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Full Length Research Paper

Screening of rice varieties for their weed competitiveness

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Weed competition is a major constraint in rice production systems in Africa. This study was conducted at the Africa Rice Experimental Station in Benin in the dry and rainy seasons to screen rice varieties for weed competitiveness. The experimental design was a split plot with 14 contrasting cultivars (including the *Oryza glaberrima* and *Oryza sativa* parents of upland New Rice for Africa (NERICA), lowland NERICA or "promising lines") planted under three weeding regimes: 0, 1 and 4 weedings. Agro-morphological characters, growth indexes and weeds were used to evaluate the cultivars. The most important weed species encountered were *Acanthospermum hispidum*, *Dactyloctenium aegyptium* and *Digitaria horizontalis.* Highly significant differences (P≤0.0001) between cultivars were observed in weed biomass. The impact of weeds on agro-morphological traits was expressed through an increasing senescence of plants in relation to the weeding regime. Weed-competitive cultivars typically showed a leaf area index less than 3, a high specific leaf area and a Soil-Plant Analyses Development (SPAD) unit less than 30. High affinities between traits were observed and three types of descriptors were identified based on their broad sense heritability. CG20, an *O. glaberrima* variety was the most competitive against weeds.

Key words: Rice, descriptor, weed, competitive variety, heritability.

INTRODUCTION

In Africa, inland valley ecosystems account for about 44% of land cropped in rice 66% of rice production (WARDA, 2004). Weeds are undoubtedly one of the major factors limiting rice cultivation (WARDA, 2000; Traoré and Yonli, 2001; Halidou et al., 2006). Weeds compete directly with the rice plant for growth factors such as water, nutrients, light and space (Akobundu, 1993; Johnson et al., 1997). Weeds, like diseases, insects and other pests are a serious and severe constraint in rice systems in uplands (Johnson et al., 1997), in irrigated rice as well as in lowland conditions (Haefele et al., 2004). Indeed, in the lowlands, direct seeding is made difficult by an upsurge of weeds. In general, potential and actual yield losses are about 32 and 9%, respectively (Oerke and Dehne, 2004). In West Africa, estimated yield losses due to weeds range between 12 and 22% (Haefele et al., 2000; Becker and Johnson, 2001). In rainfed rice, yield losses can reach up to 84%, depending on the weed species, rice varieties and the soil moisture regime (Akintayo et al., 2008). Yield losses of 40% have been reported under hydromorphic conditions (Dogbé and Aboa, 2004) compared to 8 to 30% for transplanted rice under rainfed lowland and irrigated conditions (WARDA, 2000). In exceptional circumstances, lack of weed control may cause total crop loss (Johnson et al., 1997). Weed infestation and development result from a complex interaction of many factors, such as competition, allelopathy or other cultural practices and prevailing environmental conditions (Caussanel, 1989).

The method of weed control employed by the farmer depends on his objectives. Integrated weed control may involve a combination of mechanic weeding, herbicide application or introducing cover plants in a crop rotation plan (Akintayo et al., 2008). Any combination of these

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Table 1. Plant material screened including control and parents varieties.

No	Traits	Species	Origin
1	CG 14*	*O. glaberrima*	Senegal
2	CG 17***	*O. glaberrima*	Senegal
3	CG 20***	*O. glaberrima*	Senegal
4	IG 10***	*O. glaberrima*	Ivory Coast
5	SHAWHON***	*O. glaberrima*	Liberia
6	TOG 5681**	*O. glaberrima*	Nigeria
7	IR 64**	*O. sativa*	IRRI
8	IR 31785-58-1-2-3-3**	*O. sativa*	IRRI
9	WAB 56 – 50***	*O. sativa*	WARDA
10	WITA 2***	*O. sativa*	WARDA
11	WITA 7***	*O. sativa*	WARDA
12	FKR 19****	*O. sativa*	Nigeria (IITA-Ibadan)
13	FKR 54****	*O. sativa*	-
14	JAYA****	*O. sativa*	India

* : NERICA upland ;** : NERICA lowland; *** : promising lines and ****: checks.

methods that enables the rice plant to be more competitive than weeds would improve the economic returns of the farmer NERICA (New Rice for Africa) varieties developed recently by the Africa Rice Center by crossing *Oryza sativa* L. and *Oryza glaberrima* S. have a high yield potential and some interesting potentially weed-competitive characteristics inherited from their African parent, *O. glaberrima* (Jones et al., 1997; WARDA, 2000; Kaneda, 2007; Futakuchi and Sié, 2009). A number of studies have defined characteristics that can be used to select weed-competitive varieties (Garrity et al., 1992; Callaway, 1993; Johnson et al., 1997; Dingkuhn et al., 1999; Fofana and Rauber, 1999; Tuong et al., 2000; Haefele et al., 2004; Zhao et al., 2006; Saito et al., 2010).

The objective of the current study was to determine the weed-competitiveness of 14 genotypes belonging to the two cultivated rice species, *O. glaberrima* and *O. sativa*, including parents of upland and lowland NERICA varieties and 18 "promising lines" that are yet to be given names. The goal is to use any identified weed-competitive variety as a donor parent in the breeding programme for weed-competitive varieties.

MATERIALS AND METHODS

Experiments were conducted on land that had been fallow for six months in the experimental farm of the Africa Rice Center in Benin (6°42′46''N, 1°41′07''E and 21 m altitude) in the dry season (February to May, 2009) and rainy season (June to November, 2009). All the weed species in the plot were inventoried and identified. Fourteen rice entries were evaluated for weed-competitiveness. They comprised *O. glaberrima* and *O. sativa genotypes*, including parents of upland and lowland NERICA varieties and 18 yet unnamed "promising lines" (Table 1).The experimental design was a split plot with three blocks corresponding to weeding regimes as subplot and 14 sub-blocks corresponding to varieties as main plot. There were six replications. The treatments were: W_0=0 weeding (weedy); W_1=1 weeding 14 days after sowing (DAS); W_2=4 weedings (weeded every 15 days from 14 DAS=weed-free). Seeds were planted on January 28 and June 21 in the dry and rainy seasons, respectively, in 2009. Each plot had 5 rows with seeds planted at the rate of 4 to 5 per hill at 0.25 m intervals between rows and 0.2 m within rows. Fertilizer was applied at the rate of 200 $kgha^{-1}$ of $NPK_{15-15-15}$(basal), 50 kg urea ha^{-1} at first weeding (15 DAS) and also at heading. Plants were thinned to one plant per hill at 15 to 20 DAS.

Plot weeding depended on the treatments. Sprinkler irrigation was done in the dry season. Three agro-morphological descriptors were measured - tillerjng (30 DAS), plant height (60 DAS) and grain yield (at maturity) using the evaluation scale described by Bioversity International –IRRI-AfricaRice (2007). The effect of weeds on the rice growth and development was estimated based on the agro-morphological descriptors:

$$EF(X) = \frac{P(T) - P(X)}{P(T)} \otimes 100$$

EF(X) = effect of weeds on the parameter *X; P(T)* = parameter value of the positive control «4 weedings»*; P(X)* = parameter value of the other weeding regimes «0 or 1 weeding».

Leaf area index (LAI) was measured using the area meter LI-3100 (LICOR, 4421 Superior St., Lincoln). Specific leaf area (SLA) was measured using a planimeter on the leaf fresh weight. The *in situ* chlorophyll content of the test plants (SPAD) was measured on new leaves using a chlorophyll-meter SPAD 502 (Minolta Camera Company). Weed dry biomass (WDB) evaluation and weed counting were done within two 0.25 m² quadrants per plot based on the graded string method. The predominant weed species were inventoried and identified in each plot. Soil covered density of each variety (CDR) was evaluated using the formula:

$$\%\,Cover = \frac{Dots \cdot with \cdot weeds \cdot or \cdot rice}{Total \cdot Number \cdot of \cdot dots} \otimes 100$$

Repeated mixed model ANOVA with blocks, weeding regimes, seasons and varieties as factors was performed based on agro-morphological parameters, growth indices and weeds. However, simple ANOVA was performed on SLA and yield. Analysis was done using SAS, version 9.1 (2003). In addition, the Pearson linear correlation coefficients among 8 quantitative variables in relation to weeding regime were determined with the XLSTAT 2009 software. Heritability was accessed with SAS (version 9.1, 2003) on data for both seasons - it was determined using 8 quantitative characters depending on the different variance components: «genotypes»; «genotypes x seasons» and «Variance error» based on the formula used by Zhao et al. (2006) and Saito et al. (2010):

$$h^2 = \frac{\delta_G^2}{\delta_G^2 + \delta_{GS}^2} = \frac{\delta_G^2}{\delta_{GT}^2/e + \delta_e^2/(e \times r)}$$

Where δ^2_G = variance of genotypes; δ^2_{GS} = variance genotypes x season; δ^2_{GT} = variance genotypes x treatment; δ^2_e = error variance; e = number of crop seasons and r = number of replications.

RESULTS

Weed species involved in the competition

Table 2 shows the 20 weed species belonging to 14 families that were identified before cropping started. The most representative weeds in terms of population density were *Acanthospermum hispidum* DC. (Asteraceae), *Cleome viscosa* L. (Capparidaceae), *Cynodon dactylon* (Linn) Pers. (Poaceae), *Dactyloctenium aegyptium* (Linn) *P. beauv* (Poaceae), *Digitaria horizontalis* Willd (Poaceae) and *Richardia brasiliensis* (Rubiaceae) (Akobundu and Agyakwa, 1987).There were 17 species in 14 families in the dry season and 24 species in 13 families during the rainy season (Table 3). Seven species and eight families were common to both seasons. During the rainy season, new weed species (mostly Dicotyledonous) appeared while 14 species (Poaceae) disappeared. The weed dry biomass recorded from the 0.25 m² quadrants during the two cropping seasons ranged from 161.80 g (CG20) to 286.66 g (IR64); from 220.70 g (CG14) to 287 g (SHAWHON) for the African varieties and 204.21 g/(IR64) to 280.58 g/(WITA2) for Asian varieties. The competitiveness of the African varieties against weeds differed, depending on the season.

Evaluation of different factors and their interactions on the growth and development of the varieties

There were significant (P<0.0001) changes in the quantitative variables -H30, Hmat, T30, T60, CDR, WDB, LAI and SPAD- depending on the data collection time, irrespective of the weeding regimes (Table 3a). However, differences between seasons and the « season x weeds» interaction were not significant (Table 3a and b). Differences were significant to highly significant (P≤0.0001) at 45 and 75 DAS for all variables. Weeding regime affected the growth and development of the rice varieties with regard to H30, Hmat, T30, T60, CDR, WDB, LAI, SPAD and yield.

Effect of weeds on the growth and development of the varieties

Plant height

During the two seasons, irrespective of the weeding regime, WITA7 was 49% shorter compared with 22% for CG20 and SHAWHON.At 30 DAS, plant height reductions ranged from 1 to 9% and nearly 60% for FKR19, FKR54, WITA2, WITA7, IG10, TOG5681 and JAYA. At this vegetative stage, with 0-weeding, Asian varieties were stunted, filiform, and had weeds in the vicinity of the crop. At maturity, African varieties grew and developed, despite the high weed pressure under the 1-weeding regime. Under the 1-weeding regime, the critical period of competition between weeds and cultivated plants varied between 30 and 60 DAS. In the rainy season, more than 45% of plants in the 0-weeding and 1-weeding regimes had died at 60 DAS.

Tillering ability

During the dry season, the highest reduction in the number of tillers at 30 DAS was 38% (CG14) and the lowest was 7% (CG20 and WITA7) (Table 4); there was no significant difference among the 14 varieties in the rainy season. The reduction in the number of tillers at 60 DAS was significant (P≤0.0001) only in the rainy season, ranging from 52.80% (CG20) to 78.63% (CG14).

Grain yield

Under the 0-weeding regime in the dry season, grain yield ranged from 0 (IG10, SHAWHON, FKR19, FKR54, JAYA, IR64, IR31875-58-1-2-3-3, WITA2, WITA7) to 547 gm^{-2} (CG20) (Table 5) and from 191 (WITA7) to 2023 gm^{-2} (TOG5681) in the rainy season. The six African varieties yielded 345 (CG17) to 2023 gm^{-2} (TOG5681) compared to 191 (WITA7) to 994 gm^{-2} (WITA2) for the Asian varieties. CG20 gave the highest grain yield (547gm^{-2}) in the dry season and 1130 gm^{-2} in the rainy season under 0-weeding. However, the average yield for CG20 was low, 96.25 gm^{-2} with 1-weeding and 5.53 gm^{-2} with4-weeding.

LAI

No significant difference was detected among varieties in terms of leaf area index, which ranged from 0.46 (CG17)

Table 2. Predominant weed species.

Before cultivation			Dry season			Rainy season		
Species	**Population density**	**Family**	**Species**	**Population density**	**Family**	**Species**	**Population density**	**Family**
Acanthospermum hispidium	+	Asteraceae	*Boerhavia erecta* L	++	Nyctaginaceae	*Acanthospermum hispidum* DC.	+	Asteraceae
Boerhavia erecta L	-	Nyctaginaceae	*Cassia occidentalis* L	+	Caesalpinioideae	*Ageratum conyzoides* Linn.	+	Asteraceae
Cassia occidentalis L	-	Caesalpinioideae	*Celosia trigyna L.*	+	Amaranthaceae	*Amaranthus viridis* Linn.	+	Amaranthaceae
Cassia rotundifolia	-	Caesalpinioideae	*Cleome ciliati*	++	Capparidaceae	*Bracharia falcifera* (Trin.) Staff	+	Poaceae
Cleome viscosa L	+++	Cleomaceae	*Commelina benghalensis L.*	++	Commelinaceae	*Chloris pilosa* Schumacht.	+	Poaceae
Celosia laxa	-	Amaranthaceae	*Croton lobatus*	+	Euphorbiaceae	*Celosia isertii C. Townsend*	++	Amaranthaceae
Croton lobatus	-	Euphobiaceae	*Cynodon dactylon* (Linn.) Pers	+++	Poaceae	*Cleome viscosa* L.	+	Cleomaceae
Cynodon dactylon (Linn.)Pers	++	Poaceae	*Cyperus rotundus L*	+	Cypreraceae	*Commelina benghalensis* L.	++	Commelinaceae
Cyperus sphacelatus Rottb	-	Cyperaceae	*Dactyloctenium aegyptium* (Linn.)	+++	Poaceae	*Cyperus esculentus* Linn	++	Cyperaceae
Dactyloctenium aegyptium(Linn.)	+++	Poaceae	*Digitaria horizontalis* Willd.	+++	Poaceae	*Dactyloctenium aegyptium* (Linn.) P. Beauv.	+++	Poaceae
Digitaria horizontalis Willd.	+++	Poaceae	*Euphorbia heterophylla*	+	Euphorbiaceae	*Digitaria horizontalis* Willd.	+++	Poaceae
Eragrostis ciliaris (Linn.)	-	Poaceae	*Mullugo nudicaulis* Lam	+	Molluginaceae	*Euphorbia heterophylla* Linn	++	Euphorbiaceae
Eragrostis tenella	-	Poaceae	*Panicum maximum* Jacq	-	Poaceae	*Euphorlia hirta* Linn	++	Euphorbiaceae
Hyptis suaveolens Poit	-	Labiatae	*Portulaca oleracea*	+	Portulacaceae	*Launaea cornuta* (olive. Hiera)	+	Asteraceae
Mariscus alternifolius Vahl	-	Cyperaceae	*Richardia brasiliensis*	+	Rubiaceae	*Mariscus alternifolius Vahl*	+	Malvaceae
Mimosa invisa Mart.	-	Mimosoideae	*Triumfetta rhomboidea* Jacq	+	Tiliaceae	*Mariscus flabelliformis* Kunth var. *flabelliformis*	+	Malvaceae
Passiflora foetida	-	Passifloraceae	*Vernonia cinerea*	+	Verbenaceae	*Mitracarpus villosus* (Sw.) DC.	++	Rubiaceae
Richardia brasiliensis	+	Rubiaceae				*Panicum maximum* Jacq	++	Poaceae
Sida linifolia Juss ex Cav.	-	Malvaceae				*Portulaca oleracea* Linn	+	Portulacaceae
Triumfeta pentandra	-	Tiliaceae				*Phyllanthus amarus* Schum & Thonn	+	Euphorbiaceae
						Trianthema portulacastrum Linn	+	Aizoaceae
						Tridax procumbens Linn	-	Asteraceae
						Triumfetta cordifolia A. Rich	+	Tiliaceae
						Rottboellia cochinchinensis (Lour). Clayton	-	Poaceae

- : Rare; +: fairly abundant; ++: abundant; +++: highly abundant.

Table 3a. Results of the repeated measure analysis, mixed model with three factors (F values and significance level).

Source	D F	Tillering	Plant height	Cover density RICE	Weed dry biomass	LAI	SPAD
Dates (D)	1(3)	1924.8***	885.1***	399.3***	3937.1***	1676.5***	3.4***
Weeds (MH)	2	167.5***	51.2***	251***	69.2***	183.1***	68.7***
Varieties (V)	13	23.6***	14.1***	5.6***	1.35*	1.46^{ns}	19.38***
Season (S)	1	2.5^{ns}	3.2^{ns}	0.5ns	7.34*	4.1^{ns}	729.8***
MH x S	2	3.4^{ns}	0.8 ^{ns}	14.8**	0.1 ^{ns}	10.8**	6.8*
MH x V	26	5.9***	1.9 ^{ns}	0.8 ^{ns}	1.5 ^{ns}	1.5^{ns}	47***
S x V	13	5.6***	11.6***	2.9**	2.5 ^{ns}	3.1**	3**
MH x S x V	26	1.6*	2.2**	1.1^{ns}	1.7**	1.1ns	0.8^{ns}
D x MH	2(6)	971.2***	325.1***	241.8***	1233.8***	134.1***	28.12***
D x V	13(39)	19.4***	8.6***	1.1 ^{ns}	2.2*	0.9^{ns}	2.8***
D x S	1(3)	188.5***	24.7***	165.5***	0.1^{ns}	35.22***	197.6***
D x S x MH	2(6)	42.9***	0.1^{ns}	127.1***	1.4^{ns}	29***	9.8***
D x S x V	13(39)	4.8***	5.1***	1.7 ^{ns}	2.1*	1.5*	3.1***
D x MH x V	26(78)	7.8***	2.4**	0.9 ^{ns}	1.3 ^{ns}	1.8***	1.3^{ns}
D x S x MH x V	26(78)	2.3**	2.93***	0.8 ^{ns}	1.8 ^{ns}	1.3^{ns}	1.51**

ns: Non significant at 0.05; * : significant at 0.05; ** : significant at 0.01- 0.001 ; *** : significant at 0.0001. LAI: Leaf Area Index; SPAD: Soil Plant Analyse Development; Degree of freedom in bracket are related to parameters LAI and SPAD; D: the different data collection dates on for the same sample.

Table 3b. Results of simple ANOVA, mixed model with three factors (F values and significance level).

Source	DF	SLA30	SLA45	SLA60	SLA75	Yld
Weeds (MH)	2	1.2^{ns}	1.8^{ns}	2.7^{ns}	1.2^{ns}	11.3**
Varieties (V)	13	1.8^{ns}	2.4**	0.5^{ns}	6.6***	1.1*
Season (S)	1	10.5*	5^{ns}	0.4^{ns}	6.54**	19.8**
MH x S	2	0.9^{ns}	0.1^{ns}	1.2^{ns}	4.7*	3.5^{ns}
MH x V	26	0.6^{ns}	1.3^{ns}	1.5^{ns}	1.7*	3.1***
MH x S x V	26	0.9^{ns}	0.7^{ns}	0.7^{ns}	1.5^{ns}	1.8*
S x V	13	1.9*	0.5^{ns}	0.9^{ns}	6.1***	1.5^{ns}

ns: Not significant at 0.05 ; * : significant at 0.05; ** : significant at 0.01- 0.001; *** : significant at 0.0001. SLA: Specific Leaf Area; Yld: Yield in gm^{-2}.

to7.73 (IR31785-58-1-2-3-3) for the two seasons.

SLA

During the two crop seasons, IG10 had the highest SLA values (23.42 m^2kg^{-1} in the off-season to 19.73m^2kg^{-1} in rainy season) and WITA7 had the lowest mean SLA values were 18.4m^2kg^{-1} in the dry season and 20.40m^2kg^{-1} in the rainy season. Except for IG10, the African varieties had similar SLA values. The SLA values were lower in the rainy season than in the dry season for most of the varieties, except WAB56-50 and WITA2 for which slight increases were observed during the rainy season.

SPAD

Irrespective of the weeding regime, SPAD values ranged from 22.11 to 34.42 units - largely lower than 30 units in the dry season and nearly 35 units in the rainy season. During the two cropping seasons, the lowest values were recorded onCG14 (22.11 in the dry season and 26.07 SPAD units in the rainy season).

Relationship among the eight quantitative traits

Pearson correlations (Table 6) were evaluated between traits such as « Hmat », « T60 », « Yld », «SLA», « LAI », « SPAD », «CDR » and « WDB ». These quantitative traits showed significant differences (P≤0.05) between the 14 tested varieties. Variables were significantly correlated (P≤0.05) irrespective of the weeding regime, varieties and season. For the «0-weeding» treatment, « Yld » was positively correlated to « Hmat » (0.52) and «T60 » (0.59). The latter was also positively correlated to« Hmat » (0.52). « Yld », « Hmat » and « T60 » were

Table 4. Impact of weeds on tillering ability.

Dry season			Rainy season		
Traits	**T30 (%)**	**T60 (%)**	**Varieties**	**T30 (%)**	**T60 (%)**
CG14	38.33^{a}	82.33^{a}	JAYA	8.8^{a}	65.36^{bdc}
WAB 56-50	31.75^{ba}	71.33^{a}	WITA 7	4.81^{a}	68.79^{bac}
IG 10	30.75^{ba}	81.41^{a}	IR 64	29.75^{a}	70.65^{ba}
IR64	29.00^{ba}	75.5^{a}	WITA 2	19.74^{a}	64.72^{bdc}
CG17	28.50^{ba}	71.83^{a}	IR 31785-58-1-2-3-3	15.09^{a}	56^{ed}
WITA 2	27.50^{ba}	75.00^{a}	FKR 54	24.14^{a}	65.76^{bdc}
SHAWHON	25.83^{ba}	76.33^{a}	TOG 5681	16.55^{a}	77.10^{a}
FKR 54*	21.50^{bac}	74.66^{a}	FKR 19	7.96^{a}	60.72^{bedc}
IR31785-58-1-2-3-3	19.91^{bac}	69.58^{a}	CG 20	18.01^{a}	52.80^{e}
JAYA*	15.58^{bac}	69^{a}	CG 17	4.1^{a}	59.79^{bedc}
FKR 19*	14.75^{bac}	74.66^{a}	IG10	3.5^{a}	68.85^{bac}
TOG 5681	11.41^{bac}	78.33^{a}	CG14	1.62^{a}	78.63^{a}
CG 20	6.08^{c}	68.75^{a}	SHAWHON	15.96^{a}	59.16^{bedc}
WITA 7	4.91^{c}	76.00^{a}	WAB 56-50	19.74^{a}	57.16^{edc}

Means with the same letter within a column are not significantly different at 5%.

Table 5. Grain yield (g/m²) of the varieties in relation to weeding regime.

Traits	Dry season				Rainy season			F value
	0 weeding	1 weeding	4 weeding	F value	0 weeding	1 weeding	4 weeding	
CG14	118	1326	1480	9.64**	1309	1243	1901	9.45**
CG17	254	1419	1773	16.4***	345	1336	1570	0.09^{ns}
CG20	547	1990	2824	5.28*	1130	1754	2560	0.04*
IG10	0	1575	2211	7.81**	1505	2430	1888	16.77***
SHAWHON	0	1285	1942	5.29*	906	1367	1824	2.44^{ns}
TOG5681	415	1137	1658	2.25^{ns}	2023	1267	1613	13.3***
IR64	0	1355	1817	5.38^{ns}	766	1347	2165	4.95^{ns}
IR31875	0	1487	2216	2.1^{ns}	843	2286	2592	20.96***
WAB 56-50	164	1629	2512	5.62**	436	1232	2481	0.12^{ns}
WITA 2	0	1285	2120	6.97**	994	1252	2430	7.5**
WITA 7	0	1571	2318	3.26*	191	2172	2638	5.74*
FKR 19	0	1576	2753	2.95^{ns}	416	1784	2903	3.08^{ns}
FKR 54	0	1264	2378	6.12**	381	1752	2708	6.66**
JAYA	0	1525	1657	2.17^{ns}	797	1491	2139	7.97***
Means	150	1458.86	2118.5		860.14	1622.4	2243.7	

ns: Not significant at 0.05; * : significant at 0.05; ** : significant at 0.01- 0.001; ***: significant at 0.0001.

positively correlated to « SPAD ». The correlation values were less than 0.70 and described the morphology of varieties 60 DAS. Varieties had high number of tillers, were tall and were very low to low yielding. For the « 1-weeding » treatment, high to medium and negative correlation were shown between « SPAD and CDR» , « SPAD and WDB», « T60 and CDR » and « T60 and WDB ». Positives correlations were obtained between « Yld and T60 » and « CDR and WDB». These values were comprised between -0.39 and 0.72. Weeds proliferation, showed by a high dry mass weight, depends upon the quality of the shadow made by the plant leaves attitude. For the « 4 weedings» treatment, « CDR and WDB »; « LAI and WDB », « Hmat and T60 » and « SLA and SPAD » were highly and negatively correlated, confirming that the proliferation of weeds depend significantly on the aptitude of the plant to cover the soil by its leave attitude.

Table 6. Pearson correlation coefficient between variables in relation to weeding regime.

Traits	LAI	SLA	SPAD	Yield	Hmat	T60	CDR	WDB
0weeding								
LAI	1**							
SLA	0,29^{ns}	1**						
SPAD	-0.74**	-0.09^{ns}	1**					
Yield	-0.37^{ns}	-0,09^{ns}	0.45*	1**				
Hmat	-0.36^{ns}	0.01^{ns}	0.49*	0.52**	1**			
T60	-0.63**	-0.08^{ns}	0.77**	0.59**	0.52**	1**		
CDR	0.34^{ns}	-0.26^{ns}	-0.32^{ns}	-0.22^{ns}	-0.26^{ns}	-0.14^{ns}	1**	
WDB	-0,09^{ns}	-0.07^{ns}	-0.09^{ns}	-0.09^{ns}	-0.46*	-0.06^{ns}	0.04^{ns}	1**
1weeding								
LAI	1**							
SLA	-0.01^{ns}	1**						
SPAD	0.21^{ns}	-0.18^{ns}	1**					
Yield	-0.01^{ns}	-0.19^{ns}	0.22^{ns}	1**				
Hmat	-0.12^{ns}	-0.36^{ns}	0.36^{ns}	0.19^{ns}	1**			
T60	0.26^{ns}	-0.10^{ns}	0.47*	0.54*	-0.11^{ns}	1**		
CDR	-0.16^{ns}	0.04^{ns}	-0.67**	-0.34^{ns}	-0.33^{ns}	-0.39*	1**	
WDB	-0.03^{ns}	-0.02^{ns}	-0.56*	-0.31^{ns}	-0.28^{ns}	-0.47*	0.72*	1**
4weeding								
LAI	1**							
SLA	-0.26^{ns}	1**						
SPAD	0.62**	-0.44*	1**					
Yield	0.26^{ns}	-0.04^{ns}	0.26^{ns}	1**				
Hmat	0.01^{ns}	0.04^{ns}	0.10^{ns}	-0.08^{ns}	1**			
T60	0.21^{ns}	-0.02^{ns}	-0.16^{ns}	0.06^{ns}	-0.58**	1**		
CDR	0.78**	-0.34^{ns}	0.34^{ns}	0.45*	0.07^{ns}	0.07^{ns}	1**	
WDB	-0.75**	0.26^{ns}	-0.33^{ns}	-0.35^{ns}	-0.10^{ns}	0.02^{ns}	-0.89**	1**

Ns: Not significant at 0.05; * : significant at 0.05 ; **: significant at 0.01- 0,001 ; ***: significant at 0.0001.

Determination of variance component and assessment of broad sense heritability

«Genotype × weed regime » and «genotype» variance component were low to nil based on the variables T60, yield, SPAD and CDR under the three weeding regimes (Table 7). However, high «genotype × treatment» variances were detected based on the variables Hmat and SLA for the three weeding regimes except for the variable WDB under 0-weeding regime. With this latter regime, estimated broad sense heritability was nil for most of the characters except the variables CDR (0.57), SPAD (0.42) and T60 (0.17). Under 1-weeding, two characters (SLA and LAI) showed nil broad sense heritability while this heritability varied between 0.13 and 0.63 for the other characters. The highest broad sense heritability was recorded, under the 4-weeding regime, with the variable T60(0.84) while broad sense heritability estimates varied between 0 (LAI, SLA, WDB and CDR) and 0.58 (Yld).

DISCUSSION

The weed flora involved in the competition varied according to the season. They are all annual weed species that occur in many rice farms in sub Saharan Africa and Asia (Akobundu et al., 1987; Moody, 1989; Johnson, 1997; Zhao et al., 2006; Rodenburg and Johnson, 2009). However, the occurrence of new weed species in the rainy season would indicative of their introduction into the rice fields. Indeed, runoff water, wind

Table 7. Variances combining the two cropping seasons, the three weeding regimes and corresponding broad heritability.

Traits	0weeding				1weeding				4weeding			
	δ^2_G	$\delta^2_{G\times T}$	δ^2_E	H_{1-2}	δ^2_G	$\delta^2_{G\times T}$	δ^2_E	H_{1-2}	δ^2_G	$\delta^2_{G\times T}$	δ^2_E	H_{1-2}
Tiller	0.05	0.26	1.44	0.17	4.17	3.27	9.26	0.63	11.81	2.74	11.15	0..
Height at maturity	0	394.98	546.80	0	45.72	9974	239.50	0.40	50.97	95.15	112.19	0.47
Yield	0	0.07	0.45	0	002	0.10	0.93	0.13	0.11	0.04	0.72	0.58
LAI	0	0	2.62	0	0	0	2.74	0	0	0.33	1.47	0
SLA	0	201.37	13143.74	0	0	544.40	6615.77	0	0	644.31	6682.63	0
SPAD	3.62	3.09	40.46	0.42	602	12.03	34.74	0.40	7.1	6.72	74.54	0.43
CDR	0	581.80	3624.95	0	12145	0	3063.01	0.32	0	0.41	11.50	0
WDB	11.85	4.87	78.59	0.57	108	0.	48.31	0.21	0	0	191.60	0

δ^2_G: Variance of genotypes; $\delta^2_{G\times T}$: interaction genotype × season; and δ^2_E: variance error.

and anthropogenic inputs may be responsible for this new weed seed dissemination although climatic factors during the dry season may also favour the occurrence of some weed species. It could be that some seeds were dormant and needed the dry season conditions to germinate. There important differences among the 14 varieties in the effect of weeds on phenotypic expression based on agro-morphological characters. Weeds caused a reduction in plant height and number of fertile tillers. Rice plants that were resistant to weed pressure in the 0-weeding regime were filiform and stunted. The morphology of the plants showed nutrient unavailability, limited space and light for growth and development. Indeed, Nyarko and De Datta (1991) and Halidou (2004), indicated that weeds are rustic plants able to compete with cultivated plants due to their similarity with these plants and their ability to reproduce and disseminate faster. They grow and develop faster than rice plants and are then able to use most of the nutrients available in the soil. This results in light reduction and thereafter to low photosynthetic activity (Caussanel, 1989).

Although it is difficult to assess weed competitiveness based only on agro–morphological characters (Ni et al., 2000), plant height is, however, one of the main characters often used to explain this performance (Caton et al., 2003). Moreover, 0-weeding and 1-weeding regimes showed that the critical period for rice competitiveness ranged between 30 and 60 DAS. During this period under 0-weeding regime, rice plants completely degenerated while, for the same variety under 1-weeding regime at 14 DAS, many rice plants showed resistance to weed pressure. At this vegetative stage, rice plants absorb more nutrients with intensive photosynthetic activity to synthesize different organic substances that are important for plant metabolism (Fabre, 2007). Weeding once at 14 DAS resulted in a higher production level under the 0-weeding regime. Dogbé and Aboa (2004) reported a rice weed competitiveness critical phase of 45 to 60 DAS. Beyond this period, weeding is not economically recommendable to farmers (Ahanchede and Saïdou, 2009). With no weeding, the highest grain yields were attained by CG20.

Growth indices (LAI, SLA and SPAD) were used to characterize weed-competitive varieties. Under 0-weeding, varieties of African origin were of intermediate height at maturity, low tillering, had an open culm habit and SLA values below 3 (medium to high). They had vegetative vigour in their early growth stage. All these characteristics were reported by Piggin et al. (1996), Johnson et al. (1998), Dingkuhn et al. (1999), WARDA (2000), and Haefele et al. (2004). Most of the African varieties were able to cover the soil to varying degrees and might, therefore, be effective in limiting space, light and nutrients for weeds. LAI values under the 1-weeding regime confirm that these varieties were able to provide a close vegetative cover following analyses according to Fabre (2007). African varieties also showed high SLA values at 45 DAS that likely yielded high biomass accumulation because photosynthetic activity was less disturbed until 45 DAS. At this time, all O. glaberrima varieties had high SLA similar to that of IG10 during both cropping seasons. This result is consistent with that recorded by Johnson et al. (1998). These authors assessed the weed-competitiveness of three rice varieties- IG10, Moroberekan and IDSA6 - and showedthat IG10 was the best. Compared to *O. sativa* varieties, IG10 accumulates more biomass, and produces more tillers with higher LAI and SLA during its early growth stage. SLA is an excellent criterion after tillering ability and LAI in terms of breeding for weed-competitive varieties (Dingkuhn et al., 2001; Caton et al., 2003). These parameters indicate the ability of a variety to stifle weeds through shading them with long and droopy leaves. SPAD values in the current study ranged from 0 to 35 units and fall into the limits suggested by Fabre (2007). Balasubramanian et al. (2007) have also shown the kind of variation in SPAD values. It is an important characteristic for measuring the impact of weeds on cultivated crops. This parameter indicates when a plant requires nitrogen because the chlorophyll content is highly correlated with that of carboxylase, the predominant protein in the leaf, and therefore nitrogen content.

Correlation showed variables that better explain the weed-competitiveness of the 14 varieties. With 0-weeding and 1-weeding, tillering, plant height and grain yield were highly and positively correlated. It is therefore feasible to use these variables in breeding for more weed-competitive varieties. The results of the current study corroborate those reported earlier by Jennings and Aquino (1968) and Zhao et al. (2006), although Fischer et al. (2001) found no relationship between plant height and tiller ability regarding weed-competitiveness. On the other hand, variables like CDR and DBR were negatively correlated and therefore confirm the results mentioned earlier. Indeed, these descriptors showed that shading by rice leaves slowed down weed proliferation, which therefore shows the ability of a variety to limit light and photosynthesis necessary for the growth of weeds.

Assessment of broad sense heritability (h^2) based on agro-morphological characters and growth indices under the three weeding regimes led to three categories of variables according to the model suggested by Robinson et al. (1949), low heritable ($h^2<0.2$), moderately heritable ($0.2<h^2<0.4$) and highly heritable ($h^2>0.4$). Although the assessment of h^2 strongly depends on the genetic material and the methods used (Griffiths et al., 2000; Cuguen, 2010; Fahliani et al., 2010), it nevertheless constitutes an important indicator for the selection of variables selection and then character expression. Thus, based on the current data, there are three types of variables T60, SPAD, Hmat and yield had heritability values higher than or equal to 0.40 with 1-weeding and 4-weeding, except for variable yield under 1-weeding. These four variables may be considered as highly heritable under these prevailing conditions, while h^2 obtained under on 0-weeding and using variables SPAD and CDR was higher than or equal to 0.40 contrary to other studied variables. Under these conditions, variables T60, Hmat and yield have low heritability. Indeed, heritability reduces with complexity and increased difficulties of the environment and changes with the time (Cuguen, 2010). It improves when a variety grows in a favourable environment. Heritability also varies depending on the character being considered. For example, Sabu et al. (2009), obtained a h^2 of 0.35 based on tillering trait while Laxuman et al. (2010) obtained h^2 values of about 0.60 based on SPAD, number of fertile tillers per plant, panicle weight, number of grains per panicle and weight of 1000 grains.

Indeed, assessment of h^2 based on agro-morphological variables is contradictory, since it strongly depends on the genetic material used (Fahliani et al., 2010). The absence of genetic variations in the total phenotypic expression of the 14 genotypes resulted in no h^2, irrespective of the weeding regime, for the variables LAI, SLA and DBR. The *O. glaberrima* variety CG20 was more competitive than the other tested varieties and could be recommended as a donor parent in a breeding program for weed-competitive rice varieties in West Africa. Indeed, Sarla and Mallikarjuna (2005) have mentioned this in an earlier study. Moreover, African varieties showed different levels of weed-competitiveness. Dingkuhn et al. (1999) observed that African rice varieties present a strong association taking into account their competitiveness against weeds. Many earlier studies showed that IG10 (Johnson et al., 1998; Fofana and Rauber, 1999; Sarla et al., 2005), CG14 (Haefele et al., 2004) and TOG 5681 (Rodenburg et al., 2009; Moukoumbi et al., 2011) are more competitive than weeds, although the level of competitiveness depends on the prevailing environmental conditions. The results of the current study are consistent with these earlier findings with regard to grain yield recorded under 0-weeding by TOG5681, IG10, SHAWHON, CG14 and CG17, all *O. glaberrima* varieties.

Conclusions

During the two cropping seasons, a large phenotypic variation in weed-competitiveness was observed among varieties derived from African rice species. Based on agro-morphological and physiological characters and the impact of weeds on the growth and development of the 14 test varieties, CG20 was the most weed-competitive, while FKR19 was the least. Using the correlation and broad sense heritability, three types of heritable variables were obtained based on quantitative characters and weeding regime. The screening of CG20 is of paramount importance as it could be used in the breeding program for the genetic analysis of weed-competitiveness in rice.

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