 425	-1.82**	0.42	0.58*	0.11*	-0.18	0.35	-0.23	2.04	-0.04*	-0.38*	3.48*	-0.31
10	NC 468	-0.87**	-0.01	0.24*	0.62*	-0.03*	-0.02*	-0.33	0.41	-0.39*	-0.62*	6.34**	1.91
C. D. @ 95 %		0.61**	1.69**	0.98**	0.90**	0.46**	0.51**	2.65**	3.41**	0.55**	0.41	3.62**	2.74**
G_i--G_j at 95%		0.91**	2.44**	1.46**	1.34**	0.68**	0.76**	3.95**	5.09**	0.82**	0.62	5.40**	4.09**

Table 5: General combining ability in parents for yield components in non-stress and stress

Sl. No.	Parent lines	Cob length		Cob girth		No of seeds per cob		Cob weight per plant		Grain yield per plant	
		Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
1	DMIL 230	0.02	0.21	0.01	0.11	31.29	-8.39*	3.35	0.11	2.16	-0.48**
2	DMIL 438	-0.42	-0.71**	-0.66*	-0.88**	-66.58**	3.36	-1.57	-2.61**	-1.07	0.14
3	DMIL 447	0.31	-0.38	0.77**	-0.44	50.97**	-2.81	4.75	3.92**	1.51	-0.15
4	DMIL 516	0.45	0.91**	0.17	1.15**	44.38*	17.38**	2.57	2.52**	1.67*	1.17**
5	DMIL 553	0.16	0.35	-0.56	0.4	-34.76	6.55	-2.19	0.79	-1.85	0.39*
6	DMIL 607	-0.28	0.54*	-0.49	-0.13	-33.72	-6.09	-8.49	0.41	-3.26	-0.32
7	DMIL 692	-0.24	-0.21	-0.62*	-0.12	-23.67	-14.14**	2.40	-3.91**	-2.56	-0.84**
8	DMIL 715	-0.12	-1.19**	0.24	-0.37	-4.14	0.08	-2.82	-2.39**	3.31	-0.06
9	CML 425	-0.09	0.31	0.31	0.14	-15.99	-4.45	0.95	1.24**	-0.12	-0.32
10	NC 468	0.21	0.17	0.83**	0.15	52.23**	8.51*	1.05	-0.09	0.21*	0.47**
	C. D. @ 95 %	0.67**	0.49**	0.65**	0.58**	42.57**	7.91**	3.43**	1.00**	2.48**	0.39**
	G_i--G_j at 95%	1.00**	0.74**	0.96**	0.87**	63.46**	11.79**	5.11**	1.59**	3.69**	0.58**

Table 6: General combining ability in parents for grain yield related traits and Drought susceptibility index in non-stress and stress

Sl. No.	Parental lines	Hundred grain weight (g)		Total dry matter at harvest (g /plant)		Grain yield (kg /ha)		Drought susceptibility index (DSI)	Harvest index %	
		Non-stress	Stress	Non-stress	Stress	Non-stress	Stress		Non-stress	Stress
1	DMIL 230	-1.54*	-2.51**	4.83	5.44	122.58	-27.22**	0.03*	0.42	-0.46*
2	DMIL 438	-0.96	-0.69**	-6.14	-6.66	-60.47	8.08	-0.01	0.08	0.40
3	DMIL 447	1.16	0.31	8.53*	10.56*	85.50	-8.58	0.02*	-0.05	-0.49*
4	DMIL 516	0.75	2.24**	11.70**	-1.44	94.53	66.13**	-0.02	-0.25	0.61**
5	DMIL 553	-0.39	0.81**	3.51	-4.89	-104.92	22.18*	-0.03*	-0.87*	0.36
6	DMIL 607	0.31	-2.17**	-10.68**	-3.32	-184.50**	-18.11	-0.01	-0.50	-0.01
7	DMIL 692	1.13	1.07**	5.23	-3.73	-145.19*	-47.76**	0.00	-1.22**	-0.26
8	DMIL 715	0.27	1.36**	-4.55	3.69	187.58**	-3.41	0.03*	1.46**	-0.17
9	CML 425	-0.50	1.39**	-6.32	5.78	-7.00	-17.95	0.01	0.42	-0.45*
10	NC 468	-0.24	-1.80**	-6.11	-5.43	11.89	26.65**	-0.01	0.51	0.47*
	C. D. @ 95 %	1.78**	0.41**	8.23**	9.71**	140.47**	21.88**	0.02**	0.93**	0.49**
	G_i--G_j at 95%	2.66**	0.61**	12.27**	14.48**	209.39**	32.63**	0.03**	1.39**	0.74**

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