

GENETIC VARIABILITY AND MODE OF GENE ACTION OF DIFFERENT MATURITY GROUPS OF MAIZE (*ZEAMAYS L.*) INBRED LINES FOR DROUGHT TOLERANCE

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Abstract. Drought tolerant maize (*Zea mays L.*) hybrids are crucial for the sustainability of maize production in the drought-prone areas of Sub-saharan Africa. Understanding the genetics of inheritance under drought is important in designing breeding strategies for improving grain yield and other agronomic traits under drought. Two studies were conducted to determine the genetic variability and mode of gene action for grain yield and other traits of different maturity groups of maize inbreds for tolerance to drought and identify the promising drought-tolerant maize hybrid(s) for drought-prone regions. Eleven inbred lines of different maturity groups and endosperm-modification were crossed using diallel mating scheme to generate 55 F1 hybrids. The 55 hybrids along with one check and 11 inbreds were separately evaluated under induced drought and optimum growing conditions at Samaru and Kadawa. The experiments were laid in a 7 x 8 alpha lattice design and replicated two times using single-row plot of 4-m long. Row and hill spacing were 0.75 m and 0.4 m respectively. General combining ability (GCA) and Specific combining ability (SCA) mean squares were significant ($p < 0.01$) for grain yield and most other traits under drought and optimum growing conditions. SCA accounted for 79.3% and 64.2% of the total genetic variation for grain yield under drought and optimum growing conditions, indicating that non-additive gene action largely controlled the inheritance of grain yield of the hybrids. Hybrid TZEE-W-Pop STR C5 x TZEI 87 should be further tested in multiple environments for adoption by farmers in drought prone areas of Sub-saharan Africa.

Keywords: Drought tolerance, Diallel design, Combining ability, Gene action.

INTRODUCTION

Maize (*Zea mays L.*), is a major crop for both human consumption and animal feed in Nigeria. It is the third most important cereal in the world after wheat and rice and ranks top in grain yield per unit area of land, and its demand is expected to surpass that of wheat and rice by 2020 (ODIYO ET AL., 2014). The production quantity of maize is about one billion tons worldwide, with Africa producing about 78 million tons and West Africa producing about 19.6 million tons (MIHUT, ET AL 2018). The continent production is about 8% of the world total (FAOSTAT, 2014). Maize is usually roasted or boiled and consumed as snacks; it is also widely processed into a variety of food drinks such as pap and gruel (kunu). In addition, maize is used in making cakes (masa). However, the predominant use of maize in Northern Nigeria is for making mush (tuwo). It is also the main source of energy in livestock feeds. The growing plant can be cut and made into silage or hay for the feeding of cattle and other ruminants.

Maize production in Nigeria is greatly constrained by several biotic and abiotic factors, including drought, low soil fertility, and the parasitic weed, *Striga hermontica* (Del.) Benth (BADU-APRAKU ET AL., 2003; MIHUT ET AL, 2018). Globally, 160 million ha of maize is under rain fed conditions and annual yield losses to drought are estimated at about 25% (EDMEADES, 2008).

The risk of drought stress is severe particularly in the Sudan savanna zone due to unreliable and uneven distribution of rainfall (ECKEBIL, 1991). Even in those lowlands with

adequate precipitation for maize production, periodic drought may occur at the most sensitive stages of the crop such as flowering and grain filling. While drought will impact the growth and ultimate performance of a crop at any stage, it is of most detriment at flowering and grain filling resulting in yield penalties of between 40 and 90% (MENKIR AND AKINTUNDE, 2001; BADU-APRAKU ET AL., 2011A; BADU-APRAKU AND OYEKUNLE, 2012). Therefore, improved tolerance to drought is an important breeding objective to stabilize maize production in the sub-region. BETRAN ET AL. (2003), MESEKA ET AL. (2006), BADU-APRAKU ET AL. (2011a) MAKUMBI ET AL. (2011) AND OYEKUNLE AND BADU-APRAKU (2013) reported additive gene action to be more important than the non-additive gene action in early maturing maize inbreds evaluated under induced drought stress and optimal growing conditions. SIMILARLY, BADU-APRAKU AND OYEKUNLE (2012) in a study involving 20 extra-early inbreds reported additive gene action to be more important than the non-additive gene action in modulating the inheritance of grain yield and other traits associated with Striga resistance and drought tolerance.

However, information on the gene action conditioning grain yield and other traits of maize inbred lines of different maturity groups and different kernel modification for tolerance to drought is completely lacking. Such information is important for the development of acceptable hybrids for drought prone environments in Nigeria and other countries in Sub-saharan Africa.

Therefore, the objectives of the present study were to:

- i. To determine the genetic variability in maize inbreds and hybrids under drought and optimum growing conditions.
- ii. To determine the mode of gene action for grain yield and other traits of different maturity groups of maize inbreds under drought and optimum growing conditions.

MATERIALS AND METHODS

Eleven maize inbred lines comprised five early maturing, four extra-early maturing and two early QPM inbred lines were selected based on their contrasting response to drought and availability of seed and were utilized in the genetic analysis study (Table 1). The 11 inbreds were crossed using the diallel mating design to generate 55 single-cross hybrids during the rainy season of 2015. The 55 F1 hybrids plus one hybrid check were evaluated under induced drought and well-watered conditions at Samaru and Kadawa during the 2015/2016 dry season. The experiments were laid in a 7 x 8 alpha lattice design and replicated two times using single-row plot of 4-m long. Row and hill spacing were 0.75 m and 0.4 m respectively. Three seeds were planted per hill and seedlings were thinned to two per stand about two weeks after emergence, giving a population density of 66,666 plants per hectare. A compound fertilizer (NPK 15:15:15) was applied at the rate of 60 kg N ha⁻¹, 60 kg P ha⁻¹ and 60 kg K ha⁻¹ two weeks after planting. An additional 60 kg N ha⁻¹ urea was top-dressed two weeks later in the drought experiment and 4 weeks later in the well-watered experiment. Irrigation was supplied twice every week using furrow irrigation system. The managed drought stress was achieved by supplying irrigation water twice a week up to 35 days after planting. Thereafter, the irrigation water was withdrawn in the drought experiment, so that the maize plants relied on stored water in the soil for growth and development. On the other hand, the experiment under optimum growing conditions, continue to receive irrigation until physiological maturity. Except for the water treatment, all management practices were the same for both the optimum and drought experiments.

Table 1

| Description of the 11 maize parental inbred lines used for the diallel cross | | | | |
|--|--|----------------|------------------|--------------|
| Name | Pedigree | Maturity group | Drought Response | Grain Colour |
| TZEI 108 | WEC STR S7 Inbred 7 | Early | T | White |
| TZEI 65 | TZE-W Pop STR Co S6 Inbred 141-1-2 | Early | T | White |
| TZEEI 21 | TZEE-W Pop x LD S6 (Set B) Inb.44 | Extra-early | T | White |
| TZEE-W- Pop STR C5 | | Extra-early | T | White |
| TZEEI 6 | TZEE-W SR BC5 x 1368 STR S7Inb. 100 | Extra-early | T | White |
| TZEQI 4 | TZE-W Pop x 1368 STR S7 Inb 1 x Pool 15 SR QPM BC2S6 1-1-1-1-4-11 | Early QPM | T | White |
| TZEQI 24 | TZE-W Pop x 1368 STR S7 Inb 2 x Pool 15 SR QPM BC2S6 31-42-1-1-1-6 | Early QPM | T | White |
| TZEI 86 | | Early | S | White |
| TZEI 59 | TZE-W Pop STR Co S6 Inbred 80 | Early | S | White |
| TZEI 87 | TZE-W Pop x 1368 STR S7 Inb. | Early | S | White |
| TZEEI 29 | TZEE-W SR BC5 x 1368 STR S7 Inb. 27 | Extra-early | S | White |

T: tolerant; S: susceptible

Data Collection

Days to anthesis and silking were recorded for each plot as the number of days from planting to when 50% of the plants in a row had shed pollen and had emerged silks, respectively. Anthesis-silking interval (ASI) was computed as the interval in days between days to silking and anthesis. Plant and ear heights were calculated as the average of measurements on 10 competitive plants (excluding plants at the edges) per plot and were measured after anthesis as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear, respectively. Plant and ear aspects were rated on a scale of 1 to 5, where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. Stay green characteristic was taken as leaf death score (LDS) and was recorded on a scale of 1 to 10, where 1 = 10% dead leaf area; 2 = 20% dead leaf area; 3 = 30% dead leaf area; 4 = 40% dead leaf area; 5 = 50% dead leaf area; 6 = 60% dead leaf area; 7 = 70% dead leaf area; 8 = 80% dead leaf area; 9 = 90% dead leaf area; 10 = 100% dead leaf area, for the drought stressed plots at 63 and 70 days after planting (DAP) respectively. The number of ears per plant (EPP) was computed as the total number of ears at harvest divided by the number of plants at harvest. Under drought environments, all ears harvested from each plot were shelled to determine percentage grain moisture and grain weight. Grain yield, adjusted to 150 g kg⁻¹ moisture, was computed from the shelled grain weight. On the other hand, under well-watered environments, harvested ears from each plot were weighed and representative samples of ears were shelled to determine percent grain moisture. Grain yield adjusted to 150 g kg⁻¹ moisture, was computed from ear weight and grain moisture assuming a shelling percentage of 80% (800 g grain kg⁻¹ ear weight).

Statistical Analysis

Data collected were subjected to both separate and combined analysis of variance (ANOVA) using individual plot means. All analysis were computed using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS) software, version 9.2 (SAS, Institute 2004). In the analysis of variance, genotype and location were considered as fixed effects

and thus, fixed model was used for the analysis. Mean comparison was done using Fitcher's Least Significant Difference (LSD). ANOVA was performed for each and across test environments for grain yield to determine the performance of the hybrids across test environments.

The relative importance of the GCA and SCA expressed as percentage were estimated from the total sums of squares of the GCA and SCA from the diallel analysis combined across environment. This was further confirmed using the equation;

$2k_{GCA}^2 / (2k_{GCA}^2 + k_{SCA}^2)$, modified from Baker (1978) by Hung and Holland (2012), in which k_{GCA}^2 is the quadratic form (analogous to a variance component but referring a fixed effect)

derived from the mean square of GCA effect and k_{SCA}^2 is the quadratic form of SCA effects since the total genetic variation among single-cross progeny is equal to twice the GCA component plus the SCA component. The closer this ratio is to unity, the greater the predictability of a specific hybrid's performance based on GCA alone. If the ratio is close to one, this suggests that SCA is not important and that hybrid performance can be accurately predicted based on the average of parental GCA values.

RESULTS AND DISCUSSION

Analysis of Variance, General and Specific Combining Abilities

The combined analysis of variance of the diallel crosses under drought revealed significant mean squares for Environment (Env.) for grain yield, plant height, root lodging and plant aspect, whereas, under optimum growing conditions, result shows significant mean squares ($p < 0.01$) for grain yield and all other measured traits except days to silking, anthesis silking interval, plant height, ear height, number of ears per plant, cob diameter and number of rows per cob (Table 2). Genotypes mean squares were significant ($p < 0.01$) for all measured traits across test environments under both drought and optimum growing conditions except for plant aspect, and anthesis silking interval and root lodging under drought stress and number of ears per plant and number of kernels per row under optimum growing conditions (Table 2). Partitioning of the genotypes into components revealed that GCA is significant for all measured traits under drought and optimum growing conditions except anthesis-silking interval, plant height, root lodging and leaf death score 1 under drought and root lodging, husk cover, number of ears per plant, cob length, cob diameter and number of rows per cob under optimum growing conditions (Table 2). The interaction of GCA with environment shows significant difference for grain yield, days to anthesis and the numbers of ears per plant under both drought stress and optimum growing conditions. Days to silking and plant aspect were significant only under optimum growing condition and leaf death score 1 was also significant under drought. On the other hand, SCA and environment interaction mean squares shows significant difference ($p < 0.01$) for grain yield, plant aspect, cob diameter and the number of kernels per row.

GCA and SCA Effects of grain yield and other agronomic traits

Significant ($P < 0.01$) positive GCA effects for grain yield were observed only for inbred TZEI 87 under both drought and optimum growing conditions, and TZEI 65 under induced drought stress. On the other hand, TZEI 59 was significantly negative ($p < 0.01$) under both induced drought stress and optimum growing conditions (Table 3). Inbreds, TZEI 108, TZEI 65

and TZEQI 24 had significant positive GCA effects for grain yield while negative GCA effects was observed for TZEI 86 and TZEEI 21 under induced drought stress across test environments (Table 3). Whereas, inbred TZEEI 21 and TZEEI 6 had significant ($p < 0.05$) positive and negative GCA effects respectively for grain yield only in the optimum growing condition trial. Inbred TZEEI 21 and TZEEI 6 had a significant ($p < 0.01$) negative GCA effects for both days to anthesis and silking, then significant ($p < 0.01$) positive GCA effects on days to anthesis for TZEI 108 under both drought and optimum growing conditions (Tables 3), and the same inbred was significantly positive for anthesis-silking interval, ear aspect and 1000-kernel weight under optimum growing conditions (Table 3). For plant height, TZEEI 29 had significant positive GCA effects under both research conditions, and TZEEI 6 had significant positive GCA effects under induced drought stress trial. TZEEI 21 and TZEI 65 had a significant ($p < 0.01$) negative and positive GCA effects respectively for cob length, while TZEI 108 and TZEI 59 had a significant ($p < 0.05$) positive and negative GCA effects respectively for cob length under induced drought (Table 3). Only TZEQI 4 showed significant ($p < 0.01$) positive GCA effects for 1000-kernel weight under both drought and optimum water condition, while TZEE-W-Pop STR C₅ and TZEI 65 had a significant ($p < 0.05$) negative and positive GCA effects respectively for 1000-kernel weight under induced drought experiment, and significant ($p < 0.01$) positive GCA effect for 1000-kernel weight for inbred line TZEI 108 and significant ($p < 0.01$) negative GCA effect for 1000-kernel weight for inbred lines TZEEI 6 and TZEI 87 under optimum growing conditions.

Under induced drought stress, the SCA sums of squares were larger than those of the GCA for all measured traits except days to anthesis (Fig. 1). SCA effects accounted for about 79% of the total genetic effects for grain yield and 89% of the total genetic effects for anthesis-silking interval. SCA effects accounted for about 78% of the total genetic effects for leaf death score 1 and leaf death score 2. SCA effects also accounted for about 75 to 85% of the total genetic effects for cob length, cob diameter, number of rows per cob, number of kernels per row and 1000-kernel weight (Fig. 1). On the other hand, GCA effects accounted for about 56% of the total genetic effects for days to anthesis. Similar trend was observed under the optimum growing conditions, the SCA sum of square were larger than the GCA sum of squares for all measured traits except for days to anthesis and days to silking (Fig. 2). The SCA effects accounted for 64% of the total genetic effects for grain yield. The SCA effect for all other measured traits accounted for most of the total genetic effects ranging from 62 to 91% except for days to anthesis and days to silking where GCA effects for these traits accounted for 59 and 57%, respectively of the total genetic effects.

Assessing the relative importance of GCA and SCA using the modified Baker's equation, it was observed that the ratio of GCA over SCA is smaller for all measured traits except days to anthesis and silking under both research conditions and plant aspect only under optimum growing conditions (Table 3).

The presence of significant differences among hybrids for grain yield under drought and optimum growing conditions indicated that adequate genetic variation existed among the different maize hybrids used in the present study. The presence of these genetic variability implied significant progress could be made from selection for improvements in grain yield for the

development of productive maize hybrids for drought prone and optimal growing environments. This result corroborates the findings of ROSIELLE AND HAMBLIN (1981), BADU-APRAKU *ET AL.* (2011a) and BADU-APRAKU AND OYEKUNLE (2012). The result also indicated that combining inbred lines of different maturity groups and different kernel modification can provide alternative hybrids with outstanding performance in both drought stress and optimal growing environments. The significant interaction between hybrid and environment for grain yield and other measured traits across environments indicated that the expression of these traits would not be consistent in varying test environments. Similar findings have been reported by several other workers (BADU-APRAKU *ET AL.*, 2002, 2011a, b) and suggest the need to evaluate hybrids in varying environments to identify drought tolerant genotypes with consistently favorable response to unpredictable growing environments. The absence significant genotype by environment interaction mean squares for ASI, plant height, root lodging, husk cover, number of ears per plant, row per cob and 1000 kernel weight under both research conditions, indicated that the expression of these traits would be consistent in varying test environments.

The superior grain yield of hybrids involving two tolerant inbreds compared to those involving tolerant x susceptible or two susceptible inbreds indicated the importance of dosage effect of drought tolerant genes in the parental lines. This result is in agreement with the findings of (KIRKHAM *ET AL.*, 1984; BETRAN *ET AL.*, 2003; MESEKA *ET AL.*, 2007; BADU-APRAKU *ET AL.*, 2011b) who reported that hybrids with at least one drought tolerant parental lines would give higher yields than those formed from two susceptible lines. The increased anthesis-silking interval, reduced number of ears per plant, grain yield, and deterioration in plant and ear aspect observed under drought is consistent with the results of several earlier workers (BOLANOS AND EDMEADES, 1993; EDMEADES *ET AL.*, 1993). The high grain yield reduction observed among hybrids revealed that the level of drought stress imposed during the flowering and grain-filling stages were severe enough to elucidate the differences among the hybrids. The severe grain yield reduction observed under induced drought stress in this study falls within the range reported by earlier workers (BADU-APRAKU *ET AL.*, 2005; CAMPOS *ET AL.*, 2006; BADU-APRAKU *ET AL.*, 2011b). Under drought stress, the hybrids had delayed in days to anthesis and silking and hence longer anthesis-silking interval. This result is in disagreement with the findings of DERERA *ET AL.* (2008) and OYEKUNLE *ET AL.* (2014) who reported that under drought stress, the hybrids flowered 5 days earlier and hence had shorter growing cycles and reduced leaf area duration and that this might have accounted for the lower grain yield compared to that under well-watered conditions.

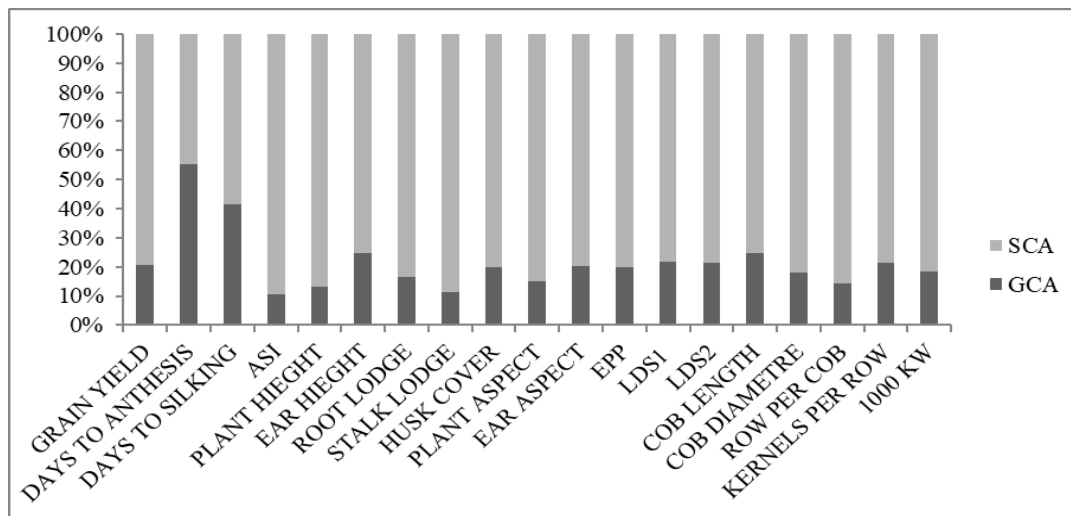


Fig. 1. Proportion of additive (lower bar) and non-additive (upper bar) genetic variance for grain yield and other measured traits for a 11 x 11 diallel cross evaluated under induced drought stress at Samaru and Kadawa in 2015/2016 dry season

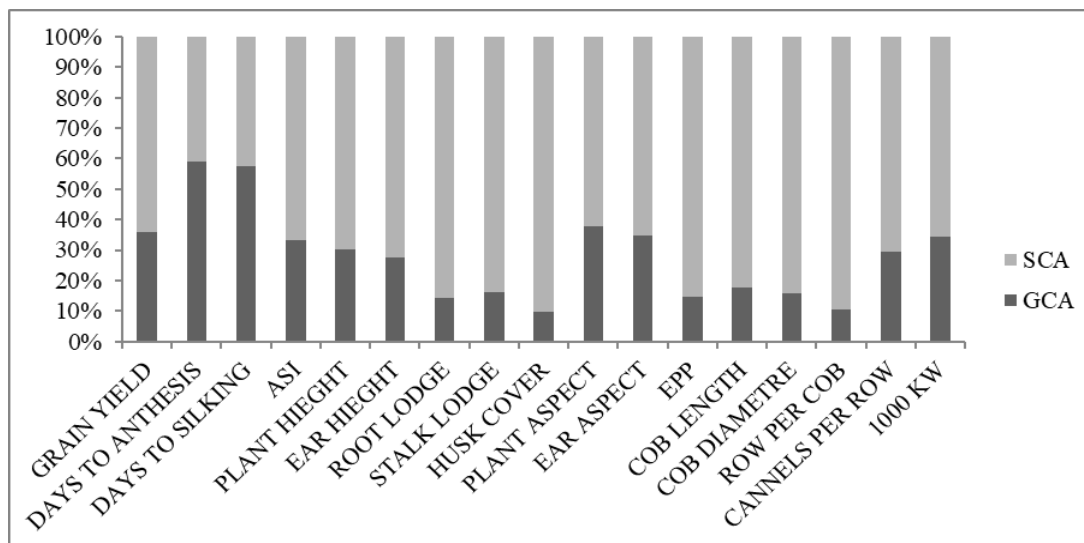


Fig. 2. Proportion of additive (lower bar) and non-additive (upper bar) genetic variance for Grain Yield and other measured traits for a 11 x 11 diallel cross evaluated under optimum growing conditions across research environments.

The presence of significant GCA and SCA mean squares for all measured traits except the GCA for anthesis-silking interval, plant height, root lodging and leaf senescence and the SCA for root lodging indicated that both additive and non-additive gene actions were important in the set of inbreds and that there was scope for improvement of these traits through selection. The significant interaction of GCA effects with environment on grain yield, days to anthesis, plant aspect, number of ears per plant, leaf death score 1, leaf death score 2 and number of kernels per row shows that there were significant variations in the combining abilities of the lines for the mentioned traits under contrasting environments. This implies that selection for improvement in these traits has to be carried out for specific environments. On the other hand, the significant SCA interaction with environment mean squares for grain yield, plant aspect, ear aspect, cob length, cob diameter and number of kernels per row across test environments indicated that the expression of these traits would vary in different test environments. The larger proportion of SCA effects for grain yield and all other measured traits (except days to anthesis and days to silking under induced drought stress and days to anthesis under optimum water conditions) than those of the GCA effects across test environments suggested that non-additive gene action played dominant role in the inheritance of the traits. This result is in agreement with the findings of de SOUZA *ET AL.* (2009) AND BADU-APRAKU *ET AL.* (2011b). However, this is contrary to the findings of BETRAN *ET AL.* (2003), MESEKA *ET AL.* (2006), DERERA *ET AL.* (2007), BADU-APRAKU *ET AL.* (2011A) MAKUMBI *ET AL.* (2011) AND OYEKUNLE AND BADU-APRAKU (2013) who reported additive gene action to be more important than the non-additive gene action in early maturing maize inbreds evaluated under induced drought stress and optimal growing conditions. The result is also in contrast with the findings of BADU-APRAKU AND OYEKUNLE (2012) who in a study involving 20 extra-early inbreds reported additive gene action to be more important than the non-additive gene action in modulating the inheritance of grain yield and other traits associated with *Striga* resistance and drought tolerance. The differences in the results of the present study and those of earlier workers may be attributed to the fact that the inbred lines used in the present study were derived from composites of a wide range of germplasm (extra-early, early normal and early QPM) and these might have had some genes with a different mode of action.

The significant positive GCA effects for grain yield observed for inbred lines TZEI 108, TZEI 24, TZEI 65 and TZEI 87 across test environments indicate that these inbreds could be useful for contributing favorable alleles for breeding for improved grain yield for drought prone environments. The significant negative GCA effects observed for TZEI 65 for the leaf death score 2 indicated that these inbreds would be useful in breeding for delayed leaf senescence. Also inbreds with significant negative GCA effects for days to anthesis, days to silking, husk cover, cob length, cob diameter and number of kernels per row and those with significant positive GCA effects for plant height, number of ears per plant, number of rows per cob and 1000-kernel weight would contribute positively to the improvement of these traits across the research environments.

The preponderance of non-additive gene action and the observed high positive mid-parent and better-parent heterosis for grain yield combined across locations under both research conditions justifies that it is highly economical to develop hybrids from these parents and also the possibility of exploiting favorable alleles in the inbred lines for the development of drought tolerant hybrids for drought prone and optimal growing environments.

CONCLUSIONS

Maize is the third most important cereal in the world after wheat and rice, its productivity has greatly been constrained by several biotic and abiotic factors, among which is drought which remain the single most important factor threatening the food security of people in the developing world. Therefore, improved tolerance to drought is an important breeding objective to stabilize its production so as to address the problems of food insecurity. Information on the gene action conditioning grain yield and other traits of maize inbred lines of different maturity groups and different kernel modification for tolerance to drought is completely lacking. Based on this, 11 inbreds of different maturity groups and different kernel modification were crossed using the diallel mating design to generate 55 single-crossed hybrids which were evaluated along with one check (SAMMAZ 42) in Samaru and Kadawa during the 2015 dry season. Irrigation was withdrawn 35 days after planting so that plants rely on available soil water for growth under the induced drought stress. Data collected were subjected to diallel analysis and combined analysis of variance (ANOVA) for inbreds and hybrids, using appropriate software.

The result shows that adequate genetic variation existed among the different maize hybrids used in the study. The presence of these genetic variability implied significant progress could be made from selection for improvements in grain yield for the development of productive maize hybrids for drought prone and optimal growing environments. GCA and SCA mean squares were significant for most measured traits under both research conditions, indicating the importance of additive and non-additive gene action for controlling the traits. Preponderance of SCA effects over GCA effects for most traits under both research conditions, indicates that non-additive gene effect play major roles in controlling the traits under both research conditions.

There was genetic variability among hybrids with yield and most other agronomic traits under dominance gene actions. Gene for drought tolerance in the drought tolerant inbreds should be introgress into tropically adapted maize germplasm for the development of drought-adaptable hybrid for the drought prone environments.

Recommendation

The drought tolerant inbred lines identified in this study, which are of different maturity group and different germplasm modification should be useful to maize breeders interested in breeding drought tolerant hybrids and synthetic cultivars for the drought prone regions of Nigeria.

The high-yielding hybrid identified in this study TZEE-W-Pop STR C₅ x TZEI 87 should be tested extensively in multi-location under both induced drought stress and optimum growing conditions and promoted for adoption and commercialization especially in drought prone region to contribute to increased food security.

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Table 2.

Mean squares from the combined ANOVA of combining ability of 11 maize inbred lines for grain yield and other agronomic traits evaluated under induced drought stress and optimum growing conditions at Samaru and Kadawa in 2016.

| Source | D F | Grain Yield (t/ha) | Days to anthesis | Days to silking | A SI | Plant Height (m) | Root Lodging(%) | Husk Cover | Plant Aspect | Ear Aspect | E P P | Cob Length (cm) | Cob Dmter (cm) | Row/Cob | Kernels/Row | 1000 -KW (g) | LDS1 | LDS2 |
|-----------------------|--------|----------------------|------------------|-----------------|---------------|------------------|-----------------|----------------|-----------------|----------------|----------------|-----------------|----------------|-----------------|------------------|-------------------|-------------------|----------------|
| Drought Stress | | | | | | | | | | | | | | | | | | |
| Env | 1 | 8318 90.29 * | 0.1 1 | 1.4 5 | 2. 36 | 617 .79 * | 50. 16 ** | 0. 16 | 4.5 7* * | 1 | 0. 08 | 3.3 | 0. 38 | 15. 54 | 5.1 6 | 224 | 0. 0 7 | 1. 14 |
| Rep (Env) | 2 | 2459 54.62 | 7.4 3* | 6.6 1 | 0. 17 | 266 .15 | 0.1 5 | 1. 3 | 0.6 8 | 0. 97 | 0. 04 | 2.1 6 | 0. 85 ** | 21. 89 * | 52. 72 | 3055 .4 | 1. 1 6 | 0. 89 |
| Genotype | 5 5 | 1412 485.1 2** | 10. 01 ** | 11. 28 ** | 3. 62 | 350 .14 ** | 0.6 2 | 1. 16 ** | 0.7 7 | 1. 26 * | 0. 09 ** | 12. 70 ** | 0. 45 * | 12. 79 ** | 161 .29 ** | 2012 .17* * | 0. 8 4 | 2. 31 * |
| GC A | 1 0 | 1501 674.8 1** | 29. 82 ** | 25. 72 ** | 2. 01 | 251 .66 | 0.4 8 | 1. 28 ** | 0.6 1* ** | 1. 34 ** | 0. 09 ** | 15. 50 ** | 0. 42 ** | 10. 03 * | 165 .72 ** | 2034 .82* * | 0. 9 7 | 2. 61 ** |
| SC A | 4 4 | 1305 128.4 4** | 5.5 2* * | 8.2 5* * | 3. 90 * | 380 .45 ** | 0.5 4 | 1. 16 ** | 0.7 9* * | 1. 20 ** | 0. 08 ** | 10. 82 ** | 0. 44 ** | 13. 49 ** | 139 .78 ** | 2028 .66* * | 0. 7 9 * | 2. 16 ** |
| G x E | 5 5 | 4070 18.59 ** | 4.0 0* * | 5.8 6 | 2. 55 | 37. 09 | 0.6 7 | 0. 29 | 0.6 5* * | 0. 68 ** | 0. 05 | 5.9 6* ** | 0. 24 ** | 3.5 1 | 60. 92* * | 194. 08 | 0. 8 1 * | 1. 47 * |
| GC A*E NV | 1 0 | 4123 06.01 * | 10. 61 ** | 7.6 2* | 3. 17 | 30. 87 | 0.4 4 | 0. 31 | 0.6 7* * | 0. 51 | 0. 08 * | 5.6 4 | 0. 21 | 2.0 8 | 65. 24* * | 324. 66 | 1. 1 8 * | 2. 34 ** |

| | | | | | | | | | | | | | | | | | | |
|-----------------------------------|-------------|----------------------|-----------------|-----------------|----------------|------------------|-----------------|----------------|-----------------|----------------|----------------|-----------------|----------------|----------------|------------------|--------------------|--------------|----------|
| SC A*E NV | 4 4 | 4149 08.72 ** | 2.3 8 | 5.5 1 | 2. 44 | 39. 33 | 0.7 2 | 0. 29 | 0.6 3* * | 0. 73 ** | 0. 04 | 6.1 6* | 0. 25 ** | 3.9 1 | 61. 31* * | 166. 94 | 0. 7 4 | 1. 3 |
| Error | 1 1 0 | 1718 25.2 | 1.8 9 | 4.1 8 | 2. 56 | 140 .68 | 0.5 5 | 0. 45 | 0.2 7 | 0. 34 | 0. 04 | 3.5 6 | 0. 13 | 4.7 9 | 32. 03 | 1031 .97 | 0. 5 1 | 0. 89 |
| Optimum Growing Conditions | | | | | | | | | | | | | | | | | | |
| Env | 1 | 6409 902.9 2** | 15. 02 ** | 6.4 46 43 | 1. 78 6 | 110 .04 | 36. 97 ** | 3. 02 * | 27. 16 ** | 4. 72 ** | 0. 02 6 | 93. 22 ** | 0. 25 8 | 4.0 18 | 265 .79 ** | 1483 6.29 ** | | |
| Rep (Env) | 2 | 1525 7.65 | 1.3 66 07 | 2.7 23 21 | 0. 23 2 | 124 .62 9 | 0.3 79 5 | 0. 00 9 | 0.4 37 5 | 0. 37 2 | 0. 00 6 | 1.0 82 01 | 0. 01 2 | 2.8 04 | 56. 017 9 | 4399 .29* | | |
| Entry | 5 5 | 1386 672.0 2** | 11. 23 ** | 18. 68 ** | 2. 39 ** | 579 .47 ** | 0.6 9* ** | 0. 64 ** | 0.2 04 22 | 0. 59 5 | 0. 01 9 | 3.1 2* ** | 0. 17 ** | 5.8 0* * | 25. 594 8 | 3464 .38* * | | |
| GC A | 1 0 | 2617 069.2 8** | 36. 04 ** | 56. 16 ** | 3. 77 ** | 924 .97 ** | 0.5 40 4 | 0. 34 3 | 0.4 3* 3 | 1. 12 ** | 0. 01 5 | 3.0 41 62 | 0. 14 2 | 3.1 96 | 40. 07* * | 6530 .72* * | | |
| SC A | 4 4 | 1066 598.6 4** | 5.6 9* * | 9.5 0* * | 1. 73 ** | 488 .44 ** | 0.7 4* * | 0. 72 * | 0.1 58 33 | 0. 47 5 | 0. 02 | 3.2 04 75 | 0. 17 ** | 6.1 6* * | 21. 646 5 | 2843 .70* * | | |
| G x E | 5 5 | 2461 98.7 | 2.6 4* | 3.8 5* | 0. 74 | 15. 867 5 | 0.3 86 9 | 0. 33 6 | 0.2 26 62 | 0. 45 9 | 0. 01 8 | 1.2 76 04 | 0. 02 4 | 0.3 81 | 20. 503 9 | 219. 3175 | | |
| GC A x ENV | 1 0 | 2629 84.13 * | 8.7 3* * | 10. 97 ** | 0. 63 2 | 9.8 88 | 0.3 21 2 | 0. 23 7 | 0.2 06 19 | 0. 61 9 | 0. 01 9* | 1.5 76 | 0. 03 5 | 0.4 53 | 20. 767 2 | 535. 02* | | |
| SC A x ENV | 4 4 | 2416 39.46 | 1.3 11 1 | 2.3 05 1 | 0. 77 1 | 16. 986 | 0.4 09 9 | 0. 36 5 | 0.2 10 73 | 0. 42 1 | 0. 01 9 | 1.2 36 86 | 0. 02 2 | 0.3 62 | 18. 512 6 | 152. 48 | | |
| Error | 1 1 0 | 5772 48.1 | 1.8 20 62 | 2.5 23 21 | 0. 72 3 | 104 .10 2 | 0.4 52 2 | 0. 47 3 | 0.1 96 59 | 0. 37 8 | 0. 01 5 | 2.4 71 74 | 0. 08 3 | 2.6 22 | 18. 554 2 | 1272 .790 2 | | |

Table 3

GCA effects of maize inbreds for grain yield and other agronomic traits evaluated under induced drought stress and optimum water condition at Samaru and Kadawa in 2016.

| Parameter | Grain Yield (t/ha) | | Days to anthesis | | Days to silking | | ASI | | Husk Cover | | Ear Aspect | | EPP | | L D S | Cob Length (cm) | | Kernels /Row | | 1000 KW (g) | | | |
|-----------------------------|--------------------|--------|------------------|--------|-----------------|--------|-------|--------|------------|-------|------------|--------|--------|--------|--------|-----------------|--------|--------------|---------|-------------|-------|-----|-----|
| | DS | W W | D S | W W | D S | W W | D S | W W | D S | W W | D S | W W | D S | W W | | D S | W W | D S | W W | D S | W W | D S | W W |
| | | | | | | | | | | | | | | | | | | | | | | | |
| TZ EI 86 | 18.70* | 15.25 | 0.169 | 0.311 | 0.391 | 0.169 | 0.222 | 0.141 | 0.005 | 0.016 | 0.087 | 0.041 | 0.044 | 0.111 | 0.161 | 0.384 | 1.967 | 1.081 | 7.997 | 4.581 | | | |
| TZ EE I 21 | 28.62** | 27.9* | 1.136* | 1.449* | 1.831* | 2.114* | 0.300 | 0.664* | 0.024 | 0.005 | 0.347* | 0.053 | 0.098* | 0.048* | 0.167 | 1.216* | 0.106 | 2.939* | 0.058 | 1.891 | 6.114 | | |
| TZ EE I 29 | 62.073 | 18.99 | 0.725* | 0.227 | 0.475 | 0.114 | 0.225 | 0.114 | 0.144 | 0.058 | 0.014 | 0.044 | 0.026 | 0.194 | 0.545 | 0.165 | 0.838 | 0.169 | 1.391 | 8.475 | | | |
| TZ EI 108 | 168.191* | 16.52 | 1.836* | 2.217* | 1.614* | 2.803* | 0.222 | 0.586* | 0.144 | 0.016 | 0.423* | 0.066* | 0.033 | 0.389* | 0.695* | 0.26 | 3.227* | 0.997 | 2.503 | 13.86* | | | |
| TZ EQ I 24 | 199.021* | 14.93 | 0.884* | 0.003 | 0.997* | 0.116 | 0.114 | 0.061 | 0.016 | 0.022 | 0.052* | 0.058 | 0.005 | 0.278 | 0.253 | 0.238 | 2.088 | 0.164 | 3.28 | 4.497 | | | |
| TZ EE I 16 | 86.624 | 23.7* | 1.164* | 1.172* | 1.109* | 1.086* | 0.056 | 0.086 | 0.144 | 0.011 | 0.097 | 0.109 | 0.005 | 0.138 | 0.197 | 0.106 | 1.273 | 0.003 | 8.442 | 29.72* | | | |
| TZ EI 59 | 29.2522** | 53.88* | 0.447 | 0.106 | 0.078 | 0.109 | 0.333 | 0.003 | 0.356* | 0.012 | 0.208 | 0.003 | 0.054 | 0.222 | 0.772* | 0.024 | 2.245* | 0.692 | 4.247 | 1.97 | | | |
| TZ EE - W-Pop ST RC5 | 66.188 | 18.72 | 0.497 | 0.033 | 0.024 | 0.227 | 0.255 | 0.083 | 0.128 | 0.012 | 0.058 | 0.037 | 0.018 | 0.278 | 0.558 | 0.102 | 1.884 | 0.225 | 10.914* | 3.947 | | | |
| TZ EI 65 | 29.2055** | 93.04 | 0.225 | 0.662* | 0.114 | 0.525 | 0.111 | 0.136 | 0.245* | 0.019 | 0.236* | 0.011 | 0.029 | 5.000 | 0.444* | 0.951* | 2.561* | 0.914 | 11.419* | 8.419 | | | |

| | | | | | | | | | | | | | | | | | | | | | |
|--|-----------------------|---------------------|--------------------------|--------------------|--------------------------|---------------------|-------------------------|---------------------|---------------|--------------------|---------------------|---------------------|---------------|--------------------|---------------|---------------|---------------|---------------------|--------------------|----------------------|---------------------|
| TZ EQ I4 | - 31. 95 8 | - 9. 67 3 | 0. 28 | - 0. 25 5 | 0. 05 8 | - 0. 44 7 | - 0. 22 2 | - 0. 19 2 | 0. 14 4 | 0. 08 6 | - 0. 08 3 | - 0. 23 9* | 0. 02 6 | - 0. 01 8 | 0. 19 4 | 0. 26 4 | 0. 22 7 | 0. 72 7 | 0. 75 3 | 11 .8 08 ** | 15 .7 5* * |
| TZ EI 87 | 22 0.4 88 ** | 39 3. 5* * | - 1. 05 3* * | - 0. 42 2 | - 1. 24 7* * | - 0. 72 5* | - 0. 11 9 4 | - 0. 30 3* | 0. 11 6 | - 0. 05 3 | - 0. 25 3* | 0. 03 4 | 0. 01 2 | 0. 19 4 | 0. 19 5 | 0. 43 3 | 0. 86 6 | 2. 64 1* * | - 0. 69 2 | - 15 .8 ** | |
| Rel ativ e Im por tan ce of GC A ove r SC A | 0.1 6 | 0. 42 | 0. 89 | 1 | 0. 54 | 0. 94 | 0. 03 | 0. 35 | 0. 16 | 0. 03 | 0. 16 | 0. 46 | 0. 17 | 0. 08 | 0. 18 | 0. 21 | 0. 13 | 0. 17 | 0. 35 | 0. 14 | 0. 37 |

*, **, significant at 0.05 and 0.01 levels of probability

ASI: anthesis silking interval; EPP: ears per plant; LDS: leaf death score ; 1000 KG: 1000 kernels weight.