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ORIGINAL RESEARCH

Agronomic performance and combining ability estimates of yellow maize inbred lines under adequate and deficit moisture conditions

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Abstract
Breeding for drought tolerance and increased grain yield is vital in mitigating the threat posed by recurrent drought stress on maize production, as well as tackling malnutrition with plant-based food products. The study was conducted to assess the combining ability of yellow maize lines and the performance of their single-cross hybrids under drought and rain-fed conditions. A total of 24 yellow maize inbred lines from CSIR-Savanna Agricultural Research Institute Maize Improvement Programme gene pool were selected and inter-mated using North Carolina II mating design to generate 96 single-cross hybrids. The 96 hybrids together with four advanced hybrids used as checks (a total of 100 hybrids) were evaluated under drought and rain-fed conditions for two years using a 10 × 10 lattice design with two replications. The hybrids differed significantly in their grain yield (GY) and agronomic performance under the growing conditions. In the present study, drought stress reduced GY by 50.3%. The general combining ability (GCA) and specific combining ability (SCA) for GY and its related traits were significant. Even though additive and non-additive gene actions controlled the inheritance of the traits, additive gene action was found to be more important than non-additive genetic effects. Hybrids 27, 81 and 68 on the other hand 89, 18 and 26 were identified as the outstanding genotypes under drought and rain-fed conditions, respectively. These hybrids should be extensively evaluated under varied conditions and commercialized to enhance food insecurity in sub-Saharan Africa.

Keywords Combining ability · Hybrid · Drought tolerance · Association among traits

Introduction

Maize accounts for one of the largest areas to which cereal crops are planted in sub-Saharan Africa (SSA) and demand for its grains for human, animal and industrial uses has continued to rise (Cairns et al. 2013). However, drought stress has continued to be a major abiotic constraint to its production. As a result of change in climatic conditions, which is further compounded by intermittent drought and heat is expected to continue to negatively impact maize productivity and production (Trachsel et al. 2016a). About 80% of the maize produced in SSA is grown under rain-fed conditions, during the rainy season when available moisture is adequate to support growth and development of the maize crop (Yadav et al. 2015). Reports have shown that annually, drought stress alone causes about 15–20% loss in maize grain yield (Maazou et al. 2016). Although irrigation could be used to grow maize during the dry season, it remains not an option for the resource-constrained farmers in the subregion due to the high cost of acquiring and maintaining irrigation equipment (Wossen et al. 2017).

One of the essential components of the strategy toward ensuring sustainable global food production is the use of genetic materials with improved drought tolerance and stable yields. This has necessitated the development and cultivation of improved maize varieties which are tolerant to drought coupled with higher water use efficiency (Mahajan et al. 2012; Zheng et al. 2019). Different strategies, such as recurrent selection and evaluation of segregating population under managed and multi-location drought-stress

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environment, use of secondary traits for selection under drought conditions, as well as genomic-based approach and transgenic technologies, have been deployed in the development of genotypes for improved tolerance to drought (Mahajan et al. 2012; Zheng et al. 2019). Understanding the genetics of how drought affects maize, and schemes used for improving drought stress-tolerant maize lines will provide opportunities to improve the breeding process (Lopes et al. 2011; Kikuchi et al. 2015; Mickelbart et al. 2015). Several multi-locational studies have been conducted on the effects of drought stress on the performance of newly developed maize varieties under rain-fed environments. Studies on drought were initiated in the 1990s which led to the identification of susceptible/tolerant crop genotypes at various stages of plant growth, moisture levels, morphological and physiological traits that are associated with drought tolerance (Yadav et al. 2015; Djemel et al. 2018). One of the ways of screening for drought tolerance is to phenotype the genetic materials under field conditions to assess the expression of the traits of interest. Taking into consideration the target environment under study and degree of the stress, phenotyping of genetic materials for drought stress has relied on selection for early flowering and grain-filling as key traits (Zaidi and Singh 2005). Shorter anthesis-silking interval (ASI), number of ears per plant (EPP), stay green ability and small tassel size have also been reported as indicator traits for drought tolerance (Yadav et al. 2015).

During the growth cycle of plants, the interaction of stress factors often exerts adverse effects on normal plant growth and crop yield. These stress factors could be classified as biotic or abiotic based on their source. Abiotic stress factors have been reported to be responsible for more than 50% yield losses in several major crops worldwide (Bray et al. 2000; Doğru and Bayram 2016). Even though there are several abiotic factors affecting maize productivity, drought remains the major one (Valliyodan and Nguyen 2006; Doğru and Bayram 2016).

The adverse effects of insufficient moisture on plants have been categorized as visible and non-visible disorders. Visible disorders are observed when the leaf or the entire plant is noticed to be wilting, having stunted growth, poor biomass accumulation, decrease in leaf area, and delayed flowering (Doğru and Bayram 2016). The invisible injuries may occur within the cytoplasmic membranes, reduction in water required by the plant organs at different levels and consequently, decrease in chlorophyll concentration (Grzesiak 2001; Izzam et al. 2017).

White maize is the predominant maize used for food in SSA and the white color of the kernels clearly demonstrates lack of carotenoids (which tend to give fruits and vegetables that contain them a range of yellow, orange and red colors) (Naqvi et al. 2009). The yellow maize which is commonly consumed in the developed countries has a higher carotenoid content owing to higher levels of lutein and zeaxanthin. However, in SSA, particularly Ghana, the yellow maize is used mainly to feed animals and to a larger extent, unavailability of these materials for cultivation. To address the nutritional limitations and substitute for white maize, this study seeks to evaluate yellow maize hybrids under drought and rain-fed condition for grain yield for yellow maize inbred lines. The objectives of this study were to investigate the combining ability of selected yellow maize inbred lines and to evaluate the agronomic performance of the single-cross hybrids under drought and rain-fed conditions.

Materials and methods

Genetic materials and experimental design

Twenty-four yellow maize inbred lines were selected from the pool of the materials available at Savanna Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) (Table 1). The selected lines were crossed using the North Carolina II mating design with six sets each consisting of four inbred lines. The four

Table 1 Descriptions of the inbred lines used in generating the hybrids

Line	Pedigree
1	SARI-BB-2-1-3-1-2-3-2-6-1
2	SARI-AA-7-1-3-1-2-1-3-1-1
3	SARI-AC-8-1-2-2-2–2-2–2-1
4	SARI-AS-2-1-1-2-2-1-1–1-1
5	SARI-BA-5-1-1-2-2-2-2–1-1
6	SARI-BB-3-3-2-2-1-2-1-4-1
7	SARI-BC-2–2-2–2-1-2-1-2-1
8	SARI-AA-5-6-1-3-3-3-1–4-1
9	SARI-SS-7-2-3-1-2–1-3–1-1
10	SARI-AD-2-2-2-2-1-2-1–1-1
11	SARI-AD-6-1-1-1-2-1-2–1-1
12	SARI-BC-7-2-3-3-3–2-2–2-1
13	SARI-BD-8-5-1-1-1-2-2-3-1
14	SARI-AL-5-6-1-3-3-3-1-4-1
15	SARI-BB-6-3-3-2-1-1-2-1-1
16	SARI-AB-2-2-2-2-3-1-3-1-1
17	SARI-AA-1-1-2-2-1-1-1-2-1
18	SARI-GH-3-2-3-2-2-2-2-1-1
19	SARI-AH-5-6-1-3-3-3-4-4-1
20	SARI-HH-6-1-1-2-2-2-2-1-1
21	SARI-CC-6-1-1-2-2-1-2-1-1
22	SARI-AG-1-1-2-1-1-2-3-1-1
23	SARI-AF-2-2-1-2-1-2-1-2-1
24	SARI-SA-3-2-3-1-3-2-3-2-1

inbred lines in one set were used as females and crossed with four lines in another set which were used as males. Consequently, a total of 96 single-cross hybrids were generated. The 96 yellow maize hybrids and four checks were evaluated under drought and rain-fed conditions at Branam-Wenchi (7.8687° N, 2.0752° W) and Agortime Kpetoe (6.555° N, 0.689° W) using a 10×10 lattice design with two replications. The experiment was made up of single-row plots, each measuring 4 m long with spacing of 0.50 m and 0.75 for within and between rows, respectively.

The 100 hybrids were evaluated for grain yield and other agronomic traits under drought stress during 2017/2018 and 2018/2019 dry seasons. The evaluation was conducted under induced moisture stress imposed by the withdrawal of irrigation water at 28 days after planting till maturity following Edmeades et al. (1999). The rain-fed experiment was conducted during 2018 and 2019 cropping seasons, where the crops depended on natural rainfall. Fertilizer was applied at the rate 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} at planting for the drought experiment and two weeks after planting (WAP) for the rain-fed experiment using NPK 15–15-15. An additional 60 kg N ha^{-1} was applied using urea at 4 and 5 WAP to the drought and rain-fed treatments, respectively. All plots were kept weed-free by manual weeding complemented with the application of pre- and post-emergence herbicides.

Data collection

Observations were made for days to 50% silking (DS) and anthesis (DA) as the number of days from planting to when 50% of the plants had extruded silks and shed pollen, respectively. Anthesis-silking interval (ASI) was calculated as the difference between DS and DA. Plant height (PH, cm) was measured from the ground to the first tassel branch, while ear height (EH, cm) was from the ground to the node bearing the upper ear. Number of ears per plant (EPP) was obtained by dividing the total number of ears per plot by the number of plants harvested. Plant aspect (PA) was rated on a scale of 1–9, where 1 = excellent and 9 = poor. Ear aspect (EA) was recorded on a scale of 1–9 where 1 = clean, uniform, large, and well-filled ears, while 9 = ears with undesirable features, such as diseases, small ears, and ears with poorly filled grains. Leaf death (LD) was scored for the drought experiments at 70 days after planting (DAP) on a scale of 1–9, where 1 = almost all leaves green and 9 = virtually all leaves dead. Root lodging (RL) and stalk lodging (SL) were recoded and proportions of plant leaning 30 ° and plant with broken stalks below the node bearing the cob, respectively. Husk cover (HC) was rated on a scale of 1–5, where 1 = tight tips and 5 = exposed tips.

Field weights of harvested ears per plot at under rain-fed conditions were recorded and converted to grain yield (kg ha^{-1}) at 15% moisture content using the formula:

$$\text{Grain yield}\left(\text{GY, kg ha}^{-1}\right) = \text{field weight (kg plot}^{-1}\text{)} \times \left(\frac{100 - \text{moisture}}{85}\right) \times \left(\frac{10{,}000}{3 \times 0.75}\right) \times \text{shelling \%}$$

Grain weight of shelled harvested ears per plot under drought stress was converted to grain yield ($kgha^{-1}$) at 15% moisture content using the formula below:

$$\text{Grain yield}\left(\text{GY, kg ha}^{-1}\right) = \text{grain weight (kg plot}^{-1}\text{)} \times \left(\frac{100 - \text{moisture}}{85}\right) \times \left(\frac{10{,}000}{3 \times 0.75}\right)$$

Data analyses

For the data taken, log transformation was performed on data related to counts, scales and scores using the formula [log (counts + 1)], while the square root transformation was used for data in percentages before subjecting them to analyses of variance (ANOVA). The ANOVA was performed separately for data collected for the drought and rain-fed environments, and thereafter combined for the two conditions based on plot means for all the traits measured using PROC GLM in SAS (SAS version 9.3, SAS Institute Inc. 2011). In the analysis, locations, replicates, blocks, and hybrids in each experiment were considered random.

The statistical model for the combined analysis of variance is as follows:

$$Y_{ijkg} = \mu + E_i + R_{j(i)} + B_{k(ij)} + G_g + (EG)_{ig} + \varepsilon_{ijkg}$$

In this model, Y_{ijkg} is the observed measurement for the gth genotype in the kth block of the jth replicate, within the ith environment; μ is the grand mean; E_i is the main effect of the environment, $i = 1, 2, 3$; $R_{j(i)}$ is the effect of replicate nested within Environment effect, $j = 1, 2, 3$; $B_{k(ij)}$ is the effect of block nested within replicate j by environment i, $k = 1, 2, \ldots 0.10$ for inbreds and 1,2,3….0.156 for hybrids; G_g is the effect of genotype, $g = 1, 2, 3, \ldots 10$ lines and 1, 2, 3…0.156 for hybrids; $(EG)_{ig}$ is the interaction effect between genotype and environment, and ε_{ijkg} is the error term.

The general linear model for NC 2 mating design is:

$$Y_{ijkl} = \mu + m_i + f_i + (m \times f)_{ij} + e_{ijk}$$

where, Y_{ijk} is the kth observation on $i \times j$th progeny; μ is the general mean; m_i is the effect of the ith set; b_{ij} is the effect of the jth replication in the ith set, f_{il} is the effect of the ith male; f_i is the effect the jth female in ith; $m \times f_{ij}$ is the interaction effect, and e_{ijk} is the error associated with each observation (Singh and Chaudhary 1985).

The hybrids component of the variation was partitioned into variation due to male sets, female sets and female × male interaction sets. The *F* test for male, female and female × male mean squares was calculated using the mean squares for their respective interaction with the environment. The mean squares from environment × female × male sets were tested using the pooled error mean squares. The main effects of the male sets and female sets are the GCA effects while the female × male sets interaction represents SCA effects.

Phenotypic and genotypic correlations were estimated using GEA-R version 4.1 (Pacheco et al. 2017).

Results and discussion

Trait variability among hybrids under drought and rain-fed conditions

The analysis of variance revealed significant variations among the hybrids for most of the traits measured under both drought and rain-fed conditions. Under both test conditions, effects of year and year × entry interaction were also significant (Table 2). Under the drought condition, the hybrids evaluated differed significantly for all the traits, except EH, RL, HC, PA and EPP. Effects of year were also found to significantly influence all the traits, except RL. However, the interaction between year and entry (hybrid) was only significant for GY, SL, EA and LD (Table 2).

For the study conducted under rain-fed condition, the hybrids differed significantly for GY and majority of the traits measured except ASI, RL, HC, and EPP. Year varied significantly for all the traits, except RL and PA. The interaction between year and entry had significant effects on GY, EA, AD and DS, while ASI, PH, EH, SL, HC and PA were not significant (Table 2). The significant mean squares observed for GY and majority of the traits examined for the hybrids under drought and rain-fed conditions suggested that genetic diversity existed among the hybrids. The significant interaction between year and the hybrids under both drought and rain-fed conditions indicated that the performance of the hybrids was not consistent across the years the study was conducted. The variation among the hybrid across years implied that, precipitation and drought intensities varied among years, thereby affecting the consistency of the performance of the hybrids which is consistent with the findings of (Ziyomo and Bernardo 2013; Trachsel et al. 2016a). These results further suggested that, inconsistency of the hybrids could be as a result of limited number of locations used for the study. These results implied that, in addition to replicating of a study for years, multi-locations trials under a particular condition could be used to examine the true performance of the hybrids (Ortiz-Covarrubias et al. 2019). Hence, the identification of stable and high yielding hybrids across contrasting environmental conditions is essential for the realization of their full potentials (Gangashetty et al. 2016; Fallahi et al. 2017; Song et al. 2018; Tesfaye et al. 2018).

Performance of the hybrids under drought and rain-fed conditions

Under drought condition, significant differences were observed among the hybrids for GY and other traits. The GY of the hybrids ranged from 1594.40 kg ha^{-1} for entry 42 to 4110.40 kg ha^{-1} for entry 68 with a mean of 2649.19 kg ha^{-1}. The PH and EH of the hybrids ranged from 115.08 cm for entry 65 to 168.50 cm for entry 91 and 56.71 cm for entry 55 to 86.36 cm for entry 81, respectively (Table 3). Entries 85 and 3 displayed desirable characteristics for EA and PA, respectively, while entries 27, 81 and 82 produced an ear per plant. Using the BI, entry 27 was identified as the best hybrid, while entry 42 was the worst.

Under the rain-fed condition, GY ranged from 3442.83 kg ha^{-1} for entry 54 to 7364.44 kg ha^{-1} for entry 26. Plant height ranged from 147.82 cm to 203.15 cm for entries 82 and 91, respectively. On the other hand, EH ranged from 79.6 cm to 104.8 cm for entries 94 and 45, respectively (Table 4). Entries 85 and 89 recorded the least scores for PA and EA, respectively. The range in EPP was 0.9 for entry 16–1.1 for entry 54.

The yield decrease under drought stress was 55.3% when compared with the study under the rain-fed condition. The present result falls within the yield reduction range of 18–78% reported by Bänziger et al. (1997), Fu et al. (2008) Beiragi et al. (2011) and Romdhane et al. (2020). The hybrids, such as 27 and 81, with high yield under drought and rain-fed conditions are ideal for production. Being yellow genotypes, the hybrids may have precursor for carotenoids, thereby having the potential of enhancing malnutrition in SSA.

Genetic analysis of yellow inbred lines evaluated under drought and rain-fed conditions

The combined analysis of variance for the two-year drought and rain-fed conditions showed that significant variation existed between the years in which the experiment was carried out, except RL under drought and RL, SL and PA under rain-fed condition (Table 5). The sets were significant for all the traits examined under both drought and rain-fed conditions except for RL and SL under drought and DA, ASI, RL and EPP under rain-fed condition. Year × sets interaction was significant for only GY, EA and LD under drought, while GY, HC and EA were the only traits with significant differences under rain-fed condition. Male set was significant for GY, SL, HC and LD under drought, while under rain-fed

Table 2 Analysis of variance for grain yield and other agronomic traits of 100 yellow maize hybrids evaluated under drought and rain-fed conditions

Source	DF	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	LD
Drought														
Rep (year)	2	143,859.62 ns	39.08**	28.36**	1.06 ns	1641.93**	467.77**	7.85 ns	223.08**	0.17 ns	0.73 ns	0.40 ns	0.01 ns	0.15 ns
Block (rep × year)	36	279,799.38 ns	3.09 ns	2.66 ns	0.62 ns	224.86 ns	85.02 ns	3.26 ns	38.87 ns	0.11 ns	0.52 ns	0.72 ns	0.01 ns	0.34 ns
Year	1	41,739,287.75**	775.62**	967.21**	8.12**	152,022.01**	85,439.29**	1.78 ns	9336.39**	2.25**	6.76**	33.64**	1.38**	90.25**
Entry	99	999,596.22**	6.24**	5.27**	1.28*	289.22**	87.86 ns	3.87 ns	71.31**	0.30**	1.08**	1.28**	0.02*	3.22**
Year × entry	99	460,389.3**	4.27 ns	2.86 ns	0.96 ns	192.3 ns	82.82 ns	4.05 ns	62.32**	0.12 ns	0.68 ns	0.87*	0.01 ns	0.70**
Error	162	293,387.1	3.73	2.98	0.85	173.41	70.76	4.27	32.18	0.15	0.7	0.66	0.01	0.25
Optimal														
Rep (year)	2	7,504,076.50**	34.85**	25.57 ns	0.93 ns	1551.72**	7688.77**	5.59 ns	1863.20**	0.60**	0.24 ns	0.26 ns	0.01 ns	–
Block (rep × year)	36	578,940.10 ns	1.54 ns	1.89 ns	0.45 ns	119.89 ns	75.03 ns	2.21 ns	146.70 ns	0.09 ns	0.06 ns	0.10 ns	0.01 ns	–
Year	1	169,030,434.40**	84.64**	110.25**	265.69**	14,896.20**	5890.56**	5.59 ns	560.03*	2.98**	0.25 ns	1.29**	0.73**	–
Entry	99	1,720,265.20**	6.99**	6.62**	0.58 ns	564.41**	185.92**	2.20 ns	212.23*	0.14 ns	0.15**	0.26**	0.02 ns	–
Year × entry	99	1,764,528.00**	3.97**	3.77*	0.51 ns	142.52 ns	80.21 ns	2.20**	191.82 ns	0.10 ns	0.11 ns	0.16**	0.02*	–
Error	162	560,153.1	2.32	2.73	0.54	144.25	104.37	2.26	146	0.11	0.09	0.09	0.01	–

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively; *ns* not significant

DF degree of freedom, *GY* $(t\ ha^{-1})$ grain yield, *DA* days to anthesis, *DS* days to silking, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *RL* root lodging, *SL* stalk lodging, *EPP* ear per plant, *HC* husk cover, *ER* ear rot, *EA* ear aspect, *LD* leaf death

Table 3 Means of grain yield and selected agronomic traits of 39 (top 15, middle 10, worse 10) yellow maize hybrids and four checks evaluated under drought stress at Agortime Kpetoe during the 2017/2018 and 2018/2019 dry seasons

Entry	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	LD	BI
27	3542.1	60.4	58.9	1.5	149.3	70.9	0.7	7.8	3.0	3.9	3.9	1.0	3.5	10.2
81	3842.6	61.9	60.0	1.9	143.5	76.9	0.3	4.4	2.4	4.3	3.8	1.0	3.1	9.7
68	4110.4	59.8	57.9	1.9	140.7	73.1	3.0	6.5	2.8	5.0	4.1	0.9	5.2	8.3
74	3427.3	61.0	59.7	1.5	158.2	71.6	0.9	3.1	2.5	4.1	4.2	0.9	2.9	8.3
82	3621.8	62.2	60.2	2.1	142.3	69.6	1.0	2.8	2.4	4.9	3.7	1.0	3.7	8.2
91	3902.5	63.8	60.5	3.3	168.5	71.6	1.0	5.6	2.4	4.4	3.4	0.9	3.1	7.7
26	3621.5	62.4	60.0	2.4	137.4	69.2	0.4	10.1	2.8	4.4	3.9	0.9	3.4	7.4
67	3473.5	60.3	58.3	2.1	134.1	63.8	0.5	8.3	2.5	4.6	4.2	0.9	3.1	6.3
78	3857.8	63.9	60.8	3.2	145.8	70.9	0.2	10.7	2.6	5.0	3.7	0.9	3.7	6.1
85	3272.9	63.4	61.2	2.2	146.0	62.0	0.0	8.5	3.1	5.0	3.1	0.9	3.1	6.1
75	3265.9	60.9	59.5	1.4	153.0	71.6	0.6	8.7	2.5	5.0	4.0	0.9	3.1	5.7
83	3018.9	60.4	59.3	2.1	146.8	76.1	4.7	0.2	2.3	4.4	4.0	0.9	3.0	5.4
92	3081.5	62.0	59.7	2.4	149.3	62.7	0.3	5.6	2.4	4.6	3.5	0.9	2.8	5.0
86	3280.9	62.0	59.7	2.5	157.4	70.9	0.2	11.5	2.7	4.6	3.9	0.9	3.9	5.0
70	2686.4	61.1	60.0	1.1	133.3	71.8	0.4	6.5	2.5	4.7	4.3	0.9	3.3	4.5
76	2703.8	62.4	59.8	2.5	135.2	68.4	1.4	4.6	3.0	5.8	4.8	0.9	5.8	− 0.1
45	2137.5	62.4	61.2	1.3	138.8	72.4	0.7	4.1	2.7	5.1	4.4	0.8	3.0	− 0.2
3	2630.3	61.5	59.5	2.0	146.1	63.5	0.2	2.6	2.5	5.3	4.7	0.8	2.7	− 0.2
24	3069.2	60.5	58.2	2.3	119.7	68.9	0.3	2.3	3.0	5.0	5.2	0.7	3.7	− 0.3
90	2941.2	61.6	57.6	3.9	149.5	75.0	3.4	15.3	2.9	4.9	4.8	0.9	5.5	− 0.4
71	2660.7	61.9	59.3	2.5	133.0	71.0	0.8	11.9	3.0	5.4	4.5	0.8	3.7	− 0.5
14	2145.5	59.5	58.2	1.4	134.1	58.9	5.5	25.7	3.0	5.4	4.8	0.9	5.0	− 0.5
66	2971.0	63.7	60.7	3.0	130.0	67.2	1.2	2.7	3.2	5.9	4.7	0.9	5.6	− 0.6
44	2198.7	60.7	58.9	1.9	137.1	63.6	0.3	0.9	2.8	5.3	5.0	0.9	3.5	− 0.7
50	2529.5	64.1	62.0	2.1	145.1	70.2	0.7	9.7	2.8	5.3	4.6	0.8	3.5	− 0.7
46	2303.4	65.4	62.4	3.1	131.6	70.3	0.8	1.4	3.0	5.7	5.3	0.7	3.0	− 6.5
61	1923.6	61.9	59.6	2.2	127.8	67.2	0.3	3.1	3.2	6.3	5.7	0.8	3.8	− 6.5
40	2275.2	62.9	59.8	3.1	132.0	69.6	0.2	3.3	3.0	6.0	5.3	0.7	2.9	− 6.7
32	1842.9	61.4	59.2	2.2	124.8	66.2	0.2	14.4	3.2	6.3	5.4	0.8	5.7	− 6.7
41	2062.3	63.2	61.0	2.2	133.4	64.7	0.2	1.6	2.9	6.3	5.7	0.7	4.7	− 7.1
53	2493.8	62.7	59.0	3.7	122.1	62.5	0.4	3.9	3.2	6.2	5.9	0.7	4.1	− 7.8
1	1799.6	63.3	59.5	3.8	135.2	63.3	0.6	2.2	3.3	5.9	5.0	0.7	4.3	− 8.9
43	1723.5	61.9	59.3	2.6	151.6	70.6	2.2	6.7	3.0	5.6	5.6	0.6	4.2	− 9.0
56	1810.5	64.4	61.5	2.9	130.9	66.4	0.6	5.7	3.3	6.4	5.3	0.7	4.4	− 9.2
42	1594.4	64.2	61.4	2.8	126.4	59.9	1.2	2.5	3.2	6.6	5.9	0.7	4.0	− 11.2
97	2544.6	62.6	60.1	2.5	130.2	59.4	0.3	8.8	2.9	5.6	5.3	0.8	5.5	− 3.4
98	2909.5	61.4	59.5	1.9	144.6	75.0	0.5	3.6	2.4	5.0	3.2	0.8	5.2	4.1
99	1948.4	61.9	60.1	1.8	134.7	60.9	0.4	18.3	2.6	5.5	4.9	0.8	3.3	− 3.2
100	2116.8	62.6	59.9	2.6	132.1	61.1	0.3	2.9	2.6	5.6	4.9	0.8	3.4	− 3.8
Mean	2649.2	61.9	59.7	2.2	137.7	66.8	0.3	6.4	2.9	5.4	4.6	0.8	3.7	

GY ($t\ ha^{-1}$) grain yield, *DA* days to anthesis, *DS* days to silking, *ASI* anthesis-silking interval, *PH* plant height (cm), *EH* ear height (cm), *RL* root lodging, *SL* stalk lodging, *EPP* ear per plant, *HC* husk cover, *ER* ear rot, *EA* ear aspect, *LD* leaf death, *BI* base index

condition, it was significant for most of the traits, except ASI, RL, HC and PA. Female set under drought was significant for most of the traits, except ASI, EH, RL, HC and EPP, while under rain-fed environment, GY, DS, DA, PH, EH, PA and EA were significant. Under drought condition, male × female interaction (SCA effect) was only significant for GY and LD while under the rain-fed condition, it was significant for GY and EA. The GCA effect for male was higher than the SCA effect; however, the SCA effect was higher than the GCA for females under drought. Under the rain-fed condition, both the GCA effects for male and for female were higher than the corresponding SCA effects.

The presence of significant mean squares for GCA and SCA effects for GY under the two conditions implied that

Table 4 Means of grain yield and agronomic traits measured on 39 (top 15, middle 10, worse 10) selected hybrids and four checks evaluated under rain-fed condition Wenchi during 2018 and 2019 cropping seasons

Entry	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	BI
89	7106.95	53.0	52.2	0.8	197.7	99.3	0.0	26.0	2.6	2.3	2.2	1.0	13.70
18	6618.09	56.3	55.4	0.7	175.8	87.8	0.0	14.0	2.5	2.4	2.6	1.1	11.73
26	7364.44	58.5	57.6	0.7	178.4	90.9	0.2	6.9	2.4	2.5	2.6	0.9	11.11
2	6421.97	54.4	53.8	1.5	185.9	101.9	0.6	5.4	2.5	2.5	2.4	1.1	9.85
85	5884.28	53.6	52.6	1.2	196.2	98.7	0.5	4.1	2.4	2.3	2.3	1.1	9.71
9	6305.95	56.7	56.5	0.2	172.7	94.6	0.2	6.5	2.5	2.9	2.5	1.0	9.39
4	6130.48	55.4	54.7	0.6	179.7	87.8	0.1	0.2	2.4	2.7	2.3	1.0	8.87
27	5457.77	55.2	54.8	0.4	186.5	95.8	0.2	6.3	2.3	2.4	2.5	1.0	8.83
19	6146.12	53.9	53.5	0.6	161.5	86.3	0.9	8.1	2.3	2.5	2.5	0.9	8.61
45	5968.41	57.9	57.5	0.4	198.2	104.8	0.2	11.5	2.8	2.9	2.5	1.0	8.20
16	6460.89	52.5	51.5	1.6	170.3	79.9	0.5	1.3	2.4	2.6	2.3	0.9	7.35
11	6112.19	55.0	54.2	1.4	183.1	89.9	0.5	5.5	2.4	2.4	2.8	1.0	7.30
75	6183.15	54.7	53.9	0.9	182.4	89.2	0.1	16.8	2.6	2.7	2.7	1.0	7.04
52	6212.56	55.8	55.1	0.8	170.3	83.5	0.7	2.1	2.6	2.8	2.4	0.9	7.03
90	6324.69	56.1	55.1	1.0	192.3	93.7	0.0	13.2	2.5	2.7	2.8	1.0	6.67
74	6069.43	58.1	56.9	1.8	167.0	84.0	0.2	8.0	2.8	2.9	2.7	0.9	2.47
14	5507.93	55.3	55.2	1.2	166.5	82.3	0.1	13.7	2.6	2.9	2.8	0.9	2.36
71	5173.71	57.5	56.5	0.9	182.6	98.0	0.0	7.5	2.7	2.7	3.1	1.0	2.29
93	5275.14	57.4	56.9	1.2	173.9	93.7	0.1	22.0	2.9	2.9	3.1	1.1	2.24
3	4454.35	53.9	53.2	0.5	197.6	93.7	0.1	17.3	2.5	2.7	3.1	1.0	2.11
73	5288.32	55.7	54.8	0.9	174.9	91.0	0.0	7.6	2.7	3.0	3.2	1.0	2.05
10	5332.65	55.8	55.1	1.2	165.6	81.6	0.0	24.5	2.7	2.7	3.2	1.0	1.97
64	5075.79	55.8	55.0	1.1	166.1	86.6	0.6	6.6	2.4	2.9	2.7	0.9	1.92
94	5413.40	58.5	57.3	1.4	169.0	79.6	0.2	19.5	2.5	3.1	2.7	1.0	1.85
33	5059.94	56.0	55.1	0.7	158.9	82.1	0.2	14.4	2.8	3.0	2.8	0.9	1.71
32	4814.56	56.1	55.5	0.9	161.8	88.0	0.1	0.3	2.7	3.1	3.0	0.9	– 1.61
7	3520.79	56.3	55.4	1.2	186.3	101.3	0.0	1.7	2.5	2.6	2.8	0.9	– 1.78
60	4778.51	57.8	56.1	1.5	173.1	79.9	0.2	1.4	2.8	3.0	3.1	0.9	– 1.79
82	4454.97	59.8	59.2	0.8	147.7	84.2	0.1	4.9	2.7	3.0	3.0	0.9	– 2.12
80	4522.36	53.4	52.6	1.4	177.2	88.4	0.5	11.1	2.6	3.0	3.0	0.9	– 2.14
13	4171.88	54.3	53.0	1.6	176.1	82.4	0.6	12.6	2.6	2.9	2.8	0.9	– 2.27
31	4393.70	55.0	54.1	0.9	177.0	88.9	0.1	4.5	2.5	3.0	3.1	0.9	– 2.47
54	3442.83	57.6	56.5	1.0	167.8	91.7	0.1	26.0	2.8	3.1	3.2	1.1	– 3.11
34	3980.79	55.9	54.7	1.0	161.1	90.5	0.1	17.1	2.8	3.1	3.3	1.0	– 3.86
62	4212.86	55.6	54.3	1.4	150.5	81.9	0.2	23.2	2.5	3.1	3.2	0.9	– 4.79
97	5393.75	56.4	55.0	1.5	174.2	93.9	0.1	15.9	2.7	3.2	3.1	1.0	0.30
98	4738.88	55.9	55.6	1.4	179.7	92.4	0.7	23.2	2.4	2.9	2.5	1.0	2.85
99	5024.48	55.6	54.0	2.1	190.6	95.3	0.4	10.0	2.3	2.6	2.9	1.0	0.33
100	5333.49	54.6	53.7	0.9	175.9	87.8	0.6	0.4	2.4	2.6	2.2	1.0	7.36
Mean	5353.07	55.8	54.9	1.1	175.3	89.67	0.1	10.4	2.6	2.8	2.8	1.0	

GY(t ha^{-1}) grain yield, *DA* days to anthesis, *DS* days to silking, *ASI* anthesis-silking interval, *PH* plant height (cm), *EH* ear height (cm), *RL* root lodging, *SL* stalk lodging, EPP ear per plant, *HC* husk cover, *ER* ear rot, *EA* ear aspect, *BI* base index

both additive and non-additive gene actions controlled the inheritance of these traits of the genetic materials used in the present study. Differences among in the inbred lines for GCA mean squares indicated that genetic the materials were variable under the two varied conditions. In addition, the relative superiority of GCA over SCA effects for GY in the present study established the relative importance of additive gene action over non-additive gene action in the transfer of GY from the parents to the hybrids. Therefore, traits such as LD could be used together with GY while selecting for improved yields under drought conditions. This result is consistent with the findings of Kumar et al. (2016), Maazou et al. (2016) and Trachsel et al. (2016b) who suggested that, genotypes with stay green ability under drought have then

Table 5 Mean squares from analysis of variance for general and specific combining ability for grain yield and other agronomic traits of 96 yellow maize hybrids under drought and optimal conditions

Source	DF	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	LD
Drought														
Year	1	43,323,688.19**	733.36**	924.33**	8.37**	147,674.44**	82,471.68**	1.96 ns	8588.48**	2.32**	9.07**	39.23**	1.29**	90.02**
SET	5	4,683,701.93**	16.79*	8.59*	2.39*	1588.67**	170.76*	6.23 ns	48.77 ns	1.57**	4.57**	5.78**	0.04*	1.86**
ENV × SET	5	792,459.32*	3.72 ns	1.33 ns	1.41 ns	189.47 ns	44.86 ns	1.53 ns	50.27 ns	0.17 ns	0.16 ns	1.82*	0.01 ns	0.95*
Rep (ENV × SET)	10	194,952.58 ns	5.12 ns	4.32 ns	0.87 ns	124.13 ns	36.05 ns	4.39 ns	18.34 ns	0.10 ns	1.06 ns	0.61 ns	0.01 ns	0.28 ns
Block (ENV × Rep)	36	246,753.29 ns	2.89 ns	2.53 ns	0.61 ns	180.27 ns	78.24 ns	3.88 ns	37.96 ns	0.11 ns	0.51 ns	0.64 ns	0.01 ns	0.24 ns
Male (SET)	18	779,126.56*	4.03 ns	2.81 ns	1.62 ns	268.79 ns	34.03 ns	4.71 ns	89.58**	0.46**	1.05 ns	0.85 ns	0.02 ns	2.50**
Female (SET)	18	1,231,340.17**	9.66**	10.48**	1.26 ns	396.45*	70.01 ns	4.41 ns	118.37**	0.16 ns	1.44**	1.58*	0.02 ns	4.17**
Female × male (SET)	54	576,456.69**	4.67 ns	3.74 ns	1.01 ns	149.8 ns	91.79 ns	4.16 ns	36.76 ns	0.13 ns	0.67 ns	0.70 ns	0.02 ns	2.68**
ENV × male (SET)	18	353,682.37 ns	2.94 ns	2.15 ns	1.18 ns	195.65 ns	84.78 ns	3.16 ns	58.75 ns	0.10 ns	0.72 ns	0.90 ns	0.01 ns	0.86**
ENV × female (SET)	18	437,958.70 ns	3.75 ns	2.19 ns	0.71 ns	160.82 ns	52.11 ns	4.33 ns	112.08**	0.12 ns	0.47 ns	0.46 ns	0.02 ns	0.63**
ENV × female × male (SET)	54	384,017.62 ns	5.01 ns	3.15 ns	1.12 ns	171.31 ns	95.28 ns	4.44 ns	34.81 ns	0.12 ns	0.68 ns	0.72 ns	0.01 ns	0.57**
Error	144	311,291.1	3.75	2.94	0.89	183.11	74.84	4.48	33.13	0.16	0.71	0.68	0.01	0.24
Optimal														
Year	1	158,011,755.00**	86.08**	91.42**	246.60**	14,297.44**	6119.09**	3.94 ns	447.46 ns	2.77**	0.25 ns	1.21**	0.63**	–
SET	5	1,345,995.30*	5.54*	3.36 ns	0.60 ns	1466.45**	308.96*	1.88 ns	351.70*	0.39*	0.36*	0.88**	0.00 ns	–
ENV × SET	5	3,753,119.60**	2.64 ns	3.24 ns	0.34 ns	132.00 ns	191.84 ns	1.88 ns	52.89 ns	0.31*	0.14 ns	0.39**	0.01 ns	–
Rep (ENV × SET)	10	339,337.10 ns	0.63 ns	0.70 ns	0.19 ns	152.88 ns	41.10 ns	2.02 ns	134.29 ns	0.08 ns	0.03 ns	0.06 ns	0.01 ns	–
Block (ENV × Rep)	36	553,432.50 ns	1.83 ns	1.91 ns	0.39 ns	104.34 ns	70.21 ns	2.46 ns	153.98 ns	0.10 ns	0.06 ns	0.10 ns	0.01 ns	–
Male (SET)	18	2,479,442.60**	8.74**	7.99**	0.66 ns	641.78**	237.79*	2.01 ns	338.97**	0.15 ns	0.11 ns	0.27**	0.02**	–
Female (SET)	18	2,798,464.00**	16.63**	15.17**	0.52 ns	1269.50**	330.79**	2.18 ns	183.84 ns	0.20 ns	0.27**	0.36**	0.02 ns	–
Female × male (SET)	54	1,030,179.90*	3.11 ns	3.27 ns	0.48 ns	206.15 ns	124.11 ns	2.54 ns	140.27 ns	0.10 ns	0.09 ns	0.15*	0.01 ns	–
ENV × male (SET)	18	1,604,188.50**	4.03 ns	3.29 ns	0.64 ns	124.42 ns	92.80 ns	2.01 ns	242.72**	0.09 ns	0.09 ns	0.17*	0.01 ns	–
ENV × female (SET)	18	2,935,935.50**	6.47**	6.06*	0.60 ns	242.44 ns	61.82 ns	2.18 ns	157.23 ns	0.09 ns	0.10 ns	0.20*	0.02 ns	–
ENV × female × male (SET)	54	1,359,069.**	3.17 ns	2.85 ns	0.47 ns	100.89 ns	63.43 ns	2.54 ns	222.08*	0.09 ns	0.11 ns	0.11 ns	0.01 ns	–
Error	144	559,253.2	2.46	3	0.53	148.14	111.5	2.36	136.37	0.11	0.09	0.1	0.01	–

*, ** significant at $p < 0.05$ and $p < 0.01$, respectively; *ns* not significant

GY grain yield, *DA* days to anthesis, *DS* days to silking, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *RL* root lodging, *SL* stalk lodging, *EPP* ear per plant, *HC* husk cover, *ER* ear rot, *EA* ear aspect, *LD* leaf death, *ENV* environment potential of producing high GY under drought conditions. The presence of significant GCA for GY and some secondary traits will help in the identification and selection of inbred lines which could be used as either female or male parents for hybrid development. The absence of significant GCA for both male and female sets under the two conditions for EPP implied that, EPP may not be an essential trait for yield improvement under drought conditions, which differed from the results reported by Monneveux et al. (2006), Gouesnard et al. (2016) and Trachsel et al. (2016b). These contradictions could be a consequence of the differences in genetic materials and mating designs used. Nevertheless, the existence of significant mean squares for GCA and SCA effects GY and LD for male and female in this study, suggests that it is essential to use a recurrent selection technique to enhance the rate of transfer of the favorable genes among the yellow maize populations. Consequently, development of synthetics and hybridization among the lines can be carried out to fully exploit the SCA effects for development of superior hybrids. The significant SCA × E for male and female sets for GY denotes distinction in performance of the hybrids under contrasting environmental conditions. This further suggests the need for selection of hybrids best adapted to each environment.

GCA effects of the inbred lines under drought and rain-fed conditions

Under drought stress, inbred lines 12 and 30 were the only lines that exhibited positive and significant GCA-female and GCA-male effects, respectively, for GY (Table 6). Inbred lines 25 and 29 recorded negative and significant GCA for ASI when used as female, while lines 1, 7 and 21 had significant negative GCA for ASI as male parents. Inbred lines 8, 15, 23, and 28 had significant and positive GCA effects for PH when used as female, while only male line 18 recorded significant and significant GCA for PH. Female parents 1, 23, 25, 27 and 28 recorded positive and significant GCA for EH, while none of the male parents on the other hand did not show positive GCA effects for EH. For PA, inbred lines 1, 8, 12 and 29, and 2, 24, and 27 had negative and significant GCA effects for female and male parents, respectively. The GCA for EA showed that, female parents 8, 9, 10, 12, 13, 18 and 25 displayed significant and negative effects, while only male parent 9 recorded significant and GCA effects for EA. Lines 1 and 28 (female) and lines 7, 9, 18 and 21 (male) recorded positive and significant GCA effects for EPP. For LD, lines 1, 7, 8, 12, 14, 21, 29 and 30; 2, 9, 10, 11, 19 and 28 recorded significant and negative GCA effects for female and male parents, respectively.

Under the rain-fed condition, no parent had positive and significant GCA-female effect for GY, while only lines 12 and 30 recorded positive and significant GCA-male effect for GY (Table 7). For ASI, neither female nor male parents recorded negative and significant GCA. Inbred lines 8, 14, 15, 28 and 30 recorded positive and significant GCA for PH when used as female, while lines 8, 18, 23 and 28 had significant positive GCA for PH as male parents. Inbred lines 1, 14, 15, and 30 had significant and positive GCA effects for EH when used as female, while lines 10, 16, 18, 28 and 30 also had significant and significant GCA for EH. Female parents 8, 14 and 15 recorded negative and significant GCA for PA, while only line 30 had significant and negative GCA among the male parents. For EA, inbred lines 6, 8, 14 and 27; and 5, 9, and 24 exhibited negative and significant GCA effects among the female and male parents, respectively.

From this study, under the drought and rain-fed conditions, parental lines with significant and positive GCA effects for GY and secondary traits, such LD and ASI, are good combiners for those traits. This also implied that, these parents have the tendency of transferring the characteristics to their F_1s when crossed. Inbred lines for male or females set with positive and significant GCA effects for GY and secondary traits will be useful for the development high yielding hybrids under drought condition (Derera et al. 2007; Pswarayi and Vivek 2008; Weber et al. 2012). Significant and positive GCA effects observed for line 12 (female) and line 30 (male) for GY under drought stress; and male line 12 and 30 under rain-fed condition signified that, these parents are having the advantageous inheritable factor for GY which could be transferred to their F_1s under drought and rain-fed conditions. On the other hand, lines with negative but significant GCA for ASI, PA, EA and LD implied that these parents could serve as an important resource for drought tolerance gene to their hybrids, which corroborates the findings reported by Araus et al. (2012), Ye et al. (2016) and Wang et al. (2018).

Phenotypic and genotypic associations among traits measured under drought and rain-fed conditions

The phenotypic correlation of the traits showed that, GY was positively correlated PH, EH and EPP under the drought condition. On the other hand, GY had significant and negative relationship with HC, PA and EA (Table 8). Genotypic correlation analysis revealed positive and significant correlation between GY and EPP under drought. Also, GY had significant and negative associations with HC, PA, EA and LD.

Under the rain-fed condition, GY had positive and significant phenotypic correlation with PH, while its relationships with PA and EA were negative and significant. The association between PH and EH was positive, while EA had negative and significant correlation with both PH and EH. Contrary to the genotypic correlation, there was neither positive nor negative and significant association was found between GY and all the traits measured. However, there was

Table 6 General combining ability effects of 24 lines for grain yield and other traits evaluated at drought stress during 2017 and 2018 dry seasons

Line	GY		ASI		PH		EH		PA		EA		EPP		LD	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1	217.9	– 116.7	– 0.18	– 0.50*	– 0.1	– 2.1	5.0**	1.5	– 0.40*	0.10	– 0.20	0.30	0.08*	– 0.60*	– 0.50*	0.80**
2	171.3	179.4	0.05	– 0.20	– 1.3	3.3	– 2.2	– 1.0	0.20	– 0.50*	0.40	– 0.10	– 0.01	– 1.00**	– 0.20	– 0.60**
5	– 246.9	– 333.9*	0.20	0.20	– 0.3	2.0	– 3.6*	0.1	0.10	0.30	0.00	0.00	0.03	– 0.90**	0.90**	-0.20
6	47.8	48.6	– 0.02	0.20	– 1.5	– 6.6*	– 2.3	– 0.4	0.10	0.20	– 0.20	0.30	– 0.06	– 0.04	0.40*	0.10
7	184.3	238.4	– 0.32	– 0.47*	– 3.9	– 2.2	2.3	1.6	0.10	– 0.10	0.00	– 0.30	– 0.06	0.08**	– 0.60**	0.50*
8	284.1	– 88.8	0.12	– 0.16	9.0*	4.3	1.0	– 0.6	– 0.90**	-0.20	– 0.30*	– 0.10	0.01	0.03	– 0.60**	– 0.30
9	– 516.4**	– 198.2	0.13	0.17	– 3.5	4.4	– 0.8	– 0.8	0.80**	0.10	0.50**	0.30	– 0.07*	0.05*	0.70**	– 0.40*
10	317.2	241.5	– 0.19	0.25	– 1.1	2.1	– 0.2	1.7	0.10	0.00	– 0.40*	0.10	0.04	– 0.04	0.50*	– 0.50*
12	356.3*	219.1	0.20	– 0.14	– 2.1	– 3.7	1.1	– 0.4	– 0.30*	0.00	– 0.30*	-0.40*	0.05	– 0.03	– 0.30	– 0.40*
13	– 497.0	63.6	– 0.02	– 0.31	1.6	5.1	– 3.1*	– 1.4	0.30*	– 0.20	0.60**	0.00	– 0.06	– 0.01	0.40*	0.40*
14	– 176.4	– 524.4**	– 0.15	0.12	1.6	– 3.5	2.1	0.2	0.00	0.20	0.00	0.30	– 0.03	– 0.11**	– 0.70**	0.30
15	193.3	67.0	– 0.12	– 0.14	8.1*	– 4.9	1.6	– 2.4	– 0.10	0.00	– 0.30	0.00	0.05	– 0.02	– 0.30	0.30
16	29.6	-48.6	0.02	– 0.10	– 2.4	– 4.2	– 0.3	1.3	0.00	0.00	0.40*	0.00	0.01	– 0.02	0.20	0.00
18	32.7	29.5	0.18	0.31	– 1.2	7.1*	– 1.1	– 0.5	– 0.20	– 0.10	– 0.50**	0.20	0.03	0.05*	– 0.20	0.00
19	– 255.4	– 47.7	– 0.15	– 0.22	– 4.4	2.1	-0.3	1.6	0.20	0.00	0.40*	– 0.30	– 0.02	0.00	0.20	– 0.40*
20	114.2	– 173.3	0.18	0.37	– 7.2*	– 2.9	-2.4	– 0.6	0.00	0.40*	0.10	0.40*	0.01	– 0.01	0.90**	0.40*
21	– 396.1*	85.4	0.02	– 0.63*	– 4.2	4.2	1.8	2.6	– 0.10	– 0.10	0.20	– 0.30	– 0.04	0.05*	– 0.50*	– 0.40*
23	94.9	140.0	– 0.30	– 0.14	8.8**	0.2	5.8**	– 0.1	– 0.20	– 0.40*	– 0.10	0.10	– 0.02	0.04	– 0.20	0.20
24	187.0	– 52.0	0.07	0.33	2.4	– 1.3	0.2	– 1.9	0.10	0.00	– 0.10	– 0.20	– 0.05	– 0.01	– 0.30	– 0.30
25	272.3	– 443.2**	– 0.42*	0.27	– 6.5*	– 7.0*	6.3*	– 2.0	– 0.20	0.30	– 0.30*	0.10	0.12	– 0.06*	0.00	0.20
27	-221.2	155.6	– 0.05	0.00	5.3	4.6	4.5*	2.8	– 0.10	– 0.40*	0.00	– 0.10	0.04	0.01	– 0.20	0.00
28	212.5	52.1	0.79**	– 0.32	6.6*	2.6	3.2*	0.1	– 0.20	– 0.30	0.10	0.00	0.11**	– 0.03	0.60**	– 0.40*
29	-263.5	235.4	– 0.50*	0.01	– 5.3	– 0.4	-1.1	– 0.8	0.30*	0.20	0.30*	0.10	0.00	– 0.03	– 0.40*	0.30
30	-142.3	271.3*	0.08	0.60*	1.6	– 3.1	0.7	– 0.6	0.10	0.00	– 0.10	– 0.10	0.01	– 1.00**	– 1.10**	– 0.10
SE	143.3	128.8	0.18	0.23	2.7	3.0	1.6	2.0	0.15	0.18	0.15	0.21	0.03	0.02	0.17	0.20

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively

GY Grain yield, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *EPP* ear per plant, *ER* ear rot, *EA* ear aspect, *LD* leaf death, *SE* standard error

Table 7 General combining ability effects of 24 lines for grain yield and other traits evaluated at rain-fed condition during 2018 and 2019 cropping seasons

Line	GY		ASI		PH		EH		PA		EA		EPP	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1	− 429.8	10.0	− 0.10	0.00	− 2.3	− 10.4**	3.5*	− 4.8*	− 0.10	0.12	0.03	0.07	− 0.07*	− 0.06**
2	519.9	− 551.0*	− 0.10	− 0.10	− 5.2	10.5**	− 2.7	1.0	0.00	0.03	0.12	0.13	− 0.01	− 0.03
5	− 240.9	− 24.3	0.20	0.10	− 5.7	− 2.9	− 8.2**	− 3.5	0.10	0.13*	0.05	− 0.22*	− 0.08*	− 0.07**
6	323.7	− 15.6	− 0.10	− 0.30	− 2.3	1.8	− 0.3	1.5	− 0.10	0.01	− 0.22*	0.04	0.00	0.00
7	− 588.3	326.0	0.00	0.20	0.8	− 6.8*	1.1	0.2	0.10	− 0.10	0.10	0.06	− 0.03	− 0.01
8	644.8	− 754.2*	− 0.10	− 0.10	13.0**	7.8**	3.2	1.8	− 0.30**	− 0.11	− 0.29*	0.23*	− 0.07*	− 0.04*
9	− 380.1	444.0	0.10	− 0.10	− 11.3**	− 2.9	− 4.0*	− 3.6	0.30**	0.02	0.23*	− 0.21*	− 0.08*	− 0.06**
10	− 438.0	-294.9	− 0.30	0.00	− 11.3**	2.6	− 5.8**	4.6*	0.10	0.04	0.18	0.08	− 0.09**	− 0.03
12	− 14.2	783.6*	− 0.10	0.10	0.0	− 2.8	− 1.0	− 1.0	0.00	− 0.10	0.08	− 0.08	− 0.03	− 0.01
13	− 70.5	-285.0	0.20	− 0.20	-3.9	0.7	− 4.5*	− 0.7	0.00	− 0.11	0.13	− 0.07	− 0.02	− 0.04*
14	522.6	-203.5	0.10	− 0.10	15.2**	− 0.3	11.1**	− 2.8	− 0.20*	0.15*	− 0.23*	− 0.11	− 0.03	− 0.10**
15	701.2	346.1	0.20	− 0.30	14.2**	− 1.0	6.4**	− 1.3	− 0.18*	0.04	− 0.19	0.10	0.00	0.05**
16	− 268.6	-277.4	− 0.10	0.50*	− 4.7	− 3.7	− 0.7	4.6*	0.14*	− 0.07	0.18	0.05	− 0.05	− 0.04*
18	− 381.2	− 312.4	− 0.10	− 0.10	− 3.9	10.3**	− 4.9*	4.7*	0.16*	− 0.08	0.20*	0.10	− 0.04	− 0.06**
19	− 51.5	243.6	0.00	− 0.30	− 5.5	− 5.5*	− 0.7	− 8.2**	0.07	0.00	0.00	-0.09	− 0.08*	− 0.11**
20	− 82.6	− 97.5	− 0.10	− 0.10	2.3	− 1.2	3.0	0.2	− 0.04	0.11	0.14	0.17	0.00	0.00
21	411.8	− 658.8*	-0.10	0.10	− 4.3	− 5.7*	0.5	1.6	0.04	0.08	0.00	0.04	− 0.07*	− 0.04*
23	127.1	494.8	0.20	− 0.20	0.8	5.8*	− 4.4*	0.3	− 0.04	0.00	− 0.08	0.17	− 0.01	− 0.08**
24	− 456.4	261.3	0.30	0.00	1.2	1.2	0.3	− 2.1	− 0.01	0.00	− 0.05	− 0.20*	− 0.07*	− 0.05**
25	− 189.8	− 387.6	− 0.20	− 0.10	− 13.4**	− 5.9*	− 0.7	− 2.8	0.13*	0.05	0.06	0.22*	− 0.03	− 0.05**
27	17.4	444.1	0.20	0.30	9.9*	− 5.1	2.3	0.8	− 0.12	0.00	− 0.23*	− 0.11	− 0.04	− 0.08**
28	530.9	80.3	− 0.30	0.00	7.9*	9.9**	0.4	5.1*	− 0.03	− 0.10	− 0.09	− 0.01	− 0.05	0.00
29	− 358.3	− 136.9	0.30	− 0.10	− 4.4	1.2	− 2.0	− 3.2	0.17*	0.01	0.12	− 0.07	− 0.01	− 0.02
30	151.0	565.4*	− 0.20	0.00	13.1**	2.8	7.4**	7.4**	− 0.10	− 0.14*	− 0.07	− 0.12	0.05	0.03
SE	371.0	274.2	0.17	0.17	3.4	2.4	1.7	2.1	0.07	0.07	0.10	0.09	0.03	0.02

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively

GY Grain yield, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *EPP* ear per plant, *ER* ear rot, *EA* ear aspect, *SE* standard error

*$p < 0.05$

**$p < 0.01$

Table 8 Phenotypic correlation (r_P) above diagonal and genotypic correlation (r_G) below diagonal between grain yield and agronomic traits of 100 maize hybrids evaluated under drought stress during 2017 and 2018

Traits	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP	LD
GY		− 0.13	− 0.10	− 0.09	0.35**	0.26*	− 0.01	− 0.08	− 0.33**	− 0.62**	− 0.72**	0.58**	− 0.18
DS	0.14		0.89**	0.45**	0.04	− 0.02	− 0.29*	− 0.34**	0.04	0.24*	0.12	− 0.32*	− 0.18
DA	0.19	0.96**		0.00	0.06	0.06	− 0.25*	− 0.36**	− 0.11	0.14	0.02	− 0.24*	− 0.32*
ASI	− 0.10	0.15	− 0.27*		− 0.02	− 0.15	− 0.09	− 0.07	0.26*	0.25*	0.21*	− 0.24*	0.23*
PH	0.49**	0.84**	0.63**	0.31*		0.42**	0.04	− 0.02	− 0.48**	− 0.60**	− 0.41**	0.26*	− 0.29*
EH	0.32**	0.80**	0.87**	0.00	− 0.16		− 0.10	− 0.17	− 0.21*	− 0.31*	− 0.32**	0.15	− 0.14
RL	NA	NA	NA	NA	NA	NA		0.34**	− 0.02	− 0.13	0.08	0.04	0.15
SL	− 0.16	− 1.00**	− 1.00**	− 0.23*	− 0.19	− 1.00	NA		0.04	− 0.12	− 0.03	0.22*	0.37**
HC	− 0.44**	− 0.14	− 0.45**	0.54**	− 0.61**	− 0.30*	NA	− 0.03		0.53**	0.50**	− 0.32**	0.33**
PA	− 0.71**	− 0.05	− 0.14	0.22*	− 0.76**	0.04	NA	− 0.34*	0.55**		0.63	− 0.54	0.28
EA	− 0.85**	− 0.11	− 0.28*	0.37**	− 0.50**	− 0.04	NA	− 0.19	0.71**	0.69**		− 0.57**	0.21*
EPP	0.96**	− 0.43**	− 0.21*	− 0.47**	0.40**	− 0.18	NA	0.14	− 0.46**	− 0.76**	− 0.84**		− 0.05
LD	− 0.25*	− 0.25*	− 0.48**	0.56**	− 0.52**	− 0.38**	NA	0.90**	0.49**	0.43**	0.33*	− 0.08	

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively; *NA* not available

GY grain yield, *DA* days to anthesis, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *EA* ear aspect, *RL* root lodging, *SL* stock lodging, *HC* husk cover, *EPP* ear per plant, *LD* leaf death

Table 9 Phenotypic correlation (r_P) above diagonal and genotypic correlation (r_G) below diagonal between grain yield and agronomic traits of 100 maize hybrids evaluated under optimal condition during 2018 and 2019 cropping seasons

Traits	GY	DS	DA	ASI	PH	EH	RL	SL	HC	PA	EA	EPP
GY		0.02	0.03	− 0.04	0.23*	0.19	− 0.03	− 0.12	− 0.13	− 0.43**	− 0.48**	0.17
DS	NA		0.97**	0.19	− 0.17	0.05	0.08	0.03	0.29*	0.24*	0.14	− 0.03
DA	NA	1.00**		0.03	− 0.21	0.04	0.1	0	0.29*	0.25*	0.14	− 0.06
ASI	NA	− 0.39**	− 0.19		0.15	0.26*	− 0.14	0.07	0.01	− 0.18	− 0.09	0.15
PH	NA	− 0.18	− 0.24*	0.55**		0.69**	− 0.12	0.07	− 0.38**	− 0.61**	− 0.44**	0.27*
EH	NA	0.19	0.28*	0.83**	0.79**		− 0.06	0.08	− 0.13	− 0.49**	− 0.32*	0.33*
RL	NA	NA	NA	NA	NA	NA		0.05	− 0.04	− 0.02	0.01	− 0.11
SL	NA	− 0.29**	− 0.13	− 1.00**	0.11	0.05	NA		0.04	0.11	0.32*	0.30*
HC	NA	0.44**	0.40*	− 0.21*	− 0.68**	− 0.20*	NA	0.30*		0.58**	0.53**	0.01
PA	NA	− 0.02	0.11	− 1.00**	− 1.00**	− 0.96**	NA	0.86**	1.00**		0.65**	− 0.21*
EA	NA	− 0.11	− 0.05	− 0.54**	− 0.76**	− 0.63*	NA	1.00**	1.00**	1.00**		− 0.1
EPP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively; *NA* not available

GY grain yield, *DA* days to anthesis, *ASI* anthesis-silking interval, *PH* plant height, *EH* ear height, *EA* ear aspect, *RL* root lodging, *SL* stock lodging, *HC* husk cover, *EPP* ear per plant

significant but negative correlation between PH and EA, ASI and PA; and EH and EA (Table 9).

The significant and positive phenotypic correlation between GY and PH; and EH for the hybrids under the drought stress suggested that taller and robust hybrids might have produced and partitioned large amount of photosynthates into the GY. Correspondingly, the significant and positive association recorded between GY and EPP depicted that, the hybrids which produced more than a cob per plant are prolific hence have to tendency to contribute significantly to GY corroborating the earlier study by Aminu and Izge (2012) and Ali et al. (2017). The significant negative association between ASI and GY; GY and LD showed that gain in GY of the hybrids with traits of earliness for ASI and at the same time having green leaves after grain-filling period will significantly contribute to GY. This further suggests that, hybrids with this distinct characteristic under drought conditions could be selected for either drought escape or tolerant genotypes (Trachsel et al. 2016a). The significant and negative correlations detected between the LD and PH under drought conditions also points to delayed senescence in the taller plants. This is an indication that these genotypes can contribute to GY since there is positive correlation between GY and PH (Ertiro et al. 2017). Lead death had a significant and positive correlation with ASI, SL and HC for both genotypic and phenotypic correlations, suggesting that genotypes with prolonged days to senescence had significant influence onSL and tight HC; thereby, it lowers the pest and diseases infestations of the cobs.

Conclusion

The study revealed significant genetic variation among the hybrids evaluated for grain yield and most measured traits under drought and rain-fed conditions. The existence of significant mean squares for general and specific combining ability effects for the inbred lines and their hybrids for grain yield and some of the traits assessed in this study revealed that both additive and non-additive gene actions conditioned the inheritance of grain yield and some of the secondary traits, such as anthesis-silking interval, lead death, plant aspect and ear aspects, under the two growing conditions in which the experiments were carried out. Under drought conditions, three hybrids (27, 81 and 68) were identified as outstanding, while another three hybrids (89, 18 and 26) were also identified as outstanding under rain-fed conditions. These hybrids need to be extensively evaluated under varied conditions for commercialization to reduce malnutrition and food insecurity in sub-Saharan Africa.

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Declarations

Conflict of interest The authors have do not have any conflict of interest to declare.

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