Published January 15, 2018

RESEARCH

Screening African Rice (*Oryza glaberrima*) for Tolerance to Abiotic Stresses: II. Lowland Drought

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ABSTRACT

Drought is a major constraint to rice (*Oryza* spp.) production in sub-Saharan Africa. *Oryza glaberrima* Steud., the cultivated rice species that originated from West Africa, is well-adapted to its growing ecologies. This study was initiated to identify promising *O. glaberrima* accessions tolerant to lowland drought stress from the 2106 accessions held at the AfricaRice Genebank. Screening was done over a 3-yr period in West Africa using standardized protocol and involved evaluating for grain yield under drought and/or irrigated conditions, selecting the high-yielding lines, and repeating the testing with the newly selected lines. Four accessions (TOG 7400, TOG 6520, TOG 6519-A, and TOG 7442-B) with consistently higher grain yield under drought stress and irrigated conditions were selected. These four accessions originated from three countries in West Africa, namely, Ghana, Liberia, and Nigeria. The selected *O. glaberrima* accessions could be used as donors in breeding for drought tolerance in rice.

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Abbreviations: DS, dry season; DTF, days to flowering; WS, wet season.

Rice (*Oryza sativa* L.) is a staple food crop for more than half of the world's population, and it is now a strategic commodity crop of importance in Africa. In Africa, rice is grown mainly in rainfed ecosystems. Rainfed lowland and upland occupy ~38% of the total cropped rice area but contribute only 21% of the total rice production (Khush, 1997). This area occupies 20 to 50 million ha of potentially arable land in West Africa (WARDA, 1998). Drought is a major limitation for rice production in rainfed ecosystems in the world and in sub-Saharan Africa, in particular (Evenson and Gollin, 1997; Wopereis and Defoer, 2007). Drought affects rice production in both rainfed uplands and lowlands. In Asia alone, >20 million ha of lowland rice area is affected by drought (Evenson et al., 1996; Pandey et al., 2000). Breeding for drought-tolerant rice is an important objective both in sub-Saharan Africa and globally. In light of climate change, there is an urgent need to boost our efforts in developing high-yielding, drought-tolerant rice cultivars.

In breeding for drought tolerance in rice, the importance of using well-characterized donors is well documented (Venuprasad et al., 2007, 2008; Kumar et al., 2008). The number of good

Published in Crop Sci. 58:133–142 (2018).
doi: 10.2135/cropsci2017.04.0255

donors for lowland drought tolerance in rice is limited. Newer and diverse donors are needed to make consistent gains in breeding (Serraj et al., 2011). In a bid to identify new drought-tolerant donors, IRRI recently screened 988 *O. sativa* accessions from their gene bank, and four accessions were identified as useful (Torres et al., 2013). There is a need to expand this search. Wild and related species of rice are considered as potential sources of drought tolerance (Liu et al., 2004). Several efforts have been made to use wild relatives to improve drought tolerance in rice (Gouda et al., 2012). *Oryza glaberrima* Steud., a cultivated species of rice in Africa, also known as African rice, holds much promise.

It is often suggested that *O. glaberrima*, which was domesticated in West Africa ~3000 yr ago, may offer useful genetic resources in breeding for drought tolerance in rice (Portères, 1962, 1976; Vaughan et al., 2008). *Oryza glaberrima* is considered to be a reservoir of genes for tolerance to several abiotic stresses, including drought (Jones et al., 1993, 1997; Sarla and Swamy, 2005; Futakuchi et al., 2012). Breeding for improved drought tolerance will require sufficient evidence on genetic variation in the germplasm collection, and lack of this information within *O. glaberrima* hinders its utilization in breeding drought for tolerance in rice. The Africa Rice Center (AfricaRice) holds >2400 germplasm of *O. glaberrima* accessions in their gene bank (Sanni et al., 2013), and only limited efforts were made to use them in breeding. Jones et al. (1997) screened 1130 *O. glaberrima* accessions for upland drought adaptation, and the selections were further used in breeding with *O. sativa* to develop NERICAs, cultivars adapted to upland agroecosystems. Similarly, Ndjiondjop et al. (2012) evaluated 211 *O. glaberrima* accessions for vegetative-stage drought tolerance under upland conditions. Several other authors used a few *O. glaberrima* accessions as donors in drought-tolerance-related genetic studies (Dingkuhn et al., 1999; Bimpong et al., 2011a; Bocco et al., 2012; Kijoji et al., 2012, 2014). Drought during the reproductive stage is said to be most detrimental, as drastic reduction in rice grain yield can occur with even a moderate level of drought stress (Hsiao, 1982; O'Toole 1982). However, to our knowledge, no study was conducted to evaluate *O. glaberrima* for reproductive-stage drought tolerance under lowland conditions.

The objective of this study was to evaluate a large set (>2000) of *O. glaberrima* accessions held at AfricaRice's Genebank and identify the best accessions of *O. glaberrima* that are high yielding under reproductive-stage drought conditions so that they can be used in breeding new high-yielding, drought-tolerant rice breeding lines.

MATERIALS AND METHODS

Experimental Sites

Experiments were conducted at three sites in West Africa. These included two sites in Nigeria (Ibadan and Badeggi) and one site in Benin Republic (Cotonou).

The trial site in Ibadan is located inside the IITA campus. The IITA is located at 7°50′22.2222″ N and 3°91′2.7778″ E at an elevation of 248 m asl in the forest–savannah agroecosystem. The soil type is Alfisols clay loam, with a soil pH of 5.0 to 6.5. Six field experiments were conducted at this site in lowland paddy fields.

The trial site in Badeggi is located in the experiment station of the National Cereals Research Institute (NCRI), Badeggi, Niger State, Nigeria. Badeggi is located at 9°5 ′72.68″ N and 6°13′60.28″ E at an elevation of 70.5 m asl in the Guineas savannah agroecosystem. The soil is sandy loam, with a pH of 6.5 to 7.0. Iron toxicity is a common soil problem in this area. One experiment was conducted in a lowland paddy in the dry season (DS) of 2014.

The trial site in Cotonou is located in the experiment station of AfricaRice, Cotonou, Republic of Benin Cotonou at 6°49′8.33″ N and 2°51′41.67″ E at an elevation of 23.0 m asl. An experiment was conducted under a rainout shelter in the wet season (WS) of 2014.

All fields chosen for study did not have a high groundwater water table and were not prone to water logging, in case of unexpected rain events.

Plant Material and Initial Screening

Two thousand one hundred and six *O. glaberrima* accessions were obtained from the gene bank of AfricaRice, and out of these, accessions with poor seed viability and strong dormancy were eliminated (based on earlier experiments) and only 2000 accessions were selected (Table 1). CG 14, a drought-tolerant *O.*

Table 1. Geographical origin of selected *Oryza glaberrima* accessions in West Africa.

	No. of accessions tested			
	Dry season			Wet season
Country of origin	2012	2013	2014	2014
Burkina Faso	38	8	0	0
Cameroon	17	9	1	0
Chad	4	4	1	0
Egypt	1	1	0	0
Gambia	13	3	1	0
Ghana	24	8	1	0
Guinea	380	31	3	1
Guinea-Bissau	16	2	0	0
Ivory Coast	40	8	2	0
Japan	1	1	0	0
Liberia	547	131	30	7
Mali	272	34	4	3
Nigeria	456	110	17	6
Senegal	146	10	1	1
Sierra Leone	28	9	0	0
Chad	12	5	1	0
Togo	4	2	0	0
Unknown	1	46	12	3
Total	2000	412	74	21

glaberrima accession, was included as a check. One *O. sativa* cultivar, IR 77298-14-1-2-B-10, developed at IRRI, Philippines (Venuprasad et al., 2007, 2008, 2011), was included as a drought-tolerant check. FARO 52, a cultivar released in Nigeria for lowland agroecosystems, was used as a local check. These three entries will hereafter by referred to as checks in all experiments.

In DS 2012, the selected 2000 *O. glaberrima* accessions were evaluated in an augmented design in a lowland paddy field at the Ibadan station. The three checks were repeated in the experiment. Severe drought stress was imposed during the reproductive stage following a protocol similar to the one used at IRRI (Venuprasad et al., 2007). After phenotypic assessment, the entries were ranked according to grain yield and biomass. One hundred and fifty-five entries with higher yield and 257 entries with biomass greater than FARO 52 were selected. Those entries exhibiting strong photoperiodism, lodging, or grain shattering were not considered for selection. Details of the material used are provided in Table 1.

Replicated Screening of *O. glaberrima*

In DS 2013, two lowland field drought experiments (Exp. 1 and 2) were conducted at the Ibadan station. In Exp. 1, the 155 entries that were selected according to grain yield from the initial screening were evaluated for drought tolerance along with the standard checks. In Exp. 2, the 257 entries that were selected according to biomass from the initial screening, and the checks, were evaluated for drought tolerance. Selection was made based on grain yield, and a total of 74 accessions were selected. Only phenotypically uniform plants within each entry were harvested, and seeds from these were used for further experiments.

These selected accessions and the checks were evaluated in three experiments during DS 2014: two experiments were under drought and one under nonstress control conditions. The drought experiments were conducted in Ibadan (Exp. 3) and Badeggi (Exp. 4), whereas the nonstress trial was conducted in Ibadan (Exp. 5). Based on grain yield across trials, under stress and nonstress conditions, 21 high-yielding and drought-tolerant *O. glaberrima* accessions were selected.

In WS 2014, the selected 21 accessions and the checks were again evaluated in four experiments. Two lowland experiments were conducted at the Ibadan station, of which one trial was conducted under nonstress control conditions (Exp. 6) and another under rainfed conditions (Exp. 7). Two experiments were conducted at a rainout shelter in Cotonou station in Republic of Benin, one under drought conditions (Exp. 8) and another under nonstress control conditions (Exp. 9). Based on grain yield in these experiments, four drought-tolerant accessions were selected. The experimental material and conditions are presented in Tables 1 and 2.

Field Layout and Trials Management

The initial evaluation trial (DS 2012) of 2000 accessions for drought tolerance was laid out in an unreplicated augmented design, whereas all subsequent trials were laid out in α lattice design. All experiments in DS 2013 and DS 2014 had two replications, whereas all the yield trials in WS 2014 were replicated three times (Table 2).

All experiments consisted of two-row plots of 3-m length with 20-cm $\times$ 20-cm spacing between plants and rows and an area of 1.2 m^2. In all trials, seeds were first planted in a nursery, and 21-d-old seedlings were transplanted into a well-levelled puddled field. In nonstress control experiments, standing water of $\sim$2 to 5 cm was maintained in the field throughout the duration of the experiment. In both drought stress experiments and the rainfed lowland trial, management for the first 30 d after transplanting was similar to the irrigated trials. In the rainfed trial, irrigation was stopped 30 d after transplanting, and the crop was rainfed until harvest. In drought stress trials, drought stress was imposed 3 wk after transplanting. Drought stress was imposed by draining water from the field and keeping it dry. The field was watered again once the plants showed severe stress symptoms (based on leaf rolling and drying) and soil water potential reached below −50 kPa (as measured by two tensiometers at 20-cm depth in each trial). In addition, two Diviner 2000 (Sentek) tubes were installed at 45-cm depth in each replication for soil moisture content measurement. The field was reirrigated by flash flooding and drained again after $\sim$24 h for another drought cycle. This cycle of imposing stress and then relieving it after attaining a certain level was continued until harvest.

During crop growth in DS 2013, 387.7 mm of rainfall was received, whereas the total pan evaporation was 470.7 mm. The average temperature was 24.3°C (ranging between 23.5 and 37°C), and average relative humidity was 40.2% (ranging between 9.0 and 98.0%). In DS 2014, 407.5 mm of rainfall was received, whereas the total pan evaporation was 473.5 mm. The average temperature was 23.0°C (ranging between 19.0 and 37.0°C), and average relative humidity was 33.4% (ranging between 27.0 and

Table 2. Summary of experimental sites, design, and number of replications

Experiment no.	Site and season	No. of accessions	Experimental design	No. of replications	Selected entries
Initial screening	Ibadan station, dry season 2013	2000	Augmented design	Unreplicated	–155 based on grain yield, –257 based on biomass
Experiment 1	Ibadan station, dry season 2013	155	Alpha lattice	2	74 based on grain yield
Experiment 2	Ibadan station, dry season 2013	257	Alpha lattice	2	
Experiment 3	Ibadan station, dry season 2014	74	Alpha lattice	2	21 based on grain yield
Experiment 4	Badeggi station, dry season 2014	74	Alpha lattice	2	
Experiment 5	Ibadan station, dry season 2014	74	Alpha lattice	2	
Experiment 6	Ibadan station, wet season 2014	21	Alpha lattice	3	4 based on grain yield
Experiment 7	Ibadan station, wet season 2014	21	Alpha lattice	3	
Experiment 8	Cotonou station, wet season 2014	21	Alpha lattice	3	
Experiment 9	Cotonou station, wet season 2014	21	Alpha lattice	3	

74.0%). In WS 2014, 924.1 mm of rainfall was received, whereas the total pan evaporation was 266.2 mm. The average temperature was 22.2°C (ranging between 20.0 and 31.5°C), and average relative humidity was 67.1% (ranging between 53.0 and 100.0%. Evapotranspiration and rainfall were measured in DS 2013 to 2014 to show moisture fluctuation during crop growth period (Fig. 1 and 2). In Badeggi, a drier-than-normal condition after high temperature and increased evaporation effects in the north-central areas created water stress followed by erratic rainfall, whereas in Cotonou, the experiment was under rainout shelter conditions, but on average, the temperatures are always high followed by moderate rainfall.

Inorganic fertilizer was applied at the rate of 30–10–10 kg N–P–K ha^{-1} at 2 wk after transplanting with two equal split applications of urea at the tillering and booting stages at 10 kg N ha^{-1}. Weed control was done by application of the broad-spectrum, postemergence, selective herbicide OrizoPro (Candel, containing 260 g propanil and 200 g 2,4-dichlorophenoxyacetic acid L^{-1}) ~3 to 4 wk after transplanting, and at later stages by hand weeding. Field management for all trials was similar.

Data Collection and Analysis

Data of rainfall, temperature, evapotranspiration, and relative humidity during each experiment were obtained from the IITA's weather station in Ibadan. Data were recorded on four quantitative traits: days to flowering (DTF), plant height (cm), number of panicles, and grain yield (g m^{-2}).

Days to flowering was recorded when the panicle was exserted in ~50% of the plants in a plot. Plant height was measured on three randomly selected plants in each plot from the ground to the tip of the panicle and averaged. Number of panicles was counted on three randomly selected plants from each plot and averaged. Grain yield from each plot was harvested and dried to 14% moisture content and weighed. In drought stress trials, leaf rolling was scored on a scale of 0 to 9, as per the standard evaluation system (IRRI, 1996).

Statistical analysis was performed using the Breeding View in Breeding Management System version 3.0.9 (Cyverse, 2015). Replication and blocks within replication are considered as random, whereas genotype was considered as fixed. Means, broad-sense heritability, and LSDs (5%) were obtained from the output of the software.

RESULTS

Clear phenotypic variation within *O. glaberrima* for drought tolerance was observed. Surprisingly, CG 14 showed poor yields and had lower grain yield than the *O. sativa* check and at least three of the selections in most of the trials. In at least three trials, the performance of even the *O. sativa* susceptible check was better than that of CG 14. At least 50% of the accessions showed complete sterility due to stress. Only ~10% of accessions showed good seed set with complete filled grain, and the remaining showed partial seed set with

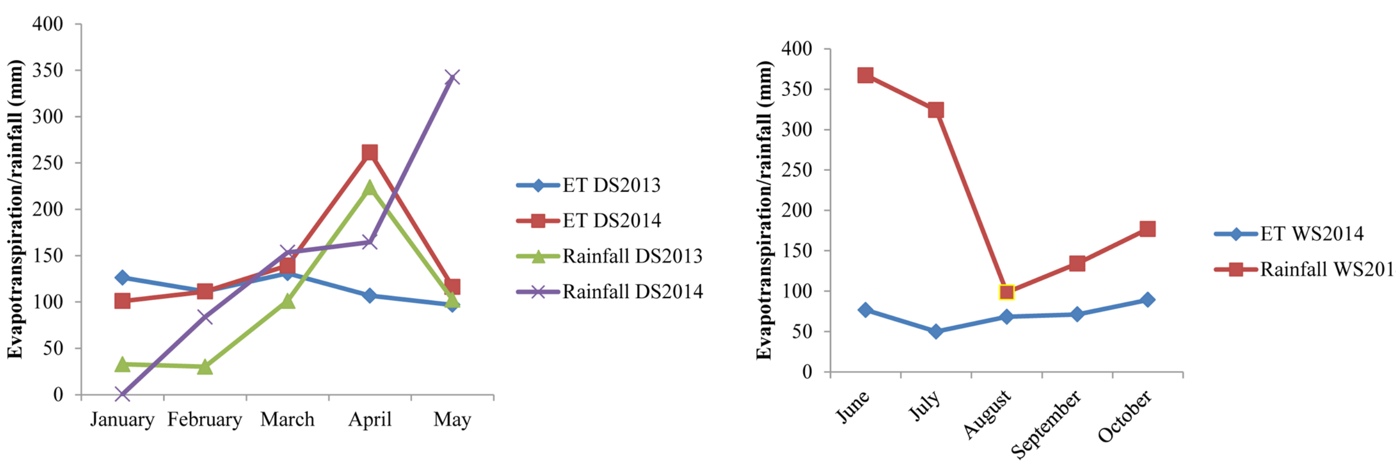

Fig. 1. Evapotranspiration (ET) and rainfall during the crop growth period in dry (DS, left) and wet (WS, right) seasons in 2013 and 2014.

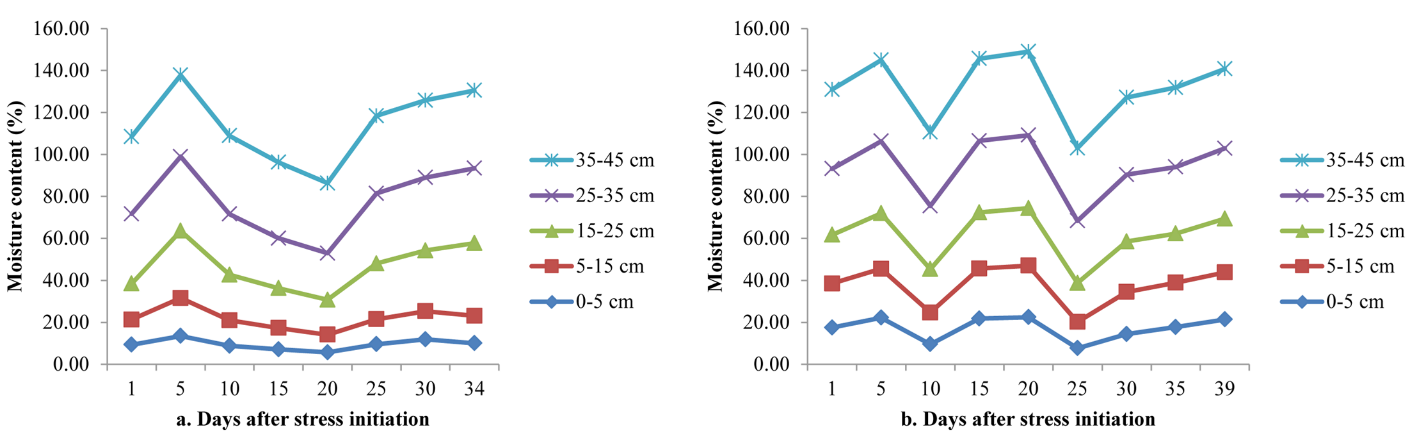

Fig. 2. Soil moisture content during drought imposition in (a) 2013 and (b) 2014.

Table 3. Grain yield of selected *Oryza glaberrima* accessions and standard checks under drought, rainfed, and control conditions during dry (DS) an wet (WS) seasons of 2013 to 2014 at three locations in West Africa.

	Drought			Rainfed			Control	
	Ibadan	Ibadan	Ibadan	Badeggi	Cotonou	Ibadan	Ibadan	Cotonou
Entries	DS 2013†	DS 2013‡	DS 2014	DS 2014	WS 2014	WS 2014	WS 2014	WS 2014
	g m^{-2}							
O. glaberrima								
No. evaluated	155	257	74	74	21	21	21	21
Minimum	18	2	9	2	11	38	23	96
Maximum	401	236	301	25	83	349	403	443
Mean	187	129	110	7	46	175	235	290
Selections								
TOG 7400‡	–	236	236	25	83	270	399	368
TOG 6520†	401	–	301	7	–	349	403	455
TOG 6519-A†	393	–	226	5	72	303	286	308
TOG 7442-B†	327	–	152	7	69	251	292	443
Check								
CG 14	217	238	51	6	60	104	415	339
O. sativa checks								
FARO 52	472	447	216	9	–	55	–	619
IR 77298-14-1-2-B-10	363	451	298	12	56	263	418	285
Trial mean	246	161	122	6	51	171	241	310
$LSD_{0.05}$	142	142	103	5	43	130	119	149
Heritability	0.87	0.75	0.71	0.69	0.70	0.85	0.90	0.84

† Accessions selected based on grain yield in DS 2012.

‡ Accessions selected based on biomass in DS 2012.

premature grain filling, whereas FARO 52 showed partial seed set. However, many accessions performed better than the susceptible check (FARO 52).

Grain Yield

Mean grain yields of *O. glaberrima* and *O. sativa* checks in eight separate trials are presented in Table 3. There was a range of stress levels in drought trials, from mild in Ibadan (DS 2013) to very severe in Badeggi trial (DS 2014). There was wide range in grain yield performance of *O. glaberrima* accessions. On average, there was a 28-fold difference between maximum and minimum grain yield among the genotypes and across trials, and this difference ranged from fivefold to 118-fold. On average, the mean of four selections was 70% higher than the *O. glaberrima* mean, and the increase was higher in stress (82%) and rainfed conditions (68%) than in the control (41%).

In the mild to moderate stress trials in Ibadan (DS 2013), two selections significantly outyielded the check CG 14, whereas the other two selections' yields were like that of CG 14 (Table 3). In the severe stress trial in DS 2014, three selections outyielded CG 14 in Ibadan, whereas in Badeggi, only TOG 7400 outyielded CG 14. In the WS trial in Cotonou, the difference between the four selections and CG 14 was not significant. In rainfed conditions, all the four selections significantly out-yielded CG 14. In control conditions in Ibadan, two selections yielded the same as CG 14, whereas the two others were lower yielding. In the Cotonou control trial, the yield of all four selections was like that of CG 14. Thus, under drought and rainfed conditions, the four selections were either significantly higher yielding than CG 14 or at least had equal yield, but they were never inferior. Under control, they had either the same yield as CG 14 or inferior yield, but never superior.

In the mild to moderate stress trials in Ibadan (DS 2013 and 2014), the *O. sativa* checks yielded significantly higher than the *O. glaberrima* check (CG 14). However, in the severe stress trials in Badeggi (DS 2014), FARO 52 yielded similar to CG 14, whereas IR 77298-14-1-2-B-10 yielded slightly higher. IR 77298-14-1-2-B-10 and CG 14 had similar yield in the drought trial in Cotonou (WS 2014). Under control conditions in both years, CG 14 and IR 77298-14-1-2-B-10 had the same yield. FARO 52 yielded significantly higher (82%) than CG 14 in the Cotonou trial.

IR 77298-14-1-2-B-10, the drought-tolerant *O. sativa* check, was significantly higher yielding than the best *O. glaberrima* selection in only one out six stress trials (i.e., in the moderate stress trial in DS 2013). Similarly, FARO 52 yielded higher than all *O. glaberrima* selections only under control conditions in Cotonou. Heritability for grain yield ranged from 0.69 to 0.90 (Table 3)

Days to Flowering

Significant differences among *O. glaberrima* accessions for DTF were seen (Table 4). There was a 1.2- to twofold difference in DTF between accessions. Mean DTF of the four selections matched closely with the mean of *O. glaberrima* under stress, but under control, the selected entries had a

Table 4. Days to 50% flowering of selected *Oryza glaberrima* accessions and standard checks under drought, rainfed, and control conditions during dry (DS) an wet (WS) seasons of 2013 to 2014 at three locations in West Africa.

Entries	Drought			Rainfed			Control	
	Ibadan DS 2013†	Ibadan DS 2013‡	Ibadan DS 2014	Badeggi DS 2014	Cotonou WS 2014	Ibadan WS 2014	Ibadan WS 2014	Cotonou WS 2014
	d							
O. glaberrima								
No. evaluated	155	257	74	74	21	21	21	21
Minimum	51	53	48	50	41.3	92	83.3	51.7
Maximum	87.5	72	83	100.5	54	110.3	107.7	73
Mean	78.8	64	80.1	89.4	51.5	104.9	89.3	61.3
Selections								
TOG 7400‡	–	72	77.5	85.5	54	103.3	104.7	58.7
TOG 6520†	87.5	–	83	100.5	–	98	103	73
TOG 6519-A†	77	–	80	93.5	46.7	108	107.7	62
TOG 7442-B†	72	–	80	78	53.7	110.3	107	59.3
Check								
CG 14	59	67.8	67.8	61	55.3	100	89	54
O. sativa checks								
FARO 52	96.8	100	95.8	99.5	–	113.3	116.7	64.3
IR 77298-14-1-2-B-10	69	68.5	68.8	90.5	62.3	117.7	89.3	61.3
Trial mean	76.6	65	65	104.5	54.5	110.7	105.1	61.1
$LSD_{0.05}$	16.2	16.2	16.2	4.8	16.1	1.9	1.8	13.6
Heritability	0.70	0.86	0.86	0.94	0.81	0.99	0.99	0.59

† Accessions selected based on grain yield in DS 2012.

‡ Accessions selected based on biomass in DS 2012.

higher mean. Significant differences among the selected accessions were observed under both stress and control.

The selected accessions and CG 14 flowered simultaneously in both stress and control conditions. The difference between CG 14 and the selections was higher under very severe stress (Badeggi) than under milder stress. Mean DTF of CG 14 was lower (59 d) than for the *O. sativa* checks in most trials.

Irrespective of management conditions, FARO 52 had the highest DTF in five out of seven trials. Under drought stress, the *O. glaberrima* selections and IR 77298-14-1-2-B-10 had the same DTF, whereas under rainfed conditions, IR 77298-14-1-2-B-10 had higher DTF, and under Ibadan control conditions, it had lower DTF than the selections. Heritability for DTF ranged from 0.59 to 0.99 (Table 4)

Plant Height

In general, height was reduced with increased stress in both *O. glaberrima* and *O. sativa*. An almost twofold range in variation for plant height among *O. glaberrima* accession was observed in earlier experiments (DS 2013). Both mean and variation decreased in later experiments (WS 2014; Table 5). The mean under control was higher than that under stress. Both the highest and lowest means in each trial were shown by an *O. glaberrima* accession. No differences in plant height were observed between mean of four selected accessions and the mean of *O. glaberrima* in different trials. Significant differences between selected accessions were observed.

The plant height of selections was either higher or equal to that of CG 14 in both stress and control conditions. The differences between CG 14 and the selections were larger under severe stress conditions than under mild stress or control conditions.

The drought-tolerant IR 77298-14-1-2-B-10 *O. sativa* check was significantly lower in height than CG 14 in five out of eight trials, whereas FARO 52 had higher plant height than CG 14 in four out of seven trials. In most cases, the selections were taller than FARO 52 and shorter than IR 77298-14-1-2-B-10. Heritability for plant height ranged from 0.53 to 0.99 (Table 5).

Panicle Numbers

On average, twofold difference was observed within *O. glaberrima* for panicle number (Table 6). No difference between mean of *O. glaberrima* and mean of selected accession was observed in any trial. Significant difference existed within the selected accessions. In most cases, the panicle number of selected accessions of *O. glaberrima* was either the same as that of CG 14 or less than it. In two trials TOG 6519-A had higher panicle number than CG 14. TOG 7400 and TOG 7442-B had higher panicle numbers than CG 14 in the control trial in Cotonou.

In all stress trials checks, IR77298-14-1-2-B-10 and CG 14 had similar panicle number. However, in the control trials, IR77298-14-1-2-B-10 showed higher panicle number than CG 14 in Cotonou, whereas in Ibadan, CG 14 had higher

Table 5. Plant height of selected *Oryza glaberrima* accessions and standard checks under drought, rainfed and control conditions during dry (DS) an wet (WS) seasons of 2013 to 2014 at three locations in West Africa.

Entries	Drought			Rainfed			Control	
	Ibadan DS 2013†	Ibadan DS 2013‡	Ibadan DS 2014	Ibadan DS 2014	Ibadan WS 2014	Ibadan WS 2014	Ibadan WS 2014	Ibadan WS 2014
	cm							
O. glaberrima								
No. evaluated	155	257	74	74	21	21	21	21
Minimum	63.3	64.5	62.2	78.3	101.7	101.7	125.8	116.9
Maximum	130.8	126.3	115.5	116.8	104	131.8	167.4	148
Mean	110.9	102.5	112.1	106	102.4	124.5	153.9	140.2
Selections								
TOG 7400‡	–	126.3	115.5	116.8	104	131.8	167.4	129.7
TOG 6520†	101.6	–	105.3	94.8	–	130.4	136.3	145
TOG 6519-A†	100.2	–	112.7	96	99.7	118.1	148.8	138
TOG 7442-B†	130.8	–	114.7	116.5	103.4	117.7	163	148
Check								
CG 14	104.5	95.3	84.8	84.8	86.6	86.6	137.9	120.7
O. sativa checks								
FARO 52	109	104.8	103.3	99.6	–	106.3	120.4	127.7
IR 77298-14-1-2-B-10	89	88.5	85.5	101	82.7	93	113.6	94.3
Trial mean	100	94.7	95.5	104.5	94.5	113.9	141.5	128.4
$LSD_{0.05}$	5.6	5.6	4.1	4.8	13.4	4.1	3.7	14.3
Heritability	0.96	0.92	0.93	0.94	0.53	0.98	0.99	0.87

† Accessions selected based on grain yield in DS 2012.

‡ Accessions selected based on biomass in DS 2012.

Table 6. Number of panicle of selected *Oryza glaberrima* accessions and standard checks under drought, rainfed and control conditions during dry (DS) an wet (WS) seasons of 2013 to 2014 at three locations in West Africa.

Entries	Drought			Rainfed			Control	
	Ibadan DS 2013†	Ibadan DS 2013‡	Ibadan DS 2014	Badeggi DS 2014	Cotonou WS 2014	Ibadan WS 2014	Ibadan WS 2014	Cotonou WS 2014
	no. m^{-2}							
O. glaberrima								
No. evaluated	155	257	74	74	21	21	21	21
Minimum	98	125	187.5	187.5	93.3	130.6	150	206.7
Maximum	358	350	391.7	267	131.7	311.1	286.1	450
Mean	276	327.5	294.8	220	126.7	232	256.3	321.3
Selections								
TOG 7400‡	–	305	275	267	131.7	200	277.8	450
TOG 6520†	358	–	391.7	200	–	311.1	252.8	206.7
TOG 6519-A†	225	–	270.8	246	120	202.8	286.1	310
TOG 7442-B†	245	–	241.7	167	128.3	213.9	208.3	318.3
Check								
CG 14	320	370	304.2	304.2	185	208.3	286.1	311.7
O. sativa checks								
FARO 52	263	278	260.4	260.4	–	211.1	266.7	136.7
IR 77298-14-1-2-B-10	358	390	295.8	295.8	186.7	225	205.6	400
Trial mean	263.6	325.8	272.2	188.7	123.8	217	241.8	334.2
$LSD_{0.05}$	67.4	67.4	58.9	50.6	13.9	38	51.9	3.7
Heritability	0.79	0.67	0.76	0.81	0.49	0.91	0.97	0.90

† Accessions selected based on grain yield in DS 2012.

‡ Accessions selected based on biomass in DS 2012.

panicle number than IR77298-14-1-2-B-10. Heritability for panicle number ranged from 0.49 to 0.97 (Table 6).

DISCUSSION

In this study, we evaluated a large set of *O. glaberrima* accessions under lowland drought stress using yield-based screening and identified the best drought-tolerant accessions that could be used in breeding for drought tolerance in rice. This is the first study reporting extensive screening from a large set of *O. glaberrima* accessions for drought tolerance in a lowland agroecosystem, with grain yield as the main selection criteria.

Out of the 2000 *O. glaberrima* accessions tested, we selected four accessions (TOG 7400, TOG 6520, TOG 6519-A, and TOG 7442-B) that were found to produce higher grain yield under drought stress. In a previous study by Ndjiondjop et al. (2012), five accessions (TOG 6208, TOG 5691, TOG 5591, TOG 6594, and RAM 122) were selected from evaluation of 327 accessions. There was no common entry selected between the two studies; this may be because the earlier study was conducted in upland conditions and during the vegetative stage, whereas our study was conducted in lowland conditions and during reproductive stage. Response of rice plants (*O. sativa*) to drought in upland and lowland conditions is quite different, and different sets of materials and donors are needed in the two ecologies. This probably holds good for *O. glaberrima* as well, and separate donors are needed for upland and lowland conditions.

The four selections were from different countries: TOG 7400 originated from Ghana, TOG 6519-A and TOG 6520 originated from Liberia, and TOG 7442-B originated from Nigeria. An online search on the AfricaRice Genebank (Africa Rice Center, 2015) showed that our four selections shared same country of origin as three of the five accessions reported by Ndjiondjop et al. (2012). This suggests that good diversity for drought tolerance among *O. glaberrima* may be prevalent in these locations. These locations could be targeted for further collection efforts from Genebank and/or breeders.

Grain yield under stress is a criterion that has been successfully used for selection for drought tolerance in *O. sativa* (Venuprasad et al., 2007, 2008). The same criterion was used for selection for drought tolerance in *O. glaberrima* by us. The effects of this selection can be clearly seen in Table 1. On average, the four selected accessions yielded 82% higher than the full group under stress. Similarly, under rainfed and control, they were 68 and 41% higher yielding, respectively. However, in terms of DTF, plant height, and panicle number, the mean of the selected group was similar to the full set tested.

CG 14 is widely cited as a drought-tolerant *O. glaberrima* accession and has been used in breeding for drought tolerance (Dingkuhn et al., 1999, Ndjiondjop et al., 2010, Bimpong et al., 2011b). CG 14 was selected as drought tolerant in upland conditions by earlier researchers, but in lowland conditions, it is not as drought tolerant as the new selections. Under different conditions (severe stress, mild stress, and control) and irrespective of the experimental locations (Ibadan, Badeggi, and Cotonou), at least one or all the four selections outyielded CG 14. However, in Ibadan, where some incidence of blast was observed, two selected accessions (TOG 6519-A and TOG 7442-B) were significantly lower yielding, whereas the other two yielded equal to CG 14. In addition, the selected accessions had similar yield to the *O. sativa* tolerant check, except for the severe drought experiment in Badeggi, where TOG 7400 was ranked first.

From the above discussion, it can be concluded that in terms of drought tolerance, the lines identified in this study are either better or at the least similar to CG 14 (the drought-tolerant *O. glaberrima* check). However, these accessions were not superior to IR 77298-14-1-2-B-10 (the drought-tolerant *O. sativa* check) in terms of drought tolerance— they were either on par with or inferior to it. Their yield potential is similar to that of IR 77298-14-1-2-B-10, but they are not superior to the high-yielding *O. sativa* local check (FARO 52). Apart from these four selections, there were other accessions that could consistently yield >4 t ha^{-1} in control conditions (Table 3). This suggests that not all *O. glaberrima* accessions are lower yielding, as noted by earlier researchers (Linares, 2002). Similar observations were made by Sikirou et al. (2017).

The four accessions were selected after strongly selecting against strong dormancy, photoperiodism, lodging, and shattering. Their plant height and DTF are similar to those of the *O. sativa* checks. They are not lower yielding than some of the *O. sativa* checks. Thus, the selections are not agronomically inferior compared with the *O. sativa* checks. The selected accessions can serve as alternatives to CG 14 in breeding for drought tolerance in the lowland agroecosystem. They could also be used in addition to the *O. sativa* donors to breed for drought-tolerant rice. They can help to broaden the genetic base of the newly developed cultivars. These donors are particularly important in Africa, as they are well adapted to local stresses (such as Fe toxicity, African rice gall midge [*Orseolia oryzivora* Harris & Gagné], *Rice yellow mottle virus*, etc.) and will be important when combining tolerance to multiple stresses (Sarla and Swamy., 2005; Venuprasad et al., 2007; Thiémélé et al., 2010; Ndjiondjop et al., 2012; Yao et al., 2016; Pidon et al., 2017; Sikirou et al., 2017). One of the main challenges in using *O. glaberrima* accessions in interspecific breeding with *O. sativa* is the problem of sterility that hinders hybridization (Ghesquière et al., 1997). However, the sterility barrier can be overcome with backcrossing, as was done during the development of lowland NERICA cultivars (Sie, 2008). Bridge lines can be used significantly to improve fertility when crossing the two species (Deng et al., 2010; Lorieux et al., 2013).

CONCLUSIONS

Considerable phenotypic variation for grain and related yield traits under drought stress was found within the selected *O. glaberrima* accessions. Four accessions with higher yield under drought-stress conditions and stability across different environments were identified. These accessions are TOG 7400 (accession no. WAB0002219), TOG 6519-A (accession no. WAB0032689), TOG 6520 (accession no. WAB001712), and TOG 7442-B (accession no. WAB0032558). These lines will probably contribute to widen the genetic base of the lowland rice breeding program gene pool.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgments

This study was funded by a Generation Challenge Program (GCP)-funded project (G7010.04.01). We appreciate the technical assistance provided by National Cereals Research Institute (NCRI) technicians and research staff in Cotonou, and the assistance of Sikirou Mouritala in conducting these experiments.

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