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Combining ability analysis of maize inbred lines from line x tester mating design under stress and under non-stress situations

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Abstract
Thirty maize inbred lines were crossed with five testers in a line × tester mating design to produce 150 experimental hybrids, which, together with 35 parental lines and standard checks, were evaluated under non-stress and managed drought-stress conditions during the early spring season of 2013-14 in a restricted randomized block design with two replications, each genotype being grown in a single 4 m row spaced 75 × 20 cm. Under non-stress conditions the material received recommended agronomic practices and irrigation at 10-12-day intervals, whereas under managed stress irrigation was given only up to 30 days after sowing and withheld thereafter so that stress coincided with flowering and grain filling; a 4 m maize buffer separated the two regimes. Specific combining ability (SCA) variance exceeded general combining ability (GCA) variance for most traits and the GCA/SCA ratios were below unity, indicating the predominance of non-additive gene action. Rajkumar × CML446 Inbredline 18, NK6240 × CI4 Inbredline 12 and NK6240 × CI4 Inbredline 24 among the lines, and HS7 among the testers, were the best general combiners. Under non-stress conditions, (Rajkumar × CML446 Inbredline 3) × HS4, (NK6240 × CI4 Inbredline 12) × HS4 and (Allrounder × HS17 Inbredline 34) × HS7 exhibited significant SCA effects coupled with superior grain yield, recording 27.85 to 38.29 per cent standard heterosis. Under managed drought stress, (Allrounder × HS17 Inbredline 34) × HS7, (NK6240 × HS17 Inbredline 14) × HS7 and (Allrounder × HS17 Inbredline 45) × HS10 recorded 45.06 to 56.30 per cent standard heterosis over the check. These hybrids merit further evaluation in multilocation and large-scale trials before consideration for commercial cultivation.

Keywords: Combining ability, drought stress, grain yield, maize, specific combining ability, standard heterosis, three-way hybrids.

Introduction
Maize (*Zea mays* L.) is one of the most important cereal crops of the world and is valued for its high genetic yield potential, wide adaptability and diverse end uses. It belongs to the tribe Maydeae of the family Poaceae, is believed to have originated in the Americas, and is a monoecious diploid with 2n = 20 chromosomes; teosinte (*Euchlaena* spp.) is regarded as its closest wild relative, while *Tripsacum* is another important related genus. Thousands of years of cultivation followed by intensive domestication and breeding have generated diverse germplasm and highly productive hybrid cultivars. As a C_4 species maize achieves high rates of photosynthesis and biomass production and is grown from temperate to tropical environments for food, feed, fuel and industrial use. In India it ranks third among cereals after rice and wheat, about 52 per cent of the grain being used as poultry, swine and fish feed, 11 per cent as cattle feed, 23 per cent as food and 13 per cent as industrial raw material, and demand continues to rise with population growth, expansion of the livestock and poultry sectors and the growing starch, sweetener and biofuel industries.
Maize occupies about 199 million hectares globally with a production of 1129.20 million tonnes and an average productivity of 5820 kg ha^{-1} (Anonymous, 2024). India produces approximately 461.49 lakh tonnes from 128.35 lakh hectares with an average productivity of 3595 kg ha^{-1}, while in Karnataka the crop is grown on about 19.02 lakh hectares producing 63.51 lakh tonnes with a productivity of 3339 kg ha^{-1} (Anonymous, 2025-26). Despite this potential, production is constrained by several biotic and abiotic stresses, of which drought

and low soil fertility are the most important in tropical and subtropical systems. A large proportion of tropical maize is rainfed, and irregular rainfall or prolonged soil moisture deficit frequently limits productivity. Stress at flowering and grain filling is particularly damaging because it disturbs pollen production, silk emergence, fertilization, kernel formation and grain development, widens the anthesis-silking interval, reduces photosynthetic activity and hastens leaf senescence. Drought is therefore considered the single most important constraint preventing maize from realizing its genetic yield potential (Edmeades *et al.*, 2001) [1], with average yield losses estimated at about per cent in temperate and 17 per cent in tropical environments (Edmeades *et al.*, 2000) [2].

Genetic improvement offers a sustainable and economically viable means of mitigating drought, particularly where irrigation is limited, and the development of genetically diverse base populations is an essential first step because such populations supply the raw material for superior inbred lines; indigenous and diverse germplasm is especially valuable for deriving lines with high yield potential and local stress adaptation (Prashanth, 2008) [3]. Combining ability analysis is an important biometrical tool for assessing the breeding value of such lines. General combining ability (GCA) reflects the average performance of a parent across hybrid combinations and is largely associated with additive effects, whereas specific combining ability (SCA) reflects the performance of particular crosses and is associated with non-additive effects, including dominance and epistasis; together they identify superior parents and promising combinations for yield improvement and stress tolerance (Falconer, 1964) [4].

Heterosis can substantially enhance grain yield, plant vigour, stress tolerance and adaptation, and its exploitation through single-cross and three-way hybrids has been central to raising maize productivity, particularly where the parental lines are genetically diverse and drought adapted. However, the expression of combining ability and heterosis varies considerably with environment, and a hybrid that performs exceptionally well under adequate moisture need not retain its productivity under drought. Simultaneous evaluation of parents and hybrids under contrasting moisture regimes therefore provides valuable information on the genetic control of yield and on the identification of stress-adapted combinations. In view of the increasing frequency of drought and the expansion of maize into marginal rainfed environments, the present investigation was undertaken to evaluate the combining ability effects and heterotic performance of maize inbred lines and their hybrids under non-stress and managed drought-stress conditions, and to identify promising combinations with superior grain yield and desirable specific combining ability for further large-scale testing.

Material and Methods

Experimental site and environmental conditions

The investigation was carried out during the kharif, rabi and summer seasons of 2011-12, 2012-13 and 2013-14 at the Main Agricultural Research Station (MARS), Dharwad, Karnataka, India, situated at approximately 15°02′ N latitude and 75°25′ E longitude at an altitude of 678 m above mean sea level; rainfall and temperature data for the crop growth periods are presented in Appendix I. The 150 F_1 hybrids developed through the line × tester mating design were evaluated under contrasting moisture regimes during Rabi 2013-14, when mean minimum and maximum temperatures ranged from 16.0 to 30.87 °C and total rainfall was only 11.40 mm. The low rainfall during the evaluation period facilitated the imposition of managed drought stress.

Selection of inbred lines and development of hybrids

An initial set of 200 inbred lines was evaluated for traits associated with grain yield and drought adaptation, and 30 superior lines were selected on the basis of grain yield greater than the population mean plus one standard deviation, anthesis-silking interval lower than the population mean minus one standard deviation, and number of cobs per plant greater than the population mean plus one standard deviation. These lines were used as female parents and crossed with five testers on 3 April 2013 during the summer season of 2013 to produce 150 experimental hybrids. The hybrid seed was harvested at physiological maturity, processed, dried properly and stored under controlled dry-room conditions until field evaluation.

Field evaluation under non-stress and managed drought-stress conditions

The 150 hybrids, along with 35 parental genotypes and selected standard checks, were evaluated under both non-stress and managed drought-stress conditions during the early spring season of 2013-14 in a restricted randomized block design (RBD) with two replications, each genotype being raised in a single row of 4 m length with 75 cm between rows and 20 cm between plants. Under non-stress conditions all genotypes received recommended agronomic practices and furrow irrigation at intervals of about 10-12 days throughout the crop growth period to ensure adequate moisture, whereas under managed drought stress irrigation was given only up to 30 days after sowing and withheld thereafter until harvest so as to impose moisture stress during the critical flowering and grain-filling stages. To minimize lateral movement of irrigation water between regimes, the two experiments were separated by a 4 m buffer zone planted with maize, and all other recommended agronomic and crop-management practices were followed uniformly in both regimes.

Observations recorded and statistical analysis

Observations were recorded on five randomly selected, healthy and competitive plants of each genotype in each replication for days to 50 per cent anthesis, days to 50 per cent silking, anthesis-silking interval (ASI), days to maturity, chlorophyll content, relative water content (RWC), plant height (cm), ear height (cm), cob length (cm), cob girth (cm), number of cobs per plant, number of kernel rows per cob, number of kernels per row, 100-grain weight (g), shelling percentage, grain yield per plant (g) and grain yield (kg ha^{-1}), and the trait means were used for statistical analysis and combining ability estimation. The mean performance data of the hybrids were subjected to line × tester analysis, partitioning the total variation among hybrids into components attributable to GCA and SCA, GCA effects being used to judge the average breeding worth of the lines and testers and SCA effects to identify specific combinations of superior performance. The analysis followed the procedure of Kempthorne (1957) and was carried out using WINDOSTAT version 8.0; the significance of GCA and SCA effects was tested against the appropriate error variances, and the relative contributions of lines, testers and their interaction to the total variation were estimated under both moisture regimes. Heterosis over the mid parent (relative heterosis) and over the best check (standard heterosis) was worked out against the commercial check Rajkumar, and the drought susceptibility index (DSI) was computed for grain yield.

Results and discussion

Analysis of variance for combining ability

The analysis of variance for combining ability for all the traits studied in the 150 hybrids evaluated under non-stress and managed-stress conditions is presented in Table 1. Significant differences among crosses were observed under non-stress conditions for cob length, cob girth, number of kernel rows per cob, number of kernels per row, number of cobs per plant, grain yield per plant and grain yield, and under managed stress for chlorophyll content at 90 days, relative water content at 60 days, number of kernel rows per cob and grain yield per plant, indicating substantial genetic diversity and considerable potential among the parents for generating superior combinations under both regimes. The line component was significant for most traits under non-stress conditions except days to maturity, chlorophyll content at 60 and 90 days, cob length, number of kernels per row, 100-seed weight, grain yield per plant, grain yield and shelling percentage; under managed stress, lines differed significantly for days to 50 per cent anthesis and silking, chlorophyll content at 90 days, relative water content at 60 and 90 days, plant height, ear height, cob length, number of kernels per row and 100-seed weight, demonstrating appreciable GCA variation and indicating that the selected lines differed in their capacity to transmit favourable genes to their progenies.

The testers also differed significantly for days to 50 per cent anthesis, chlorophyll content at 90 days, cob length, number of cobs per plant and grain yield per plant under non-stress conditions, and for chlorophyll content 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 under managed stress, showing that they differed in combining ability for both agronomic and drought-adaptive physiological traits. The line × tester interaction was significant for cob length, cob girth, number of kernel rows per cob, number of kernels per row, grain yield per plant and grain yield under non-stress conditions and for number of kernel rows per cob and grain yield per plant under managed stress, indicating that the performance of a line depended considerably on the tester with which it was crossed and emphasizing the role of SCA in identifying superior yield combinations.

The relative contribution of the two components varied with trait and moisture regime. Under non-stress conditions SCA variance exceeded GCA variance for most traits, the exceptions being days to 50 per cent anthesis and silking, chlorophyll content at 90 days and relative water content at 60 and 90 days; under managed stress SCA variance again predominated, while GCA variance was relatively higher for days to 50 per cent anthesis and silking, ASI, chlorophyll content at 60 days, relative water content at 60 and 90 days, plant height, ear height, number of cobs per plant and 100-seed weight. The GCA/SCA ratio exceeded unity only for number of cobs per plant under non-stress conditions and was below unity for all traits under managed stress, confirming the greater importance of non-additive gene action in the inheritance of these characters, particularly under moisture deficit. Lines contributed more than testers to the total variation for all traits under both regimes, reflecting the broader genetic variability among the 30 selected lines, while the line × tester interaction contributed substantially for all traits except number of cobs per plant under non-stress conditions and for all traits under managed stress. The identification of superior drought-tolerant hybrids therefore requires extensive testing of specific crosses rather than reliance on the average performance of individual parents alone, whereas the significant GCA effects recorded for several traits show that selection of parents with favourable additive effects remains important for building improved breeding material.

General combining ability effects

Under non-stress conditions the GCA effects of the lines for days to 50 per cent anthesis ranged from -1.30 (NK6240 × CI4 Inbredline 37) to 1.60 (Rajkumar × CML446 Inbredline 37) and those of the testers from -0.48 (HS7) to 0.41 (CI4); of the two significant lines, NK6240 × CI4 Inbredline 37 (-1.30) was negative and therefore desirable, since earlier flowering may permit drought escape. Under stress the line effects ranged from -2.87 (Rajkumar × CML446 Inbredline 3) to 1.73 (NK6240 × CI4 Inbredline 18) and the tester effects from -0.22 (HS4) to 0.16 (HS10), Rajkumar × CML446 Inbredline 38 (-1.77) and Rajkumar × CML446 Inbredline 3 (-2.87) being significantly negative. Days to 50 per cent silking ranged from -1.55 to 1.34 under non-stress and from -2.30 to 2.10 under stress, NK6240 × CI4 Inbredline 37 (-1.35) and Allrounder × HS17 Inbredline 34 (-1.55) being desirable in the former and Rajkumar × CML446 Inbredline 38 (-1.60), G57 × NAC6002 Inbredline 25 (-1.80) and Rajkumar × CML446 Inbredline 3 (-2.30) in the latter, which indicates favourable additive effects for early silking and better reproductive synchrony. For ASI, six lines were significant under non-stress conditions, NK6240 × CI4 Inbredline 37 (-1.35) and Rajkumar × CML446 Inbredline 1 (-0.55) in the desirable negative direction, whereas under stress only NK6240 × HS17 Inbredline 20 (0.77) was significant and unfavourably positive. Days to maturity ranged from -2.22 to 1.07 and from -2.55 to 2.35 respectively, NK6240 × CI4 Inbredline 37 (-2.22 and -2.55) and NK6240 × CI4 Inbredline 35 (-1.85) emerging as useful sources of earliness.

Chlorophyll content at 60 days ranged from -3.90 (Rajkumar × CML446 Inbredline 25) to 4.00 (NAC6002 × CI4 Inbredline 7) under non-stress and from -2.49 to 2.56 (Allrounder × HS17 Inbredline 25) under stress, four and two lines respectively being significant, with NAC6002 × CI4 Inbredline 7, Allrounder × HS17 Inbredline 25 and the tester HS4 (1.61) positive. At 90 days the effects ranged from -2.93 to 3.29 (Rajkumar × CML446 Inbredline 37) under non-stress and from -5.34 to 6.10 (Parbhat × CI4 Inbredline 5) under stress, where seven lines were significant and Allrounder × HS17 Inbredline 39 (3.41), Rajkumar × CML446 Inbredline 18 (3.60) and Parbhat × CI4 Inbredline 5 (6.10) were positive, indicating a favourable additive contribution to chlorophyll retention and hence to sustained photosynthesis during grain filling. For relative water content at 60 days, Allrounder × HS17 Inbredline 39 (0.057), Allrounder × HS17 Inbredline 21 (0.063) and Allrounder × HS17 Inbredline 34 (0.068) were positive among the five significant lines under non-stress conditions, and NK6240 × HS17 Inbredline 20 (0.068) and Rajkumar × CML446 Inbredline 1 (0.075) among the six significant lines under stress. At 90 days, Allrounder × HS17 Inbredline 34 (0.10), Allrounder × HS17 Inbredline 25 (0.12) and Allrounder × HS17 Inbredline 21 (0.13) were positive under non-stress conditions and Allrounder × HS17 Inbredline 34 (0.072) with the tester HS7 (0.036) under stress, identifying them as sources for maintaining tissue hydration under moisture deficit.

For plant height the line effects ranged from -22.97 (Rajkumar × CML446 Inbredline 3) to 12.82 (Rajkumar × CML446 Inbredline 38) under non-stress and from -23.41 (Rajkumar × CML446 Inbredline 8) to 20.33 (Rajkumar × CML446 Inbredline 1) under stress, and for ear height from -17.63 to 14.41 and from -17.42 to 10.87 respectively, the tester HS10 (6.91) being positive and CI4 negative (-5.95 for plant height and -5.44 for ear height) under stress. These contrasting effects reflect considerable diversity for plant stature, positive effects being useful for biomass and vigour and negative effects for developing shorter, lodging-resistant genotypes. Cob length showed positive effects for Rajkumar × CML446 Inbredline 18 (1.67), Rajkumar × CML446 Inbredline 25 (2.13) and the tester HS7 (0.86) under non-stress conditions and for five lines under stress, ranging from NK6240 × HS17 Inbredline 5 (1.27) to Rajkumar × CML446 Inbredline 3 (1.87), while cob girth ranged from -0.42 to 0.25 (Rajkumar × CML446 Inbredline 18) with four positive lines under non-stress conditions and from -0.24 to 0.24 (Allrounder × HS17 Inbredline 25) with two positive lines under stress.

Among the yield components, five lines recorded positive GCA effects for number of kernel rows per cob under non-stress conditions, from NK6240 × CI4 Inbredline 35 (0.69) to Rajkumar × CML446 Inbredline 40 (1.35), together with the tester CI4 (0.30), and three under stress, from NK6240 × CI4 Inbredline 37 (0.78) to Rajkumar × CML446 Inbredline 38 (1.08). For number of kernels per row, Rajkumar × CML446 Inbredline 37 (2.63) and Rajkumar × CML446 Inbredline 25 (3.53) were positive under non-stress conditions and five lines under stress, from Rajkumar × CML446 Inbredline 18 (2.92) to NK6240 × CI4 Inbredline 12 (3.56). For number of cobs per plant, NK6240 × CI4 Inbredline 24 (0.21), Allrounder × HS17 Inbredline 34 (0.28) and NK6240 × CI4 Inbredline 12 (0.41) among the lines and HS7 (0.07) and HS4 (0.09) among the testers were positive under non-stress conditions, and NK6240 × HS17 Inbredline 22 and Rajkumar × CML446 Inbredline 8 (0.16 each) under stress. No line was significantly positive for 100-seed weight under non-stress conditions, whereas NK6240 × CI4 Inbredline 37 (2.15) and NK6240 × CI4 Inbredline 12 (2.33) were positive under stress. Grain yield per plant ranged from -20.72 to 45.08 and from -11.37 to 13.93, Rajkumar × CML446 Inbredline 18 and the tester HS7 being significantly positive in both regimes, while for grain yield NK6240 × CI4 Inbredline 12 (784.73) and NK6240 × CI4 Inbredline 24 (854.57) were positive under non-stress conditions and, under stress, the highest numerical effect (Rajkumar × CML446 Inbredline 18, 515.05) was non-significant while only HS7 (261.30) was significant. Shelling percentage was favourable in NK6240 × CI4 Inbredline 35 (4.507) and NK6240 × CI4 Inbredline 42 (4.508) under non-stress conditions and in Rajkumar × CML446 Inbredline 25 (4.57) under stress. Overall, Rajkumar × CML446 Inbredline 18, NK6240 × CI4 Inbredline 12 and NK6240 × CI4 Inbredline 24 with the tester HS7 were the most promising parents for yield, whereas parents with negative effects for flowering, ASI and maturity and positive effects for chlorophyll and relative water content are particularly valuable for drought-resistance breeding, since earliness allows drought escape while chlorophyll retention and tissue water status reflect physiological adaptation.

Specific combining ability effects

The SCA effects of the 150 crosses, which are used to identify the best cross combinations for hybrid production (Izge *et al.*, 2007), showed that for days to 50 per cent anthesis only (NK6240 × CI4 Inbredline 24) × HS7 (-2.91) was significantly negative under non-stress conditions, and (Rajkumar × CML446 Inbredline 8) × KDMI16 (-3.48) and (Allrounder × HS17 Inbredline 21) × HS7 (-3.86) under stress. For days to 50 per cent silking, (Rajkumar × CML446 Inbredline 18) × CI4 (-3.47) and (Allrounder × HS17 Inbredline 21) × HS7 (-3.58) were significantly negative under the two regimes respectively; for ASI, (Rajkumar × CML446 Inbredline 18) × HS7 (-1.26) under non-stress conditions and (Rajkumar × CML446 Inbredline 40) × KDMI16 (-1.72) and (NK6240 × CI4 Inbredline 12) × CI4 (-2.13) under stress; and for days to maturity, (Rajkumar × CML446 Inbredline 46) × HS4 (-2.64) under non-stress conditions and (NK6240 × HS17 Inbredline 20) × KDMI16 (-4.11) and (Rajkumar × CML446 Inbredline 46) × HS7 (-4.85) under stress. For chlorophyll content at 60 days, three hybrids were significantly positive under non-stress conditions, from (NK6240 × HS17 Inbredline 10) × HS10 (6.74) to (Rajkumar × CML446 Inbredline 37) × KDMI16 (8.62), and none under stress; at 90 days three were positive under non-stress conditions, up to (Rajkumar × CML446 Inbredline 37) × KDMI16 (7.78), and one under stress, (NK6240 × HS17 Inbredline 10) × HS7 (8.08). For relative water content at 60 days, (NK6240 × HS17 Inbredline 20) × HS4 (0.13) was positive under non-stress conditions and three hybrids under stress, the best being (Allrounder × HS17 Inbredline 45) × CI4 (0.161); at 90 days three were positive under non-stress conditions, up to (Rajkumar × CML446 Inbredline 1) × HS7 (0.248), and none under stress. For plant height, three hybrids showed significant negative effects under non-stress conditions, up to -54.76 in (NK6240 × HS17 Inbredline 14) × HS7, while under stress two were positive, (Allrounder × HS17 Inbredline 21) × CI4 (30.70) and (Rajkumar × CML446 Inbredline 8) × CI4 (30.80), and three negative, up to -46.01 in (Allrounder × HS17 Inbredline 21) × KDMI16. For ear height, seven hybrids were significant under non-stress conditions, four positive with a maximum of 27.18 in (Allrounder × HS17 Inbredline 34) × HS7 and three negative down to -31.82 in (NK6240 × HS17 Inbredline 5) × HS7, whereas under stress (Rajkumar × CML446 Inbredline 36) × CI4 (24.14) was positive and (NK6240 × CI4 Inbredline 12) × CI4 (-24.16) and (Rajkumar × CML446 Inbredline 36) × HS10 (-24.46) negative.

Eight hybrids recorded significant positive SCA effects for cob length under non-stress conditions, from 2.48 in (G57 × NAC6002 Inbredline 25) × KDMI16 to 2.82 in (Allrounder × HS17 Inbredline 34) × KDMI16, and three under stress, the best being (Rajkumar × CML446 Inbredline 3) × HS4 (4.73). For cob girth, seven hybrids were positive under non-stress conditions, up to 0.530 in (Allrounder × HS17 Inbredline 21) × HS10, and one under stress, (NK6240 × HS17 Inbredline 22) × KDMI16 (0.60). For number of kernel rows per cob, eight hybrids were positive under non-stress conditions, up to 2.379 in (Rajkumar × CML446 Inbredline 18) × HS10, and five under stress, up to 3.25 in (Allrounder × HS17 Inbredline 21) × HS10; for number of kernels per row, six were positive under non-stress conditions, up to 7.81 in (Rajkumar × CML446 Inbredline 46) × HS4, and one under stress, (Allrounder × HS17 Inbredline 21) × HS7 (6.51). For number of cobs per plant, (Allrounder × HS17 Inbredline 25) × HS10 (0.40), (NK6240 × CI4 Inbredline 24) × HS4 (0.47) and (Allrounder × HS17 Inbredline 45) × KDMI16 (0.66) were positive under non-stress conditions and five hybrids under stress, up to 0.43 in (NK6240 × HS17 Inbredline 22) × KDMI16. Three hybrids were positive for 100-grain weight in each regime, the best being (Rajkumar × CML446 Inbredline 46) × HS4 (6.74) under non-stress conditions and (Rajkumar × CML446 Inbredline 46) × HS10 (5.40) under stress, while for shelling percentage only (Rajkumar × CML446 Inbredline 46) × KDMI16 (10.30) was significantly positive under non-stress conditions.

For grain yield per plant the SCA effects ranged from -51.62 to 100.86 under non-stress conditions, four hybrids being significantly positive, namely (NK6240 × CI4 Inbredline 37) × HS7 (51.87), (Rajkumar × CML446 Inbredline 38) × HS7 (62.76), (Rajkumar × CML446 Inbredline 18) × HS4 (82.17) and (NK6240 × HS17 Inbredline 14) × HS7 (100.86), and from -32.49 to 50.72 under stress, where seven were positive: (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). For grain yield the effects ranged from -2707.35 to 3502.08 under non-stress conditions, with (Rajkumar × CML446 Inbredline 3) × HS4 (2046.41), (NK6240 × CI4 Inbredline 12) × HS4 (2127.90), (Allrounder × HS17 Inbredline 39) × HS10 (2522.86) and (Allrounder × HS17 Inbredline 34) × HS7 (3502.08) significantly positive, and from -1874.72 to 2200.55 under stress, where six were positive: (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).

Heterosis

Relative heterosis over the mid parent and standard heterosis over the commercial check Rajkumar were computed under both moisture regimes, and the top five hybrids based on mean performance, together with their SCA effects, standard heterosis and the GCA status of their parents, are presented in Tables 2 and 3. For days to 50 per cent anthesis, relative heterosis ranged from -7.48 to 4.76 under non-stress conditions and from -11.27 to 10.27 under stress and standard heterosis from -4.70 to 4.70 and from -11.59 to 5.07; 11 and four hybrids respectively showed significant negative relative heterosis and 16 hybrids under stress significant negative standard heterosis, the best being (Rajkumar × CML446 Inbredline 3) × CI4 (-11.59), (Rajkumar × CML446 Inbredline 3) × HS4 (-10.14) and (Rajkumar × CML446 Inbredline 38) × HS4 (-8.70). For days to 50 per cent silking, relative heterosis ranged from -6.98 to 3.42 and from -10.10 to 7.97 and standard heterosis from -4.11 to 5.48 and from -9.79 to 4.30, with 11 and eight hybrids showing significant negative relative heterosis and 14 hybrids under stress significant negative standard heterosis, led by (Rajkumar × CML446 Inbredline 3) × HS4 and (Rajkumar × CML446 Inbredline 3) × CI4 (-9.79 each). For ASI, relative heterosis ranged from -69.23 to 250.00 and from -71.43 to 220.00 and standard heterosis from -33.33 to 166.67 and from -60.00 to 100.00, 13 and three hybrids showing significant negative relative heterosis but none significant negative standard heterosis. For days to maturity, relative heterosis ranged from -4.15 to 2.94 and from -5.12 to 7.06 and standard heterosis from -4.55 to 1.65 and from -3.35 to 5.74, 12 hybrids under non-stress conditions showing significant negative standard heterosis, the best being (Rajkumar × CML446 Inbredline 46) × HS4 and (NK6240 × CI4 Inbredline 37) × HS10 and × HS4 (-4.55 each). For chlorophyll content at 60 days, relative heterosis ranged from -29.96 to 20.14 under non-stress conditions and from -22.59 to 13.25 under stress and standard heterosis from -22.53 to 18.65 and from -22.85 to 9.50, only one hybrid showing significant positive relative heterosis and none significant positive standard heterosis; at 90 days the corresponding ranges were -30.92 to 26.30 and -41.96 to 108.33 for relative heterosis and -25.54 to 21.52 and -46.65 to 17.30 for standard heterosis, with two and ten hybrids showing significant positive relative heterosis but none significant positive standard heterosis. For relative water content at 60 days, relative heterosis ranged from -20.47 to 24.04 and from -26.93 to 26.32 and standard heterosis from -16.67 to 23.61 and from -27.81 to 19.21, (NK6240 × HS17 Inbredline 20) × HS4 (23.61) being the only hybrid with significant positive standard heterosis; at 90 days the ranges were -53.91 to 75.46 and -42.58 to 45.25 for relative heterosis and -54.72 to 28.69 and -50.82 to 15.57 for standard heterosis, two and three hybrids showing significant positive relative heterosis and none significant positive standard heterosis. For plant height, relative heterosis ranged from -31.31 to 13.11 and from -27.67 to 10.22 and standard heterosis from -27.27 to 13.37 and from -24.41 to 7.85, five and 13 hybrids showing significant negative relative heterosis and two and nine significant negative standard heterosis. For ear height the ranges were -37.70 to 44.34 and -31.60 to 26.79 for relative heterosis and -38.54 to 23.96 and -27.03 to 32.78 for standard heterosis, three hybrids recording significant positive standard heterosis under stress, namely (Allrounder × HS17 Inbredline 34) × HS7 (31.10), (NK6240 × CI4 Inbredline 35) × HS10 (31.34) and (Rajkumar × CML446 Inbredline 1) × HS4 (32.78).

For cob length, standard heterosis ranged from -25.97 to 19.83 under non-stress conditions and from -31.37 to 48.69 under stress, (Rajkumar × CML446 Inbredline 25) × HS10 (19.83) being significant in the former and five hybrids in the latter, the best being (Rajkumar × CML446 Inbredline 3) × HS4 (48.69) followed by (NK6240 × CI4 Inbredline 12) × CI4 (28.10) and (Parbhat × CI4 Inbredline 5) × HS4 (27.45). For cob girth, standard heterosis ranged from -14.47 to 11.70 and from -17.96 to 20.42, with (Allrounder × HS17 Inbredline 21) × HS10 (11.06) and (Allrounder × HS17

Inbredline 34) × HS7 (11.70) significant under non-stress conditions and (G57 × NAC6002 Inbredline 25) × HS7 (16.36), (NK6240 × HS17 Inbredline 14) × HS7 (18.08) and (NK6240 × HS17 Inbredline 22) × KDMI16 (20.42) under stress. For number of kernel rows per cob, standard heterosis ranged from -21.75 to 14.12 and from -17.37 to 17.80, (Rajkumar × CML446 Inbredline 18) × HS10 (14.12) being significant under non-stress conditions and (Allrounder × HS17 Inbredline 21) × HS10, (Rajkumar × CML446 Inbredline 38) × CI4 (17.77 each) and (NK6240 × CI4 Inbredline 37) × KDMI16 (17.80) under stress; for number of kernels per row it ranged from -44.03 to -6.71 and from -39.36 to 22.34, 122 and six hybrids recording significant negative standard heterosis and none significant positive heterosis. For number of cobs per plant, standard heterosis ranged from -14.16 to 71.67 and from -14.16 to 43.35, seven hybrids being significant under non-stress conditions, the best being (NK6240 × CI4 Inbredline 24) × HS4 (71.67) and (NK6240 × CI4 Inbredline 12) × HS7 (57.51), and one under stress, (NK6240 × HS17 Inbredline 22) × KDMI16 (43.35). For 100-grain weight it ranged from -38.39 to 27.33 and from -13.57 to 61.49, (Rajkumar × CML446 Inbredline 46) × HS4 (27.33) being significant under non-stress conditions and six hybrids under stress, from (Parbhat × CI4 Inbredline 5) × HS10 (39.29) to (NK6240 × CI4 Inbredline 37) × KDMI16 (61.49).

For grain yield per plant, relative heterosis ranged from -73.68 to 171.57 under non-stress conditions and from -93.48 to 122.45 under stress and standard heterosis from -67.70 to 89.99 and from -90.39 to 139.65, seven hybrids in each regime showing significant positive relative heterosis; (NK6240 × HS17 Inbredline 14) × HS7 (86.76) and (Rajkumar × CML446 Inbredline 18) × HS4 (89.99) recorded significant positive standard heterosis under non-stress conditions, whereas ten hybrids did so under stress, ranging from (NK6240 × HS17 Inbredline 5) × HS7 (97.98) to (NAC6002 × CI4 Inbredline 7) × HS4 (139.65) and including (Allrounder × HS17 Inbredline 34) × HS7 (133.94), (NK6240 × CI4 Inbredline 12) × CI4 (133.31) and (Allrounder × HS17 Inbredline 25) × HS7 (129.01). For grain yield, relative heterosis ranged from -62.76 to 133.78 [(Allrounder × HS17 Inbredline 34) × HS7] under non-stress conditions and from -93.93 to 127.34 [(Rajkumar × CML446 Inbredline 46) × HS4] under stress, and standard heterosis from -64.17 to 38.29 [(Allrounder × HS17 Inbredline 34) × HS7] and from -94.80 to 56.30 [(Allrounder × HS17 Inbredline 45) × HS10], six and five hybrids showing significant positive relative heterosis and 20 and three significant negative standard heterosis. For shelling percentage, relative heterosis ranged from -24.87 to 23.12 and from -25.69 to 10.73 and standard heterosis from -21.90 to 22.98 and from -22.51 to 11.19; three hybrids recorded significant positive standard heterosis under non-stress conditions, namely (Rajkumar × CML446 Inbredline 46) × KDMI16 (22.98), (NK6240 × CI4 Inbredline 35) × HS10 (22.01) and (NK6240 × CI4 Inbredline 35) × HS7 (21.15), and none under stress.

Drought susceptibility index

Among the 150 hybrids together with 35 parents and three checks, the drought susceptibility index for grain yield ranged from 0.04 in (Allrounder × HS17 Inbredline 39) × CI4 to 1.81 in (NK6240 × HS17 Inbredline 10), with an overall mean of 0.87, hybrids with low index values having maintained their productivity relatively better under moisture deficit and being therefore regarded as drought tolerant.

Gene action, contribution of parents and classification of combiners

The significant mean sum of squares due to line × tester for cob length, cob girth, number of kernel rows per cob, number of kernels per row, grain yield per plant and grain yield under non-stress conditions, and for number of kernel rows per cob and grain yield per plant under stress, indicates the diverse performance of the hybrids and the presence of average heterosis, in agreement with Joshi *et al.* (2002) [6], Asif *et al.* (2007) [7], Premlatha and Kalamani (2010) [8], Aminu and Izge (2013) [9] and Kuchanur *et al.* (2013) [10]. Maize, being a highly allogamous species, is expected to show a predominance of non-additive gene action, and as expected the variance due to SCA was considerably higher than that due to GCA for all the characters under both regimes except number of cobs per plant under non-stress conditions, the GCA to SCA variance ratio being far below unity. A predominance of non-additive gene action for most growth and productivity traits has similarly been reported by Singh *et al.* (1983) [11], Paul and Duara (1991) [12], Mohammad (1993) [13] Sedhom (1994) [14], Satyanarayana *et al.* (1994) [15], Sharma *et al.* (2004) [16] and Sandhu *et al.* (2006) [17], whereas Olaoye *et al.* (2005) [18] and Aminu and Izge (2013)[9] reported the importance of both GCA and SCA, and the present findings are also in agreement with Rojas and Sprague (1952) [19]. The exploitation of hybrid vigour has therefore gained much significance, being the only practical way of harnessing predominantly non-additive gene action, and the parental lines identified here can be used directly in the development of maize hybrids. The higher contribution of lines than of testers to the total variance for most traits signifies the high diversity among the lines used, attributable to the diverse source populations from which they were derived, while the contribution of either lines or testers reveals the importance of specific contributions to the expression of all the traits in the hybrids, as also reported by Kadlubiec *et al.* (2000) [20] Ramesh *et al.* (2000) [21], Rosa *et al.* (2000) [22], Mandal *et al.* (2001) [23] and Sandhu *et al.* (2006)[17]. Following Thenmozh (1983), a score was assigned on the basis of the GCA effects of each parent and pooled across characters to classify parents as good or poor combiners. Under non-stress conditions, Rajkumar × CML446 Inbredline 37 and NK6240 × CI4 Inbredline 24 recorded the highest pooled score (+4) and proved to be potential general combiners, followed by NK6240 × CI4 Inbredline 12, Allrounder × HSInbredline 34 and Allrounder × HSInbredline 25 (+3) and by Rajkumar × CML446 Inbredline 18, Allrounder × HS1 Inbredline 21 and NAC6002 × CI4 Inbredline 7 (+2). Under stress, Rajkumar × CML446 Inbredline recorded th highest score (+4), followed by NK6240 × HSInbredline 22 (+3) and by NK6240 × HSInbredline 20, NK6240 × HSInbredline 14, NK6240 × HSInbredline 5, NK6240 × CI4 Inbredline and NK6240 × CI4 Inbredline 12 (+2) Among the testers, HS7 recorded a pooled score of +4 under both regimes, indicating its superiority for use in hybridization programmes.

For ASI, NK6240 × CI4 Inbredline 37 and Rajkumar × CML446 Inbredline 1 showed significant GCA effects in the desirable direction under non-stress conditions, whereas none of the parents did so under stress. ASI is widely used in screening genotypes for stress tolerance (El-Hosary *et al.*, 1994) because it measures the nicking or synchronization of pollen shed with silking, as reported by Paul and Debanth (1999) [24] and Olaoye *et al.* (2005) [18]. For number of cobs per plant, NK6240 × CI4 Inbredline 24, Allrounder × HSInbredline 34 and NK6240 × CI4 Inbredline 12 among the lines and HS7 and HS4 among the testers were desirable under non-stress conditions, and NK6240 × HSInbredline 22 and Rajkumar × CML446 Inbredline 8 under stress, while for grain yield per plant Rajkumar × CML446 Inbredline among the lines and HS7 among the testers were desirable under both regimes. Parents with high GCA effects can be expected to throw superior segregants in the F_2 and later generations and can therefore be used in hybridization programmes for the selection of superior recombinants, a conclusion in accordance with Katna *et al.* (2002) [25], Mandal *et al.* (2001) [23], Malik *et al.* (2004) [26], Koinuma *et al.* (2004) [27], Fan *et al.* (2004) [28], Prashanth (2008) [3], Kuchanur (2010) [29], Premlatha and Kalamani (2010) [8], Izge and Dugje (2011) [30], Aminu and Izge (2013) [9] and Praveen Kumar *et al.* (2014) [31]. Of the 150 hybrids evaluated, 45 under non-stress and 30 under stress recorded positive pooled scores for SCA effects across the traits, indicating them to be heterotic combinations. Under non-stress conditions, (Allrounder × HSInbredline 34) × HS7 recorded the highest pooled score (+5), followed by (Rajkumar × CML446 Inbredline 46) × HS4, (NK6240 × CI4 Inbredline 12) × HS4, (Allrounder × HSInbredline 45) × KDMI16, (Allrounder × HSInbredline 39) × HS10, (Allrounder × HSInbredline 25) × HS10 and (Allrounder × HSInbredline 21) × HS10 (+3 each). Under stress, (Allrounder × HSInbredline 45) × HS10 and (Parbhat × CI4 Inbredline 5) × HS4 recorded the highest scores (+5), followed by (NK6240 × HSInbredline 22) × KDMI16, (Allrounder × HSInbredline 34) × HS7 and (Allrounder × HSInbredline 25) × HS7 (+3 each); none of these hybrids, however, recorded significant positive SCA effects for days to 50 per cent anthesis, days to 50 per cent silking or plant height under non-stress conditions, or for chlorophyll content at 60 days, relative water content at 90 days or shelling percentage under stress. A total of 26 and 29 hybrids recorded negative pooled scores, indicating overall inferior performance, while 79 and 91 hybrids recorded a zero pooled score owing to the cancellation of positive and negative significant effects across traits; the latter may nevertheless possess breeding value when judged on economically important traits, particularly grain yield and its components. Hybrids exhibiting high SCA effects generally involved at least one good general combiner as a parent, although the magnitude varied among crosses, as also observed by Kadams *et al.* (1999) [32], Asif *et al.* (2007) [7], Kuchanur (2010)[29], Premlatha and Kalamani (2010)[8], Aminu and Izge (2013)[9] and Praveen Kumar *et al.* (2014)[31].

A negative SCA effect for ASI is desirable because a shorter interval between anthesis and silking improves flowering synchronization and drought adaptation and thereby reduces the risk of reproductive failure under moisture stress; (Rajkumar × CML446 Inbredline 18) × HS7 under nonstress conditions and (Rajkumar × CML446 Inbredline 40) × KDMIand (NK6240 × CI4 Inbredline 12) × CI4 under stress were desirable in this respect, in agreement with Bello and Olaoye (2009) [33], Kuchanur (2010) [29] and Aminu and Izge (2013) [9]. The combinations identified for number of cobs per plant and for grain yield per plant may likewise be useful for improving cob-bearing capacity and productivity under favourable as well as moisture-limited conditions. Their superior performance underlines the importance of nonadditive gene action in the inheritance of grain yield and associated drought-adaptive traits, and their favourable SCA effects suggest complementary allelic interactions that can be exploited in developing high-yielding, drought-tolerant germplasm for environments with irregular or limited rainfall. These hybrids are therefore valuable both for direct evaluation as potential commercial combinations and as genetic resources in maize breeding programmes, a conclusion consistent with the reports of Perez-Velasquez *et al.* (1996), Kumar *et al.* (1998), Joshi *et al.* (1998), Asif *et al.* (2007) [7], Kuchanur (2010) [29], Premlatha and Kalamani (2010) [8] and Aminu and Izge (2013)[9].

Table 1: ANOVA for line x Tester under non-stress and stress situations during post *rabi* 2013

Character	Mean sum of squares											
	Crosses		Line Effect		Tester Effect		Line* Tester Eff.		Error		Total	
	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
DF	149	149	29	29	4	4	116	116	149	149	299	299
Anthesis to silking interval	0.836	1.477	1.232*	1.594	0.438	1.078	0.750	1.461	0.644	1.509	1.485	1.597
Chlorophyll at 60 DAS (mg/cm2)	28.130	17.278	30.792	20.599	16.940	84.795**	27.85	14.119	22.521	15.908	26.401	17.320
Chlorophyll at 90 DAS (mg/cm2)	24.916	37.446*	28.6	67.564**	60.364*	7.787	22.773	30.940	23.617	25.724	26.430	32.856
Relative water content at 60 DAS (%)	0.007	0.011*	0.014**	0.022**	0.004	0.004	0.005	0.008	0.007	0.008	0.007	0.010
Relative water content at 90 DAS (%)	0.027	0.012	0.047**	0.019**	0.026	0.029*	0.022	0.010	0.024	0.011	0.025	0.014
Cob length (cm)	5.154**	4.826	5.379	7.095*	17.289**	9.358	4.679**	4.103	2.743	3.737	3.948	4.319
Cob girth (cm)	0.119**	0.124	0.224**	0.159	0.114	0.093	0.093**	0.116	0.060	0.102	0.091	0.117
No. of Kernel rows/cob	2.123**	2.231*	3.963**	2.434	2.321	5.585*	1.657**	2.065*	1.020	1.536	1.566	1.919
No. of Kernels/row	21.596*	24.23	23.833	42.693**	16.919	6.028	21.199*	20.241	14.910	18.614	18.267	21.352
100-Seed weight (g)	14.143	9.009	18.964	13.891*	2.743	6.351	13.330	7.880	12.618	10.066	13.363	9.659
Grain yield kg/ha	2393382**	1101669	2642579	991764.2	3430880	3303700*	2295307**	1053213	1379333	862128.8	2142234	979026.1
Shelling%	58.124	50.291	79.590	58.264	13.419	45.122	54.299	48.477	49.665	48.892	60.540	53.268

	s ²gca		s ²sca		s ²gca/s ²sca		Contribution of Lines		Contribution of Testers		Contribution of Line * Tester	
	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress
Anthesis to silking interval	0.003	-0.004	0.014	-0.013	0.214	0.308	0.287	0.210	0.014	0.020	0.699	0.770
Chlorophyll at 60 DAS (mg/cm2)	0.028	1.051	2.488	-0.895	0.011	-1.174	0.213	0.232	0.016	0.132	0.771	0.636
Chlorophyll at 90 DAS (mg/cm2)	0.577	0.328	-0.762	2.365	-0.757	0.139	0.223	0.351	0.065	0.006	0.712	0.643
Relative water content at 60 DAS (%)	0.000	0.000	-0.001	-0.001	0.000	0.000	0.401	0.395	0.014	0.011	0.585	0.594
Relative water content at 90 DAS (%)	0.000	0.000	-0.001	-0.001	0.000	0.000	0.340	0.302	0.027	0.062	0.633	0.636
Cob length (cm)	0.234	0.137	0.775	0.330	0.302	0.415	0.203	0.286	0.090	0.052	0.707	0.662
Cob girth (cm)	0.003	0.001	0.013	0.008	0.231	0.125	0.366	0.250	0.026	0.020	0.608	0.730
No. of Kernel rows/cob	0.057	0.072	0.254	0.287	0.224	0.251	0.363	0.212	0.029	0.067	0.607	0.721
No. of Kernels/row	0.122	0.211	2.547	1.630	0.048	0.129	0.215	0.343	0.021	0.007	0.764	0.650
100-Seed weight (g)	-0.045	0.003	0.460	-1.069	-0.098	-0.003	0.261	0.300	0.005	0.019	0.734	0.681
Grain yield kg/ha	42326	37735	369996	113114	0.114	0.334	0.215	0.175	0.038	0.081	0.747	0.744
Shelling%	-0.108	0.198	2.008	1.849	-0.054	0.107	0.267	0.225	0.006	0.024	0.727	0.750

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

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 nonstress situation

Characters	Cross combination	Mean	sca effects	gca effects		Standard heterosis over Bio-9681	Standard heterosis over Rajkumar
				Female	Male		
Anthesis to silking interval	(Parbhat XCI4 line 5) X HS4	1.00	-0.843	-0.257	0.043	-71.43 **	-33.33
	(Allrounder X HS17 line 34) X HS10	1.00	-0.76	-0.357	0.06	-71.43 **	-33.33
	(Allrounder X HS17 line 39) X CI4	1.00	-0.56	-0.357	-0.14	-71.43 **	-33.33
	(Allrounder X HS17 line 45) X CI4	1.00	-0.56	-0.357	-0.14	-71.43 **	-33.33
	(NK6240 X CI4 line 24) X CI4	1.00	-1.06	0.143	-0.14	-71.43 **	-33.33
Chlorophyll content at 60 DAS	(Allrounder X HS17 line 34) X KDMI16	51.80	6.318	1.772	-0.788	27.34 *	13.15
	(NK6240 X HS17 line 5) X HS7	51.80	5.321	1.295	0.686	27.34 *	13.15
	(Rajkumar X CML446 line 46) X HS4	52.02	7.492*	-0.019	0.044	27.86 *	13.62
	(NAC6002 XCI4 line 7) X HS10	53.38	4.718	4.003**	0.161	31.22 **	16.60
	(Rajkumar X CML446 line 37) X KDMI16	54.32	8.625*	1.985	-0.788	33.53 **	18.65
Chlorophyll content at 90 DAS	(Rajkumar X CML446 line 46) X HS4	46.86	4.676	1.28	0.83	22.94	14.17
	(NAC6002 XCI4 line 7) X HS10	47.14	5.006	2.331	-0.281	23.65	14.82
	(NK6240 XCI4 line 12) X HS7	47.30	6.961*	-0.934	1.194	24.08	15.23
	(Allrounder X HS17 line 25) X HS7	48.22	7.227*	-0.285	1.194	26.48 *	17.45
	(Rajkumar X CML446 line 37) X KDMI16	49.89	7.780*	3.292*	-1.266*	30.86 *	21.52
Relative water content at 60 DAS	(Allrounder X HS17 line 34) X KDMI16	86.00	0.052	0.068**	-0.006	10.19	20.14
	(Rajkumar X CML446 line 18) X HS7	86.00	0.109	-0.004	0.006	9.55	19.44
	(G57 X NAC6002 line 17) X KDMI16	86.00	0.087	0.029	-0.006	9.55	19.44
	(Allrounder X HS17 line 34) X HS10	88.00	0.045	0.068**	0.011	11.46	21.53
	(NK6240 X HS17 line 20) X HS4	89.00	0.132*	0.015	-0.007	13.38	23.61*
Relative water content at 90 DAS	(NK6240 X CI4 line 35) X CI4	74.00	0.220*	0.002	-0.031	34.55	21.31
	(Rajkumar X CML446 line 37) X HS4	74.00	0.217*	-0.029	0.003	34.55	21.31
	(Allrounder X HS17 line 39) X HS7	78.00	0.154	0.078	-0.006	40.91	27.05

	(Rajkumar X CML446 line 1) X HS7	78.00	0.248*	-0.006	-0.006	42.73	28.69
	(Allrounder X HS17 line 21) X HS4	79.00	0.103	0.130**	0.003	42.73	28.69
Cob length (cm)	(NK6240 XCI4 line 37) X HS7	20.73	2.251	-0.183	0.867**	16.82	10.68
	(NK6240 XCI4 line 18) X HS7	20.91	2.779*	-0.531	0.867**	17.83	11.64
	(Rajkumar X CML446 line 25) X HS7	21.52	0.718	2.130**	0.867**	21.21 *	14.84
	(Rajkumar X CML446 line 18) X HS4	21.65	2.322	1.676**	-0.148	21.97 *	15.56
	(Rajkumar X CML446 line 25) X HS10	22.45	2.762*	2.130**	-0.242	26.48 **	19.83*
Cob girth (cm)	(Rajkumar X CML446 line 40) X HS7	5.12	0.342	0.116	0.038	16.82	8.94
	(NK6240 X CI4 line 35) X HS10	5.13	0.434*	0.126	0.038	8.13	9.15
	(Allrounder X HS17 line 34) X KDMI16	5.20	0.503**	0.113	-0.04	8.34	10.64
	(Allrounder X HS17 line 21) X HS10	5.22	0.530**	0.12	0.038	9.82	11.06*
	(Allrounder X HS17 line 34) X HS7	5.25	0.475*	0.113	0.038	10.24	11.70*
No. of Kernelrows/cob	(NK6240 X CI4 line 18) X CI4	17.00	1.562*	0.427	0.303*	13.33	10.86
	(NK6240 X CI4 line 35) X HS10	17.00	1.512*	0.693*	0.087	13.33	10.86
	(Rajkumar X CML446 line 40) X HS7	17.00	1.014	1.358***	-0.08	13.33	10.86
	(NAC6002 XCI4 line 7) X HS10	17.33	1.643*	0.892**	0.087	15.53 *	13.01
	(Rajkumar X CML446 line 18) X HS10	17.50	2.379**	0.326	0.087	16.67 *	14.12*
No. of Kernels/ row	(Rajkumar X CML446 line 18) X CI4	39.83	3.576	2.47	-0.107	16.60	-10.81
	(NK6240 XCI4 line 37) X HS7	40.5	6.008*	-0.163	0.759	18.54	-9.32
	(NK6240 XCI4 line 18) X HS7	40.67	4.944	1.071	0.759	19.04	-8.94
	(Rajkumar X CML446 line 25) X KDMI16	41.00	4.125	3.538**	-0.559	20.01	-8.21
	(Rajkumar X CML446 line 46) X HS4	41.67	7.816**	-0.329	0.287	21.97	-6.71
100- Grain weight (g)	(NK6240 X HS17 line 14) X HS7	31.68	4.141	0.575	0.067	26.09	13.55
	(Rajkumar X CML446 line 38) X HS4	31.75	3.719	1.042	0.102	26.41	13.84
	(NK6240 X HS17 line 22) X HS4	31.80	4.367	0.444	0.102	26.61	14.02
	(Rajkumar X CML446 line 1) X HS4	33.55	4.995*	1.556	0.102	33.54 *	20.25
	(Rajkumar X CML446 line 46) X HS4	35.52	6.743**	1.783	0.102	41.40 **	27.33*
Grain yield (kg/ha)	(Rajkumar X CML446 line 18) X CI4	6623.27	1463.763	459.743	206.217	8.80	14.49
	(NAC6002 X CI4 line 7) X HS4	6844.1	1728.082	461.243	161.233	12.43	18.31
	(Rajkumar X CML446 line 3) X HS4	7395.76	046.412*	694.573	161.233	21.49*	27.85*
	(NK6240 XCI4 line 12) X HS4	7567.42	2127.907*	784.738*	161.233	24.31*	30.81**
	(Allrounder X HS17 line 34) X HS7	7999.92	502.080**	-146.586	150.884	31.42	38.29**
Shelling%	(Allrounder X HS17 line 21) X HS4	83.64	7.504	2.853	0.162	24.37 *	19.22
	(Allrounder X HS17 line 45) X HS4	84.08	6.609	4.193	0.162	25.04 *	19.86
	(NK6240 XCI4 line 35) X HS7	84.99	7.651	4.507*	-0.289	26.38 *	21.15*
	(NK6240 X CI4 line 35) X HS10	85.59	7.476	4.507*	0.491	27.28 *	22.01*
	(Rajkumar X CML446 line 46) X KDMI16	86.27	10.309*	2.539	0.306	28.29 **	22.98*

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

Table 3: 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 content at 60 DAS	(NK6240 X HS17 line 5) X HS7	46.67	3.279	2.337	0.06	14.91	6.42
	(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 XCI4 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
	(NK6240 X HS17 line 10) X HS7	36.72	8.084 *	1.916	-0.479	16.21	17.30
Relative w ater content at 60 DAS	(NK6240 XCI4 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
	(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
Relative water content at 90 DAS	(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
	(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 XCI4 line 42) X HS7	71.00	0.126	0.006	0.036 **	25.89	15.57
Cob length (cm)	(NK6240 XCI4 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 XCI4 line 5) X HS4	19.50	3.069 *	0.489	0.186	25.40 *	27.45 *
	(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 **
Cob girth (cm)	(Allrounder X HS17 line 25) X HS10	4.63	0.204	0.244 *	-0.015	9.59	13.90
	(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 Kernel rows/cob	(G57 X NAC6002 line 25) X	17.33	2.117 *	0.920 *	-0.453 **	22.21 *	15.53

	HS7						
	(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 *
	(NK6240 X CI4 line 37) X KDMI16	17.67	2.308 **	0.787 *	-0.171	24.61 **	17.80 *
No. of Kernels/ row	(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
	(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
100- Grain weight (g)	(Allrounder X HS17 line 39) X CI4	22.34	4.465 *	-0.282	-0.195	17.31	39.64 *
	(NK6240 XCI4 line 12) X HS7	22.55	1.299	2.335 *	0.569	18.43	40.98 *
	(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 **
Grain yield (kg/ha)	(Rajkumar X CML446 line 18) X HS7	4010.79	906.016	515.05	261.302 *	31.57*	42.69**
	(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 **	-366.109	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**
Shelling%	(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
	(Rajkumar X CML446 line 25) X HS10	78.66	4.379	4.579 *	-0.758	22.17 *	11.19

Conclusion

Under non-stress conditions, three hybrids, namely (Rajkumar × CML446 Inbredline 3) × HS4, (NK6240 × CI4 Inbredline 12) × HS4 and (Allrounder × HS17 Inbredline 34) × HS7, exhibited significant positive SCA effects combined with superior mean performance for grain yield, while under managed drought stress (Allrounder × HS17 Inbredline 34) × HS7, (NK6240 × HS17 Inbredline 14) × HS7 and (Allrounder × HS17 Inbredline 45) × HS10 were identified as the most promising combinations. Since SCA variance predominated over GCA variance for most traits, heterosis breeding based on specific parental combinations appears to be the most effective strategy for improving grain yield and drought adaptation in maize, with the lines Rajkumar × CML446 Inbredline 18, NK6240 × CI4 Inbredline 12 and NK6240 × CI4 Inbredline 24 and the tester HS7 serving as valuable general combiners. The promising hybrids identified should be subjected to multilocation and large-scale performance trials under representative drought-prone environments before being considered for commercial cultivation.

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