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Full Length Research Paper

Morpho-agronomic evaluation of *Oryza glaberrima* accessions and interspecific *O. sativa* × *O. glaberrima* derived lines under drought conditions

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Two dry-season field experiments were conducted at AfricaRice research station in Benin to identify drought tolerant rice genotypes from a range of genetic resources: in 2006 using 202 backcross-inbred interspecific *Oryza sativa* × *Oryza glaberrima* lines, replicated in 2007 (experiment 1); and in 2007 (replicated in 2008) using a population of 327 genotypes comprising *O. glaberrima*, *O. sativa*, interspecific lines and local landraces (experiment 2). Plots were fully irrigated from sowing to maturity (control) or subjected to 21-day drought (drought), respectively. Plant height, number of tillers and grain yield values were higher under control than drought for most genotypes. Contrary observations were made for leaf greenness (SPAD), leaf temperature, flowering and maturity. The 24 top-yielding lines in experiment 1 and 20 top-yielding lines in experiment 2 followed this general trend. Significant genotype × environment interaction was observed for SPAD, number of tillers and grain yield. Grain yield, flowering and maturity were affected by drought for 98.0, 95.1 and 100% genotypes, respectively, for experiment 1, and 99.1, 99.4 and 98.2%, respectively, for experiment 2. The study identified 003-2-2, 77-2-4, 61-1-1, 94-1-5, 94-2-3, 117-2-6, 77-5-3 (interspecific lines), and TOG6383, TOG5691, RAM122, TOG5919 (*O. glaberrima*), as stable or high yielding genotypes under drought and potential resources for further drought studies.

Key words: West Africa, *Oryza glaberrima* Steud., *Oryza sativa* L., drought, interspecific rice, yield.

INTRODUCTION

Drought is defined as a period of rainfall/water shortage or a condition where the amount of rainfall/water is below normal average for a given region (Hounkpatin, 2007). It is a major constraint to rice (*Oryza* spp.) production in upland and hydromorphic conditions in West Africa (Jones et al., 2002; Manneh et al., 2007) and in rainfed lowland (Hanamaratti et al., 2008) where the crop is prone to varying degrees and duration of drought during its cycle. Highly variable rainfall in the forest and savannah zones of West Africa can make a drought incidence which can happen at any growth stages, unpredictable. The occurrence and influence of drought on rice production are more related to rainfall distribution than to total seasonal rainfall. Drought during the crop cycle can severely reduce rice grain yield in rainfed lowland, hydromorphic, and upland environments and sometimes lead to total crop failure (Audebert et al., 2002). Ndjiondjop et al. (2010) reported drought reducing plant height, number of tillers, number of leaves, and leaf width (13.7, 16.9, 6.7 and 14.1% reduction, respectively, compared to fully irrigated condition) and retarded flowering and maturity (drought susceptibility index reaching 26.8 and 13.5, respectively). A significant relationship was observed between grain yield and those

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Abbreviations: Exp, experiment; **DSI,** drought susceptibility index.

traits under drought (Ndjiondjop et al., 2010). Drought-affected rice produces only in 2.0 to 3.0 t ha^{-1} compared to the yield potential of more than 6.0 t ha^{-1} under West African conditions (AfricaRice, 2010). Consequently, some farmers abandon rice cultivation (AfricaRice, 2010).

To overcome yield reduction due to drought, the development of drought tolerant rice has been one of the major activities at the Africa Rice Center (AfricaRice) (Jones et al., 2002), where breeding strategies emphasize the need to understand morpho-physiological characteristics associated with drought the tolerance through mass evaluation of rice germplasm for tolerance at the vegetative and reproductive stages. Considerable variation for various traits, which may be associated with drought tolerance, has been observed in AfricaRice studies. Several promising rice genotypes with drought tolerance have been identified. These genotypes are being used in breeding programs. As well as *Oryza sativa* L., the breeding program has used *Oryza glaberrima* Steud., which is the other cultivated rice species indigenous in West Africa, mostly as a genetic source of resistance to local constraints to improve *O. sativa* by wide hybridization (Jones et al., 1997). It has become almost axiomatic that studying drought tolerance is considered complicated as it is a very complex trait (Blum, 2002). However, identification of genotypes possessing high drought tolerance is ultimately the starting point for the breeding solutions. More than 20000 rice genotypes originating from various African and other continents' countries are available in the AfricaRice gene bank. Several research activities are being carried out on these genotypes (Ndjiondjop et al., 2010), but drought tolerance of the majority of them is still unknown.

In the past, drought screening at AfricaRice, several tolerant genotypes were identified from interspecific *O. sativa* × *O. glaberrima* lines (Ndjiondjop et al., 2010; Bocco et al., 2012), although, only a few *O. glaberrima* lines have been used in the interspecific breeding. Therefore, this study also focused on *O. glaberrima* lines and another set of interspecific lines. Two series of field experiments were conducted at the AfricaRice Cotonou station, Benin, where morphological and agronomic traits of genotypes from the gene bank collection were evaluated under two irrigation regimes (well-watered and drought) to select those that best tolerate drought with high yield potential to be used as donors in breeding programs.

MATERIALS AND METHODS

Experimental details

Two series of field experiments were conducted on the experimental farm of the AfricaRice research station (25 m above sea level; 6° 25' N *latitude and* 2° 20' E longitude) at Togoudo, southern Benin. The station is located in the coastal savannah zone, with a subequatorial climate and a hydromorphic soil (Adam and Boko, 1993). The first experiment (experiment 1) was conducted during the short dry season of July to October 2006 (experiment 1) and repeated during the long dry season of December 2006 to March 2007 (experiment 1). The second experiment (experiment 2) was conducted during the long dry season of December 2006 to March 2007 (experiment 2) and repeated during the long dry season of January to April 2008 (experiment 2).

Genetic material

A population of backcross inbred lines developed from a cross between CG 14 (*O. glaberrima*) as a donor and WAB56-104 (*O. sativa*, subspecies japonica) as a recurrent parent was used in experiment 1. This population comprised 202 interspecific lines belonging to 42 families, with each family contributing with total percentages varying from 0.51 to 7.14%. The planting material used in experiment 2 comprised a population of 327 rice genotypes, including 64.65% of *O. glaberrima* originated from Côte d'Ivoire (1.70%), Ghana (1.70%), Liberia (8.50%), Mali (28.52%), Nigeria (22.50%), Senegal (1.70%) and Sierra Leone (0.03%); 3.06% of *O. sativa*, originated from Côte d'Ivoire (AfricaRice) (1.00%), Brazil (0.03%), Philippines (IRRI) (1.00%), Ibadan (IITA) (0.03%) and Mali (1.00%); 32.20% of interspecific lines from Côte d'Ivoire (AfricaRice) (1.70%) and Mali (30.50%); and 0.09% of local landraces originated from Côte d'Ivoire (AfricaRice) (0.03%), Sierra Leone (0.03%) and Guinée Conakry (0.03%). CG 14 and WAB56-104 were included in the materials as common checks with experiment 1. The materials used in both experiments were obtained from the AfricaRice gene bank. In both trials, seeds were directly sown at a rate of three seeds per hill, and seedlings were thinned to one plant per hill soon after seedling emerged. Square plantings of 20 and 25 cm distances were adopted for experiments 1 and 2, respectively. The experimental plots were 1.0 × 1.5 m and 1.5 × 1.5 m for experiments 1 and 2, respectively. In experiment 1, plots were arranged in a split-plot design replicated twice, with irrigation regime as the main plot factor and genotype as the sub-plot factor. Within each main plot, the lines were randomized using an alpha lattice design. In experiment 2, the experimental plots were arranged in a lattice design with four blocks each was replicated twice. Eighteen incomplete blocks were used in total.

In all cases, the following two irrigation regimes were used: fully irrigated conditions up to maturity (control) and drought conditions (no rainfall and no artificial irrigation) imposed only for 21 days (drought treatment) in the reproductive stage with the full irrigation during the remaining growth period. The drought treatment started from 45 and 34 days after sowing in experiments 1 and 2, respectively, which coincided with the beginning of the reproductive stage—panicle initiation—of rice plants. Irrigation was made by sprinkler using a pipe with water from a borehole and soil moisture above field capacity was maintained during irrigation. Compound fertilizer (NPK, 15-15-15) was applied at the rate of 200 kg ha^{-1} at two weeks after sowing, followed by 40 kg Na^{-1} of urea at 40 days after sowing. Both experiments were kept weed-clean by regular hand-weeding and bird damage was controlled using bird scares. Plants were harvested at maturity, four months after sowing (Hounkpatin, 2007).

Measurements

In both trials, data of above-ground agronomic and morphological traits [plant height, number of tillers, leaf greenness (SPAD reading), leaf temperature, days from seeding to flowering, grain yield and days from seeding to maturity] of the plants were recorded following the Standard Evaluation System (SES) for rice (IRRI, 1996). Leaf temperature and leaf greenness were collected non-destructively every two weeks. Four plants were randomly

Table 1. Proportion (%) of interspecific lines with negative, nil and positive drought susceptibility index (DSI) in the first experiment (experiment 1) in 2006 to 2007.

Trait	All lines^{+a}			Parents (checks)$^{b\#}$	
	Negative	Nil	Positive	CG 14	WAB54-106
Plant height	7.8^{b}	1.6^{c}	90.7^{a}	Pos.	Pos.
No of tillers	0.0^{b}	0.0^{b}	100.0^{a}	Pos.	Pos.
SPAD	73.1^{a}	3.1^{c}	23.8^{b}	Neg.	Neg.
Leaf temperature	62.1^{a}	6.8^{c}	31.1^{b}	Neg.	Neg.
Flowering	80.8^{a}	2.1^{c}	17.1^{b}	Neg.	Neg.
Grain yield	8.4^{b}	1.5^{c}	90.1^{a}	Pos.	Pos.
Maturity	86.6^{a}	2.5^{c}	10.9^{b}	Neg.	Neg.

[a] Including the parents; [b] Pos. and Neg. = positive and negative drought susceptibility index, respectively. For each trait, means with same letters are not significantly different according to the Student–Newman Keuhl (SNK) test (*P*≤0.05).

selected from the central area of each plot excluding the border plants. The selected plants were labeled and used for the evaluation of the traits. During the vegetative stage, plant height was considered as the distance from the soil surface to the tip of the last developed leaf of the main tiller. After heading, plant height was considered as the distance from the soil surface to the tip of the tallest panicle of each plant. Leaf temperature was recorded under non-windy conditions and perfectly clear skies between 9 and 10 a.m. using a hand-held infrared thermometer (Model AG-42, Telatemp Corporation, Inc., Fullerton, CA, USA) placed in the middle (the widest part) of the last fully-developed leaf. Due to failure of the thermometer, leaf temperature was not evaluated in the second year of experiment 2.

Greenness of leaves was recorded between 9 and 10 a.m. using a SPAD meter (SPAD-502, Konica-Minolta) on the last fully developed leaf before flowering and on the flag leaf during flowering. In both cases, the SPAD meter was placed in the middle of the widest part of the leaf. The number of tillers was determined per plant. Regarding phenology data, days from seeding to 100% flowering and to maturity (when 85% of grains on panicles are matured) were recorded. However, days from seeding to maturity were not recorded during the first year of experiment 1. At maturity, all plants were harvested in each sub-plot and manually threshed. Matured grains were dried at 50°C for 3 days and weighed. Yield was represented at the adjusted moisture content of 14%. Drought susceptibility index (DSI) for trait X was calculated as described by Reyniers et al. (1982) such as:

$$\frac{(\text{X fully irrigated condition} - \text{X drought condition})}{\text{X fully irrigated condition}} \times 100$$

Genotypes were classified into groups according to plant height or number of tillers following IRRI (1996). Semidwarf, intermediate, and tall plants were those less than 90 cm, 90 to 125 cm, and more than 125 cm, respectively. Very many, many, intermediate number, few, and very few tillers produced were considered for plants producing more than 25 tillers plant^{-1}, 20 to 25 tillers plant^{-1}, 10 to 19 tillers plant^{-1}, 5 to 9 tillers plant^{-1}, and less than 5 tillers plant^{-1}, respectively. The modified scale of Raemaerkers (2001) was used to evaluate the flowering and maturity types of the genotypes. Early, intermediate, and late flowering were classified as flowering occurring by 70 days, between 71 and 90 days, and after 90 days after sowing, respectively.

Meanwhile, early, intermediate, and late maturity were considered as maturity less than 100 days, between 101 and 120 days, and more than 120 days after sowing, respectively. Analysis of variance (ANOVA) was performed using SAS (version 9.1) statistical software (SAS, 1999) and difference between means was tested using the Student–Newman Keuhl (SNK) test (P≤0.05). Drought susceptibility index (DSI) and values in percentages were arcsin(x) transformed for the statistical analysis but back-transformed values are used in the tables.

RESULTS

In experiment 1, almost all lines showed positive DSI for plant height (90.7%), number of tillers (100.0%) and grain yield (90.1%) (Table 1). However, a few genotypes had negative DSI for plant height (7.8%) and grain yield (8.4%). For SPAD, leaf temperature, flowering, and maturity, most genotypes (62.1 to 86.6%) gave negative DSI. Drought had no effect on a maximum of 6.8% of genotypes, while the proportion of genotypes with positive DSI ranged between 10.9 and 31.1% for these four traits.

The two parents of the interspecific lines evaluated had positive DSI for plant height, number of tillers, and grain yield, and negative DSI for SPAD, leaf temperature, flowering and maturity (Table 2). In the second experiment (experiment 2), observations similar to those of experiment 1 were made for all traits, that is, more genotypes had positive DSI than negative DSI in plant height, number of tillers, and grain yield but did negative DSI than positive DSI in SPAD, leaf temperature, flowering and maturity (Table 2). For a maximum of 8.3% of genotypes, the traits evaluated were not influenced by drought. None of the local landraces was unaffected by drought. The DSI of the two checks was positive for plant height, number of tillers, and grain yield, and negative for the remaining traits evaluated, with the exception of the leaf temperature for CG 14 which was not affected by drought.

Of the traits evaluated in year 1 of experiment 1, only SPAD showed a highly significant G × E interaction (*P* = 0.0062) (Table 3). No significant differences were

Table 2. Proportion (%) of negative, nil, and positive drought susceptibility index (DSI) for the respective genotype groups in the second experiment (experiment 2) in 2006 to 2008.

Trait	*Oryza glaberrima*			*O. sativa*			Interspecific lines			Local landraces			Checks	
	Neg.	Nil	Pos.	Neg.	Nil	Pos.	Neg.	Nil	Pos.	Neg.	Nil	Pos.	CG 14	WAB54-106
Plant height	12.1^{b}	1.0^{c}	86.9^{a}	41.7^{b}	0.0^{c}	58.3^{a}	34.7^{b}	2.0^{c}	63.3^{a}	0.0^{b}	0.0^{b}	100.0^{a}	Pos.	Pos.
No of tillers	13.6^{b}	2.5^{c}	83.8^{a}	33.3^{b}	0.0^{c}	66.7^{a}	13.3^{b}	7.1^{c}	79.6^{a}	0.0^{b}	0.0^{b}	100.0^{a}	Pos.	Pos.
SPAD	89.9^{a}	0.5^{c}	9.6^{b}	83.3^{a}	8.3^{b}	8.3^{b}	93.9^{a}	0.0^{c}	6.1^{b}	100.0^{a}	0.0^{b}	0.0^{b}	Neg.	Neg.
Leaf temp.	63.4^{a}	6.5^{c}	30.1^{b}	72.7^{a}	0.0^{c}	27.3^{b}	58.8^{a}	8.2^{c}	33.0^{b}	66.7.0^{a}	0.0^{c}	33.3.0^{b}	Nil	Neg.
Flowering	68.0^{a}	0.6^{c}	31.5^{b}	66.7^{a}	0.0^{c}	33.3^{b}	55.1^{a}	2.0^{c}	42.9^{b}	66.7.0^{a}	0.0^{c}	33.3.0^{b}	Neg.	Neg.
Yield	7.9^{b}	1.3^{c}	90.7^{a}	8.3^{b}	0.0^{c}	91.7^{a}	8.3^{b}	2.1^{c}	89.6^{a}	0.0^{b}	0.0^{b}	100.0^{a}	Pos.	Pos.
Maturity	84.8^{a}	2.3^{c}	12.9^{b}	90.9^{a}	0.0^{c}	9.1^{b}	89.2^{a}	3.2^{b}	7.5^{b}	100.0^{a}	0.0^{b}	0.0^{b}	Neg.	Neg.

DSI: Neg. = negative, Nil = 0, Pos. = positive. For each trait, means with same letters are not significantly different according to the Student–Newman Keuhl (SNK) test ($P \leq 0.05$).

Table 3. Analysis of variance performed on agronomic traits of 202 inbred lines (experiment 1) with the 2 parents and 327 genotypes (experiment 2) evaluated under fully irrigated and drought conditions in 2006 to 2008.

		Experiment 1				Experiment 2			
		Year 1		Year 2		Year 1		Year 2	
Source		DF	Mean square	DF	Mean square	DF	Mean square	DF	Mean square
Plant height	Genotype (G)	197	113.60^{ns}	200	2228.46^{ns}	263	576.82**	283	269.76**
	Environment (E)	1	27559.07**	1	162016.12*	1	7319.22**	1	22183.44**
	G X E	193	58.24^{ns}	198	960.76^{ns}	263	157.26^{ns}	283	110.58^{ns}
No of tillers	G	200	0.16^{ns}	201	37.08**	263	59.22**	283	122.36**
	E	1	1.53*	1	444.57**	1	27.34^{ns}	1	1.51^{ns}
	G X E	199	0.05^{ns}	200	8.42**	263	16.9**	282	27.2^{ns}
SPAD	G	200	30.39**	201	30.18^{ns}	263	79.85**	283	30.82**
	E	1	769.33**	1	129.04*	1	4569.64**	1	2744.21**
	G X E	199	17.70**	200	12.43^{ns}	263	17.24^{ns}	282	11.66^{ns}
Leaf temp.	G	200	0.59^{ns}	201	1.57^{ns}	263	2.51^{ns}	263	–
	E	1	44.70**	1	56.41**	1	14.76*	1	–
	G X E	199	0.69^{ns}	200	1.52^{ns}	263	2.48^{ns}	263	–
Flowering	G	197	143.36^{ns}	201	162.49^{ns}	263	791.63**	256	779.87**
	E	1	1080.56*	1	1445.71*	1	7339.24**	1	14175**
	G X E	195	15.90^{ns}	199	20.49^{ns}	263	240.96^{ns}	232	82.65^{ns}

Table 3. Contd.

Grain yield	G	200	728784.00^{ns}	201	206011.09^{ns}	263	3094864.90**	254	565301.70**
	E	1	13622554.20*	1	9794805.27**	1	2104135.00^{ns}	1	21039349.20**
	G × E	196	387141.40^{ns}	200	61540.07^{ns}	262	2169686.90^{ns}	232	348108.80**
Maturity	G	–	–	200	82.58^{ns}	197	111.34**	262	608.94**
	E	–	–	1	1792.17**	1	238.51*	1	18507.40**
	G × E	–	–	198	14.89^{ns}	172	29.37^{ns}	241	68.61^{ns}

ns = not significant, * = significant at P≤0.05 and ** = significant at P≤0.01.

observed between genotypes for all traits with the exception of SPAD, for which the difference was highly significant (*P*<0.0001). Differences were significant between environments for plant height, SPAD, leaf temperature, number of tillers, flowering and grain yield (Table 3). For the repeated experiment, only number of tillers showed a significant (*P*<0.0001) G×E interaction (Table 5). Significant differences were observed between environments for all traits, but only the number of tillers was significantly different (*P*<0.0001) among genotypes. In the first year of experiment 2, only number of tillers showed significant G×E interactions (*P* = 0.0086) (Table 3). Differences between environments were significant for leaf temperature and maturity (*P* = 0.0205 and 0.0250, respectively) and highly significant for plant height, SPAD and flowering (*P*<0.0001). The differences among genotypes were significant (*P*<0.01) for all traits with the exception of leaf temperature (*P* = 0.7817). In the repeated experiment of the second year, only grain yield showed a significant G×E interaction (*P*<0.0001). Differences were highly significant (*P*<0.0001) both between environments and between genotypes for all traits with the exception of number of tillers, which showed no significant difference between environments (*P* = 0.8352).

For plant height, number of tillers, flowering, and maturity, the percentages of lines in the various category types of each trait, based on SES for rice (IRRI, 1996), in experiment 1 are shown in Table 4. Due to the general reduction on plant height by drought, the percentages of semidwarf and tall categories significantly changed from 46.6 to 54.7% and 50.3 to 45.0%, respectively, by the drought treatment. Very few lines belonged to the intermediate category. Both parents were in the tall category under both irrigation conditions. None of the lines evaluated had very many or many tillers. The percentage of lines with few tillers was significantly lower under drought than under fully irrigated conditions (31.7 and 39.2%, respectively). However, the percentage of lines with very few tillers was significantly higher under drought than under fully irrigated conditions (67.3 and 58.0%, respectively). Under fully irrigated condition, the two parents had few tillers, while under drought, CG 14 had few and WAB56-104 very few tillers. Under both irrigation conditions, the majority of lines (55.2 and 57.7% under fully irrigated and drought conditions, respectively) had intermediate flowering, but a delay in flowering was observed under drought compared to under fully irrigated condition—an increase and a decrease of the percentages of late and early flowering groups, respectively, by drought (Table 6). Both parents had intermediate flowering under both irrigation conditions. None of the lines evaluated showed very late maturity.

The percentage of lines with late maturity was increased by drought, while those with early and very early maturity were decreased. Under both irrigation conditions, the highest percentage of genotypes had early maturity (62.9 and 51.1% under fully irrigated and drought, respectively). Both parents had very early maturity under fully irrigated conditions but early maturity under drought.

All genotype groups evaluated (including the two checks, CG 14 and WAB56-104) in experiment 2 had semidwarf plants (mean height ≤ 90 cm) under both irrigation conditions (Table 5). For number of tillers, the highest percentage of *O. glaberrima* was observed in the intermediate category under full irrigation. Although, percentages of very many, many, and intermediate categories were significantly (*P*≤0.05) decreased by drought, most *O. glaberrima* lines were still in the intermediate (75.4%) under drought. Although, the largest percentage in number of tillers were few tillers for both *O. sativa* genotypes and interspecific lines under full irrigation; under drought this category

Table 4. Effect of drought on percentage of lines in the respective category types of four agronomic traits for 202 interspecific lines and their parents in the first experiment (experiment 1) in 2006 to 2007.

Trait	Type	All lines		Parents[a]	
		Fully irrigated	**Drought**	**Fully irrigated**	**Drought**
Plant height	Semidwarf	46.6^{bAB}	54.7^{aA}		
	Intermediate	3.1^{aB}	0.3^{bB}		
	Tall	50.3^{aA}	45.0^{bA}	CW	CW
No of tillers	Very many	0.0^{aC}	0.0^{aC}		
	Many	0.0^{aC}	0.0^{aC}		
	Intermediate number	2.8^{aC}	1.0^{aC}		
	Few	39.2^{aB}	31.7^{bB}	CW	C
	Very few	58.0^{bA}	67.3^{aA}		W
Flowering	Early	37.9^{aB}	25.5^{bB}		
	Intermediate	55.2^{bA}	57.7^{aA}	CW	CW
	Late	7.0^{bC}	16.8^{aC}		
Maturity	Very late	0.0^{a}D	0.0^{aC}		
	Late	0.0^{b}D	20.0^{aB}		
	Medium	11.3^{aC}	25.3^{aB}		
	Early	62.9^{aA}	51.1^{bA}		CW
	Very early	25.8^{aB}	3.6^{bC}	CW	

[a] C = CG14, W = WAB54-106. For each trait type, means with the same lower-case letters in a row are not significantly different according to the Student–Newman Keuhl (SNK) test ($P \leq 0.05$). Means followed by the same capital letters in a column for a plant trait are not significantly different according to the SNK test ($P \leq 0.05$).

Table 5. Effect of drought on the percentage of genotypes in the respective category types of four agronomic traits for 327 rice genotypes in experiment 2 in 2006 to 2008.

Trait	Trait type	*Oryza glaberrima*		*O. sativa*		Interspecific lines		Local landraces		Checks[a]	
		Fully Irrig.	**Drought**	**Fully Irrig.**	**Drought**	**Fully Irrig.**	**Drought**	**Fully Irrig.**	**Drought**	**Fully Irrig.**	**Drought**
Plant height	Semidwarf	100.0^{aA}	100.0^{aA}	100.0^{aA}	100.0^{aA}	100.0^{aA}	100.0^{aA}	100.0^{aA}	100.0^{aA}	CW	CW
	Intermediate	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}		
	Tall	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}	0.0^{aB}		
No of tillers	Very many	3.0^{aC}	0.5^{bC}	0.0^{aC}	0.0^{aD}	0.0^{aD}	0.0^{aC}	0.0^{aB}	0.0^{aB}		
	Many	4.5^{aBC}	2.0^{bC}	0.0^{aC}	0.0^{aD}	0.0^{aD}	0.0^{aC}	0.0^{aB}	0.0^{aB}		
	Intermediate	80.9^{aA}	75.4^{bA}	33.3^{aAB}	16.7^{bC}	16.3^{aC}	10.2^{bB}	100.0^{aA}	100.0^{aA}	C	C
	Few	11.1^{bB}	20.6^{aB}	42.7^{bA}	58.3^{aA}	48.0^{aA}	40.8^{aA}	0.0^{aB}	0.0^{aB}		

Table 5. Contd.

	Very few	0.5^{aC}	1.5^{aC}	24.0^{aB}	25.0^{aB}	35.7^{bB}	49.0^{aA}	0.0^{aB}	0.0^{aB}	W	W
Flowering	Early	16.9^{bB}	24.2^{aB}	0.0^{bB}	25.0^{aB}	11.2^{bC}	33.7^{aA}	0.0^{aB}	0.0^{aC}		
	Intermediate	69.7^{aA}	49.4^{bA}	50.0^{aA}	15.0^{bC}	64.3^{aA}	34.7^{bA}	100.0^{aA}	66.7^{bA}	CW	C
	Late	13.5^{bC}	26.4^{aB}	50.0^{bA}	60.0^{aA}	24.5^{bB}	31.6^{aA}	0.0^{bB}	33.3^{aB}		W
Maturity	Very early	76.5^{aA}	45.5^{bA}	36.4^{aA}	18.2^{bB}	62.8^{aA}	9.6^{bBC}	0.0^{aC}	0.0^{aC}	C	
	Early	11.4^{bB}	36.4^{aAB}	27.3^{aB}	27.3^{aAB}	18.1^{bB}	60.6^{aA}	66.7^{aA}	0.0^{bC}	W	CW
	Medium	9.8^{aB}	11.4^{aB}	36.4^{aA}	36.4^{aA}	12.9^{aBC}	13.8^{aB}	0.0^{aC}	66.7^{bA}		
	Late	2.3^{bBC}	6.1^{aB}	0.0^{bC}	18.2^{aB}	6.2^{bC}	13.8^{aB}	33.3^{aB}	0.0^{bC}		
	Very late	0.0^{aC}	0.8^{aC}	0.0^{aC}	0.0^{aC}	0.0^{aC}	2.1^{aC}	0.0^{bC}	33.3^{aB}		

[a] C = CG14, W = WAB54-106. Interm. = intermediate number, Irrig. = irrigated. For each trait type, means with the same lower-case letters in a row are not significantly different according to the Student–Newman Keuhl (SNK) test (*P*≤0.05). Means followed by the same capital letters in a column for a plant trait are not significantly different according to the SNK test (*P*≤0.05).

Table 6. Differences in values for plant height, number of tillers, SPAD, leaf temperature, flowering, grain yield, and maturity between fully irrigated and drought conditions for the 20 top-yielding genotypes under drought conditions in each of the two experiments a.

Experiment 1								
Genotype	**Family**	**Plant height (cm)**	**No. tillers**	**SPAD**	**Leaf temperature (°C)**	**Flowering (days)**	**GY difference (kg/ha)**	**GY under drought (kg/ha)**
55-4-1	55	68	2.3	0.3	0.0	–5.0	666	1272^{d}
61-1-1	61	47	2.0	–1.0	–0.7	–3.0	45	1427^{d}
0003-1-02	3	36	2.5	–3.7	–1.0	22.0	108	1465^{d}
104-3-5	104	3	2.5	–0.7	–0.7	–4.0	576	1492^{d}
116-2-4	116	44	1.3	0.7	–1.3	–13.0	684	1506^{cd}
77-1-4A5	77	9	–0.3	–7.3	–1.3	–5.0	567	1536^{cd}
114-1-2A3	114	36	0.0	–4.7	0.0	3.0	549	1575^{cd}
94-5-3	94	35	3.5	–0.7	–0.3	–3.0	576	1584^{cd}
003-2-2	3	36	1.3	–4.7	0.7	–3.0	9	1604^{cd}
94-1-5	94	34	2.3	–4.0	–0.7	–3.0	72	1628^{cd}
77-2-4	77	49	2.0	–4.3	–0.7	–7.0	27	1685^{cd}
77-5-3	77	14	0.8	–2.7	0.0	1.0	90	1703^{c}
94-1-10	94	67	1.0	–1.7	–0.3	–7.0	783	1728^{c}
WAB56-104	*O. sativa*[a]	8	4.5	–1.7	–0.7	–8.0	792	1744^{c}
46-2-2	46	21	–2.0	–3.3	0.0	0.0	207	1760^{bc}
77-5-4	77	9	0.8	0.3	0.3	–8.0	459	1788^{bc}
107-2	107	22	1.5	–2.3	–0.7	–6.0	153	1793^{bc}

Table 6. Contd.

94-5-10	94	9	0.8	–2.0	0.7	–2.0	549	1797[bc]
151-3-8	151	3	1.5	–1.0	–1.0	–5.0	261	1807[bc]
94-2-3	94	38	2.3	2.3	–0.3	–6.0	81	1830[b]
94-1-1	94	20	0.5	3.3	0.0	–2.0	783	1865[b]
138-31-2	138	68	2.5	–1.3	–1.0	–11.0	720	1911[b]
94-4-3A7	94	63	1.8	–0.7	–1.0	–9.0	603	1912[b]
116-2-2	116	43	0.8	–2.3	0.3	–7.0	504	1922[b]
CG 14	*O. glaberrima*[a]	10	3.5	–1.0	–1.3	–9.0	387	2283[b]
117-2-6	117	29	6.3	–0.7	–0.3	–5.0	278	3484[a]
Mean		32	1.8	–1.7	–0.4	–4.0	405	1773
Percent positive or nil		100	92.3	19.2	34.6	15.4	100	
Percent negative		0	7.7	80.8	65.4	84.6	0	

Experiment 2

Genotype	Species	Plant height (cm)	No. tillers	SPAD	Leaf temperature (°C)	Flowering (days)	Maturity (days)	GY difference (kg/ha)	GY under drought (kg/ha)
TOG 5334	*O. glaberrima*	3.0	1.1	–5.5	–0.4	–11.3	–17.5	222	1636[c]
TOG 5523	*O. glaberrima*	15.9	–0.1	–2.9	–0.9	–2.0	–1.5	666	1683[c]
TOG 5486	*O. glaberrima*	16.6	5.3	–1.5	–1.1	–20.3	–13.0	475	1701[c]
CG 14	*O. glaberrima*	6.5	2.8	–1.5	0.0	–8.5	–7.0	110	1723[c]
TOG 6291	*O. glaberrima*	19.4	1.4	1.2	0.3	–8.5	–17.0	359	1760[b]
TOG 5498	*O. glaberrima*	15.4	1.7	–1.6	–0.4	–7.5	–3.5	206	1764[b]
TOG 5406	*O. glaberrima*	13	2	–5.7	–0.5	–3.5	8.0	342	1818[b]
TOG 5919	*O. glaberrima*	9.9	2.3	–4.3	1.0	–4.0	–12.5	54	1818[bc]
RAM100	*O. glaberrima*	25.5	8.1	–9.1	–1.0	–3.5	0.0	316	1836[bc]
SIK398-b-17-166	Interspecific line	11.4	2.7	6	8.2	–5.8	–13.5	188	1846[bc]
PaDCKONO	Local landrace	0.5	4.8	–8.7	–0.1	–0.3	10.0	329	1907[bc]
TOG 7230	*O. glaberrima*	7.7	–2.1	–8.3	–1.3	–7.5	–1.0	450	1962[bc]
TOG 5464	*O. glaberrima*	16.5	1.5	–3.3	0.6	–5.5	–13.0	261	1967[abc]
TOG 6223	*O. glaberrima*	10.5	6.4	–5.9	–0.2	–14.3	–15.0	113	2026[abc]
BG90-2	*O. sativa*	1.8	–1.5	–6.8	–0.7	–3.8	–7.5	427	2069[abc]
TOG 5639	*O. glaberrima*	2.9	8.9	–4.2	–1.3	–8.8	5.0	284	2128[ab]
RAM138	*O. glaberrima*	18.8	9.7	–7.4	–1.1	–41.0	–10.0	577	2174[ab]
TOG 5979	*O. glaberrima*	3.8	0.8	–2.2	0.5	–0.3	–13.0	225	2245[ab]
TOG 6383	*O. glaberrima*	21.3	9.2	–0.2	–0.2	–36.5	–5.5	50	2291[ab]
TOG 6679	*O. glaberrima*	23.1	3.6	1.4	–0.8	–10.0	–13.5	539	2303[ab]

Table 6. Contd.

TOG 6208	*O. glaberrima*	4.9	0.3	–1.5	–1.0	–2.5	–1.0	468	2340[a]
TOG 5691	*O. glaberrima*	1.2	0.6	–5.5	–0.6	–2.0	–4.5	52	2530[a]
TOG 5591	*O. glaberrima*	26.2	5.9	–2.4	–0.4	–7.5	–1.5	889	2534[a]
TOG 6594	*O. glaberrima*	0.2	6.9	–2.6	–0.8	0.0	–17.0	376	2616[a]
RAM122	*O. glaberrima*	24.4	12.9	0.7	–2.2	–33.0	–1.5	456	2806[a]
Mean		12.0	3.8	–3.3	–0.2	–9.9	–6.7	337	2059
Percent positive or nil		100	88.5	15.4	23.1	3.8	15.4	100	
Percent negative		0	11.5	84.6	76.9	96.2	84.6	0	

[a] species, GY = grain yield (kg ha^{-1}), each value represents mean for two experiments. CG14 and WAB56-104 are included in the table as checks and for data comparisons.

was still largest in *O. sativa* genotypes (58.3%) but that of very few tillers became dominant in interspecific lines (49.0%). Different from *O. glaberrima*, none of the *O. sativa* genotypes or interspecific lines had very many or many tillers. The local landraces evaluated all had intermediate number of tillers under both irrigation conditions. CG 14 and WAB54-106 had intermediate number and very few tillers, respectively, under both irrigation conditions.

In fully irrigated condition, the highest percentage of genotypes was observed in the intermediate flowering category in *O. glaberrima*, interspecific lines and local landraces, while *O. sativa* genotypes had equal percentage (50%) for late and intermediate categories (Table 5). Under drought condition, the percentage of intermediate flowering was decreased and the percentages of early and late categories were increased in all genotype groups except local landraces. Under both irrigation conditions, CG 14 had intermediate flowering, whereas WAB54-106 had intermediate flowering under fully irrigated conditions and late flowering under drought. Under full irrigation, most *O. glaberrima* (76.5%) and interspecific lines (62.8%) fell in the category of very early maturity, while local landraces (66.7%) showed early maturity. *O. sativa* genotypes showed the same highest percentage (36.4%) in the categories of very early and medium maturities under full irrigation. Most *O. glaberrima* accessions were still in the category of very early maturity under drought but its percentage (45.5%) was significantly smaller than that under full irrigation. Most *O. sativa*, interspecific lines and local landraces showed medium, early and medium maturities, respectively, under drought.Under fully irrigated condition, CG 14 and WAB54-106 presented very early and early maturity, respectively, but under drought both genotypes showed early maturity.

Table 6 shows the difference in values of the traits between the fully-irrigated and drought conditions for the traits evaluated in the top yielding genotypes under drought condition (Table 6 for 24 lines selected from experiment 1 including the checks, and for 20 genotypes selected from experiment 2 including the checks). For all traits, the average values of the first and second year results were used. The top yielding genotypes are those with mean grain yield under drought followed by the letter “a” in the table of mean separations obtained in the statistical data analysis. Actual grain yield of the top-yielders under drought is also shown. The general observations made earlier on the traits evaluated for all genotypes considered together were similar to those for the top-yielding ones. For both experiments, most of the top-yielding genotypes had higher values of SPAD, leaf temperature, flowering, and maturity (this was evaluated only in experiment 2 since the first year result of experiment 1 was missing) under drought than under fully irrigated condition (65.4 to 96.2% of genotypes) (Table 6). However, lower values were recorded for the majority of these genotypes under drought for plant height, number of tillers and grain yield (88.5 to 100%).

No drought effect was observed on some traits for some genotypes such as: number of tillers for line 114-1-2A3 in experiment 1; leaf temperature for 114-1-2A3, 46-2-2, 55-4-1, 77-5-3 and 94-1-1 in experiment 1 and CG 14 in experiment 2; flowering for 46-2-2 in experiment 1 and TOG 6594 in experiment 2; and maturity for RAM100 in experiment 2. In experiment 1, lines possessing stable grain yield under drought were 003-2-2, 77-2-4, 61-1-1, 94-1-5, 94-2-3, and 77-5-3 with grain yield differences of 9, 27, 45, 72, 81, and 90 kg ha^{-1}, respectively. Under drought, the grain yield of those lines ranged between 1427 and 1830 kg Na^{-1}; and 94-2-3 had significantly higher yield than the other lines with stable yield. The top yielder under drought, 117-2-6 (3484 kg ha^{-1}) had significantly higher yield than the others including 94-2-3 (1830 kg ha^{-1}). The yield reductions of 117-2-6 and 94-2-3 were 7.4 and 4.2%, respectively. The *O. glaberrima* parent, CG 14, showed the second highest yield (2283 kg ha^{-1}), which was significantly higher than that of 003-2-2, 77-2-4, 61-1-1, 94-1-5 and 77-5-3. In experiment 2, TOG 6383, TOG 5691, and TOG 5919 were the most stable genotypes for grain yield with differences of 50.0, 52, and 54 kg ha^{-1}, respectively.

TOG 5691 additionally had good stability for plant height, number of tillers, SPAD, leaf temperature and flowering. TOG 6383 also had good stability for SPAD and leaf temperature. Yields of TOG 5691 (2530 kg ha^{-1}) and TOG 6383 (2291 kg ha^{-1}) under drought were not significantly lower than the yield of RAM122 (2806 kg ha^{-1}), which was the top yielder. RAM122 had good stability for SPAD, leaf temperature and maturity.

DISCUSSION

A total of 527 (202 in experiment 1 and 327 in experiment 2 with two common checks) rice genotypes obtained from the AfricaRice gene bank were screened for tolerance to drought in this study. These genetic materials constitute representative samples of West Africa as most of the materials originated from that region (from eight West African countries). Also, the materials comprised *O. glaberrima* and *O. sativa* accessions, interspecific lines from more than 42 families and local landraces indicating their wide genetic variability. Therefore, the results obtained from this study could give an overall idea on the drought tolerance potential of the materials originated from West Africa. The results presented in this paper show the effect of drought on seven rice plant traits evaluated under field conditions and confirmed the observations of Yang and Luo (2002). These authors studied rice production under different types of drought (spring, early summer, hot summer, autumn/fall, and seasonal successive droughts) and reported significant influence of all the drought types on yield and yield component. In the results of our experiments, drought decreased plant height, number of tillers, and grain yield, shown by the high percentage of genotypes with higher mean trait values under fully irrigated conditions than under drought, and consequently by the positive DSI values for those traits. These results were consistent across the experiments and genotype types (including the common checks of the two experiments).

Conversely, values for leaf temperature, SPAD, flowering, and maturity were increased under drought and gave negative DSIs. These results corroborate observations of Hounkpatin (2007) and Efisue (2006), who additionally observed significant correlations among those traits and also between the traits under irrigation and under drought. Efisue (2006) reports that rice drought resistance ability should be defined as a complex trait related to a number of plant characters. For example, under drought, rice root, which plays a key role in water and nutrient uptake for the development of the plant and is responsible to resistance to various stresses including drought, is significantly short and thin compared to that under irrigated condition (Mahmoud et al., 2002). The reduced height and tillering ability of plants under drought could be related to the limited water and nutrient uptake under drought. The increase on leaf temperature under drought as compared to under full irrigation is a result of transpiration decrease due to stomatal closure. Leaf temperature was reported as a good indicator of plant stress level for its association with plant water status under drought (Serraj et al., 2009) and as a good drought avoidance indicator, based on the principle of the cooling effect of transpiration on plants' canopy (Maurya and O'Toole, 1986). The results on the effect of drought on leaf greenness (SPAD readings) corroborate those of Hounkpatin (2007). Drought can inhibit both chlorophyll synthesis and leaf area expansion as a consequence of cell elongation and cell wall synthesis. Chlorophyll synthesis, cell elongation, and cell wall synthesis are relatively sensitive to drought compared to other physiological processes such as photosynthesis, respiration, and maintenance of open stomata, and cell elongation and cell wall synthesis are slightly more sensitive to drought than chlorophyll synthesis (Nonami, 2001). In our studies and those of Hounkpatin (2007), leaf area expansion might have been more affected by the drought imposed than chlorophyll synthesis as chlorophyll content per leaf area (which has a strong correlation to SPAD readings) became higher in plants under drought than in those under full irrigation. Under severe drought, leaf death occurs and is easily recognizable in the field, so green leaf retention is often used as a selection criterion for drought resistance in rice (De Datta et al., 1988). In the drought condition imposed in our study, however, green leaf retention was not a suitable selection criterion. The results of this study indicate delay in flowering and maturity under drought condition as compared to under fully irrigated condition, which is in agreement with other studies (Novero et al., 1985; Arraudeau, 1998). Delay in flowering can be coincident with the delay of maturity. Ndjiondjop et al. (2010) observed significant relationship between these two traits. The reduced grain yield under drought observed in this study could be a consequence of the effect of drought on the various traits evaluated. However, other traits not evaluated in this study might also affect grain yield under drought; for example, plant biomass production is reduced under drought, leading to the limitation of potential yield even when favorable conditions return in the late growth stages (Begg, 1980; Puckridge and O'Toole, 1981).

As indicated in this study, plant height, number of tillers, flowering and maturity are affected by drought. For instance, one of the common checks, WAB54-106, was in the ‘few tillers’ category under fully irrigated condition but in the ‘very few’ category under drought (Table 4). Detailed information such as experimental/production conditions should therefore be given when characterizing rice genotypes. In our study, significant G×E interactions were observed for SPAD, number of tillers and grain yield. Similar results were obtained by other researchers (Blum, 2002). Blum (2002) summarized traits and characteristics, negative effects on which by drought inhibit crop growth and yield: i) root traits (root depth and extension into deep soil), which are components of plant adaptation to drought environment; ii) leaf surface traits (form, shape, composition of cuticular and epicuticular wax, leaf pubescence, and leaf color) that affect the radiation load on the leaf canopy and, consequently, transpiration (transpiration change can be recognized by leaf temperature), and leaf water potential; iii) non-senescence or “stay-green,” which is the delay or reduced rate of normal plant senescence as it approaches maturity; and iv) stem reserve, a major resource providing carbohydrates and nitrogen for grain filling when the transient photosynthetic source is inhibited by stress.

Lafitte et al. (2002) observed that rice had a range of genetic variation in various characteristics associated with water relations in a plant, such as stomatal conductance under drought stress and osmotic adjustment, which is a mechanism to maintain turgor potential under the reduction of water potential under the stress. These characteristics might explain the varietal differences in the effects of drought on the traits evaluated in the two experiments. Blum (2005) concludes that in drought stress, the most common and effective factor of drought resistance in crop plants as well as native vegetation is to avoid dehydration conditions in a plant rather than to tolerate to internal dehydration caused by drought stress. In our study, the seven traits evaluated were affected by drought and there was a varietal difference in the intensities of damages or adaptive changes in these traits. Further studies will be necessary to determine how closely those traits can be linked to the mechanism to avoid internal dehydrated conditions or to characteristics derived from internal dehydration conditions. In breeding for tolerance to a complicated stress such as drought, direct selection for high yield under drought could be the first approach, but using traits with close linkage to dehydration avoidance will also help.

Conclusion

The results of this study corroborated those of previous research on drought effects on agronomic traits and production in rice. Based on these traits, a number of genotypes which did not suffer functionally negative influences by drought in some agronomic traits—reductions of plant height, number of tillers, and yield, increase of leaf temperature and SPAD, and delays of flowering and maturity—were identified in experiments 1 and 2. These can potentially be sources of drought tolerance. Among genotypes showing high yield under drought, 003-2-2, 77-2-4, 61-1-1, 94-1-5, 94-2-3 and 77-5-3 were identified as lines possessing stable grain yield under drought in experiment 1 (although grain yield of CG 14 and line 117-2-6 were higher under drought); and TOG 6383, TOG 5691 and TOG 5919 were the most stable genotypes for grain yield in experiment 2. Yield of these three genotypes was not significantly lower than that of the top yielder, RAM122, in experiment 2. RAM122 was additionally stable for SPAD, leaf temperature and maturity. Further studies on these rice genotypes still needs to be carried out.

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