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Agronomic performance of elite drought tolerant maize *(Zea mays L.)* hybrids under natural disease inoculation in the rainforest of Nigeria.

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Abstract

The tropical rainforest agroecology is highly vulnerable to a myriad of plant disease infections and the likelihood that farmers would adopt a new maize cultivar largely depends on its resistance to the common diseases. In the present study, a set of newly developed single cross drought tolerant maize hybrids were evaluated under natural disease inoculation and their performance for grain yield, breeder's traits, and response to infections by four cosmopolitan foliar diseases were assessed. A trial comprising 96 experimental hybrids and 4 hybrid checks were planted over two rainy seasons at Ikenne using a 10 x 10 triple-lattice design. Hybrids differed significantly ($p < 0.0001$) for grain yield and other measured traits. Significant hybrid x year interaction was also observed for all traits except plant aspect. Ranking of mean grain yields of hybrids between the two years revealed moderate but highly significant correlation ($r = 0.50$, $p < 0.0001$). All measured traits except curvularia were negatively and significantly correlated ($r = -0.16$ to -0.58, $p < 0.0001$) with grain yield. Mean grain yields ranged between 2,282 and 6,132 kg ha^{-1} with a trial mean of 4,509 kg ha^{-1}. The top five yielders exceeded the best drought tolerant check (M1026-7; 5,485 kg ha^{-1}) by a least 2 standard errors whereas the top 20 hybrids produced significantly higher yields than the best commercial check (Oba 98; 4,150 kg ha^{-1}) and had mostly favorable scores for the breeder's traits and response to foliar disease infections. Promising high yielding and drought tolerant hybrids that have appreciable resistance to common foliar diseases can be selected among the tested genotypes.

Introduction

Maize is an important cereal crop whose ranking as a staple food crop in Nigeria has exceeded that of traditional African cereals like sorghum and millet. Although, Nigeria ranks 10th among the largest maize producers in the world, and as the largest producer in Africa (USDA, 2013), the country still produces less than 40% of her annual maize requirement which is between 20 and 30 million tons, with a shortfall of over 12 million tons. Maize is mainly produced for local consumption in Nigeria with only small quantities being imported and exported: 55% of the country's production is used as food, 31% as feed, and 2% is processed (Cadoni and Angelucci, 2013). With high quality seed of improved cultivars and improved farming technologies, Nigeria has the potential of meeting her local consumption needs and becoming a major exporter of maize.

Maize production and productivity in the rainforest agro-ecological zone of southwest Nigeria is being limited by annual incidences of endemic foliar diseases during the main cropping season. The yield reduction of over 30% that could be attributed to the cumulative effects of these diseases (Adebayo, 2012) has cost the rainforest agro-ecological zone its place of pride as Nigeria's maize belt (Bello and Olaoye, 2009). Cosmopolitan foliar diseases that attack maize in the zone are common rust caused by *Puccinia sorghi*, corn leaf blight caused by *Helminthosporum turcicum*, maize leaf spots caused by *Curvularia lunata*, and maize leaf streak (Iken and Amusa, 2004). These disease pathogens thrive under the warm and humid conditions that are prevalent in the tropical rainforest agroecology.

Maize breeders invest skills, time and resources into developing superior genotypes that are high-yielding and well adapted to the different agro-ecologies where specific stress factors are prevalent (Bello and Olaoye, 2009). They also look into exotic germplasm for novel alleles that can be introduced into locally available materials to confer tolerance and/or resistance against various biotic and abiotic stresses (Giauffret *et al*., 2000; Dhliwayo *et al*., 2009). Although IITA maize breeders have developed resistance to the common foliar diseases in their elite germplasm (Van Eijnatten, 1963; Fajemisin *et al*., 1978; Efron *et al*., 1989), there is the possibility that new strains of the pathogens causing the diseases might have evolved over time and are now causing significant maize yield reduction in the rainforest. This has necessitated that newly developed maize hybrids be evaluated under the endemic disease conditions in the rainforest agroecology in order to select the ones that possess appreciable resistance to the diseases and consequently produce comparative grain yields at harvest. In this study, a set of new drought tolerant hybrids developed from exotic and adapted maize inbred lines were assessed for grain yield and reaction to foliar disease infections under natural disease inoculation in order to identify the high yielding ones.

Materials and Methods

Germplasm

The 96 single-cross drought tolerant maize hybrids evaluated in this study were developed using 12 adapted inbred lines obtained from IITA and 12 exotic inbred lines obtained from CIMMYT. The 24 drought tolerant inbred lines were a subset of an association panel of 359 diverse collections recently genotyped using single nucleotide polymorphism (SNP) markers by Wen *et al*. (2011). The details of how the crosses were produced can be found in Adebayo *et al*. (2014).

Table 1: The 96 single-cross drought tolerant maize hybrids and 4 hybrid checks evaluated under natural disease inoculation in the rainy seasons of 2010 and 2011at Ikenne, southwest Nigeria.

Entry	Hybrid	Entry	Hybrid	Entry	Hybrid
1	EXL01 x ADL34	35	ADL37 x EXL02	68	ADL39 x ADL27
2	EXL04 x ADL34	36	ADL38 x EXL02	69	ADL34 x ADL32
3	EXL05 x ADL34	37	ADL27 x EXL03	70	ADL35 x ADL32
4	EXL24 x ADL 34	38	ADL32 x EXL03	71	ADL36 x ADL32
5	EXL01 x ADL35	39	ADL37 x EXL03	72	ADL39 x ADL32
6	EXL04 x ADL35	40	ADL38 x EXL03	73	ADL34 x ADL37
7	EXL05 x ADL35	41	ADL27 x EXL06	74	ADL35 x ADL37
8	EXL24 x ADL35	42	ADL32 x EXL06	75	ADL36 x ADL37
9	EXL01 x ADL36	43	ADL37 x EXL06	76	ADL39 x ADL37
10	EXL04 x ADL36	44	ADL38 x EXL06	77	ADL34 x ADL38
11	EXL05 x ADL36	45	ADL27 x EXL07	78	ADL35 x ADL38
12	EXL24 x ADL36	46	ADL32 x EXL07	79	ADL36 x ADL38
13	EXL01 x ADL39	47	ADL37 x EXL07	80	ADL39 x ADL38
14	EXL04 x ADL39	48	ADL38 x EXL07	81	EXL02 x ADL31
15	EXL05 x ADL39	49	EXL10 x EXL01	82	EXL03 x ADL31
16	EXL24 x ADL39	50	EXL15 x EXL01	83	EXL06 x ADL31
17	ADL31 x EXL10	51	EXL16 x EXL01	84	EXL07 x ADL31
18	ADL41 x EXL10	52	EXL17 x EXL01	85	EXL02 x ADL41
19	ADL33 x EXL10	53	EXL10 x EXL04	86	EXL03 x ADL41
20	ADL47 x EXL10	54	EXL15 x EXL04	87	EXL06 x ADL41
21	ADL31 x EXL15	55	EXL16 x EXL04	88	EXL07 x ADL41
22	ADL41 x EXL15	56	EXL17 x EXL04	89	EXL02 x ADL33
23	ADL33 x EXL15	57	EXL10 x EXL05	90	EXL03 x ADL33
24	ADL47 x EXL15	58	EXL15 x EXL05	91	EXL06 x ADL33
25	ADL31 x EXL16	59	EXL16 x EXL05	92	EXL07 x ADL33
26	ADL41 x EXL16	60	EXL17 x EXL05	93	EXL02 x ADL47
27	ADL33 x EXL16	61	EXL10 x EXL24	94	EXL03 x ADL47
28	ADL47 x EXL16	62	EXL15 x EXL24	95	EXL06 x ADL47
29	ADL31 x EXL17	63	EXL16 x EXL24	96	EXL07 x ADL47
30	ADL41 x EXL17	64	EXL17 x EXL24	97	M1026-7 - *Check*
31	ADL33 x EXL17	65	ADL34 x ADL27	98	M1026-8 - *Check*
32	ADL47 x EXL17	66	ADL35 x ADL27	99	OBA SUPER 1 -*Check*
33	ADL27 x EXL02	67	ADL36 x ADL27	100	OBA 98 - *Check*
34	ADL32 x EXL02				

Field Experiment

The experiments were conducted under natural disease inoculation in the rainy seasons of 2011 and 2012 at Ikenne (6°54´N, 3°42´E, and altitude 60 m) in the rainforest agro-ecology in south-western Nigeria. The 96 single-cross hybrids and four checks (Table 1) were laid out in the field using a 10 x 10 triple-lattice design with three replications. The four checks consist of two commercial hybrid maize varieties being marketed in Nigeria (Oba super 1 and Oba 98) and two synthetic drought tolerant hybrids (M1026-7 and M1026-8) developed at IITA. Each experimental hybrid and check was planted in a 5-m row plot spaced 0.75 m apart and 0.50 m spacing between plants within each row. Three seeds were planted per hill and later thinned to two plants per stand two weeks after planting (2 WAP) to attain a plant population density of 53,333 plants ha^{-1}. Fertilizer was applied at the rate of 60 kg N, 60 kg P, and 60 kg K per hectare at planting. An additional 60 kg ha^{-1} N was applied in the form of urea as top dressing four weeks later. In each trial, gramoxone and primextra were applied as pre-emergence herbicides at 5.0 l ha^{-1} each of paraquat (N,N'-dimethyl-4,4'-bipyridinuim dichloride) and atrazine (2-Chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine). Subsequently, manual weeding was done to keep the trials weed-free.

Data Collection

Data were collected in each year on plot basis on many agronomic traits but data on plant aspect, ear aspect, streak, leaf rust, leaf blight, and curvularia leaf spot were reported in this study. After the crop has attained physiological maturity, plant aspect was visually rated on a scale of 1 to 5 where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. Symptom severity of each of common rust, corn leaf blight, maize leaf spots, and maize leaf streak, was scored on a scale of 1 to 5, where 1 = slight leaf infection and 5 = severe leaf infection. Ear aspect (EASP) was also visually rated on a scale of 1 to 5, where 1 = clean, uniform, large, and well-filled ears and 5 = rotten, variable, small, and partially filled ears. All ears harvested from each plot were weighed and shelled to determine grain weight and a representative grain sample was taken to determine percent moisture. Grain yield (GY), measured in kg ha^{-1} adjusted to 15% moisture content was calculated from grain weight and percent moisture.

Statistical analyses

General analyses of variance for the lattices were performed for all the hybrid and check trait means. Years, replications, and incomplete blocks were considered as random effects while hybrids were considered fixed effects. Spearman's rank correlation coefficient was estimated using hybrid yield means for the two years, and Pearson's correlation coefficients were calculated between pairs of mean values of grain yield and other measured traits. All analyses were performed with SAS software (SAS Institute, 2009).

Table 2: Mean squares of measured traits of 96 single-crosses and 4 checks evaluated under natural disease inoculation in the rainy seasons of 2011 and 2012 at Ikenne, southwest Nigeria.

Source of Variation	Df	Grain yield (kg ha^{-1})	Plant aspect (1-5)	Ear aspect (1-5)	Streak (1-5)	Rust (1-5)	Blight (1-5)	Curvularia (1-5)
Year	1	27828.7	37.3	11.1	171***	127***	97***	17***
Blk	9	716912.7	0.1	0.3	0.2	0.4**	0.1	0.2*
Blk (Rep x Year)	49	691738.1**	0.2	0.3	0.7***	0.3**	0.2**	0.1**
Hybrid	99	3098537***	0.7***	1.2***	0.5**	0.5***	1.1***	0.3***
Hybrid x Year	99	789108***	0.2	0.4**	0.5**	0.3***	0.2*	0.2***
Error	342	414082	0.2	0.2	0.3	0.2	0.1	0.1

*, **, *** Mean squares significant at $p < 0.05$, 0.01, and 0.0001, respectively.

Table 3: Correlation coefficients of grain yield (kg ha^{-1}) with other measured traits of the 96 hybrids and 4 hybrid checks evaluated under natural inoculation over two rainy seasons at Ikenne, southwest Nigeria

Trait	Correlation coefficient (r)
Plant aspect (1-5)	-0.46***
Ear aspect (1-5)	-0.58***
Streak (1-5)	-0.20***
Rust (1-5)	-0.16***
Blight (1-5)	-0.29***
Curvularia (1-5)	-0.06ns

*** r significant at $p < 0.0001$; ns = data not significant.

Results

Mean squares for years were significant ($p < 0.0001$) for the four foliar diseases only (Table 2). Hybrids differed significantly ($p < 0.0001$ or 0.01) for all measured traits, and their interaction with year was also significant for all traits except plant aspect (Table 2). Further investigation of the significant hybrid x year interaction using rank correlation analysis revealed that the correlation between hybrid means of the two years was positive and significant ($r = 0.50$, $p < 0.0001$). Grain yield was negatively and significantly ($p < 0.0001$) correlated with all measured traits except with curvularia (Table 3). Among the four foliar diseases, leaf blight had the most appreciable but negative correlation coefficient ($r = -0.29$) with grain yield.

Table 4: Trait means of 20 highest yielding hybrids evaluated under natural disease inoculation during the rainy seasons of 2011 and 2012 at Ikenne, southwest Nigeria.

HYBRID	Grain yield (kg ha^{-1})	Plant aspect (1-5)	Ear aspect (1-5)	Streak (1-5)	Rust (1-5)	Blight (1-5)	Curvularia (1-5)
ADL33xEXL15	6132	2.4	1.7	2.0	2.3	2.3	1.5
EXL06xADL33	5960	2.8	2.8	2.1	2.1	1.8	1.8
ADL47xEXL10	5955	2.6	3.0	2.0	2.7	2.4	1.3
ADL47xEXL16	5944	2.7	2.3	1.6	2.6	2.3	1.4
ADL33xEXL16	5869	2.6	2.2	2.0	2.1	2.4	1.4
EXL06xADL47	5781	2.7	2.1	2.1	2.2	2.0	1.6
EXL03xADL33	5588	2.8	2.2	2.3	2.2	2.3	1.8
ADL32xEXL06	5587	2.7	2.4	1.5	2.2	2.4	1.5
ADL47xEXL17	5477	3.0	2.3	1.9	2.0	1.9	1.3
ADL27xEXL06	5445	2.8	2.5	1.8	1.8	2.0	1.7
ADL32xEXL02	5392	2.8	2.6	2.1	2.1	2.5	1.4
ADL37xEXL03	5385	3.0	3.1	2.5	2.1	2.3	1.5
ADL31xEXL16	5360	2.8	3.0	1.9	2.0	2.5	1.3
ADL31xEXL17	5354	3.0	2.1	1.8	2.3	2.6	1.4
EXL05xADL35	5324	2.5	2.6	2.3	1.9	2.2	1.2
EXL10xEXL04	5312	2.9	3.1	2.4	2.4	2.1	1.4
ADL47xEXL15	5239	2.8	2.3	1.8	2.3	2.2	1.5
EXL05xADL34	5225	2.6	2.8	2.0	1.8	2.1	1.3
EXL06xADL31	5201	2.9	2.4	1.9	2.1	2.5	2.0
EXL16xEXL04	5180	2.8	3.2	2.2	2.2	2.3	1.6
Checks							
M1026-8	5749	3.1	2.3	2.2	1.7	1.8	1.1
M1026-7	5485	3.2	2.4	2.3	2.1	1.8	1.2
OBA98	4150	3.3	3.0	2.6	2.4	2.6	1.3
OBASUPER1	3622	3.4	3.3	2.6	2.8	3.2	1.8
Statistics							
Mean±SE	*4509±41*	*3.1±0.02*	*3.0±0.03*	*2.1±0.03*	*2.3±0.03*	*2.6±0.03*	*1.6±0.02*
CV (%)	*14.3*	*11.4*	*15.5*	*26.2*	*17.1*	*14.2*	*18.3*
R^2	*76.4*	*76.1*	*71.7*	*74.8*	*81.2*	*84.2*	*74.9*
$LSD_{0.05}$	*731*	*0.4*	*0.5*	*0.6*	*0.5*	*0.4*	*2.0*

The trait means and statistics of the 20 highest yielding hybrids and four checks are presented in Table 4. Mean grain yields of hybrids varied from 2,282 to 6,132 kg ha^{-1} with a trial mean of 4,509 kg ha^{-1}. Only the top five hybrids exceeded the best check in this study (M1026-8) by at least two standard errors (> 2 SE) whereas all the top 20 hybrids produced significantly higher grain yields than the best commercial check (Oba 98). The top five hybrids had favorable ratings for plant aspect and ear aspect, and all the four foliar diseases. When compared with trial mean of the same set of hybrids evaluated under full irrigation conditions over two consecutive dry seasons, over 30% mean yield reduction could be attributed to the cumulative effects of these four foliar diseases and other associated factors (data not shown). Among the top five crosses, ADL33 was either of the two parents in three crosses; ADL47 and EXL16 were either of the parents in two other different crosses. Both ADL33xEXL16 and ADL47xEXL16 were among the five crosses. Eighteen out of the top 20 hybrids are crosses involving adapted and exotic inbred lines while the remaining two are crosses of exotic x exotic line combinations.

Discussion

The adapted IITA-bred and exotic CIMMYT- bred drought tolerant parental lines that were used for developing the hybrids evaluated in this study have been previously selected for satisfactory response under diverse environmental conditions including the natural disease inoculation conditions in the rainforest agroecology. However, the well-known fact that the *per se* performance of maize inbred lines is not predictive of the performance of their progenies for any particular trait of interest (Hallauer *et al*., 2010) has necessitated the evaluation of these hybrids under endemic disease conditions. Significant differences recorded among hybrids for grain yield and all other traits including the foliar diseases suggest that high yielding hybrids with satisfactory resistance to all the measured foliar diseases can be selected. Although hybrid x year interaction was significant for grain yield and other traits, hybrid performance over the two years was expected to be consistent based on the observed positive and significant rank correlation coefficient. Menkir and Ayodele (2005) have reported consistent hybrid performance over several environments based on observed positive and significant rank correlation coefficient, thereby foreclosing the presence of crossover genotype x environment interaction (GEI).

The highest yielding hybrids in this study also exhibited favorable ratings for the breeder's traits and the foliar diseases. The top five hybrids that out-yielded the best check by at least two standard errors showed enormous potential as high yielding single cross hybrids that may be selected and released to maize farmers in the rainforest agroecolgy of Nigeria.

The four foliar diseases that were assessed in this study were earlier reported to account for significant yield reduction in maize (Van Eijnatten, 1963; Fajemisin *et al*., 1978; Efron *et al*., 1989; Iken and Amusa, 2004), particularly in the rainforest agroecology of Nigeria (Akinwale *et al*., 2013). Though three out of the four foliar diseases significantly affected the grain yield of hybrids, leaf blight had the strongest correlation with grain yield, suggesting that it was the most important disease that reduced maize yield in this study. This was consistent with the results of Akinwale *et al.* (2013). Leaf blight caused by *Helminthosporum turcicum* would account for significant economic damage in maize when conditions are optimum and the infection occurs between tasseling and silking.

All except two of the top 20 hybrids were crosses involving adapted and exotic line combinations, suggesting that alleles for high productivity and resistance to the diseases in the exotic inbred lines largely complimented the alleles in the adapted germplasm. Hybrids formed from combinations of maize inbred lines developed at CIMMYT and IITA have been reported to produce high grain yields under optimum and stressed conditions (Dhliwayo *et al*., 2009; Adebayo, 2012).

Our results underscore the benefits of sourcing unique alleles from exotic germplasm and introgressing them into adapted materials in order to enhance hybrid maize productivity under varying growing conditions of the sub-Saharan Africa

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