Experimental Agriculture (2019), **55**, 934–944
doi:10.1017/S0014479719000048

CAMBRIDGE UNIVERSITY PRESS

RESEARCH ARTICLE

Gains in grain yield of released maize (*Zea mays* L.) cultivars under drought and well-watered conditions

Muhyideen Oyekunle*, Shehu G. Ado, Inuwa S. Usman, Rekiya O. Abdulmalik, Hauwa O. Ahmed, Lateefat B. Hassan and Muhammad A. Yahaya

Department of Plant Science, Institute for Agricultural Research, Samaru Ahmadu Bello University, P.M.B. 104, Zaria, Kaduna State, Nigeria
*Corresponding author. Email: moyekunle@abu.edu.ng

(Received 23 January 2018; revised 20 December 2018; accepted 23 January 2019; first published online 04 March 2019)

Abstract
Maize (*Zea mays* L.) grain yield is severely constrained by drought and this study was conducted to assess gains in grain yield and other traits of released maize cultivars. Twenty-three maize cultivars plus a check were evaluated under drought and well-watered conditions at Zaria and Kadawa during 2015/2016 and 2016/2017 dry seasons. The 24 cultivars were evaluated using 6 x 4 lattice design with three replications. Genotypes differed significantly for all measured traits except anthesis-silking interval (ASI), husk cover, and number of ears per plant under drought, and ASI, husk cover, and ear aspect under well-watered conditions. Under drought, grain yield ranged from 2251 kg ha^{-1} for SAMMAZ 31 to 4938 kg ha^{-1} for SAMMAZ 19, with a genetic gain of 1.93% yr^{-1}. Under well-watered conditions, grain yield varied from 3082 kg ha^{-1} for SAMMAZ 37 to 5689 kg ha^{-1} for SAMMAZ 51, with the same genetic gain found under drought conditions. Grain yield reduction as a result of drought was 28.4% and performance under drought predicted performance under well-watered conditions better than vice versa with regression coefficient value of 0.8. Grain yield had significant correlations with all measured traits under both water conditions, except for husk cover, plant and ear heights under drought. Our data revealed that substantial genetic gains have been made in breeding for high grain yield cultivars under drought and well-watered conditions over a period of 16 years in Nigeria.

Keywords: Breeding period; correlation; genetic gain; maize variety; regression

Introduction

Maize (*Zea mays* L.) is the most important cereal crop among the resource-poor small-scale farmers in West Africa (WA) and ranks third after rice and wheat in the world (Olaniyan, 2015). It has rapidly gained popularity due to its high potential as source of calories in human diets and livestock feeds and raw materials for industrial products in the sub-region. Maize is the most widely grown cereal crop in Nigeria (FAOSTAT, 2016) due to its high productivity, wide adaptation, relative ease of cultivation, processing, storage, transportation, and income generation. Also, maize production is stimulated with the availability of high-yielding, pest-and disease-resistant cultivars. The availability of different maturity groups of maize varieties that can be consumed either as green maize or grain has helped to fill the hunger gap in the savannas of the sub-region in July when all other food reserves are depleted after the long dry period (Badu-Apraku *et al.*, 2013).

Despite the potential of maize as a staple crop in WA, its production is hindered by several biotic and abiotic factors, including recurrent drought, poor soil fertility, and *Striga hermonthica* (Delile) Benth. parasitism, maize streak virus, and turcicum leaf blight, among others. Drought is the major abiotic factor contributing to maize yield loss in the lowland savanna belt of the sub region (Badu-Apraku *et al.*, 2004; NeSmith and Ritchie, 1992). Drought causes major reduction in maize productivity, especially during the most drought-sensitive stages of maize growth and development. Yield loss as a result of drought at flowering and grain-filling periods ranged from 39 to 91% (Badu-Apraku *et al.*, 2011b; Badu-Apraku and Oyekunle, 2012; NeSmith and Ritchie, 1992; Oyekunle and Badu-Apraku, 2014). The annual yield loss due to drought is about 24 million tons, which is equivalent to 17% of a normal year's production in the developing world (Edmeades *et al.*, 1992).

Genetic gain studies comparing old and new cultivars have been conducted routinely in the temperate zones in an effort to understand how genetic selection has shaped important traits such as grain yield in maize (Campos *et al.*, 2006; Wang *et al.*, 2011). Maize breeders in developed countries have measured breeding progress by comparing the performance of cultivars developed and released over a long period of time in the same environments (Badu-Apraku *et al.*, 2013; Tollenaar, 1989). Similar studies have also been carried out in other crops such as wheat (*Triticum aestivum* L.) (Lopes *et al.*, 2012; Xiao *et al.*, 2012), oats (*Avena sativa* L.), and soybean [*Glycine max* (L.) Merr.] (Tefera *et al.*, 2009). Generally, the studies reported demonstrated that the varieties developed in later breeding eras (2001–2006 and 2007–2010) are superior in terms of grain yield and other agronomic traits. Similar studies have also been conducted in the tropics; Kamara *et al.* (2004) reported a genetic gain of 0.4% per year for late-maturing maize cultivars released from 1970 to 1999 in the Nigerian savannas. In addition, Badu-Apraku *et al.* (2013) reported genetic gain of 1.1% yr^{-1} under drought and 1.33% yr^{-1} under optimum growing conditions for early maize cultivars developed during three breeding eras from 1988 to 2007.

During the last two decades, the development of maize varieties with tolerance to drought, nutrient use efficiency, resistance to *Striga hermonthica* and major foliar diseases has been a major focus of the maize improvement program at International Institute of Tropical Agriculture (IITA) and Institute for Agricultural Research (IAR), Samaru. The maize breeders in IAR in collaboration with IITA conducted several researches to develop and release early, extra-early, and intermediate/late maturing maize varieties with high yield potential and resistance or tolerance to biotic and/or abiotic stresses for Nigerian farmers. These cultivars were developed, tested, and released under different environmental conditions over a period of times. However, no direct comparisons of grain yield potential and other agronomic traits of the released cultivars have been made under drought and well-watered conditions to justify the huge efforts and investments in maize breeding. It is therefore important to assess genetic gain in grain yield and associated changes in agronomic traits of maize cultivars released during the last two decades in order to assess progress made in breeding for improved maize varieties and to identify traits of potential value for accelerating genetic gains in future breeding as well as valuable information for the seed enterprise in Nigeria. The objectives of the study, therefore, were (i) to assess genetic gains in grain yield and other agronomic traits of released maize cultivars from 2001 to 2016 and (ii) to determine the relationship between grain yield and other agronomic traits of released maize cultivars.

Materials and Methods

Genetic materials and experimental procedures

Twenty-three maize cultivars registered and released in the IAR, Samaru from 2001 to 2016 were used for the present study. The 23 released cultivars along with one experimental variety (check) were evaluated under induced drought and well-watered conditions at Zaria (northern Guinea savanna, 11º11'N, 7º38'E, 640 m a.s.l., 1200 mm annual rainfall) and Kadawa (Sudan savanna, 12º00'N, 8º22'E, 580 m a.s.l., 800 mm annual rainfall) during 2015/2016 and 2016/2017 dry seasons, using 6 x 4 lattice design with three replications. The two experimental conditions were irrigated twice every week with furrow irrigation system. Sufficient irrigation water was channeled

https://doi.org/10.1017/S0014479719000048 Published online by Cambridge University Press

from the water source into the furrow of each planted ridge. In the drought experiment, the induced drought was achieved by withdrawing irrigation (furrow irrigation) water from 35 days after planting until maturity so that the maize plants relied on stored water in the soil for growth and development. In the well-watered experiment, the plants were irrigated throughout the growth period. The drought and well-watered experiments were planted in two adjacent blocks in the same field that received the different irrigation treatments during the dry seasons. Each experimental unit consisted of two-row plots 5 m long, with inter- and intra-row spacing of 0.75 m and 0.40 m, respectively. Three seeds were planted per hill, and the resulting maize plants were thinned to two per stand about 2 weeks after emergence to give a final plant population density of 66,000 plants ha^{-1}. All trials received 60 kg NPK ha^{-1} in form of NPK (15–15–15) 2 weeks after planting (WAP). An additional 60 kg N ha^{-1} was supplied (top-dressed) at 5 WAP. Weeds were controlled with herbicides and/or manually when necessary.

Data collection and statistical analyses

Data were collected from each plot on the following traits: days to 50% anthesis and days to mid-silk were recorded as the number of days from planting to when 50% of plants shed pollen and had emerged silks, respectively. Anthesis-silking interval (ASI) was calculated as difference between number of days to mid-silk and days to 50% anthesis. Plant and ear heights were measured as the distance from the base of the plant to the first tassel branch and from the base to the node bearing the upper ear, respectively. Plant aspect was rated on scale of 1–5, where 1 is for plants with minimal reduction in height, ear size, low ear placement, resistance to foliar diseases, and lodging, and 5 is for plants with severally stunted growth, small ears, susceptible to foliar diseases, and lodging (Supplementary Material Table S1 available online at https://doi.org/10.1017/S0014479719000048). Ear aspect was scored from 1–5 scale, where 1 is clean, uniform, and large ears, and 5 is rotten, variable, and small ears (Supplementary Material Table S1). Husk cover was also rated on a scale of 1–5, where 1 is husks tightly arranged and extended beyond the ear tip, and 5 is very loosely arranged husk with ear tip exposed (Supplementary Material Table S1). Number of ears per plant (EPP) was calculated as number of ears harvested divided by the number of plants at harvest. Ears harvested from each plot were shelled to determine percent moisture and grain weight. Grain yield adjusted to 150 g kg^{-1} moisture was computed from grain weight.

Combined analyses of variance for all the traits measured under drought and well-watered conditions were performed separately. A random model of the PROC GLM in SAS was used (SAS Institute, 2002), in which cultivars, location–year combination (environments), block, and replications were considered as random factors. The linear model for the combined ANOVA is as follows:

$$Y_{bklmi} = \mu_i + E_{ki} + B(RE)_{b(kl)i} + R(E)_{l(k)i} + G_{mi} + GE_{kmi} + \varepsilon_{bklmi} \quad (1)$$

where Y_{bklmi} is the observed measurement of trait i of m genotype within l replicate, in k environment, b block within l replicate and k environment, μ_i is mean effect, E_{ki} is the effect of environment k on trait i, $B(RE)_{b(kl)i}$ is the effect of block b within replicate l and environment k on trait i, $R(E)_{l(k)i}$ is the effect of replication l within environment k on trait i, G_{mi} is the effect of genotype m on trait i, GE_{kmi} is the effect of the interaction between genotype m and environment k on trait i, and ε_{bklmi} is the experimental error effect associated with genotype m and block b within replication l and environment k on trait i.

Pearson correlation coefficients were computed between grain yield and other measured traits of maize cultivars under drought and well-watered conditions. In addition, the mean values of yield under drought were regressed on yield under well-watered conditions and vice-versa. The relationship between cultivar grain yield and year of released (expressed as number of years since 2001) was determined using regression analysis. The mean grain yield of the maize cultivars under drought and well-watered conditions was used as the dependent variable and regressed on the year of released as independent variables to obtain regression coefficient (b-value). The b-value was then divided by the intercept (a) and multiplied by 100 to obtain the relative genetic gain per year (Badu-Apraku *et al.*, 2013). Both correlation and regression analyses were carried out using SAS version 9.2 (SAS Institute, 2002). Grain yield reduction due to drought was calculated as follows:

$$\text{Yield reduction} = \frac{(Y_W - Y_D) \times 100}{Y_W} \quad (2)$$

where Y_W = yield under well-watered conditions and Y_D = yield under drought.

Results

Analysis of variance and mean performance of maize cultivars

The combined analysis of variance for grain yield and other agronomic traits of the 24 maize cultivars revealed that environment mean squares were significant ($P < 0.01$) for all measured traits, except husk cover and EPP under drought and well-watered conditions (Table 1). Similarly, cultivar mean squares were significant for all measured traits, except ASI, husk cover, and EPP under drought, and ASI, husk cover, and ear aspect under well-watered conditions (Table 1). In contrast, cultivar × environment interaction mean squares were significant only for grain yield and plant height under drought and days to anthesis and mid-silk, and ASI under well-watered conditions (Table 1).

The mean grain yield of the cultivars ranged from 2251 kg ha^{-1} for SAMMAZ 31 to 4938 kg ha^{-1} for SAMMAZ 19 with an average of 3131 kg ha^{-1} under drought and from 3082 kg ha^{-1} for SAMMAZ 37 to 5689 kg ha^{-1} for SAMMAZ 51 with an average of 4373 kg ha^{-1} under well-watered conditions (Table 2). The highest yielding cultivar SAMMAZ 19 out-yielded the check by 41% under drought and SAMMAZ 51 out-yielded the check by 28% under well-watered conditions. The grain yield reduction under drought ranged from 8.8% for SAMMAZ 37 to 48.1% for SAMMAZ 15 when compared with grain yield under well-watered conditions. On average, grain yield of cultivars under drought was 71.6% of the yield obtained under well-watered conditions.

Correlation between grain yield and other agronomic traits

Results of Pearson's correlation analysis revealed significant positive correlations between grain yield and EPP ($r = 0.74^{**}$) but negative correlations with days to anthesis ($r = -0.20^{**}$) and mid-silk ($r = -0.37^{**}$), plant aspect ($r = -0.53^{**}$), and ear aspect ($r = -0.63^{**}$) under drought (Table 3). On the other hand, grain yield had significant positive correlations with plant height ($r = 0.32^{**}$), ear height ($r = 0.35^{**}$), and EPP ($r = 0.56^{**}$) but negative correlations with days to anthesis ($r = -0.37^{**}$) and mid-silk ($r = -0.40^{**}$), plant aspect ($r = -0.67^{**}$), and ear aspect ($r = -0.70^{**}$) under well-watered conditions. Plant height had significant positive correlations with ear height under drought ($r = 0.65^{**}$) and well-watered conditions ($r = 0.72^{**}$). Similarly, days to anthesis had significant positive correlations with days to mid-silk under drought ($r = 0.82^{**}$) and well-watered conditions ($r = 0.93^{**}$) (Table 3). Plant aspect had significant positive correlations with ear aspect under drought ($r = 0.65^{**}$) and well-watered conditions ($r = 0.61^{**}$). The results of regression analysis of grain yield under drought and well-watered conditions showed positive predictive relationship between one level and the other, although performance under drought predicted performance under well-watered conditions better than vice-versa (Figure 1).

Genetic gain in grain yield of released maize cultivars

Substantial increase in the grain yield of released maize cultivars was observed during the breeding period (Table 4, Figure 2). The average rate of increase in grain yield was 50 kg ha^{-1} yr^{-1},

https://doi.org/10.1017/S0014479719000048 Published online by Cambridge University Press

Table 1. Analysis of variance of yield and other agronomic traits of released maize cultivars evaluated under drought and well-watered conditions at Zaria and Kadawa during 2015/2016 and 2016/2017 dry seasons

Source	df	Grain yield, kg ha^{-1}	Days to anthesis	Days to silking	ASI	Plant height, cm	Ear height, cm	Husk cover	Plant aspect	Ear aspect	EPP
Drought											
Environment, E	3	147 515 453**	1392.5**	2447.1**	81.4**	4011.2**	4413.3**	0.0	62.9**	37.9**	0.1
Block (E x Rep)	36	3 991 137*	8.5*	6.4	1.2	283.9	722.7**	0.2	0.2	0.5	0.1
Rep (E)	8	2 864 570	8.7	20.2**	1.9	553.0*	624.0	0.8	0.1	0.6	0.1
Cultivar	23	5 064 551**	12.5**	7.4*	0.8	514.5**	607.4**	0.3	0.6*	0.9**	0.2
Cultivar x E	69	4 030 861*	4.4	3.3	0.8	327.6*	446.5	0.2	0.2	0.4	0.3
Error	148	2 027 407	4.6	4.1	0.9	195.4	292.2	0.4	0.3	0.5	0.2
Well-watered conditions											
Environment, E	3	155 167 375**	87.3**	425.8**	65.3**	1863.5*	1309.3**	0.0	39.6**	66.0**	0.2
Block (E x Rep)	36	7 708 213	4.8	3.5	1.6	542.1	208.3	0.4	0.4**	9.1	0.7
Rep (E)	8	23 204 853*	3.5	1.6	2.3	677.2	271.6	0.2	1.1**	9.5	1.2
Cultivar	23	20 916 284**	10.0**	10.1**	2.1	851.8**	554.7**	0.4	0.5**	7.5	0.9*
Cultivar x E	69	5 169 606	14.2**	9.5**	2.2*	237.1	163.0	0.5	0.3	7.4	0.5
Error	148	7 446 157	3.9	3.9	1.3	342.8	151.4	0.4	0.2	7.7	0.5

*, ** Significant difference at $P < 0.05$ and $P < 0.01$ levels, respectively. ASI = anthesis-silking interval; EPP = number of ears per plant.

https://doi.org/10.1017/S0014479719000048 Published online by Cambridge University Press

Table 2. Grain yield and other agronomic traits of released maize cultivars evaluated under drought (DS) and well-watered (WW) conditions at Zaria and Kadawa during 2015/2016 and 2016/2017 dry seasons

Cultivar	Year of release	Year from 2001	Grain yield, kg ha^{-1}		Yield reduction, %	Days to silking		ASI		Plant height, cm		Ear height, cm		Husk cover		Ear aspect		Plant aspect		EPP	
			DS	WW		DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
SAMMAZ 13	2001	1	2395	3672	34.8	60	61	4.0	3.2	153	165	75	91	1.8	1.6	2.6	2.7	2.3	1.9	0.7	0.8
SAMMAZ 14	2005	5	3395	4672	27.3	60	61	4.0	3.2	163	175	77	93	1.7	1.6	2.5	2.6	2.2	1.8	0.8	0.9
SAMMAZ 15	2008	8	2314	4458	48.1	62	60	3.3	3.8	160	173	83	84	1.6	1.6	3.8	2.6	2.6	2.2	0.7	0.7
SAMMAZ 16	2008	8	3438	4831	28.8	61	60	3.5	3.5	155	168	65	87	1.6	1.2	2.7	2.2	2.8	1.9	0.9	0.9
SAMMAZ 17	2009	9	2931	3990	26.6	63	62	3.8	2.7	177	182	83	96	1.2	1.9	3.0	2.2	1.9	1.9	0.8	0.9
SAMMAZ 18	2009	9	3751	4435	15.4	59	60	2.9	2.7	159	156	84	70	1.7	1.7	1.2	2.2	2.3	1.8	0.9	0.9
SAMMAZ 19	2009	9	4938	5532	10.7	60	60	3.8	2.7	173	176	77	85	2.1	1.3	3.0	2.0	2.2	1.6	0.9	1.1
SAMMAZ 20	2009	9	2354	3210	26.7	58	58	4.0	2.7	141	172	62	80	1.5	2.0	1.9	2.3	2.6	2.5	0.9	0.9
SAMMAZ 26	2009	9	3002	5157	41.8	59	61	3.7	2.2	166	155	75	82	1.7	1.7	3.4	1.6	2.5	2.0	0.9	0.9
SAMMAZ 27	2009	9	2712	3829	29.2	59	57	3.4	3.0	133	158	57	58	1.7	1.6	1.7	2.8	3.2	2.6	0.8	1.0
SAMMAZ 28	2009	9	2653	3386	21.6	57	60	3.9	2.6	126	141	44	64	1.4	1.7	3.9	3.1	3.0	2.8	0.9	1.1
SAMMAZ 29	2009	9	2691	4718	43.0	61	62	3.3	2.7	126	177	52	39	2.3	1.6	2.9	2.5	2.5	2.5	1.0	1.0
SAMMAZ 31	2009	9	2251	3566	36.9	56	58	3.8	3.6	151	150	57	68	1.2	2.1	2.4	3.1	2.9	2.9	1.0	1.0
SAMMAZ 32	2011	11	3347	4427	24.4	60	59	3.5	2.8	165	176	68	89	2.1	1.8	2.8	2.1	2.3	2.2	1.0	1.0
SAMMAZ 33	2011	11	2624	3777	30.5	60	58	4.7	2.4	154	161	79	76	1.6	2.0	8.0	2.5	2.6	2.3	0.8	1.0
SAMMAZ 34	2011	11	2984	4157	28.2	60	59	4.1	3.3	160	165	74	82	1.3	2.1	2.3	2.8	2.3	2.6	1.0	1.1
SAMMAZ 35	2011	11	3484	3926	11.3	60	60	4.4	2.8	153	172	65	90	1.5	1.4	1.9	2.0	2.3	2.2	1.0	1.0
SAMMAZ 37	2011	11	2810	3082	8.8	59	58	3.7	3.8	168	158	73	71	1.5	2.0	2.5	2.4	2.3	2.7	0.6	0.7
SAMMAZ 38	2013	13	2951	3935	25.0	60	59	4.0	3.1	169	171	82	93	1.6	1.8	2.4	2.0	2.4	1.9	0.6	0.7
SAMMAZ 39	2013	13	3388	4909	31.0	59	61	3.7	2.8	159	173	75	84	1.8	2.1	2.5	1.9	2.4	2.2	0.8	0.9
SAMMAZ 40	2013	13	3436	5526	37.8	58	60	3.3	2.5	153	165	70	84	1.5	1.6	1.7	1.7	2.5	2.1	0.9	1.0
SAMMAZ 48	2016	16	3253	5267	38.2	59	59	3.7	3.5	165	166	71	82	1.9	2.4	2.4	1.6	2.1	2.3	1.0	0.9
SAMMAZ 51	2016	16	3998	5689	29.7	59	59	3.6	2.3	156	150	69	67	1.6	1.5	3.2	2.3	1.9	2.5	0.9	1.1
Check			2907	4107	29.2	59	58	3.8	5.1	166	176	70	81	1.3	2.2	2.2	2.5	2.2	2.2	0.8	0.9
Mean			3131	4373	28.4	60	59	3.8	3.1	156	166	70	79	1.6	1.8	2.8	2.3	2.5	2.2	0.9	1.0
SE			1228	1163		2	2	0.8	0.9	15	11	10	14	0.5	0.5	2.3	0.6	0.3	0.4	0.2	0.1

ASI = anthesis-silking interval; EPP = number of ears per plant.

Table 3. Correlation coefficients of grain yield and other agronomic traits of released maize cultivars evaluated under drought and well-watered conditions at Zaria and Kadawa during 2015/2016 and 2016/2017 dry seasons

Trait	Grain yield	Days to anthesis	Days to silking	ASI	Plant height	Ear height	Husk cover	Ear aspect	Plant aspect	EPP
Grain yield		−0.20*	−0.37**	−0.38**	−0.04	−0.02	0.02	−0.63**	−0.53**	0.74**
Days to anthesis	−0.37**		0.82**	0.10	0.26**	0.25**	−0.14	0.21*	0.15	−0.26**
Days to silking	−0.40**	0.93**		0.52**	0.26**	0.21*	−0.12	0.45**	0.40**	−0.31**
ASI	−0.44**	0.52**	0.64**		0.10	−0.06	−0.01	0.43**	0.43**	−0.24**
Plant height	0.32**	−0.27**	−0.27**	−0.17*		0.65**	0.03	−0.09	−0.27**	−0.15
Ear height	0.35**	−0.25**	−0.22*	−0.17*	0.72**		0.05	−0.06	−0.17*	−0.20*
Husk cover	0.04	0.05	0.06	−0.09	−0.02	0.00		−0.04	−0.12	0.07
Ear aspect	−0.70**	0.41**	0.42**	0.40**	−0.34**	−0.46**	−0.09		0.65**	−0.40**
Plant aspect	−0.67**	0.63**	0.67**	0.52**	−0.49**	−0.43**	0.02	0.61**		−0.34**
EPP	0.56**	−0.18*	−0.25**	−0.27**	0.18*	0.12	0.03	−0.21*	−0.37**	

*, **Significant difference at $P < 0.05$ and $P < 0.01$ levels, respectively. ASI = anthesis-silking interval; EPP = number of ears per plant.

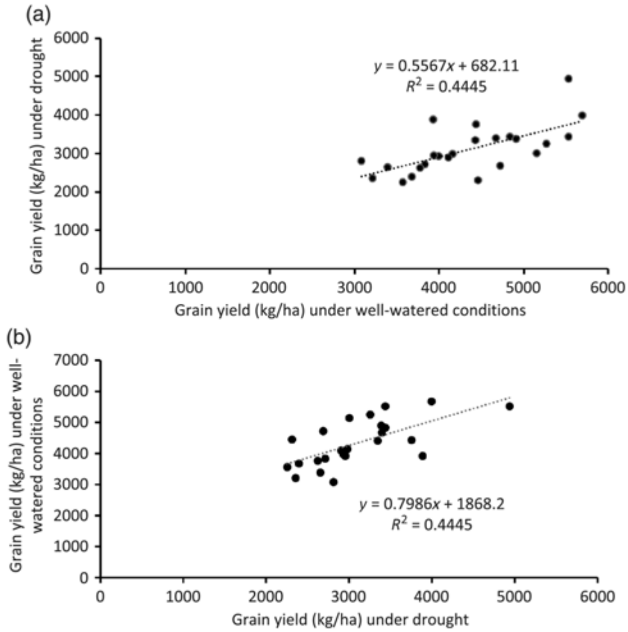

Figure 1. Regression of (a) grain yield of well-watered conditions on grain yield of drought environments and (b) grain yield of drought environments on grain yield of well-watered conditions.

corresponding to a genetic gain of 1.93% yr^{-1} under drought (Table 4). Similarly, the average rate of increase in grain yield was 70 kg ha^{-1} yr^{-1}, corresponding to a genetic gain of 1.93% yr^{-1} under well-watered conditions. Plant aspect had a genetic gain of −0.94% yr^{-1}, −0.36% yr^{-1} for ear aspect, 0.55% yr^{-1} for plant height, and 0.75% yr^{-1} for EPP under drought. On the other hand, ear aspect had a genetic gain of −1.76% yr^{-1}, −0.38% yr^{-1} for ear height, −0.29% yr^{-1} for days to anthesis, −0.21% yr^{-1} for days to mid-silk, and 0.69% yr^{-1} for EPP under well-watered conditions.

https://doi.org/10.1017/S0014479719000048 Published online by Cambridge University Press

Table 4. Relative genetic gain, coefficient of determination (R^2), slope (*a*), and regression coefficients (*b*) of grain yield and other agronomic traits of released maize cultivars evaluated under drought and well-watered conditions at Zaria and Kadawa during 2015/2016 and 2016/2017 dry seasons

Trait	Relative genetic gain (% per year)	R^2	*a*	*b*
Drought				
Grain yield, kg/ha	1.93	0.073	2589.72	50.018
Days to anthesis	−0.07	0.008	57.20	−0.038
Days to mid-silk	−0.17	0.057	60.57	−0.100
ASI	−0.05	0.000	3.77	−0.002
Plant height, cm	0.55	0.042	148.01	0.810
Ear height, cm	0.01	0.000	70.22	0.008
Husk cover	−0.44	0.009	1.70	−0.008
Plant aspect	−0.94	0.072	2.68	−0.025
Ear aspect	−0.36	0.001	2.90	−0.010
EPP	0.75	0.029	0.01	0.796
Well-watered conditions				
Grain yield, kg/ha	1.93	0.099	3629.65	69.981
Days to anthesis	−0.29	0.104	57.86	−0.169
Days to mid-silk	−0.21	0.106	60.87	−0.130
ASI	0.79	0.014	2.82	0.022
Plant height, cm	−0.05	0.001	166.71	−0.087
Ear height, cm	−0.38	0.007	82.22	−0.316
Husk cover	2.84	0.206	1.38	0.039
Plant aspect	1.06	0.043	2.03	0.022
Ear aspect	−1.76	0.159	2.83	−0.050
EPP	0.69	0.0.031	0.01	0.870

ASI = anthesis-silking interval; EPP = number of ears per plant.

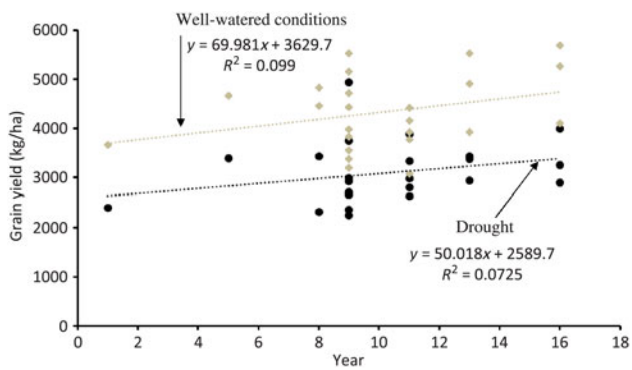

Figure 2. Regression of grain yield of released maize varieties under drought and well-watered conditions on years of release.

Discussion

The present study provided an opportunity to assess the performance of the maize cultivars released in Nigeria within the last two decades under drought and well-watered conditions. The presence of significant difference among environments for most of the measured traits indicated that the test environments were unique under both research conditions in identifying high-yielding cultivars. The presence of significant difference among the cultivars for grain yield and most other traits under both drought and well-watered conditions indicated genetic variability among the cultivars released during the two decades of maize breeding. The existence of variability among the cultivars would allow significant progress from selection for improvements in most of the measured traits and identification of source of genetic materials for development of inbred lines and populations. In addition, the differences observed among the cultivars would allow identification of superior genotypes for varietal replacement and commercialization in the country. The information generated in the present study is invaluable in guiding the small- and medium-scale seed companies and farmers in Nigeria for adoption and commercialization of improved maize cultivars. The differential response of genotypes to varying environmental conditions constitutes a major challenge in the identification of superior maize cultivars for narrow or wide adaptation. The significant cultivar × environment interaction observed for grain yield and plant height under drought (Table 1) indicated that the expression of these traits would not be consistent in varying test environments. This result suggests the need for extensive testing of the cultivars in multiple environments for identification of genotypes with consistent performance under varying resource availability, such as water. In contrast, the lack of significant cultivar × environment interaction for grain yield under well-watered conditions (Table 1) indicated that the trait was not affected by cultivar × environment interaction and hence the expression of these traits would be consistent in varying test locations. The grain yield reduction of 8.8–48.1% observed among the cultivars fell within the ranged reported by Oyekunle and Badu-Apraku (2014), who reported yield reduction of 4–84% among the early-maturing inbreds evaluated under drought and well-watered conditions.

Information on the relationships among traits is vital for designing effective breeding programs for maize improvement. The significant correlations observed between grain yield and EPP, days to anthesis and mid-silk, plant and ear aspects under both drought and well-watered conditions (Table 3) were desirable for improvement of grain yield under both research conditions. The presence of significant correlations between grain yield and days to anthesis and mid-silk indicated that later maturing cultivars tend to give higher yields than those earlier maturing. On the other hand, significant correlations between grain yield and EPP, and plant and ear aspects under both drought and well-watered conditions (Table 3) indicate the possibility of using secondary traits (plant and ear aspects, and EPP) in improving grain yield and thus, justifying the inclusion of the traits in the selection index for the identification and improvement of drought-tolerant cultivars. These results are in agreement with the findings of Badu-Apraku *et al.* (2011a, 2012). However, the lack of significant correlation between grain yield and plant and ear heights under drought was in disagreement with previous research (Badu-Apraku *et al.*, 2011a, 2012, 2013). The presence of significant correlations between pair of traits such as plant and ear heights, days to anthesis and mid-silk, and plant and ear aspects under both water conditions (Table 3) indicated that improving one of the traits would lead to improvement in the other. This is advantageous in breeding and would reduce cost of measuring two different traits that provide similar information. The positive predictive relationship observed between grain yield under drought and well-watered conditions (Figure 1) indicated that performance under drought could be utilized in predicting the performance under well-watered conditions better than vice-versa.

An important objective of the present study was to assess the progress made in maize breeding during the last two decades. It is important to determine the magnitude of the increase in grain yield and genetic gain so as to effectively assess progress made within a period of time of breeding. In fact, substantial increase in the grain yield of released maize cultivars was observed under drought and well-watered conditions during the breeding period. The genetic gain in grain yield was 1.93% yr^{-1}, regardless of water condition (Table 4). Such gains are higher than 1.1 and 1.33% yr^{-1} reported by Badu-Apraku *et al.* (2013) for 50 early-maturing open-pollinated maize cultivars developed between 1988 and 2007. Similarly, the genetic gains obtained here are substantially higher than the 0.41% yr^{-1} reported by Kamara *et al.* (2004) for late-maturing maize cultivars developed from 1970 to 1999 in the West African savannas. The genetic gain in grain yield under drought was associated with improvement in plant and ear aspects, plant height, EPP, and earliness, whereas gain in grain yield under well-watered conditions was associated with improvement in ear aspect, good standability, ear height, EPP, and earliness (Table 4). Our results suggest that the breeding strategies including recurrent selection, backcrossing, hybridization, and selection indices utilized in developing improved maize cultivars over a breeding period of 16 years were effective. The results clearly indicated that new cultivars possess favorable genes that make them better performing than the old cultivars. In addition, accumulation of new favorable alleles through rapid breeding cycles is one of the possible scenarios that substantially boost the rate of gain, and modern crop breeding and advances in management practices have contributed substantially to the annual gain in crop productivity.

In conclusion, we found that the average rate of increase in grain yield varied between 50 (drought) and 70 kg ha^{-1} yr^{-1} (well-watered conditions), corresponding to a genetic gain of 1.93% yr^{-1} in both water regimes. Grain yield had significant correlations with all measured traits under both water conditions, except husk cover, and plant and ear heights under drought. The substantial genetic gain in grain yield was associated with improvement in agronomic traits and SAMMAZ 19 and SAMMAZ 51 were the highest yielding cultivars under drought and well-watered conditions, respectively. Those cultivars should serve as genetic source for development of inbred lines, synthetic varieties, and populations.

Supplementary materials. For supplementary material for this article, please visit https://doi.org/10.1017/S0014479719000048.

Acknowledgements. The authors are grateful to the staff of IAR's Maize Improvement Program for technical support. The financial support of STMA Project and IAR for this research is also gratefully acknowledged.

Financial support. STMA-IITA project and IAR, Samaru.

Disclosure statement. No potential conflict of interest.

References

Badu-Apraku B., Akinwale R.O., Ajala S.O., Menkir A., Fakorede M.A.B. and Oyekunle M. (2011a). Relationships among traits of tropical early maize cultivars in contrasting environments. *Agronomy Journal* **103**, 717–729.

Badu-Apraku B., Akinwale R.O., Franco J. and Oyekunle M. (2012). Assessment of reliability of secondary traits in selecting for improved grain yield in drought and low-nitrogen environments. *Crop Science* **52**, 2050–2062.

Badu-Apraku B., Fakorede M.A.B., Menkir A., Kamara A.Y., Akanvou L. and Chabi Y. (2004). Response of early maturing maize to multiple stresses in the Guinea savanna of West and Central Africa. *Journal of Genetics and Breeding* **58**, 119–130.

Badu-Apraku B., Lum A.F., Akinwale R.O. and Oyekunle M. (2011b). Biplot analysis of diallel crosses of early maturing tropical yellow maize inbreds in stress and nonstress environments. *Crop Science* **51**, 173–188.

Badu-Apraku B. and Oyekunle M. (2012). Genetic analysis of grain yield and other traits of extra-early yellow maize inbreds and hybrid performance under contrasting environments. *Field Crops Research* **129**, 99–110.

Badu-Apraku B., Oyekunle M., Menkir A., Obeng-Antwi K., Yallou C.G., Usman I.S. and Alidu H. (2013). Comparative performance of early maturing maize cultivars developed in three eras under drought stress and well-watered environments in West Africa. *Crop Science* **53**, 1298–1311.

Campos H., Cooper M., Edmeades G.O., Löffler C., Schussler J.R. and Ibañez M. (2006). Changes in drought tolerance in maize associated with fifty years of breeding for yield in the U.S. Corn Belt. *Maydica* **51**, 369–381.

Edmeades G.O., Bolanõs J. and Lafitte H.R. (1992). Progress in breeding for drought tolerance in maize. In Wilkinson D. (ed), *Proceedings of the 47th Annual Corn and Sorghum Industrial Research Conference*. Washington, DC: ASTA, pp. 93–111.

FAOSTAT (2016). *Food and Agriculture Organization of the United Nations, Food Security Statistics 2014*. Rome, Italy: FAO.

Kamara A.Y., Menkir A., Fakorede M.A.B., Ajala S.O., Badu-Apraku B. and Kureh I. (2004). Agronomic performance of maize cultivars representing three decades of breeding in the Guinea savannas of West and Central Africa. *Journal of Agricultural Science* **142**, 567–575.

Lopes M.S., Reynolds M.P., Manes Y., Singh R.P., Crossa J. and Braun H.J. (2012). Genetic yield gains and changes in associated traits of CIMMYT spring bread wheat in a "Historic" set representing 30 years of breeding. *Crop Science* **52**, 1123–1133.

NeSmith D.S. and Ritchie J.T. (1992). Effects of water-deficits during tassel emergence on development and yield components of maize (*Zea mays* L.). *Field Crops Research* **28**, 251–256.

Olaniyan A.B. (2015). Maize: Panacea for hunger in Nigeria. *African Journal of Plant Science* **9**, 155–174.

Oyekunle M. and Badu-Apraku B. (2014). Genetic analysis of grain yield and other traits of early maturing maize inbreds under drought and well-watered conditions. *Journal of Agronomy and Crop Science* **200**, 92–107.

SAS Institute (2002). *SAS User's Guide. Version 9.2.* Cary, NC: SAS Institute Inc.

Tefera H., Kamara A.Y., Asafo-Adjei B. and Dashiell K.E. (2009). Improvements in grain and fodder yields of early maturing promiscuous soybean cultivars in the Guinea savannas of Nigeria. *Crop Science* **49**, 2037–2042.

Tollenaar M. (1989). Genetic improvement in grain yield of commercial maize hybrids grown in Ontario from 1959 to 1988. *Crop Science* **29**, 1365–1371.

Wang T.Y., Ma X.L., Li Y., Bai D.P., Liu C., Liu Z.Z., Tan X.J., Shi Y.S., Song Y.C., Carlone M., Bubeck D., Bhardwaj H., Jones E., Wright K. and Smith S. (2011). Changes in yield and yield components of single-cross maize hybrids released in China between 1964 and 2001. *Crop Science* **51**, 512–525.

Xiao Y.G., Qian Z.G., Wu K., Liu J.J., Xia X.C., Ji W.Q. and He Z.H. (2012). Genetic gains in grain yield and physiological traits of winter wheat in Shandong province, China, from 1969 to 2006. *Crop Science* **52**, 44–56.

Cite this article: Oyekunle M, Ado SG, Usman IS, Abdulmalik RO, Ahmed HO, Hassan LB, and Yahaya MA (2019). Gains in grain yield of released maize (*Zea mays* L.) cultivars under drought and well-watered conditions. *Experimental Agriculture* **55**, 934–944. https://doi.org/10.1017/S0014479719000048