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Genetic gains in grain yield of extra-early maturing maize cultivars of three breeding eras under multiple stress environments

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Introduction

Maize is an important staple food, animal feed, and industrial crop in sub-Saharan Africa (SSA). The savannas of West and Central Africa (WCA) offer ideal environments for maize production because they are characterized by high incoming solar radiation, low incidence of pests and diseases, and low night temperatures. However, recurrent drought, low soil nitrogen (low-N), and *Striga hermonthica* (Del.) Benth. act and interact to limit maize production and productivity in the savannas. Drought can reduce grain yield of maize by as much as 90% when it occurs at the most sensitive stage of the crop growth, i.e. a few days before anthesis to the beginning of grain filling period (NeSmith and Ritchie 1992). Nitrogen is a major requirement for high levels of maize productivity but it is the most limiting nutrient in tropical soils. A fertilizer rate of 90–120 kg N/ha is recommended for increased maize grain yield in SSA. However, fertilizer application rates are far below the recommended doses in the sub-region due to the unavailability or the exorbitant prices of inorganic fertilizer for resource-poor farmers. The estimated annual loss of maize yield due to low-N stress varies from 10 to 50% per year in SSA (Wolfe et al. 1988). Breeding for tolerance to low-N offers the most economical and sustainable approach for increased maize yield in WCA. *Striga* infestation can cause total crop failure (Badu-Apraku et al. 2010) and in the recent past has forced farmers in the sub-region to abandon their farmlands. Under field conditions, drought, *Striga*, and soil nutrient deficiency occur simultaneously and the combined effects can be disastrous. Studies by Badu-Apraku et al. (2004) have shown a grain yield loss of 53% under drought stress and 42% under *Striga* infestation. Consequently, breeding for extra-early maturing cultivars with enhanced tolerance to drought and resistance to *Striga* is crucial for improved productivity and stable maize production in WCA. The International Institute of Tropical Agriculture has developed extra-early maturing maize cultivars during three breeding eras (Era 1,1995–2000; Era 2, 2001–2006; and Era 3, 2007–2012). The availability of these extra-early maize cultivars has resulted in the expansion of maize production into new frontiers replacing the traditional cereal crops such as sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) in the savannas of WCA. However, information is completely lacking on the genetic gains in grain yield and other agronomic traits during the three breeding eras. The identification of traits of potential value and modifications in breeding methodologies and strategies are crucial for increased progress in future breeding of extra-early maize cultivars. The objectives of this study were to determine the gains in grain yield under multiple stresses and non-stress environments, identify traits associated with yield improvement during the three breeding eras under multiple stress and non-stress environments, and identify high-yielding and stable cultivars across environments for commercialization in the sub-region.

Materials and methods

Fifty-six extra-early maturing maize cultivars comprising 12 from Era 1, 19 from Era 2, and 25 from Era 3 were evaluated under 23 multiple stress (drought, *Striga*, and low-N) and 29 nonstress environments in WA (Nigeria, Benin, and Ghana) in 2013 and 2014. The trials were laid out in 8 × 7 lattice design with three replications. Each experimental plot consisted of two rows, 5 m long, spaced 0.75 m apart with 0.40 m between plants within the row in all environments. Three seeds were planted per hill and seedlings thinned to two per stand about 2 weeks after emergence, resulting in a final plant population density of 66 667 plants/ha. Data were collected on grain yield and other agronomic traits in the stress and non-stressed environments. Analyses of variance, combined across multiple stress and non-stress environments were performed on plot means of each trait with PROC GLM in SAS 9.3 (SAS Institute 2011). Regression of each variable on year of cultivar development was done to estimate gain/year. The regression analysis and the graphical display of the regression lines as well as the distinction among the different eras were performed using Excel software 2007. The GGE biplot software was used to identify the highest yielding and stable cultivars across test environments.

Results and Discussion

Under multiple stress environments, grain yield ranged from 1752 kg/ha for cultivars bred during Era 1 to 2066 kg/ha for those developed during Era 3 with a corresponding genetic gain of 1.42% per year. Under non-stress environments, grain yield ranged from 3217 kg/ha for cultivars bred during Era 1 to 3673 kg/ha for those developed during Era 3 with an annual genetic gain of 1.07%. The average rate of increase in grain yield was 24 kg/ha per year under multiple stress and 34 kg/ha per year under non-stress environments (Table 1).

Genetic gains in grain yield from first to third era cultivars under multiple stresses was associated with improved ear aspect, increased days to silking, increased anthesis-silking interval, and decreased root and stalk lodging whereas no significant gain was observed for grain yield under non-stress environments. However, good progress was made for improved husk cover, increased ears per plant, and reduced anthesis-silking interval from first to third era cultivars (Table 1).

Table 1. Relative genetic gain and regression coefficients (b) of grain yield and other agronomic traits of extra-early maize cultivars of three breeding eras under multiple stress and non-stress environments in Nigeria, Benin and Ghana in 2013 and 2014.

Trait	Relative gain (% per year)	R^2	a	b
Multiple stress environments				
Grain yield, kg/ha	1.42	0.3473	1690	24**
Days to anthesis	0.18	0.0817	51.791	0.091
Days to silk	0.15	0.0588	54.533	0.0796**
Anthesis-silking interval	–0.43	0.0711	2.7474	–0.0117**
Plant height (cm)	0.39	0.2908	144.93	0.5699
Ear height (cm)	0.37	0.1049	66.693	0.2487
Root lodging (%)	–1.00	0.0759	9.3865	–0.0941**
Stalk lodging (%)	–1.09	0.0998	11.968	–0.1299**
Husk cover	–0.47	0.224	2.6201	–0.0122
Plant aspect	–0.78	0.2734	3.2778	–0.0255
Ear aspect	–0.97	0.3311	3.8966	–0.0377**
Ears rot	–1.16	0.0807	2.4464	–0.0284
Ears/plant	0.48	0.2404	0.7754	0.0037
Non-stress environments				
Grain yield, kg/ha	1.07	0.3055	3177	34
Days to anthesis	0.20	0.1046	51.361	0.1006
Days to silk	0.17	0.0771	53.249	0.0897
Anthesis-silking interval	–0.60	0.14	1.9255	–0.0116**
Plant height (cm)	0.43	0.2612	156.82	0.6797
Ear height (cm)	0.67	0.1923	71.852	0.478
Root lodging (%)	–1.37	0.0942	6.0926	–0.0832
Stalk lodging (%)	–1.09	0.0744	10.131	–0.1106
Husk cover	–0.59	0.2014	2.186	–0.0129**
Plant aspect	–0.93	0.2107	2.7405	–0.0255
Ear aspect	–1.12	0.3418	3.1934	–0.0359
Ears rot	–1.23	0.134	1.8914	–0.0232
Ears/plant	0.17	0.2523	0.9205	0.0016**

The regression analysis of the mean grain yield of the extra-early maize cultivars under multiple stress and non-stress environments showed clear separation of the maize cultivars into three distinct breeding eras (Figs. 1a and 1b), with the exception of a few cultivars from the second generation of extra-early cultivars that produced yields comparable to those of the third generation of extra-early cultivars, while a cultivar of the second generation produced a yield that was lower than those of the entries from the first generation. The third generation extra-early cultivars displayed outstanding performance under multiple stress and non-stress environments. Grain yield of the extra-early cultivars under multiple stress environments could predict the grain yield of the extra-early cultivars under optimal environments with a corresponding R^2 value of 86% (Fig. 2).

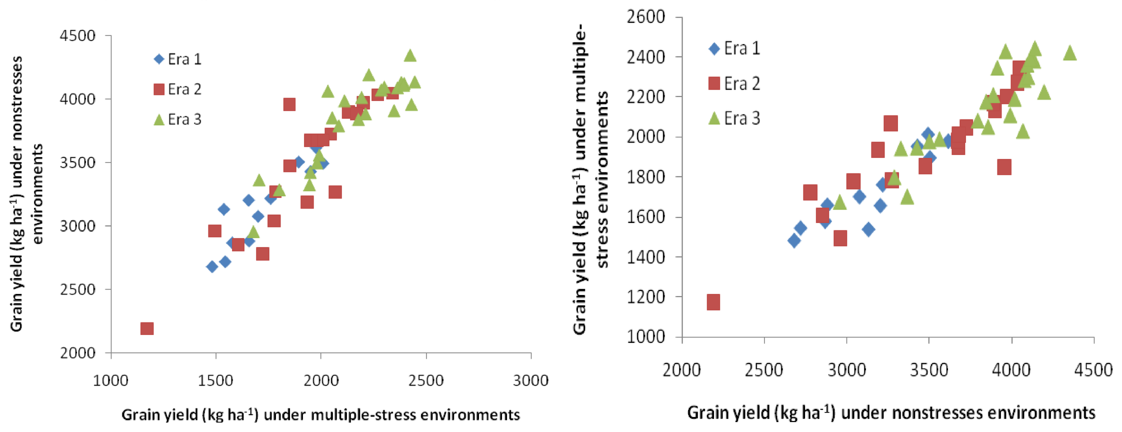


Figure 1a and1 b. Relationship between grain-yield of extra-early maturing maize cultivars developed during three breeding eras and evaluated under multiple stress and non-stress environments.

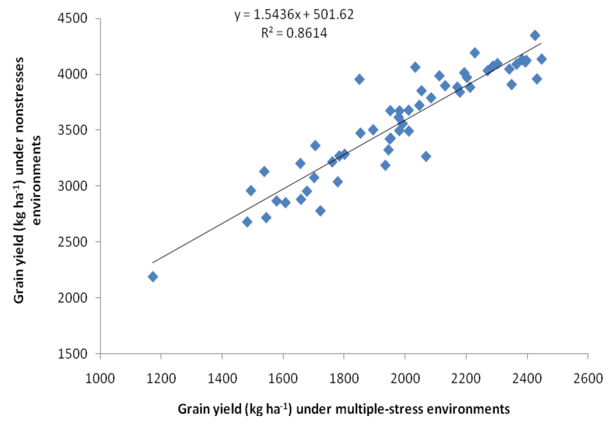
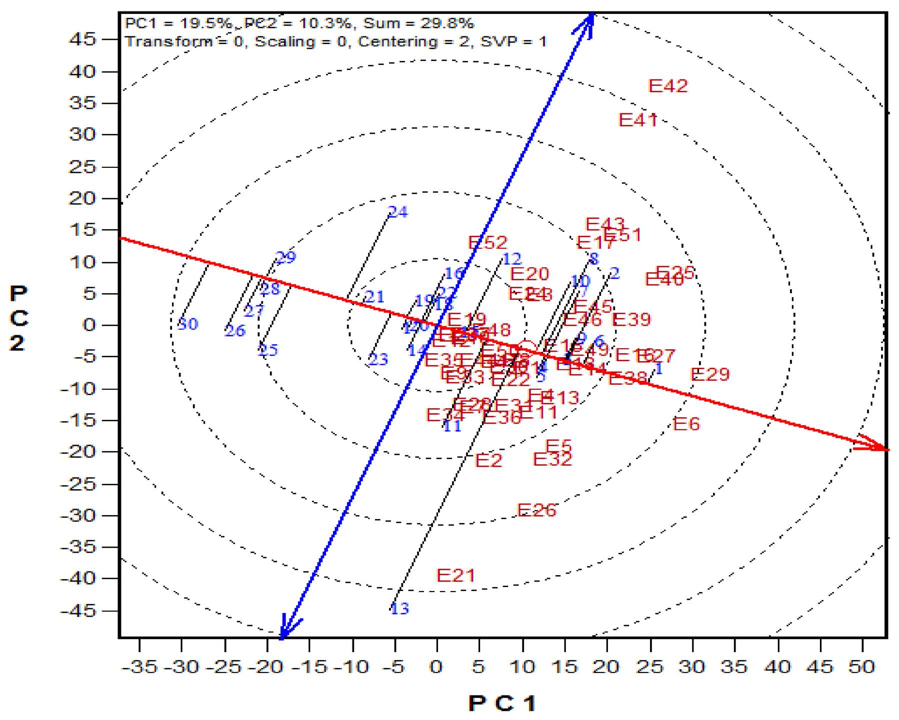


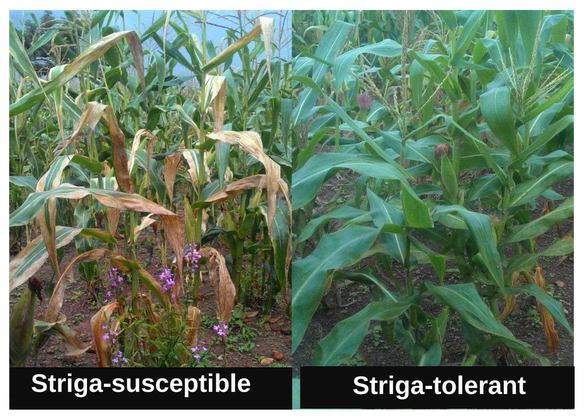
Figure 2. Regression of grain yield of extra-early cultivars of the three breeding eras under multiple stress and non-stress environments.

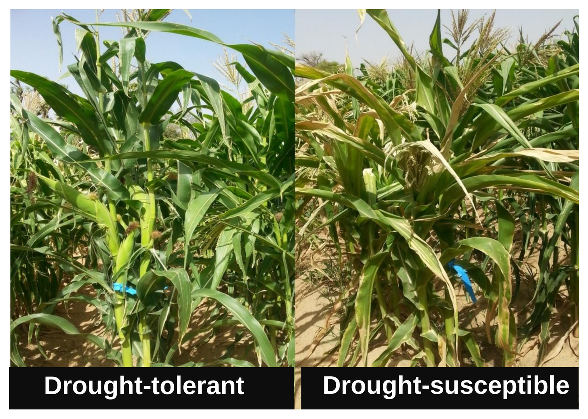
The cultivars TZEE-W STR 105 BC_1 and 2004 TZEE-W Pop STR C_4 of Era 2 and TZEE-W Pop STR C_5, TZEE-W STR 105, TZEE-W STR 108, and TZEE-W STR 104 from the latest era of improvement (Era 3) were identified as outstanding in grain yield and stability across test environments and should be commercialized to contribute to food security in WCA (Fig. 3).



Entry	Pedigree
1	TZEE-W STR 108
2	2012 TZEE-W DT STR C5
3	TZEE-W POP STR C5
4	TZEE-W STR 105 BC1
5	TZEE-W STR 105
6	TZEE-W STR 104
7	2009 TZEE-OR2 STR
8	2008 TZEE-W STR
9	2004 TZEE-W POP STR C4
10	TZEE-W STR 104 BC1
11	TZEE-W DT C0 STR C5
12	TZEE-W POP STR QPM C0
13	2009 TZEE-OR1 STR
14	TZEE-Y STR 106
15	TZEE-W POP STR C3
16	2009 TZEE-OR2 STR QPM
17	2009 TZEE-OR1 STR QPM
18	TZEE-W STR 107 BC1
19	TZEE-W POP STR C4
20	TZEE-W POP STR BC2 C0
21	2009 TZEE-W STR
22	TZEE-W STR 108 BC1
23	TZEE-W STR 107
24	TZEE-W POP X LD S6 F2 (SET A2)
25	2004 TZEE-Y POP STR C4
26	TZEE-Y Pop STR QPM C0
27	TZEE-Y POP STR C4
28	FERKE TZEE-W STR
29	98 SYN EE-W
30	TZEE-Y POP STR C5

Figure 3. The "mean vs. stability" view of genotype × environment interaction of top 30 extra-early maturing maize cultivars of three breeding eras in 52 environments across multiple stress and non-stress environmentss, in 2013 and 2014 in WA. E1 = Ikenne drought, 2013; E2 = Bagauda drought, 2013; E3 = Ile-Ife low-N, 2013; E4 = Mokwa low-N, 2013; E5 = Abuja STR, 2013; E6 = Mokwa STR, 2013; E7 = Femusua, 2013; E8 = Ejura, 2013; E9 = Manga, 2013; E10 = Dusu, 2013; E11 = Angaradebou, 2013; E12 = Ina, 2013; E13 = Nyapala, 2013; E14 = Ife Low-N, 2014; E15 = Mokwa Low-N, 2014; E16 = Abuja STR, 2014; E17 = Mokwa STR, 2014; E18 = Angaradebou, 2014; E19 = Ina, 2014; E20 = Nyankpala, 2014; E21 = Ikenne drought, 2014; E22 = Kpeve, 2014; E23 = Pokuase, 2014; E24 = Ikenne OPT, 2013; E25 = Ife HN, 2013; E26 = Zaria OPT, 2013; E27 = Mokwa HN, 2013; E28 = Abuja OPT, 2013; E29 = Mokwa OPT, 2013; E30 = Ina OPT, 2013; E31 = Angaradebou OPT, 2013; E32 = Manga OPT, 2013; E33 = Kpeve OPT, 2013; E34 = Yendi OPT, 2013; E35 = Nyankpala OPT, 2013; E36 = Angaradebou UNSTR, 2013; E37 = Ina UNSTR, 2013; E38 = Ikenne OPT, 2014; E39 = Ile-Ife HN, 2014; E40 = Mokwa HN, 2014; E41 = Zaria OPT, 2014; E42 = Bagauda OPT, 2014; E43 = Abuja UNSTR, 2014; E44 = Manga OPT, 2014; E45 = Angaradebou OPT, 2014; E46 = Angaradebou UNSTR, 2014; E47 = Ina UNSTR, 2014; E48 = Nyapala UNSTR, 2014; E49 = Ina OPT, 2014; E50 = Yendi OPT, 2014; E51 = Zaria OPT, 2014; E52 = Femsua OPT, 2014.





Conclusion

Based on the relatively high average rate of increase in grain yield of 24 kg/ha per year under multiple stress and 34 kg/ha per year under nonstress environments, with a corresponding annual genetic gain of 1.42 and 1.07%, respectively, it may be concluded that considerable progress has been made in breeding for multiple stress-tolerant, extra-early maize cultivars in the sub-region. Commercialization of these cultivars should contribute to food security and improved livelihoods of farmers in SSA.

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