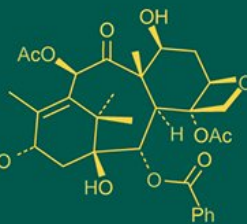
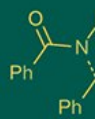


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Analysis of combining ability in maize inbred lines from line X tester mating design under stress situation

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Abstract

The present investigation was undertaken to estimate the combining ability effects of maize (*Zea mays* L.) inbred lines under stress and non-stress conditions. A total of 30 inbred lines were crossed with five testers using a line × tester mating design to generate 150 experimental hybrids. The hybrids, along with 35 parental lines and appropriate commercial checks, were evaluated during the early spring season of 2013 (sown on 11 December 2013) under both stress and non-stress environments. The experiment was laid out in a Randomized Block Design (RBD) with two replications. Each genotype was grown in a single 4 m row with a spacing of 75 × 20 cm.

Under non-stress conditions, all recommended agronomic practices were followed, including regular furrow irrigation at 10-12-day intervals throughout the crop growth period to prevent moisture stress. Under stress conditions, irrigation was provided only up to 30 days after sowing, after which no irrigation was applied until harvest to impose moisture stress during the flowering and grain-filling stages.

Analysis of combining ability revealed significant variability among the parental lines and hybrids for grain yield and associated traits. Under stress conditions, three hybrids, namely (All Rounder × HS17 Inbred Line 34) × HS7, (NK6240 × HS17 Inbred Line 14) × HS7, and (All Rounder × HS17 Inbred Line 45) × HS10, exhibited superior grain yield and recorded standard heterosis ranging from 45.06% to 56.30% over the commercial check. These hybrids demonstrated excellent combining ability and superior performance under moisture stress, indicating their potential for use in maize improvement programmes. However, further evaluation through multilocation trials is necessary before their recommendation for commercial cultivation.

Keywords: *Zea mays*, combining ability, line × tester analysis, heterosis, grain yield, inbred lines, stress, non-stress

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops worldwide because of its high productivity, broad adaptability, and diverse utilization. It belongs to the family Poaceae, tribe Maydeae, and has a chromosome number of $n = 20$. The crop originated in Central America and was domesticated nearly 9,000 years ago from its wild ancestor, teosinte (*Zea mays* ssp. *parviglumis*). As a monoecious and predominantly cross-pollinated species, maize possesses enormous genetic diversity, making it suitable for cultivation under a wide range of agro-climatic conditions.

Globally, maize is cultivated for food, feed, fodder, and industrial purposes. The grain is extensively utilized in the manufacture of starch, ethanol, biofuels, pharmaceuticals, and numerous processed food products. The development of specialty maize types, including Quality Protein Maize (QPM), sweet corn, baby corn, popcorn, and waxy corn, has further enhanced its economic importance. Owing to its high genetic yield potential and versatility, maize continues to play a significant role in ensuring food, nutritional, and livelihood security.

According to recent estimates, maize is cultivated on approximately 199 million hectares worldwide, producing about 1.13 billion tonnes of grain with an average productivity of 5.82 t ha⁻¹ (Anonymous, 2024) [1]. In India, maize occupies approximately 12.84 million hectares, producing 46.15 million tonnes with an average productivity of 3.60 t ha⁻¹. Karnataka is one of the leading maize-producing states, where the crop is grown on nearly 1.90 million hectares, yielding 6.35 million tonnes with an average productivity of 3.34 t ha⁻¹ (Anonymous, 2025-26).

Among the various abiotic constraints affecting maize productivity, drought is considered the most severe, particularly in tropical and subtropical regions where the crop is largely cultivated under rainfed conditions. Water deficit during flowering and grain-filling stages significantly reduces pollination efficiency, kernel set, and ultimately grain yield (CIMMYT, 1999; Edmeades *et al.*, 2001) ^[2, 3]. Global estimates indicate that drought account for yield losses ranging from 15-20% annually, depending on the severity and duration of moisture stress. Therefore, the development of drought-tolerant maize hybrids remains a major objective of modern breeding programmes.

The development of superior inbred lines forms the foundation of successful hybrid breeding. Well-characterized base populations possessing broad genetic diversity are essential for developing elite inbred lines with enhanced yield potential and tolerance to environmental stresses (Prashanth, 2008) ^[4]. The success of hybrid breeding largely depends on the identification of parents with superior combining ability capable of producing highly productive and stable hybrids.

Combining ability analysis is an effective breeding tool for understanding the genetic control of economically important traits and for identifying desirable parental combinations. The line $\times$ tester mating design proposed by Kempthorne (1957) is widely employed to estimate general combining ability (GCA) and specific combining ability (SCA) effects. General combining ability primarily reflects additive gene action, whereas specific combining ability is associated with non-additive gene effects, including dominance and epistasis (Falconer, 1964) ^[5]. Knowledge of GCA and SCA facilitates the selection of superior parental lines and efficient hybrid combinations for exploitation in maize improvement programmes.

The exploitation of heterosis through single-cross hybrids has substantially enhanced maize productivity worldwide. Single-cross hybrids generally exhibit superior vigour, greater uniformity, higher yield potential, and improved adaptability compared with open-pollinated varieties and composite populations. Their enhanced physiological efficiency and genetic constitution enable them to tolerate adverse environmental conditions, particularly drought stress, more effectively than conventional cultivars (Anonymous, 2009) ^[6]. Consequently, the identification of high-performing hybrids with desirable combining ability under both stress and non-stress environments is essential for developing resilient maize cultivars.

Keeping these considerations in view, the present investigation was undertaken to evaluate the combining ability of 30 maize inbred lines and five testers using a line $\times$ tester mating design under stress and nonstress conditions. The study aimed to identify superior general and specific combiners for grain yield and its associated traits, and to identify promising hybrid combinations suitable for future maize hybrid development programmes.

Materials and Methods

The present investigation was conducted at the Main Agricultural Research Station (MARS), Dharwad, Karnataka, India (15°25' N latitude, 70°25' E longitude; 678 m above mean sea level) during the kharif, rabi, and summer seasons of 2011-12, 2012-13, and 2013-14. Meteorological data, including rainfall and minimum and maximum temperatures recorded throughout the crop growth period,

were obtained from the station's meteorological observatory and are presented in Appendix I. During the evaluation period (rabi 2013-14), the mean minimum and maximum temperatures ranged from 16.00 to 30.87 °C, and a total rainfall of 11.40 mm was recorded.

Development of Experimental Hybrids

Early-generation screening of inbred lines was undertaken to identify suitable parental material for combining ability analysis using the line $\times$ tester mating design. A total of 200 maize inbred lines were initially evaluated, and the best 30 lines were selected based on superior grain yield (mean + 1 SD), reduced anthesis-silking interval (ASI; mean - 1 SD), and a higher number of cobs per plant (mean + SD). These selected inbred lines were crossed with five testers during the summer season (3 April 2013), resulting in the development of 150 F₁ single-cross hybrids. After harvest, hybrid seeds were properly processed, dried, and stored under suitable conditions until field evaluation.

Field Evaluation

The 150 F₁ hybrids, together with 35 parental lines and standard commercial checks, were evaluated during early spring 2013 (11 December 2013), under drought stress conditions. The experiment was laid out in a Restricted Randomized Block Design (RBD) with two replications. Each experimental plot consisted of a single 4 m row with an inter-row spacing of 75 cm and a plant-to-plant spacing of 20 cm.

To impose moisture stress, all experimental entries received irrigation only up to 30 days after sowing. Thereafter, irrigation was withheld until harvest, allowing the crop to experience water deficit during the critical flowering and grain-filling stages. All other recommended agronomic and crop management practices were followed uniformly throughout the experimental period.

Data Recording

Observations were recorded from five healthy and competitive plants selected at random in each replication for every genotype. Data were collected for the following traits: days to 50% anthesis, days to 50% silking, anthesis-silking interval (ASI), plant height (cm), ear height (cm), days to maturity, cob length (cm), cob girth (cm), number of cobs per plant, number of kernel rows per cob, number of kernels per row, shelling percentage, 100-grain weight (g), grain yield per plant (g), relative water content (RWC), and chlorophyll content. The mean value of each trait for every genotype was used for statistical analysis.

Statistical Analysis

The experimental data were subjected to line $\times$ tester analysis following the method proposed by Kempthorne (1957). The total genetic variation among the hybrids was partitioned into components attributable to general combining ability (GCA) and specific combining ability (SCA) to estimate the relative importance of additive and non-additive gene effects governing the studied traits. All statistical analyses were performed using WINDOSTAT version 8.0 software.

Results and Discussion

The ANOVA in respect of all the characters studied on hybrids under stress situation are presented in Table 1. The

mean sum of squares for crosses were significant for four traits viz. chlorophyll at 90 days, relative water content at 60

days, number of kernel rows per cob and grain yield per plant under stress.

Table 1: ANOVA for Line x Tester under stress situation during post *rabi* 2013

Character	Crosses 149	Line Effect 29	Tester Effect 4	Line* Tester Eff. 116	Line* Tester Eff. 149	Error 299	σ^2_{GCA}	σ^2_{sca}	$\sigma^2_{GCA/s^2_{sca}}$	Contribution of Lines	Contribution of Testers	Contribution of Line * Tester
DF												
Anthesis to silking interval	1.477	1.594	1.078	1.461	1.509	1.597	-0.004	-0.013	0.308	0.210	0.020	0.770
Chlorophyll at 60 DAS (mg/cm ²)	17.278	20.599	84.795**	14.119	15.908	17.320	1.051	-0.895	-1.174	0.232	0.132	0.636
Chlorophyll at 90 DAS (mg/cm ²)	37.446*	67.564**	7.787	30.940	25.724	32.856	0.328	2.365	0.139	0.351	0.006	0.643
Relative water content at 60 DAS (%)	0.011*	0.022**	0.004	0.008	0.008	0.010	0.000	-0.001	0.000	0.395	0.011	0.594
Relative water content at 90 DAS (%)	0.012	0.019**	0.029*	0.010	0.011	0.014	0.000	-0.001	0.000	0.302	0.062	0.636
Cob length (cm)	4.826	7.095*	9.358	4.103	3.737	4.319	0.137	0.330	0.415	0.286	0.052	0.662
Cob girth (cm)	0.124	0.159	0.093	0.116	0.102	0.117	0.001	0.008	0.125	0.250	0.020	0.730
No. of Kernel rows/cob	2.231*	2.434	5.585*	2.065*	1.536	1.919	0.072	0.287	0.251	0.212	0.067	0.721
No. of Kernels/row	24.23	42.693**	6.028	20.241	18.614	21.352	0.211	1.630	0.129	0.343	0.007	0.650
100-Seed weight (g)	9.009	13.891*	6.351	7.880	10.066	9.659	0.003	-1.069	-0.003	0.300	0.019	0.681
Grain yield kg/ha	1101669	991764.2	3303700*	1053213	862128.8	979026.1	37735	113114	0.334	0.175	0.081	0.744
Shelling %	50.291	58.264	45.122	48.477	48.892	53.268	0.198	1.849	0.107	0.225	0.024	0.750

* & ** - Significant at 0.05 and 0.01 level of probability, respectively

Further, under stress condition, lines showed significant differences for days to 50 per cent anthesis, days to 50 per cent silking, chlorophyll at 90 days, relative water content at 60 days, relative water content at 90 days, plant height, ear height, cob length, number of kernels per row and 100- seed weight. The testers under stress situation, they revealed significant differences for chlorophyll at 60 days, relative water content at 90 days, plant height, ear height, number of kernel rows per cob, grain yield per plant and grain yield kg/ha.

The interaction between lines and testers under stress situation the interaction was significant for number of kernel rows per cob and grain yield per plant. under stress situation SCA variance was higher than the GCA variance for most of

the traits except days to 50 per cent anthesis, days to 50 per cent silking, anthesis to silking interval (ASI), chlorophyll at 60 days, relative water content at 60 days, relative water content at 90 days, plant height, ear height, Number of cobs per plant and 100-seed weight. This revealed the preponderance of non-additive gene effects over the additive gene effects as most of the GCA/SCA ratios were less than unity for all traits under stress situation. The proportional contribution of lines to total variation was higher than the testers in all of the traits under stress situation. The results of the interaction between line x tester were higher for all the traits under stress situation.

The GCA effects of 30 lines and 5 testers for various characters is presented in Table 2.

Table 2: Top five hybrids based on mean performance and their sca effects, standard heterosis and GCA status of parents for 12 traits in maize under stress situation

Characters	Cross combination	Mean	sca effects	GCA effects		Standard heterosis over NK6240	Standard heterosis over Rajkumar
				Female	Male		
Anthesis to silking interval	(Allrounder X HS17 line 25) X HS7	1.00	-0.92	-0.33	-0.18	-71.43 *	-60.00
	(Allrounder X HS17 line 34) X CI4	1.00	-1.137	-0.43	0.137	-71.43 *	-60.00
	(Allrounder X HS17 line 39) X HS10	1.00	-0.903	-0.53	0.003	-71.43 *	-60.00
	(NK6240 X CI4 line 12) X CI4	1.00	-2.137 *	0.57	0.137	-71.43 *	-60.00
	(NK6240 X HS17 line 10) X HS10	1.00	-1.103	-0.33	0.003	-71.43 *	-60.00
Chlorophyll	(NK6240 X HS17 line 5) X HS7	46.67	3.279	2.337	0.06	14.91	6.42

content at 60 DAS	(Rajkumar X CML446 line 40) X HS7	47.12	5.302	0.769	0.06	16.03	7.46
	(NK6240 X HS17 line 22) X HS4	47.22	2.48	2.135	1.611 **	16.26	7.67
	(Allrounder X HS17 line 34) X HS4	47.57	3.161	1.804	1.611 **	17.13	8.47
	(G57 X NAC6002 line 17) X HS4	48.01	4.912	0.503	1.611 **	18.23	9.50
Chlorophyll content at 90 DAS	(Allrounder X HS17 line 45) X HS7	34.40	5.193	2.492	-0.479	8.88	9.90
	(NK6240 X CI4 line 12) X CI4	34.77	5.018	2.676	-0.123	10.03	11.07
	(Parbhat X CI4 line 5) X HS4	35.60	1.989	6.103 **	0.314	12.68	13.74
	(Parbhat X CI4 line 5) X KDMI16	36.25	3.07	6.103 **	-0.117	14.73	15.81
Relative water content at 60 DAS	(NK6240 X CI4 line 35) X HS7	36.72	8.084 *	1.916	-0.479	16.21	17.30
	(NK6240 X CI4 line 35) X HS7	88.00	0.074	0.048	0.011	14.29	16.56
	(Rajkumar X CML446 line 1) X HS4	88.00	0.054	0.075 **	0.004	14.29	16.56
	(Rajkumar X CML446 line 8) X HS7	88.00	0.076	0.046	0.011	14.29	16.56
Relative water content at 90 DAS	(Rajkumar X CML446 line 25) X HS7	88.00	0.09	0.027	0.011	13.64	15.89
	(Allrounder X HS17 line 45) X CI4	90.00	0.161 *	-0.009	0.001	16.88	19.21
	(NK6240 X HS17 line 20) X HS4	67.00	0.076	0.057	0.00	19.64	9.84
	(Allrounder X HS17 line 21) X HS4	69.00	0.085	0.063	0.00	22.32	12.30
Cob girth (cm)	(Allrounder X HS17 line 34) X HS4	69.00	0.081	0.072 *	0.00	23.21	13.11
	(Allrounder X HS17 line 34) X KDMI16	69.00	0.09	0.072 *	-0.009	23.21	13.11
	(NK6240 X CI4 line 42) X HS7	71.00	0.126	0.006	0.036 **	25.89	15.57
	(Allrounder X HS17 line 25) X HS10	4.63	0.204	0.244 *	-0.015	9.59	13.90
No. of Kernel rows/cob	(Rajkumar X CML446 line 18) X HS4	4.66	0.292	0.172	0.003	10.41	14.76
	(G57 X NAC6002 line 25) X HS7	4.73	0.361	0.121	0.05	11.95	16.36 *
	(NK6240 X HS17 line 14) X HS7	4.80	0.352	0.200 *	0.05	13.61	18.08 *
	(NK6240 X HS17 line 22) X KDMI16	4.89	0.607 **	0.146	-0.056	15.86 *	20.42 **
No. of Kernels/ row	(G57 X NAC6002 line 25) X HS7	17.33	2.117 *	0.920 *	-0.453 **	22.21 *	15.53
	(Rajkumar X CML446 line 3) X HS4	17.34	2.849 **	-0.466	0.206	22.25 *	15.57
	(Allrounder X HS17 line 21) X HS10	17.66	3.251 **	-0.479	0.147	24.58 **	17.77 *
	(Rajkumar X CML446 line 38) X CI4	17.66	1.461	1.187 **	0.271	24.58 **	17.77 *
No. of Kernels/ row	(NK6240 X CI4 line 37) X KDMI16	17.67	2.308 **	0.787 *	-0.171	24.61 **	17.80 *
	(Rajkumar X CML446 line 37) X HS7	35.50	3.149	2.395	0.417	12.90	13.29
	(NK6240 X HS17 line 22) X KDMI16	37.50	4.668	3.526 **	-0.233	19.26	19.67
	(Rajkumar X CML446 line 3) X HS4	37.50	4.743	3.428 **	-0.21	19.26	19.67
100- Grain weight (g)	(Rajkumar X CML446 line 18) X CI4	37.50	4.766	2.928 *	0.267	19.26	19.67
	(NK6240 X CI4 line 12) X CI4	38.33	4.969	3.560 **	0.267	21.91	22.34
	(Allrounder X HS17 line 39) X CI4	22.34	4.465 *	-0.282	-0.195	17.31	39.64 *
	(NK6240 X CI4 line 12) X HS7	22.55	1.299	2.335 *	0.569	18.43	40.98 *
Grain yield (kg/ha)	(NK6240 X HS17 line 14) X HS7	22.92	2.443	1.561	0.569	20.38	43.29 *
	(Rajkumar X CML446 line 46) X HS10	23.91	5.400 *	0.384	-0.221	25.58	49.48 *
	(NK6240 X CI4 line 37) X KDMI16	25.83	5.382 *	2.156 *	-0.055	35.66 *	61.49 **
	(Rajkumar X CML446 line 18) X HS7	4010.79	906.016	515.05	261.302 *	31.57*	42.69**
Shelling %	(Rajkumar X CML446 line 46) X HS4	4011.63	1242.208	367.052	73.944	31.60*	42.72**
	(Allrounder X HS17 line 34) X HS7	4077.46	1853.845 **	-	261.302 *	33.76*	45.06**
	(NK6240 X HS17 line 14) X HS7	4153.3	1363.851 *	199.72	261.302 *	36.25**	47.76**
	(Allrounder X HS17 line 45) X HS10	4393.29	2200.558 **	103.22	-238.915 *	44.12**	56.30**
Cob length (cm)	(Allrounder X HS17 line 34) X HS4	77.30	8.144	-1.676	0.372	20.06	9.27
	(G57 X NAC6002 line 25) X KDMI16	77.31	5.49	2.133	-0.773	20.07	9.28
	(NK6240 X HS17 line 14) X HS7	78.42	5.324	1.335	1.296	21.79 *	10.84
	(NK6240 X CI4 line 35) X HS10	78.66	7.423	1.535	-0.758	22.17 *	11.19
Cob length (cm)	(Rajkumar X CML446 line 25) X HS10	78.66	4.379	4.579 *	-0.758	22.17 *	11.19
	(NK6240 X CI4 line 12) X HS7	19.27	1.664	1.406 *	0.439	23.89 *	25.92 *
	(NK6240 X HS17 line 22) X KDMI16	19.40	2.629 *	1.453 *	-0.433	24.79 *	26.83 *
	(Parbhat X CI4 line 5) X HS4	19.50	3.069 *	0.489	0.186	25.40 *	27.45 *
Cob length (cm)	(NK6240 X CI4 line 12) X CI4	19.60	2.225	1.406 *	0.213	26.05 *	28.10 *
	(Rajkumar X CML446 line 3) X HS4	22.75	4.930 **	1.878 **	0.186	46.30 **	48.69 **

* & ** - Significant at 0.05 and 0.01 level of probability, respectively

GCA effects of lines for days to 50 per cent anthesis ranged from -2.87 (Rajkumar × CML446 Inbredline 3) to 1.73 (NK6240 × CI4 Inbredline 18) and -0.22 (HS4) to 0.16 (HS10) for testers, three out of 30 parents showed significant GCA effects, two parents viz., Rajkumar × CML446 Inbredline 38 (-1.77) and Rajkumar × CML446 Inbredline 3 (-2.87) showed GCA effects in negative

direction. GCA effects of lines for days to 50 per cent silking ranged from -2.3 (Rajkumar × CML446 Inbredline 3) to 2.1 (NK6240 × CI4 Inbredline 18) and -0.10 (HS4) to 0.16 (HS10) for testers, four out of 30 parents showed significant GCA effects, three parents viz., Rajkumar × CML446 Inbredline 38 (-1.60), G57 × NAC6002 Inbredline 25 (-1.80) and Rajkumar × CML446 Inbredline 3 (-2.30)

showed GCA effects in negative direction.

GCA effects of lines for ASI ranged from -0.53 (Allrounder × HS17 Inbredline 21) to 0.77 (NK6240 × HS17 Inbredline 20) and -0.18 (HS7) to 0.13 (CI4) for testers. One out of 30 parents showed significant GCA effects viz., NK6240 × HS17 Inbredline 20 (0.77) in positive direction. GCA effects of lines for days to maturity ranged from -2.55 (NK6240 × CI4 inbredline 37) to 2.35 (NK6240 × HS17 Inbredline 22) and -0.25 (HS7) to 0.18 (HS10) for testers, three out of 30 parents showed significant GCA effects, one parent viz., NK6240 × HS17 Inbredline 22 (2.35) showed positive GCA effects, whereas two parents viz., NK6240 × CI4 Inbredline 35 (-1.85) and NK6240 × CI4 inbredline 37 (-2.55) showed GCA effects in negative direction. GCA effects of lines for chlorophyll content at 60 days ranged from -2.49 (Rajkumar × CML446 Inbredline 46) to 2.56 (Allrounder × HS17 Inbredline 25) and -1.73 (KDMI16) to 1.61 (HS4) for testers, two out of 30 parents showed significant GCA effects one parent viz., Allrounder × HS17 Inbredline 25 (2.56) showed positive GCA effects, Among the testers, HS4 (1.61) exhibited significant positive GCA effects. GCA effects of lines for chlorophyll content at 90 days ranged from -5.34 (G57 × NAC6002 Inbredline 25) to 6.10 (Parbhat × CI4 Inbredline 5) and -1.47 (HS7) to 0.40 (HS10) for testers, seven out of 30 parents showed significant GCA effects, three parents viz., Allrounder × HS17 Inbredline 39 (3.41), Rajkumar × CML446 Inbredline 18 (3.60) and Parbhat × CI4 Inbredline 5 (6.10) showed positive GCA effects.

GCA effects of lines for relative water content at 60 days ranged from -0.113 (G57 × NAC6002 Inbredline 25) to 0.075 (Rajkumar × CML446 Inbredline 1) and -0.009 (KDMI16) to 0.011 (HS7) for testers, six out of 30 parents showed significant GCA effects, two parents viz., NK6240 × HS17 Inbredline 20 (0.068) and Rajkumar × CML446 Inbredline 1 (0.075) showed positive GCA effects. GCA effects of lines for relative water content at 90 days ranged from -0.086 (Rajkumar × CML446 Inbredline 8) to 0.072 (Allrounder × HS17 Inbredline 34) and -0.022 (CI4) to 0.036 (HS7) for testers, two out of 30 parents showed significant GCA effects, one parent viz., Allrounder × HS17 Inbredline 34 (0.072) showed positive GCA effects. Among testers HS7 (0.036) showed significant positive GCA effects. GCA effect of lines and testers for plant height ranged from -23.41 (Rajkumar × CML446 Inbredline 8) to 20.33 (Rajkumar × CML446 Inbredline 1) and -5.95 (CI4) to 4.31 (HS10), respectively. three out of 30 parents exhibited significant GCA effect among them, two is in positive direction viz., NK6240 × HS17 Inbredline 10 (12.28) and Rajkumar × CML446 Inbredline 1 (20.33) and one are in negative direction viz., Rajkumar × CML446 Inbredline 8 (-23.41). Among testers CI4 (-5.95) exhibited significant GCA effect in negative direction. GCA effect of lines and testers for ear height ranged from -17.42 (Rajkumar × CML446 Inbredline 8) to 10.87 (NK6240 × HS17 Inbredline 14) and -5.44 (CI4) to 6.91 (HS10), respectively. one of the line viz., NK6240 × HS17 Inbredline 14 (10.87) showed GCA effect in positive direction, The lines viz., Rajkumar × CML446 Inbredline 38 (-10.87) and Rajkumar × CML446 Inbredline 8 (-17.42) showed GCA effect in negative direction. However, among testers, HS10 (6.91) showed significant GCA effect in positive direction and CI4 (-5.44) showed significant GCA effect in negative direction.

GCA effect of lines and testers for cob length ranged from -1.98 (G57 × NAC6002 Inbredline 17) to 1.87 (Rajkumar × CML446 Inbredline 3), -0.43 (KDMI16) to 0.43 (HS7), respectively. Six of the lines viz., Rajkumar × CML446 Inbredline 18 (1.20), NK6240 × HS17 Inbredline 5 (1.27), NK6240 × CI4 Inbredline 12 (1.40), NK6240 × HS17 Inbredline 22 (1.45) and Rajkumar × CML446 Inbredline 3 (1.87) showed GCA effect in positive direction. The GCA effect of lines and testers for cob girth ranged from -0.24 (Rajkumar × CML446 Inbredline 25) to 0.24 (Allrounder × HS17 Inbredline 25) and -0.05 (KDMI16) to 0.05 (HS7), respectively. Two of the lines viz., NK6240 × HS17 Inbredline 14 (0.20) and Allrounder × HS17 Inbredline 25 (0.24) showed GCA effect in positive direction.

The GCA effect of lines and testers for number of kernel rows per cob ranged from -0.89 (NK6240 × HS17 Inbredline 22) to 1.18 (Rajkumar × CML446 Inbredline 38) and -0.45 (HS7) to 0.27 (CI4), respectively. Three lines viz., NK6240 × CI4 inbredline 37 (0.78), G57 × NAC6002 Inbredline 25 (0.92) and Rajkumar × CML446 Inbredline 38 (1.08) showed GCA effects in positive direction. The GCA effect of lines and testers for number of kernels per row ranged from -3.80 (G57 × NAC6002 Inbredline 17) to 3.56 (NK6240 × CI4 Inbredline 12) and -0.24 (HS10) and 0.41 (HS7), respectively. Five out of 30 lines viz., Rajkumar × CML446 Inbredline 18 (2.92), Rajkumar × CML446 Inbredline 3 (3.42), NK6240 × HS17 Inbredline 22 (3.526), NK6240 × HS17 Inbredline 5 (3.529) and NK6240 × CI4 Inbredline 12 (3.56) showed positive GCA effect.

The GCA effect of lines and testers for Number of cobs per plant ranged from -0.07 (Parbhat × CI4 Inbredline 5) to 0.16 (Rajkumar × CML446 Inbredline 8) and -0.006 (HS10) and 0.007 (KDMI16), respectively. Two out of 30 lines viz., NK6240 × HS17 Inbredline 22 (0.161) and Rajkumar × CML446 Inbredline 8 (0.162) showed positive GCA effect. The GCA effect of lines and testers for 100-seed weight ranged from -3.06 (Rajkumar × CML446 Inbredline 25) to 2.33 (NK6240 × CI4 Inbredline 12) and -0.22 (HS10) to 0.56 (HS7), respectively. Two out of 30 lines viz., NK6240 × CI4 inbredline 37 (2.15) and NK6240 × CI4 Inbredline 12 (2.33) showed positive GCA effect. The GCA effect of lines and testers for grain yield per plant ranged from -11.37 (Rajkumar × CML446 Inbredline 8) to 13.93 (Rajkumar × CML446 Inbredline 18) and -7.79 (HS10) to 6.98 (HS7), respectively. One out of 30 lines viz., Rajkumar × CML446 Inbredline 18 (13.93) showed positive GCA effect. Among testers HS7 (6.98) showed significant GCA effect in positive direction. The GCA effect of lines and testers for grain yield (kg/ha) ranged from -682 (Allrounder × HS17 Inbredline 21) to 515.05 (Rajkumar × CML446 Inbredline 18) and -254.05 (KDMI16) to 261.30 (HS7), respectively. None of the lines showed GCA effect in positive direction among testers HS7 (261.30) showed significant GCA effect in positive direction. The GCA effect of lines and testers for shelling percentage ranged from -6.31 Allrounder × HS17 Inbredline 25) to 4.57 (Rajkumar × CML446 Inbredline 25) and -0.77 (KDMI16) and 1.29 (HS7), respectively. One out of 30 lines viz., Rajkumar × CML446 Inbredline 25 (4.57) showed GCA effect in positive direction.

The specific combining ability effects of 150 crosses are presented in Table16.

SCA effects for days to 50 per cent anthesis ranged from -3.86 (Allrounder × HS17 Inbredline 21) × HS7 to 3.73 (NK6240 × CI 4 Inbredline 18) × HS7. Two hybrids viz.

(Rajkumar × CML446 Inbredline 8) × KDMI16 (-3.48) and (Allrounder × HS17 Inbredline 21) × HS7 (-3.86) showed significant sca effects in negative direction. sca effects for days to 50 per cent silking ranged from (Allrounder × HS17 Inbredline 21) × HS7 (-3.58) to (Allrounder × HS17 Inbredline 45) × CI4 (3.55). One hybrid viz. (Allrounder × HS17 Inbredline 21) × HS7 (-3.58) showed significant sca effect in negative direction.

sca effects for ASI ranged from (NK6240 × CI4 Inbredline 12) × CI4 (-2.13) to (NK6240 × CI4 Inbredline 18) × CI4 (2.06). Two hybrids viz. (Rajkumar × CML446 Inbredline 40) × KDMI16 (-1.72) and (NK6240 × CI4 Inbredline 12) × CI4 (-2.13) showed significant sca effects in negative direction. sca effects for days to maturity ranged from (Rajkumar × CML446 Inbredline 46) × HS7 (-4.85) to (Rajkumar × CML446 Inbredline 40) × KDMI16 (4.78). Two hybrids viz. (NK6240 × HS17 Inbredline 20) × KDMI16 (-4.11) and (Rajkumar × CML446 Inbredline 46) × HS7 (-4.85) showed significant sca effects in negative direction.

SCA effects for chlorophyll at 60 days ranged from (G57 × NAC6002 Inbredline 17) × HS10 (-5.62) to (Rajkumar × CML446 Inbredline 40) × HS7 (5.30). None of the hybrids showed significant sca effects in positive direction. sca effects for chlorophyll at 90 days ranged from (Allrounder × HS17 Inbredline 21) × CI4 (-9.36) to (NK6240 × HS17 Inbredline 10) × HS7 (8.08). One hybrid viz. (NK6240 × HS17 Inbredline 10) × HS7 (8.08) showed significant sca effects in positive direction. sca effects for relative water content at 60 days ranged from (Allrounder × HS17 Inbredline 45) × HS7 (-0.20) to (Allrounder × HS17 Inbredline 45) × CI4 (0.16). The three hybrids viz. (NK6240 × CI4 Inbredline 12) × KDMI16 (0.132) (NAC6002 × CI4 Inbredline 7) × CI4 (0.133) and (Allrounder × HS17 Inbredline 45) × CI4 (0.161) showed significant sca effects in positive direction. sca effects for relative water content at 90 days ranged from (NK6240 × CI4 Inbredline 12) × CI4 (-15) to (Allrounder × HS17 Inbredline 45) × CI4 (0.14). None of the hybrids showed significant sca effects in positive direction.

Sca effects for plant height ranged from (Allrounder × HS17 Inbredline 21) × KDMI16 (-46.01) to (Rajkumar × CML446 Inbredline 8) × CI4 (30.80). Two hybrids viz. (Allrounder × HS17 Inbredline 21) × CI4 (30.70) and (Rajkumar × CML446 Inbredline 8) × CI4 (30.80) showed significant sca effects in positive direction and three hybrids viz. (NK6240 × CI4 Inbredline 12) × CI4 (-27.84) (NK6240 × CI4 Inbredline 18) × HS4 (-30.84) and (Allrounder × HS17 Inbredline 21) × KDMI16 (-46.01) showed significant sca effect in negative direction. sca effects for ear height ranged from (Rajkumar × CML446 Inbredline 36) × HS10 (-24.46) to (Rajkumar × CML446 Inbredline 36) × CI4 (24.14). One hybrids viz. (Rajkumar × CML446 Inbredline 36) × CI4 (24.14) showed significant sca effects in positive direction and two hybrids viz. (NK6240 × CI4 Inbredline 12) × CI4 (-24.16) and (Rajkumar × CML446 Inbredline 36) × HS10 (-24.46) showed significant sca effect in negative direction. sca effects for cob length ranged from (Allrounder × HS17 Inbredline 21) × KDMI16 (-4.07) to (Rajkumar × CML446 Inbredline 3) × HS4 (4.73). Three hybrids viz. (NK6240 × HS17 Inbredline 22) × KDMI16 (2.62) (Parbhat × CI4 Inbredline 5) × HS4 (3.06) and (Rajkumar × CML446 Inbredline 3) × HS4 (4.73) showed significant sca effects in positive direction

sca effects for cob girth ranged from (Allrounder × HS17 Inbredline 21) × KDMI16 (-0.75) to (NK6240 × HS17 Inbredline 22) × KDMI16 (0.60). One hybrid viz. (NK6240 × HS17 Inbredline 22) × KDMI16 (0.60) showed significant sca effects in positive direction. sca effects ranged number of kernel rows per cob from (Allrounder × HS17 Inbredline 34) × CI4 (-1.93) to (Allrounder × HS17 Inbredline 21) × HS10 (3.25). Five viz. (G57 × NAC6002 Inbredline 25) × HS7 (2.11) (Allrounder × HS17 Inbredline 34) × HS4 (2.12), (NK6240 × CI4 Inbredline 37) × KDMI16 (2.30) (Rajkumar × CML446 Inbredline 3) × HS4 (2.84) and (Allrounder × HS17 Inbredline 21) × HS10 (3.25) showed significant sca effects in positive direction. sca effects for number of kernels per row ranged from (Allrounder × HS17 Inbredline 21) × KDMI16 (-8.33) to (Allrounder × HS17 Inbredline 21) × HS7 (6.51). One hybrid viz. (Allrounder × HS17 Inbredline 21) × HS7 (6.51) showed significant sca effects in positive direction

The sca effects for Number of cobs per plant ranged from (Rajkumar × CML446 Inbredline 8) × HS7 (-0.23) to (NK6240 × HS17 Inbredline 22) × KDMI16 (0.43). Five hybrids viz. (Allrounder × HS17 Inbredline 45) × HS10 (0.264) (NK6240 × CI4 Inbredline 35) × HS4 (0.268) (Rajkumar × CML446 Inbredline 3) × CI4 (0.268) (Rajkumar × CML446 Inbredline 18) × CI4 (0.36) and (NK6240 × HS17 Inbredline 22) × KDMI16 (0.43) showed significant sca effects in positive direction. the sca effects for 100 grain weight ranged from (Allrounder × HS17 Inbredline 34) × HS7 (-4.47) to (Rajkumar × CML446 Inbredline 46) × HS10 (5.4). Three hybrids viz. (Allrounder × HS17 Inbredline 39) × CI4 (4.46) (NK6240 × CI4 Inbredline 37) × KDMI16 (5.38) and (Rajkumar × CML446 Inbredline 46) × HS10 (5.40) showed significant sca effects in positive direction. The sca effects for grain yield per plant ranged from (Rajkumar × CML446 Inbredline 46) × HS7 (-32.49) to 50.72 (NAC6002 × CI4 Inbredline 7) × HS4. Seven hybrids viz. (Parbhat × CI4 Inbredline 5) × HS4 (29.61) (Allrounder × HS17 Inbredline 25) × HS7 (33.96) (Rajkumar × CML446 Inbredline 40) × CI4 (34.46) (NK6240 × CI4 Inbredline 12) × CI4 (36.98) (Allrounder × HS17 Inbredline 34) × HS7 (37.58) (Allrounder × HS17 Inbredline 45) × HS10 (46.14) and (NAC6002 × CI4 Inbredline 7) × HS4 (50.72) showed significant sca effects in positive direction. The sca effects for grain yield (kg/ha) ranged from (Rajkumar × CML446 Inbredline 18) × HS4 -1874.72 to 2200.55 (Allrounder × HS17 Inbredline 45) × HS10. Six hybrids viz (Allrounder × HS17 Inbredline 21) × CI4 (1349.59) (NK6240 × HS17 Inbredline 14) × HS7 (1363.85) (Allrounder × HS17 Inbredline 25) × HS7 (1506.18) (Parbhat × CI4 Inbredline 5) × HS4 (1660.70) (Allrounder × HS17 Inbredline 34) × HS7 (1853.84) and (Allrounder × HS17 Inbredline 45) × HS10 (2200.55) showed significant sca effects in positive direction. The sca effects for shelling percentage ranged from (Rajkumar × CML446 Inbredline 36) × HS7 -13.39 to 9.25 (Allrounder × HS17 Inbredline 21) × CI4. None of the hybrids showed significant sca effects in positive direction.

Heterosis over mid-parent and check

The per cent heterosis over mid parent (relative heterosis) and over best check (standard heterosis) was worked out against commercial check Rajkumar under both stress and non-stress condition (Table 2). Days to 50 per cent anthesis the per cent heterosis over mid parent under stress condition,

it ranged from -11.27 (Rajkumar × CML446 Inbredline 3) × CI4 to 10.27 (NK6240 × CI 4 Inbredline 18) × HS7. The per cent standard heterosis under stress condition, it ranged from -11.59 (Rajkumar × CML446 Inbredline 3) × CI4 to 5.07 (NK6240 × CI 4 Inbredline 18) × HS7 over check. Four hybrids under stress exhibited significant negative heterosis over mid parent for this trait. 16 hybrids under stress exhibited negative significant heterosis over check, respectively. Top five hybrids viz. (Rajkumar X CML446 Inberdline3) X CI4 (-11.59) (Rajkumar X CML446 Inberdline3) X HS4 (-10.14) (Rajkumar X CML446 Inberdline38) X HS4 (-8.70) (Rajkumar X CML446 Inberdline18) X CI4 (-7.97) and (Rajkumar X CML446 Inberdline8) X KDMI16 (-7.97)

Days to 50 per cent silking, the per cent heterosis over mid parent under stress condition, it ranged from -10.10 (Rajkumar × CML446 Inbredline 3) × CI4 to 7.97 (NK6240 × CI 4 Inbredline 18) × HS7. The per cent standard heterosis under stress condition, it ranged from -9.79 (Rajkumar × CML446 Inbredline 3) × CI4 to 4.3 (NK6240 × CI 4 Inbredline 18) × HS7 over check. Eight hybrids under stress exhibited significant negative heterosis over mid parent for this trait. 14 hybrids under stress exhibited negative significant heterosis over check. Top five hybrids viz. (Rajkumar X CML446 Inberdline3) X HS4 (-9.79) (Rajkumar X CML446 Inberdline3) X CI4 (-9.79) (G57 X NAC6002 Inberdline25) X CI4 (-9.09) (Rajkumar X CML446 Inberdline18) X CI4 (-8.39) and (G57 X NAC6002 Inberdline25) X HS4 (-7.69).

Anthesis to silking interval (ASI), the per cent heterosis over mid parent under stress condition, it ranged from -71.43 (NK6240 × CI4 Inbredline 12) × CI4 to 220 (Rajkumar × CML446 Inbredline 40) × HS10. The per cent standard heterosis under stress condition, it ranged from -60 (Allrounder × HS17 Inbredline 25) × HS7 to 100 (NK6240 × HS17 Inbredline 20) × CI4 over check. Three hybrids under stress exhibited significant negative heterosis over mid parent.

Days to maturity, the per cent heterosis over mid parent under stress condition, it ranged from -5.12 (NK6240 × CI4 Inbredline 37) × HS10 to 7.06 (Allrounder × HS17 Inbredline 39) × HS7. The per cent standard heterosis under stress condition, it ranged from -3.35 (Rajkumar × CML446 Inbredline 40) × HS4 to 5.74 (G57 × NAC6002 Inbredline 25) × HS4 over check. Two hybrids under stress exhibited significant negative heterosis over mid parent, respectively. None of the crosses under stress exhibited significant negative heterosis over check.

Chlorophyll content (mg/cm²) at 60 days, the per cent heterosis over mid parent under stress condition, it ranged from -22.59 (Rajkumar × CML446 Inbredline 1) × KDMI16 to 13.25 (Allrounder × HS17 Inbredline 21) × HS10. The per cent standard heterosis under stress condition, it ranged from -22.85 (Rajkumar × CML446 Inbredline 1) × KDMI16 to 9.5 (G57 × NAC6002 Inbredline 17) × HS4 over check.

None of the hybrids under stress exhibited significant positive heterosis over mid parent, respectively.

Chlorophyll content (mg/cm²) at 90 days, The per cent heterosis over mid parent under stress condition, it ranged from -41.96 (Rajkumar × CML446 Inbredline 40) × CI4 to 108.33 (Parbhat × CI4 Inbredline 5) × KDMI16. The per cent standard heterosis under stress condition, it ranged from -46.65 (Allrounder × HS17 Inbredline 21) × CI4 to 17.30 (NK6240 × HS17 Inbredline 10) × HS7 over check.

10 hybrids under stress exhibited significant positive heterosis over mid parent, respectively.

Relative water content at 60 days, the per cent heterosis over mid parent heterosis under stress condition, it ranged from -26.93 (G57 × NAC6002 Inbredline 25) × HS10 to 26.32 (Allrounder × HS17 Inbredline 45) × CI4. The per cent standard heterosis under stress condition, it ranged from -27.81 (Allrounder × HS17 Inbredline 45) × HS7 to 19.21 (Allrounder × HS17 Inbredline 45) × CI4 over check. Four hybrids under stress exhibited significant positive heterosis over mid parent, respectively. None of the crosses under stress exhibited significant positive heterosis

Relative water content at 90 days, the per cent heterosis over mid parent under stress condition, it ranged from -42.58 (NK6240 × CI4 Inbredline 12) × CI4 to 45.25 (Allrounder × HS17 Inbredline 25) × HS7. The per cent standard heterosis under stress condition, it ranged from -50.82 (NK6240 × CI4 Inbredline 12) × CI4 to 15.57 (NK6240 × CI 4 Inbredline 42) × HS7 over check. Three hybrids under stress exhibited significant positive heterosis over mid parent.

Plant height (cm), the per cent heterosis over mid parent heterosis under stress condition, it ranged from -27.67 (Allrounder × HS17 Inbredline 21) × KDMI16 to 10.22 (Rajkumar × CML446 Inbredline 1) × CI4). The per cent standard heterosis under stress condition, it ranged from -24.41 (Allrounder × HS17 Inbredline 21) × KDMI16 to 7.85 (Rajkumar × CML446 Inbredline 1) × CI4) over check. 13 hybrids under stress exhibited significant negative heterosis over mid parent. Nine hybrids under stress exhibited significant negative heterosis over check.

Ear height (cm), the per cent heterosis over mid parent under stress condition, it ranged from -31.60 (Rajkumar × CML446 Inbredline 8) × HS7 to 26.79 (NK6240 × CI4 Inbredline 35) × HS10. The per cent standard heterosis under stress condition, it ranged from -27.03 (NK6240 × CI4 Inbredline 12) × CI4 to 32.78 (Rajkumar × CML446 Inbredline 1) × HS4 over check. one hybrid under stress exhibited significant positive heterosis over mid parent, respectively. 13 hybrids under stress exhibited significant negative heterosis over mid parent. Three hybrids under stress exhibited significant positive standard heterosis over check. viz., (Allrounder × HS17 Inbredline 34) × HS7 (31.10) (NK6240 × CI4 Inbredline 35) × HS10 (31.34) and (Rajkumar × CML446 Inbredline 1) × HS4 (32.78).

cob length (cm), The per cent heterosis over mid parent under stress condition, it ranged from -36.43 (Allrounder × HS17 Inbredline 21) × KDMI16 to 46.07 (Rajkumar × CML446 Inbredline 3) × HS4. The per cent standard heterosis under stress condition, it ranged from -31.37 (Allrounder × HS17 Inbredline 21) × KDMI16 to 48.69 (Rajkumar × CML446 Inbredline 3) × HS4 over check. Four hybrids under stress exhibited significant positive heterosis over mid parent. Five hybrids exhibited significant positive heterosis viz. (NK6240 × CI 4 Inbredline 12) × HS7 (25.92) (NK6240 × HS17

Inbredline 22) × KDMI16 (26.83) (Parbhat × CI4 Inbredline 5) × HS4 (27.45) (NK6240 × CI4 Inbredline 12) × CI4 (28.10) and (Rajkumar × CML446 Inbredline 3) × HS4 (48.69) over check under stress condition.

cob girth (cm), The per cent heterosis over mid parent under stress condition, it ranged from -19.81 (NK6240 × CI 4 Inbredline 37) × HS4 to 13.29 (G57 × NAC6002 Inbredline 25) × HS7. The per cent standard heterosis under stress condition, it ranged from -17.96 (Allrounder × HS17

Inbredline 21) × KDMI16 to 20.42 (NK6240 × HS17 Inbredline 22) × KDMI16 over check. Two hybrids under stress exhibited significant positive heterosis over mid parent, respectively. Three hybrids exhibited significant positive heterosis viz. (G57 × NAC6002 Inbredline 25) × HS7 (16.36) (NK6240 × HS17 Inbredline 14) × HS7 (18.08) and (NK6240 × HS17 Inbredline 22) × KDMI16 (20.42) over check under stress condition

Number of kernel rows per cob, the per cent heterosis over mid parent under stress condition, it ranged from -21.63 (NK6240 × HS17 Inbredline 10) × HS7 to 23.25 (Allrounder × HS17 Inbredline 21) × HS10. The per cent standard heterosis under stress condition, it ranged from -17.37 (Rajkumar × CML446 Inbredline 3) × KDMI16 to 17.80 (NK6240 × CI4 Inbredline 37) × KDMI16 over check. four hybrids under stress exhibited significant positive heterosis over mid parent. Three hybrids exhibited significant positive standard heterosis viz. (Allrounder × HS17 Inbredline 21) × HS10 (17.77) (Rajkumar × CML446 Inbredline 38) × CI4 (17.77) and (NK6240 × CI4 Inbredline 37) × KDMI16 (17.80) over check under stress condition,

Number of kernels per row, the per cent heterosis over mid parent under stress condition, it ranged from -39.04 (Allrounder × HS17 Inbredline 21) × KDMI16 to 28.57 (Rajkumar × CML446 Inbredline 3) × HS4. The per cent standard heterosis under stress condition, it ranged from -39.36 (Allrounder × HS17 Inbredline 21) × KDMI16 to 22.34 (NK6240 × CI4 Inbredline 12) × CI4 over check. Two hybrids under stress exhibited significant positive heterosis over mid parent, respectively. Six hybrids under stress exhibited significant negative standard heterosis over check. Number of cobs per plant, the per cent heterosis over mid parent under stress condition, it ranged from -24.75 (Allrounder × HS17 Inbredline 25) × KDMI16 to 50.00 (Rajkumar × CML446 Inbredline 18) × CI4. The per cent standard heterosis under stress condition, it ranged from -14.16 (Parbhat × CI4 Inbredline 5) × CI4 to 43.35 (NK6240 × HS17 Inbredline 22) × KDMI16 over check. 10 hybrids under stress exhibited significant positive heterosis over mid parent. One hybrid exhibited significant positive heterosis viz. (NK6240 × HS17 Inbredline 22) × KDMI16 (43.35) over check under stress condition.

100 grain weight, the per cent heterosis over mid parent under stress condition, it ranged from -35.43 (Rajkumar × CML446 Inbredline 3) × HS10 to 46.22 (NK6240 × CI4 Inbredline 37) × KDMI16. The per cent standard heterosis under stress condition, it ranged from -13.57 (Rajkumar × CML446 Inbredline 3) × HS10 to 61.49 (NK6240 × CI4 Inbredline 37) × KDMI16 over check. One hybrid under stress exhibited significant positive heterosis over mid parent. six hybrids exhibited significant positive heterosis viz. (Parbhat × CI 4 Inbredline 5) × HS10 (39.29) (Allrounder × HS17 Inbredline 39) × CI4 (39.64) (NK6240 × CI 4 Inbredline 12) × HS7 (40.98) (NK6240 × HS17 Inbredline 14) × HS7 (43.29) (Rajkumar × CML446 Inbredline 46) × HS10 (49.48) and (NK6240 × CI4 Inbredline 37) × KDMI16 (61.49) over check under stress condition.

Grain yield per plant (g), the per cent heterosis over mid parent under stress condition, it ranged from -93.48 (Allrounder × HS17 Inbredline 21) × KDMI16 to 122.45 (NK6240 × CI4 Inbredline 12) × CI4. The per cent standard heterosis under stress condition, it ranged from -90.39 (Allrounder × HS17 Inbredline 21) × KDMI16 to 139.65

(NAC6002 × CI 4 Inbredline 7) × HS4 over check. seven hybrids under stress exhibited significant positive heterosis over mid parent. ten hybrids exhibited significant positive heterosis viz. (NK6240 × HS17 Inbredline 5) × HS7 (97.98) (Parbhat × CI4 Inbredline 5) × HS4 (99.57) (Rajkumar × CML446 Inbredline 18) × CI4 (103.69) (Allrounder × HS17 Inbredline 45) × HS10 (109.42) (Rajkumar × CML446 Inbredline 46) × HS4 (112.22) (Rajkumar × CML446 Inbredline 40) × CI4 (116.33) (Allrounder × HS17 Inbredline 25) × HS7 (129.01) (NK6240 × CI4 Inbredline 12) × CI4 (133.31) (Allrounder × HS17 Inbredline 34) × HS7 (133.94) and (NAC6002 × CI 4 Inbredline 7) × HS4 (139.65) over check under stress condition.

Grain yield (kg/ha), the per cent heterosis over mid parent under stress condition, it ranged from -93.93 (Allrounder × HS17 Inbredline 21) × KDMI16 to 127.34 (Rajkumar × CML446 Inbredline 46) × HS4. The per cent standard heterosis under stress condition, it ranged from -94.8 (Allrounder × HS17 Inbredline 21) × KDMI16 to 56.30 (Allrounder × HS17 Inbredline 45) × HS10 over check. Five hybrids under stress exhibited significant positive heterosis over mid parent, respectively. Three hybrids under stress exhibited significant negative standard heterosis over check. Shelling percentage, the per cent heterosis over mid parent stress condition, it ranged from -25.69 (Rajkumar × CML446 Inbredline 36) × HS7 to 10.73 (NK6240 × CI4 Inbredline 35) × HS10. The per cent standard heterosis under stress condition, it ranged from -22.51 (Allrounder × HS17 Inbredline 25) × HS10 to 11.19 (Rajkumar × CML446 Inbredline 25) × HS10 over check. None of the hybrids under stress exhibited significant positive heterosis over mid parent. None of the hybrids exhibited significant positive heterosis over check under stress condition

Drought susceptibility index (DSI), Drought susceptibility index (DSI) presented in Table 18. 150 hybrids along with 35 parents and 3 checks, the hybrids viz. (NK6240 × HS17 inbredline 10) recorded highest (1.81) and (Allrounder × HS17 inbredline 39) × CI4 lowest (0.04) DSI values for grain yield (kg/ha) with an overall mean of (0.87).

Analysis of variance indicated under stress situation, lines exhibited significant differences for days to 50 per cent anthesis, days to 50 per cent silking, chlorophyll at 90 days, relative water content at 60 days, relative water content at 90 days, plant height, ear height, cob length, number of kernels per row, and 100-seed weight, indicating there was considerable variability for these traits among lines (Table 1)

The variability due to tester was under stress situation, significant differences for chlorophyll at 60 days, relative water content at 90 days, plant height, ear height, number of kernel rows per cob, grain yield per plant and grain yield (kg/ ha), indicating the presence of variability among the selected lines.

Mean sum of square for line × tester was significant under stress situation, the interaction was significant for number of kernel rows per cob and grain yield per plant indicating the diverse performance of hybrids for most of the traits. Indicated the presence of average heterosis. These results are in agreement with that of Joshi *et al.* (2002)^[7], Asif *et al.* (2007)^[8], Premalatha and Kalamani (2010)^[9], Aminu and Izge (2013)^[10] and Kuchanur *et al.* (2013)^[11]

Maize a highly allogamous species is expected to contain predominant of non-additive gene action. As per the expectation, the variance due to SCA was considerably high

compared to that of variance due to GCA for all the characters under stress. The ratio of GCA to SCA variance was much below unity indicating preponderance of non-additive gene effects in the inheritance of all traits under study for stress situation. The predominance of non-additive gene action for most of the growth and productivity traits have been reported by Sharma *et al.* (2004) [12], Sandhu *et al.* (2006) [13], Singh *et al.* (1983) [14], Paul and Duara (1991) [15], Sedhom (1994) [16], Mohammad (1993) [17] and Satyanarayana *et al.* (1994) [18]. Whereas, Olaoye (2005) [19] and Aminu and Izge (2013) [10] reported predominance of both GCA and SCA for most of the traits under stress and non-stress situations.

These results also in agreement with Rojas and Sprague (1952) [20] and Gama *et al.* (1995) who worked on millet and maize respectively. These results exhibited that parental lines would be utilized in the development of maize hybrids. Exploitation of hybrid vigour has gained much significance in view of enormous higher yield in hybrids, which is the only way to harness the predominant non-additive gene action

The contribution of lines to total variances was higher than testers for most of the traits which signifies the prevalence of high diversity among the lines used for this investigation. This is mainly attributed to the enormous diversity in different source populations from which these lines have been derived. The contribution of either lines or tester revealed the importance of specific contribution for expression of all the traits studied in hybrids. Similar observations were also reported by Kadlubiec *et al.* (2000) [21], Ramesh *et al.* (2000) [22], Rosa *et al.* (2000) [23], Mandal *et al.* (2001) [24] and Sandhu *et al.* (2006) [13].

A high GCA effect for specific trait in a parent indicates presence of additive gene effects for that trait. When parents possessing high GCA effects were combined by hybridization, a large proportion of progenies would have high value for the trait concerned facilitating easy selection for that trait.

In the present study, a score was given based on the GCA effects of the parents (Table 15). The total score of each parent across the characters was worked out for the classification of parents as high or best combiner and low or poor combiner (Thenmozhi, 1983) [25]

under stress situation, among the lines, Rajkumar $\times$ CML446 inberdline 18 exhibited maximum positive GCA effect for quantitative traits with a pooled score for GCA effects of +4 and proved itself as a potential general combiner. this was followed by NK6240 $\times$ HS17 inberdline 22 with poo score of +and NK6240 $\times$ HS17 inberdline 20, NK6240 $\times$ HS17 inberdline 14, NK6240 $\times$ HS17 inberdline 5, NK6240 $\times$ CI4 inberdline 18, NK6240 $\times$ CI4 inberdline 12 with pool score of +for GCA effects. Among the testers, HS7 recorded pool score of +4 indicating its superiority for utilization in hybridization programme.

General combining ability effects of selected triats. The results of these triats presented in (Table 2).

Under stress none of the parents recorded significant GCA effects in desirable direction. Anthesis silking interval is a trait used mostly in screening genotypes for tolerance to stresses (EL-Hosary *et al.*, 1994) [26]. It is a measure of nicking (synchronization) of pollen shed with silking as reported by

Paul and Debenth (1999) [27] and (Olaoye *et al.*, 2005) [19]. For number of cobs per plant three parents viz., NK6240 $\times$

CI4 inberdline 24, Allrounder $\times$ HS17 inberdline 34 and NK6240 $\times$ CI4 inberdline 12 exhibited significant GCA effects in desirable direction. Among testers, under stress situation, two parents viz., NK6240 $\times$ HSinberdline 22 and Rajkumar $\times$ CML446 inberdline 8 exhibited significant GCA effects in desirable direction

The GCA effects for grain yield per plant Rajkumar $\times$ CML446 inberdline exhibited significant GCA effect in desirable direction under stress. Among testers HS7 exhibited significant GCA effect in desirable direction under stress situation. The parents with a high GCA effects for traits could produce superior segregants in F_2 as well as in later generations. Significant GCA effects in desirable direction for most of the quantitative traits Therefore, these parents could be utilized in a hybridization programme for selection of superior recombinants. These findings are in accordance with Mandal *et al.* (2001) [24], Malik *et al.* (2004) [28], Koinuma *et al.* (2004) [29], Fan *et al.* (2004) [30], kanta *et al.* (2005), Prashanth (2008) [4], Kuchanur (2010) [31], Premlatha and Kalamani (2010) [9], Izge and Dugje (2011) [32], Aminu and Izge (2013) [10] and Praveen Kumar *et al.* (2014) [33]

The estimates of specific combining ability effects for traits in maize under stress situation are presented in Table 16. These estimates are used to identify the best cross-combinations for hybrids production (Izge *et al.*, 2007) [34]

Among 150 hybrids evaluated, 45 and 30 hybrid combinations recorded positive score under stress situation, across triats, indicating them as heterotic hybrids for these traits. under stress situation, among hybrids viz. (Allrounder $\times$ HS17 Inberdline 45) $\times$ HS10 and (Parbhat $\times$ CI4 Inberdline 5) $\times$ HSexhibited maximum positive GCA effect for quantitative traits with a pooled score for sca effects of +and (NK6240 $\times$ HS17 Inberdline 22) $\times$ KDMI16 (Allrounder $\times$ HS17 Inberdline 34) $\times$ HS7 and (Allrounder $\times$ HS17 Inberdline 25) $\times$ HS7 recorded a positive score of +for sca effects. However, under stress for chlorophyll content at 60 days, relative water content 90 days and shelling percentage

29 hybrid combinations were found to be inferior with negative score for sca effects across traits under stress. 91 hybrid combinations scored zero under stress, because of cancellation positive and negative significant sca effects for different characters. Such hybrids may also be considered as heterotic hybrids depending on the importance of productivity trait with positive significant sca effects (Table 16). The study revealed that hybrids with high SCA effects involved at least one or two of the several higher general combiners as parent. Gama *et al.* (1995), Kadams *et al.* (1999) [35] Asif *et al.* (2007) [8], Kuchanur (2010) [31], Premlatha and Kalamani (2010) [9], Aminu and Izge (2013) [10] and Praveen Kumar *et al.* (2014) [33] reported similar result where a hybrid with high SCA effects involved one or both of the good general combiners as parents.

Specific combining ability effects of selected triats. The results of these triats presented in (Table 2).

Under stress situation, the hybrids viz. (Rajkumar $\times$ CML446 Inberdline 40) $\times$ KDMI16 and (NK6240 $\times$ CIInberdline 12) $\times$ Cl exhibited significant sca effects in negative direction. Negativity of these traits is important, implying that these hybrids could mature earlier and could escape drought. Similar results were reported by Bello and Olaoye (2009) [36], Kuchanur (2010) [31] and Aminu and Izge (2013) [10]. Under stress situation, the hybrid viz. (Allrounder

× HS17 Inberdline 45) × HS10 (NK6240 × CI Inberdline 35) × HSand (Rajkumar × CML446 Inberdline 3) × CI4 (Rajkumar × CML446 Inberdline 18) × CIand (NK6240 × HS17 Inberdline 22) × KDMI16 exhibited significant sca effects in positive direction under stress situation, the hybrids viz., (Parbhat × CI Inberdline 5) × HS4 (Allrounder × HS17 Inberdline 25) × HS7 (Rajkumar × CML446 Inberdline 40) × CI4 (NK6240 × CIInberdline 12) × CIand (Allrounder × HS17 Inberdline 34) × HS7 (Allrounder × HS17 Inberdline 45) × HS10 and (NAC6002 × HSInberdline 7) × HSexhibited significant sca effects in positive direction, These are good hybrids when breeding for drought stress and grain yield. These hybrids probably have potential as parents of hybrid varieties, as well as for inclusion in breeding programmes, since they may contribute superior alleles in new populations for high grain yield and other abiotic stresses in maize production especially in areas where low rainfall. These results are in line with earlier independent studies of Perez-Velasquez *et al.* (1996)^[37], Kumar *et al.* (1998)^[38] and Joshi *et al.* (1998) who reported that maize grain yield and flowering traits were under the control of non-additive (SCA effects) type of gene action. Similar results were reported by Asif *et al.* (2007)^[8], Kuchanur (2010)^[31], Premalatha and Kalamani (2010)^[9] and Aminu and Izge (2013)^[10].

In order to identify the superior line through their test cross performance, the top five crosses based on their mean performance for each of the trait were identified along with their sca effects, GCA status of parents and standard heterosis over Rajkumar under stress situation, are presented in the Table 2. However the discussion has been made only on selected triats viz., anthesis to silking interval, grain yield per plant

Under stress situation, it is interesting to note that there were most of them are no common crosses across the traits, out of the identified hybrids based on the mean performance. However, under stress situation, recorded significant sca effects, one hybrid for anthesis to silking interval viz. (NK6240 × CIInberdline 12) × CI4, two hybrids for number of cobs per plant viz. (Rajkumar × CML446 Inberdline 18) × CIand (NK6240 × HS17 Inberdline 22) × KDMI16 and five hybrids for grain yield per plant viz. (Rajkumar × CML446 Inberdline 40) × CI4 (Allrounder × HS17 Inberdline 25) × HS7 (NK6240 × CIInberdline 12) × CI4 (Allrounder × HS17 Inberdline 34) × HS7 and (NAC6002 × CIInberdline 7) × HS4. The above hybrids can be utilized for the exploitation of heterosis based on components of the grain yield thereby the grain yield performance can be improved through heterosis breeding.

Under stress situation, grain yield (kg/ha) and grain yield per plant varied from 4010.79 to 4393.29 kg, 92.62 to 102.6 g, respectively. Among the top five hybrids selected on the basis of mean yield. Three hybrids for grain yield (kg/ha) viz. (Allrounder × HS17 Inberdline 34) × HS7 (NK6240 × HS17 Inberdline 14) × HS7 and (Allrounder × HS17 Inberdline 45) × HS10 and five hybrids for grain yield per plant viz. (Rajkumar × CML446 Inberdline 40) × CI4 (Allrounder × HS17 Inberdline 25) × HS7 (NK6240 × CIInberdline 12) × CI4 (Allrounder × HS17 Inberdline 34) × HS7 and (NAC6002 × CIInberdline 7) × HS4. Standard heterosis over check ranging from 45.06 to 56.30 for grain yield (kg/ha) and 116.33 to 139.65 for grain yield per plant. These three and five hybrids need to be further evaluated in

large scale trials before these are identified for commercial cultivation.

Drought susceptibility index (DSI) among 150 hybrids along with 35 parents and checks (Allrounder × HS17 inbredline 39) × CI4 (0.04) lowest DSI values for grain yield (kg/ ha).

It is concluded that under stress situation, Three hybrids for grain yield (kg/ha) viz. (Allrounder × HS17 Inberdline 34) × HS7 (NK6240 × HS17 Inberdline 14) × HS7 and (Allrounder × HS17 Inberdline 45) × HS10. These three hybrids need to be further evaluated in large scale trials before these are identified for commercial cultivation

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