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Varietal Differences in Lodging Resistance of African Rice (*Oryza glaberrima* Steud.)

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Abstract: To identify resistant genotypes to lodging in African rice (*Oryza glaberrima*), 6 genotypes, three of which were selected by prescreening for the resistance and the remaining three were used in an interspecific breeding program at WARDA, were tested in terms of resistance to lodging. The trial was conducted in rainfed upland in 2005 and in irrigated lowland in 2006 and all genotypes showed higher yield and larger plant length in 2006 than in 2005. There was a clear varietal difference in lodging incidence of the *O. glaberrima* genotypes at maturity, which was ranged from 0.0 to 91.0% and from 68.6 to 99.7% in 2005 and 2006, respectively. In 2005, four *O. glaberrima* genotypes, TOG 7235, IRGC Accession Code 104038, CG 14 and CG 20, depicted the resistance at maturity since their lodging incidences were from 0.0 to 6.7%. With heavier panicles by higher yield and larger plant length in 2006, however, two of those four genotypes almost completely lodged at maturity. The remaining two genotypes, TOG 7235 and CG 14, showed moderately low lodging incidences of 74.1 and 68.6%, respectively. However, those rates are still very high as a commercial variety and further screening for lodging resistance is necessary.

Key words: Culm strength, cultivated *Oryza* species, rice breeding

INTRODUCTION

African rice (*Oryza glaberrima* Steud.), which is the principal cultivated *Oryza* species other than Asian rice (*Oryza sativa* L.), was domesticated in West Africa (WA) more than 3500 years ago (Jones *et al*., 1997b) and is still cultivated in this sub-region. In *O. glaberrima*, a number of genotypes possessing resistance to various biotic and abiotic constraints in WA have been identified (Jones *et al*., 1997b; Abo *et al*., 1998; Johnson *et al*., 1998; Fofana and Rauber, 2000; Ndjiondjop *et al*., 1999, 2001; Kawano *et al*., 2008). Thus, the species is a rich genetic reservoir to develop tailor-made varieties suitable for resource-poor farmers in WA, who are suffering from low yield caused by various constraints. However, *O. glaberrima* also has some unfavourable characteristics for a cultivated species such as grain shattering and lodging. Interspecific breeding of *O. glaberrima* and *O. sativa* could be one approach to use only the assets of *O. glaberrima* (Ghesquière *et al*., 1997). WARDA commenced wide crosses between the two cultivated rice species and attempted to utilize only the assets of *O. glaberrima* in interspecific breeding with *O. sativa* (Jones *et al*., 1997a). Several commercial varieties have been officially released in sub-Saharan Africa (SSA) from the fixed interspecific progeny, which is known as NERICA® (Futakuchi, 2008).

Among the noteworthy characteristics of *O. glaberrima* to be utilized, there are some all-inclusive traits. A typical example is that a certain single genotype shows resistance to various stresses in WA, although some *O. sativa* varieties with stronger resistance for individual constraints can de found; and such multiple resistance has been reported in CG 14, the *O. glaberrima* parent of all upland NERICA varieties (Futakuchi, 2008). In developing the NERICA varieties released in SSA, backcrossing to the *O. sativa* parents was carried out two to four times (Jones *et al*., 1997a; Sie *et al*., 2005). To introgress such a broad character of *O. glaberrima* into NERICA in future, the number of backcrossings to *O. sativa* will be limited, which could induce a sterility problem in obtaining fixed fertile interspecifics. On the other hand, intraspecific breeding of *O. glaberrima* could be the best way to exploit its unique assets such as multiple resistance to major constraints in WA because fixed fertile progeny can be obtained without suffering from the incompatibility barrier that always arises in interspecific breeding.

To explore *O. glaberrima*×*O. glaberrima* crosses, genotypes possessing favourable characteristics that compensate for general drawbacks of *O. glaberrima* like low yielding, which is sometimes given as a cause for the decline of *O. glaberrima's* cultivated area in WA (Linares, 2002), should be identified in *O. glaberrima*.

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Low yield of *O. glaberrima* is caused by grain shattering, frequently enhanced by lodging. The sink capacity of *O. glaberrima* estimated by the spikelet number is not inferior to that of *O. sativa* (Dingkuhn *et al*., 1998). In preparing for the launch of intraspecific breeding in *O. glaberrima*, WARDA attempted to identify *O. glaberrima* genotypes with resistance to lodging.

Following the 2002 civil crisis in Côte d'Ivoire, WARDA relocated its research division to Samanko near Bamako, Mali to which just 20 g of each breeding line, genotypes/lines/varieties to be used for breeding and segregating progeny were retrieved from the Headquarters. Of the 20 g of seed, 15 g was used for multiplication in 2003 for the following year's selection and evaluation for the segregating progeny (5601 progeny) at Samanko and at Sikasso, Mali for genotypes/lines/varieties (3951 lines), with the remaining 5 g kept in reserve. Multiplication was carried out in a plot comprising two rows of 4.5 m with between- and within-row spacing of 0.25 m with no replication during the rainy season. In the multiplication at Sikasso (11°42' N, 6°30' W), located in southern Mali in the Guinea Savannah zone, 86 *O. glaberrima* genotypes were included in the list. The site was in rainfed lowland where severe flooding by flowing water on the ground due to excess rainfall was observed in the growth period. Of those 86 genotypes cultivated, only three genotypes, i.e. TOG 7235, TOG 7291 and IRGC accession code 104038 did not lodge after heading. The objective of this study was to evaluate those three *O. glaberrima* genotypes for their resistance to lodging.

MATERIALS AND METHODS

In addition to the three genotypes selected during the seed multiplication at Sikasso, another three *O. glaberrima* genotypes, which had been previously used in the interspecific breeding program at WARDA but were yet to receive detailed evaluation for resistance to lodging, were also used. In total, six *O. glaberrima* genotypes were tested: TOG 7235, TOG 7291, IRGC 104038, CG 14, CG 20 and IG 10, originating respectively from Mali, Burkina Faso, Senegal, Senegal, Senegal and Côte d'Ivoire. All genotypes belong to an upland type. As check varieties, Gambiaka, an indica-type traditional *O. sativa* variety and Bouaké 189, an indica-type improved *O. sativa* variety, were included in the entry.

In 2005, the trial was conducted in rainfed upland at Dassa (7°46' N, 2°11' E) in the Guinea Savannah area of Benin using a section of farmers' fields. Prior to the trial, areas to be used were weeded then plowed manually. On 18 July 2005, five seeds were directly sown in each hill in the plots arranged in a randomized complete block design with three replications. Hills were arranged in a square planting of 0.2 m and each plot measured 3.2×4.2 m (17 rows × 22 hills). After seedling establishment, seedlings were thinned to two per hill. The plots received a basal application of (10% N, 15% P_2O_3 and 18% K_2O) at a rate of 20 g m^{-2} and top-dressing of urea (46% N) at a rate of 8.7 g m^{-2} around the maximum tillering and panicle initiation stages. The plots were maintained weed-free during the trial by hand-weeding. No water control was made and the materials were raised strictly by rainfall. In 2006, the trial was repeated in irrigated lowland at Deve (6°45' N, 1°37' E) in the Guinea Savannah zone of Benin, again using part of farmers' fields. The cultivation practice was the same as in 2005. However, the land was prepared by mechanized plowing and the plots were irrigated to maintain flooded conditions after seedling establishment. The seeding date was 25 July 2006. The plot size was 3.0×4.0 m (16 rows × 21 hills).

Lodging incidence was determined as a percentage ratio of plants that lodged (IRRI, 2002), with the exception of plants in the first row and first hill from the border at the maximum tillering and maturity stages. Therefore, 336 plants (16 × 21 plants) and 300 plants (15 × 20 plants) were used for the evaluation of lodging incidence in 2005 and 2006, respectively.

Culm strength was rated at the heading stage following the Standard Evaluation System for Rice by IRRI (2002), namely the score of the strength was given according to the inclination of a plant after gently pushing the tillers back and forth a few times. Ten plants per plot were assessed for the evaluation. Lower scores corresponded to stronger culms. The culm strength was evaluated only in 2006.

As additional agronomic traits, yield, plant length and tiller number were determined. Plant length and tiller number were measured at the maximum tillering and maturity stages with 4 and 10 plants per plot, respectively. Yield determination was made with 48 plants (6 × 8 plants) for each plot. At harvesting, the whole aboveground part was collected and air-dried on paved ground. After drying, the manually-threshed paddy samples were winnowed and weighed. Regarding statistical analysis, LSD at the probability level of 5% was calculated only for a trait for which a significant difference between genotypes/varieties was identified by single factor ANOVA.

RESULTS

The field at Dassa was upland and there was no flooding during the growth period in 2005, whereas

Table 1: Lodging rates and several agronomic traits of *O. glaberrima* in upland in 2005

Genotype/Variety	Yield (kg ha^{-1})	Duration[1)] (days)	Lodging rate (%) Heading	Lodging rate (%) Maturity	Plant length (cm) Tillering	Plant length (cm) Maturity	Tiller No. hill^{-1} Tillering	Tiller No. hill^{-1} Maturity
TOG 7235	984	82.7	0.0	5.6	68.0	108.4	9.3	15.6
TOG 7291	1868	70.7	0.0	91.0	73.8	110.4	10.8	13.4
IRGC Acc. code 104038	1020	70.0	0.0	0.8	74.8	86.4	9.5	17.4
CG 14	1888	76.7	0.0	6.7	54.3	104.9	11.5	16.3
CG 20	2068	71.7	0.0	0.0	69.2	97.4	13.1	15.3
IG 10	1830	72.0	0.0	33.1	68.2	79.3	14.8	13.8
Gambiaka (*O. sativa* check)	2226	92.3	0.0	0.0	67.0	107.8	12.3	13.9
Bouake 189 (*O. sativa* check)	2510	92.7	0.0	0.0	52.6	105.8	14.9	14.8
Average of *O. glaberrima*	1610	73.9	0.0	22.9	68.0	97.8	11.5	15.3
Level of significance	**	**	ns	**	**	**	**	ns
LSD (5%)	679	2.3		32.1	11.9	5.8	1.4	

[1)]: Days from seeding to 50% flowering, ns: Not significant, **: Indicates significance at the p<0.01 level

Table 2: Lodging rates, culm strength scores and several agronomic traits in *O. glaberrima* in irrigated lowland in 2006

Genotype/Variety	Yield (kg ha^{-1})	Duration[1)] (days)	Lodging rate (%) Heading	Lodging rate (%) Maturity	CSS[2)]	Plant length (cm) Tillering	Plant length (cm) Maturity	Tiller No. hill^{-1} Tillering	Tiller No. hill^{-1} Maturity
TOG 7235	1757	94.7	0.0	74.1	6.00	92.9	120.1	10.8	14.1
TOG 7291	3481	90.7	12.4	95.3	6.27	104.3	118.4	9.3	15.0
IRGC Acc. code 104038	3334	82.3	3.7	99.7	6.00	102.9	107.9	11.5	18.9
CG 14	3451	94.7	8.4	68.6	6.40	98.2	113.3	12.8	16.8
CG 20	3539	88.3	62.9	96.3	5.33	121.2	118.8	11.3	22.5
IG 10	3481	93.7	6.0	77.6	5.53	99.2	113.9	11.7	17.9
Gambiaka (*O. sativa* check)	5386	113.0	0.0	0.0	4.73	81.8	150.0	13.2	17.6
Bouake 189 (*O. sativa* check)	6438	108.0	0.0	0.0	2.33	69.3	113.2	14.8	22.4
Average of *O. glaberrima*	3174	90.7	15.6	85.3	5.92	103.1	115.4	11.2	17.5
Level of significance	**	**	**	**	**	**	**	*	ns
LSD (5%)	1284	2.7	18.3	19.5	0.91	22.3	5.7	2.8	

[1)]: Days from seeding to 50% flowering, [2)]: CSS indicates a culm strength score, ns: Not significant,**: Indicate significance at the p<0.05 and p<0.01 levels, respectively

flooded conditions were maintained in the 2006 trial in irrigated lowland at Deve. For all genotypes/varieties tested, therefore, growth duration was shorter in 2005 than in 2006 and overall growth judged from tiller number at maturity, from plant length and yield was much poorer in 2005 compared to that in 2006 (Table 1, 2).

Varietal difference of lodging incidence was clearly observed in *O. glaberrima* at maturity in 2005 and at heading and maturity in 2006 (Table 1, 2). Lodging incidence in *O. glaberrima* was generally more obvious in 2006 than in 2005, which may caused by greater plant length and heavier panicles in 2006, during which no lodging was observed in *O. sativa*. In 2005, no tested line lodged at the heading stage, but a clear difference was observed between *O. glaberrima* genotypes in terms of lodging at the maturity stage; the lodging scores of TOG 7235, IRGC 104038, CG 14 and CG 20 were not significantly different from those of the *O. sativa* checks, which was 0 and those lines seemed to resist lodging, whereas some IG 10 plants lodged, along with almost all the TOG 7291 plants. In the irrigated lowland of 2006, TOG 7235 showed no lodging at heading and only CG 20 depicted a significantly higher lodging rate than TOG 7235 at that stage. At maturity, TOG 7291, IRGC 104038 and CG 20 almost completely lodged, with a lodging rate of more than 95%. Although TOG 7235 and CG 14 had significantly lower lodging rates than the three *O. glaberrima* genotypes almost entirely lodged, TOG 7291, IRGC 104038 and CG 20; about 70% of the plants were lodged in the conditions where the *O. sativa* check did not lodge. There was a clear difference in the culm strength score between *O. sativa* and *O. glaberrima*. Of the *O. glaberrima* genotypes, CG 20 seemed to have slightly stronger culms (Table 2) and was not significantly different from that of the weaker *O. sativa* check (Gambiaka).

DISCUSSION

TOG 7291 and CG 20 were highly susceptible to lodging. The former line lodged at maturity even under poor growth conditions in 2005. This could be due to large plant length compared to the other *O. glaberrima* genotypes since the weight of its panicles (yield) is similar to the others. Although CG 20 depicted no lodging in 2005, it was the only genotype to lodge at heading under favorable growth conditions in 2006. The strength of its culm is not low compared to the other *O. glaberrima* genotypes and the high lodging rate at heading could be caused by its greater plant length at that stage. TOG 7235 and CG 14 were fairly resistant to lodging in the *O. glaberrima* genotypes with almost no lodging showing in 2005 and a lower lodging rate than the other *O. glaberrima* at maturity in 2006 when most *O. glaberrima* genotypes lodged completely. However, their culms were not tougher than the other *O. glaberrima* (Table 2) and the moderate resistance displayed in TOG 7235 could be due to lighter panicles since its yield was always lowest (Table 1, 2). However, further investigation will be necessary for the cause of the fair resistance of CG 14 since its yield was not low among the *O. glaberrima* genotypes (Table 1, 2).

To identity *O. glaberrima* genotypes possessing complete resistance to lodging, screening should be continued. The lodging incidence of *O. glaberrima* depended on the growth conditions; for example, CG 20 and IRGC 104038 completely lodged under favourable growth conditions but did not lodge in environments where their growth was inhibited (Table 1, 2). Three *O. glaberrima* genotypes, TOG 7235, TOG 7291 and IRGC 104038, did not lodge after the heading stage in the seed multiplication at Sikasso, Mali in 2003. It is likely that this was due to inhibited growth caused by flowing water on the field used for seed multiplication. Although all *O. glaberrima* genotypes tested were classified as an upland type, all showed better growth performance in flooded conditions in the irrigated lowland in 2006 than in non-flooded conditions in the upland in 2005 (Table 1, 2). *O. glaberrima* is sometimes sub-grouped into two ecotypes, that is, upland and deep water (for example, Oka, 1974). However, the species seems to grow more vigorously in flooded conditions of lowland than in non-flooded conditions of upland, irrespective of its ecotypes. It is therefore suggested that screening of *O. glaberrima* for lodging resistance should be made in flooded conditions of irrigated lowland where its innate growth performance could be expected.

Lodging in *O. sativa* has been well studied; for example, its mechanisms of resistance (Oladokun and Ennos, 2006) and its agronomic effect on yield (Setter *et al*., 1997). However, lodging of *O. glaberrima* is a well-known character of the species and has not been accorded research interest, although its resistance to constraints (Jones *et al*., 1997b; Abo *et al*., 1998; Johnson *et al*., 1998; Fofana and Rauber, 2000; Ndjiondjop *et al*., 1999; Ndjiondjop *et al*., 2001; Kawano *et al*., 2008) and genetic structure and diversity (Barry *et al*., 2007) have been a great interest of researchers. In view of intraspecific breeding in this species, however, the search for resistant genotypes to lodging becomes important and this study firstly revealed that there is a varietal difference of lodging incidence in *O. glaberrima*. Although two *O. glaberrima* genotypes (TOG 7235 and CG 14) showed relatively low lodging rates, they are still very high for a commercial variety and further screening for lodging resistance is necessary.

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