Genetics of Tolerance to Drought and Low-soil Nitrogen in IITA and CIMMYT Early Yellow Maize Inbreds

B. Badu-Apraku[1*], M. Gedil[1], M.A.B. Fakorede[2], T. Y. Fasanmade[1] B. Annor[1], A.O. Talabi[1], M. Oyekunle[3], R.O. Akinwale[2] , I. A. Akaogu and B. Oluwaranti[2]

1. International Institute of Tropical Agriculture (UK) Limited, Carolyn House, 26 Dingwall Road, Croydon, CR9 3EE, UK
2. Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ile. Nigeria
3. IAR, Amadu Bello University, Samaru, Nigeria. *Email:b.badu-apraku@cgiar.org

Introduction

Promotion and wide adoption of early-maturing maize cultivars developed by IITA and partners have significantly contributed to the rapid spread of maize into the savannas of West Africa (WA), making it the second most important cereal crop after rice. However, production in the savanna agro-ecology is severely constrained by low levels of soil nitrogen (Low N) and recurrent drought. Annual maize yield losses due to drought may approach millions of tons, equivalent to 17% of a normal annual production in the developing world (Edmeades et al. 1995). Yield losses from low N alone varies from 10 to 50% (Wolfe *et al*., 1988) in WA. In the farmer's field, drought, *Striga* and low soil nutrient deficiency do occur simultaneously, and when this happens the combined effect can be devastating (Badu-Apraku *et al*., 2013). Therefore, maize varieties targeted to the *Striga*-prone areas of WA must also be resistant or at least tolerant to drought and low N. Presently, only a few early-maturing maize hybrids have been commercialized in WA. Hybrid combinations between the IITA inbreds and selected elite CIMMYT inbreds could produce outstanding hybrids. The objectives of this study were to (i) examine the combining ability of selected IITA and CIMMYT inbreds for grain yield and other traits, (ii) classify the inbreds into heterotic groups (iii) compare the effectiveness of the heterotic grouping methods, general combining ability effects of grain yield and other traits (HGCAMT), heterotic group's specific and general combining ability (HSGCA), and genetic distance (GD) derived from the SNP marker analysis in classifying selected early yellow inbreds into contrasting heterotic groups and (iv) examine the yield performance and stability of the hybrids across drought, low N and optimum environments.

Materials and Methods

One hundred and thirty-six single-cross hybrids derived from a diallel of eleven IITA and six CIMMYT early yellow endosperm inbred lines were evaluated in three field studies. In the first study, The 136 single crosses plus four hybrid checks were evaluated under induced drought stress and well-watered conditions at Ikenne, Nigeria during the dry season of 2010/2011 and 2011/2012 and at Bagauda (drought-prone environment) during the growing seasons of 2011 and 2012. The induced drought stress was achieved by withdrawing irrigation water 28 d after planting until maturity so that the maize plants relied on stored water in the soil. In the second set of trials, the 136 F_1 single crosses plus the four hybrid checks were evaluated in low N (30 kg ha^{-1}) environments at Mokwa and Ile-Ife, Nigeria in 2011 and 2012. The third set of trials involved the evaluation of the entries under optimum growing environments (90 kg N ha^{-1}) at Mokwa and Ikenne, Nigeria in 2011 and 2012. The experimental design at all sites was a 10 x 14 simple lattice design with two replications. Standard agronomic practices were adopted at all testing sites. Data were recorded on days to 50% silking (DS) and anthesis (DA), anthesis-silking interval (ASI), plant (PLHT) and ear heights (EHT), stay green characteristic, ear aspect (EASP), ears per plant (EPP), and grain yield. Separate analyses of variance (ANOVA) were performed on data collected across years and locations with PROC GLM in SAS (SAS, 2002). General combining ability (GCA) effects of the parents and specific combining ability (SCA) effects of the crosses were estimated following Griffing's method 4 model 1 (fixed model) (Griffing, 1956). To assign inbred lines into heterotic groups, HSGCA method proposed by Fan et al. (2009) and HGCAMT method proposed by Badu-Apraku et al. (2013) and the SNP-based GD marker methods were used. GGE biplot analysis of GCA effects of the inbreds was used to assess the performance and yield stability of the single-cross hybrids (Yan, 2000).

Results and Discussion

General combining ability effects for all traits were greater than SCA effects under drought, low N, optimum and across environments suggesting that additive gene action was more important than the non-additive in the set of inbred lines. The inbred lines were classified into four heterotic groups each across environments based on the HSGCA, and the SNP-based genetic distance methods while the HGCAMT method placed them into three groups (Figs. 1, 2 and 3).

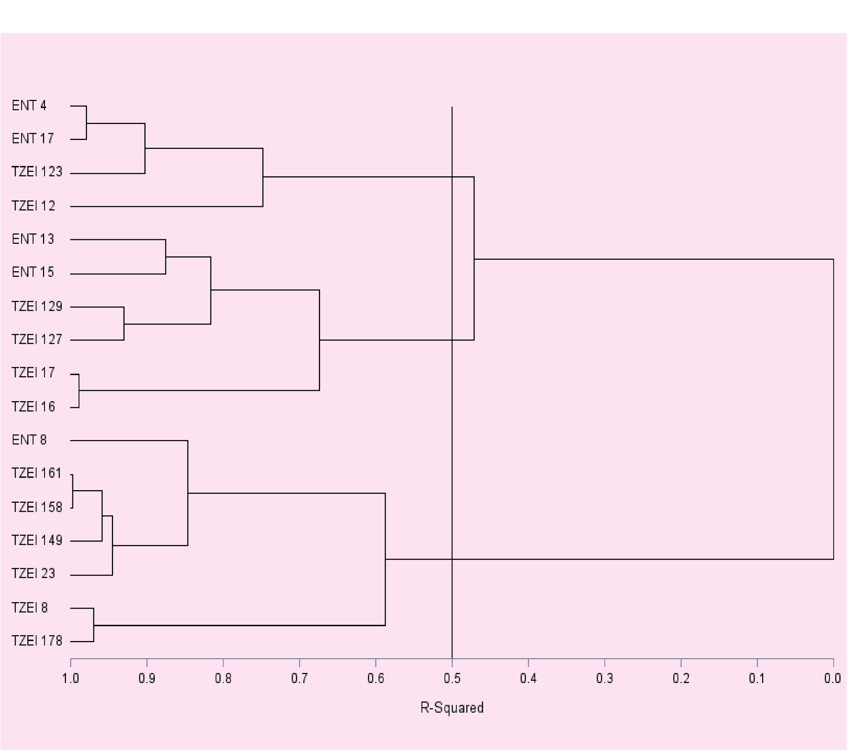


Fig. 1. Dendrogram of 17 early maturing yellow maize inbred lines constructed from GCA effects of grain yield and other traits (HGCAMT) using Ward's minimum variance cluster analysis across drought, low-N and optimum conditions.

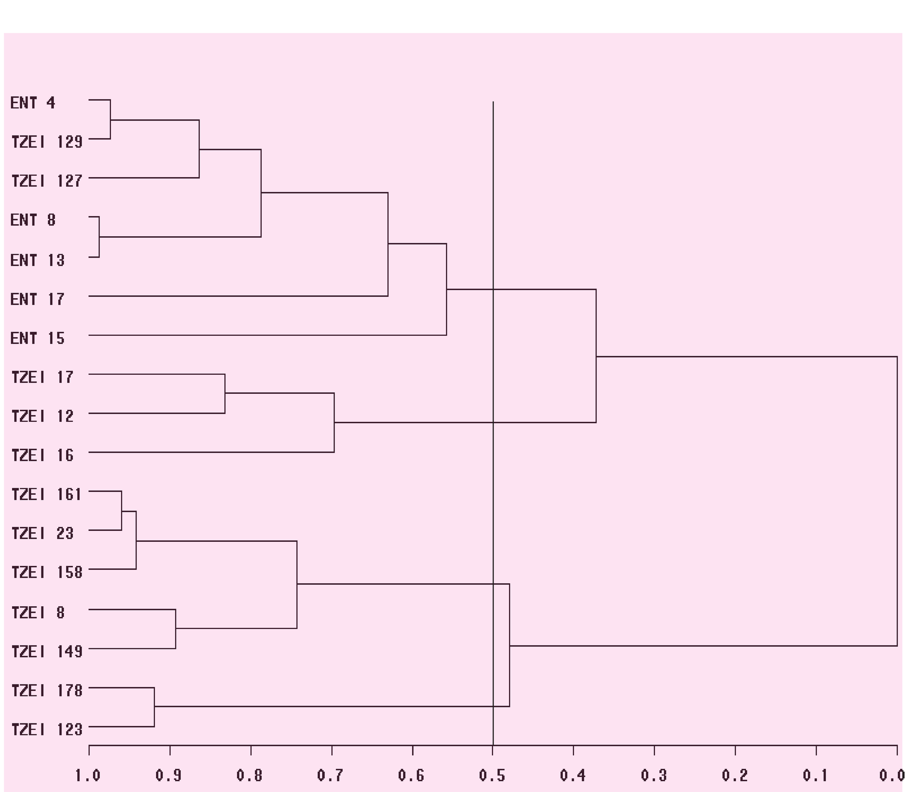


Fig. 2. Dendrogram of 17 early maturing yellow maize inbred lines based on HSGCA values using Ward's minimum variance cluster analysis across drought, low-N and optimum conditions.

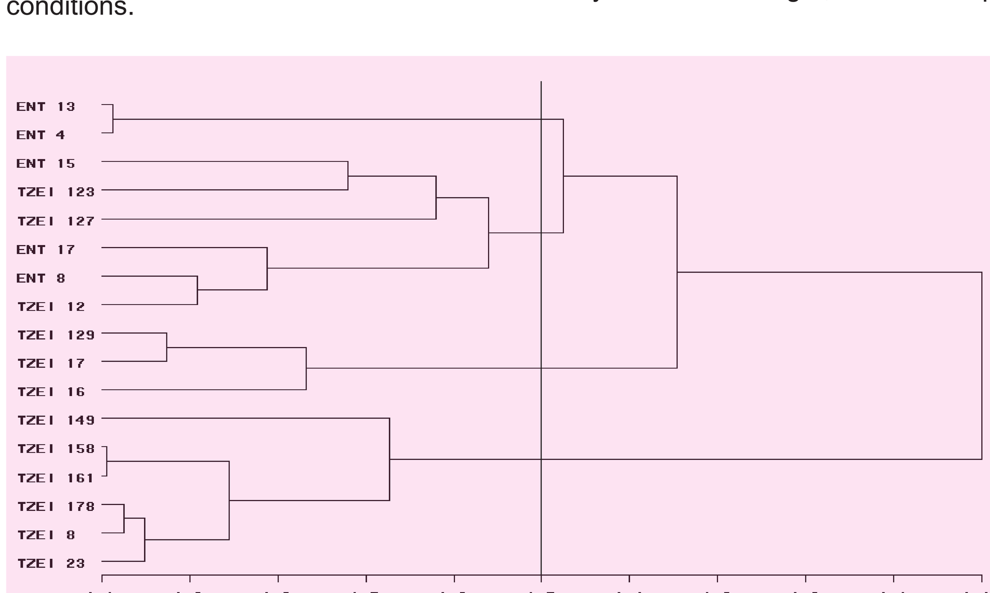
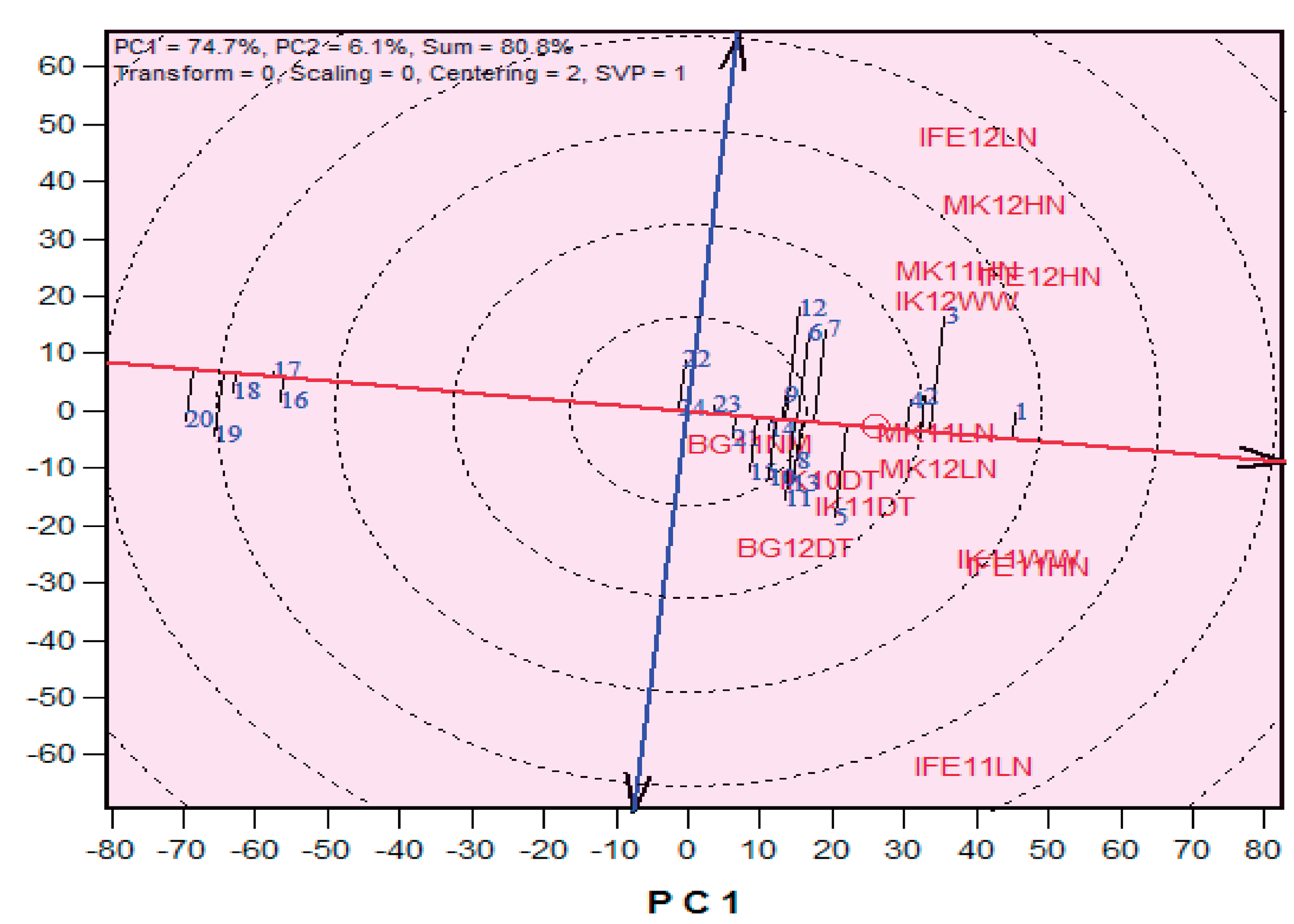


Fig. 3. Consensus UPGMA dendrogram constructed using Ward's minimum variance cluster analysis of Modified Roger's Distance coefficients for 17 early-maturing yellow maize inbred lines.

There was close correspondence between the classifications based on the three grouping methods, indicating that they were all effective in classifying the inbreds into heterotic groups. However, the HGCAMT was the most efficient method followed by the HSGCA and then the SNP-based genetic distance methods across research environments because it was the only method that had significant linear contrasts for all possible group comparisons (Table 1). HGCAMT method was used to identify CIMMYT inbreds ENT 17, ENT 15 and ENT 8 as the best testers for heterotic groups 1, 2 and 3, respectively across research environments. ENT 13 had significant and high positive GCA effects for grain yield, and EPP under all environments except EPP under drought, suggesting that the inbred could be invaluable source of favorable alleles for the traits for improving IITA germplasm. Similarly, the IITA inbreds TZEI 17 and TZEI 16 had positive and significant GCA effects for grain yield under low N, optimum and across research environments. Furthermore, TZEI 16 had significant and positive GCA effects for ASI under drought, low N, and optimum environments and negative and significant GCA effects for stay green characteristic under drought and could be used to improve the CIMMYT germplasm for drought tolerance and the stay green characteristic. Hybrids TZEI 17 x ENT 15, and TZEI 149 x ENT 15 were the highest yielding and most stable across test environments (Figure 4) and should be promoted for commercialization in WA.

Table 1. Sum of squares from the linear contrasts of heterotic groups based on HSGCA, HGCAMT and SNP-based genetic distance of grain yield under drought, low-N, optimum and across research conditions.

Contrast	df	Drought			Low N			Optimum			Across		
		HSGCA	HGCAMT	GD	HSGCA	HGCAMT	GD	HSGCA	HGCAMT	GD	HSGCA	HGCAMT	GD
Group 1 vs Group 2	1	512678.9	7675360.2**	343388.3**	29430.6	1632960.5	173322.7	4724806.6*	8920655.3**	97544.4	27836135.5**	28821725.60**	61619.8
Group 1 vs Group 3	1	2294263.3**	434972	7180897.0**	41353441.7*	57530554.2**	79672651.8**	49169274.1**	155051116.9**	145357600.70**	128704165.3**	66132581.40**	185390525.4**
Group 2 vs Group 3	1	232104.5	740569.1	3894212.7**	27367242.4**	41456696.3**	33785882.6**	89244576.2**	128742322.9**	56305811.00**	47137762.5**	136104009.40*	69267555.9**
Group 1 vs Group 4	1		5638489.6**		3944499.1*						11722929.8**		49.9
Group 2 vs Group 4	1		5638489.6**		3944499.1*						11722929.8**		49.9
Group 3 vs Group 4	1		4123804.6**		18866751.98**						4146.6		30861468.2**



Entry	Pedigree
1	ENT 15 X TZEI 17
2	ENT 15 X ENT 17
3	ENT 15 X TZEI 12
4	ENT 15 X TZEI 149
5	TZEI 17 X TZEI 129
6	ENT 8 X TZEI 16
7	ENT 4 X TZEI 17
8	TZEI 17 X TZEI 158
9	TZEI 149 X TZEI 12
10	TZEI 161 X TZEI 16
11	ENT 4 X TZEI 16
12	TZEI 16 X TZEI 127
13	ENT 13 X TZEI 123
14	TZEI 129 X TZEI 16
15	ENT 13 X TZEI 158
16	TZEI 23 X TZEI 158
17	TZEI 161 X TZEI 8
18	TZEI 8 X TZEI 178
19	TZEI 23 X TZEI 8
20	TZEI 161 X TZEI 158
21	Check 1 - TZEI 24 X TZEI 17
22	Check 2 - TZEI 8 X TZEI 16
23	Check 3 - TZEI 9 X TZEI 16
24	Check 4 - TZEI 9 X TZEI 11

Fig. 4. Mean performance and stability of 20 early maturing yellow maize hybrids and four checks in terms of grain yield evaluated across 14 environments between 2010 and 2012 in Nigeria.

Conclusions

The parental lines, ENT13, TZEI 17 and TZEI 16 could be used to broaden and diversify the genetic base of IITA and CIMMYT germplasm and develop suitable maize varieties and hybrids adapted to sub-Saharan Africa. The HGCAMT is an efficient heterotic grouping method and should be used for grouping IITA inbreds that are yet to be field-tested.

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