



## Yield loss of *Oryza glaberrima* caused by grain shattering under rainfed upland conditions

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### ABSTRACT

The general perception of *Oryza glaberrima* as low yielding is a potential drawback to intraspecific breeding of this species. Yields of 21 *O. glaberrima* accessions were evaluated alongside four *O. sativa* check varieties under two conditions in which panicles were both covered by paper sacks to avoid grain shattering (potential yield plot) and also not covered (control plot) in a rainfed upland field of Benin in 2010 and 2011. Average potential yields of *O. glaberrima* with panicles covered were 2.42 and 3.65 t ha<sup>-1</sup> in 2010 and 2011, respectively, while those of *O. sativa* were respectively 2.99 and 3.49 t ha<sup>-1</sup>. Although there was no significant difference between potential yield and control yield in *O. sativa*, 19 *O. glaberrima* accessions showed significant yield reduction by grain shattering — the average percentages of lost yield by shattering were 57.88% in 2010 and 66.76% in 2011. These results suggest that low yield of *O. glaberrima* is due to grain shattering and that its potential yield would not be inferior to *O. sativa* if the grain shattering problems were overcome. Two *O. glaberrima* accessions, TOG 12303 and TOG 9300, possessing strong resistance to grain shattering comparable to *O. sativa* checks, were identified.

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**Keywords:** Panicles, paper sacks, potential yield, yield reduction.

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### INTRODUCTION

Only two species — *Oryza glaberrima* Steud. and *Oryza sativa* L.— within the genus *Oryza* comprising 22 species were cultivated (Vaughan et al., 2003). *Oryza glaberrima*, the indigenous African rice, is thought to have been domesticated between 2000 and 3000 years ago in the inland delta of the upper Niger river in West Africa. This domestication taking place long before the introduction of *O. sativa* to the continent by the Portuguese (Linares, 2002). Because of the history of *O. glaberrima* in Africa, the species is expected

to be a rich genetic source for adaptability to African environments as compared to *O. sativa*. In fact *O. glaberrima* can provide resistance to various indigenous biotic constraints: rice yellow mottle virus (Thiémiélé et al., 2010), bacterial leaf blight (Djedatin et al., 2011), African rice gall midge (Ukwungwu et al., 1999; Williams et al., 1999), weeds (Moukoumbi et al., 2011) and nematode (Coyne et al., 1999; PlowRight et al., 1999) and to abiotic stresses such as drought (Maji et al., 2010; Ndjiondjop et al., 2010), submergence (Futakuchi et al., 2001;

Kawano et al., 2008), iron toxicity (Sahrawat and Sika, 2002) and low phosphorus availability in acid soils (Tobita et al., 2003). Interspecific breeding of *O. glaberrima* with high yielding *O. sativa* could be one approach to use the advantage (resistance to local constraints) of *O. glaberrima* while excluding its low yield characteristic (Ghesquiere et al., 1997) and to create a number of interspecific lines both for upland (Jones et al., 1997) and lowland (Sie et al., 2005). To develop the fertile interspecific lines, two to four backcrosses to the *O. sativa* were needed (Jones et al., 1997; Sie et al., 2005). Intraspecific *O. glaberrima* × *O. glaberrima* breeding, which could be another approach to better utilize the values of *O. glaberrima* for farmers in Africa (Futakuchi and Sie, 2009). *Oryza glaberrima* was previously considered as low yield (Linares, 2002) and actually shown to have negative characteristics for yield generation such as grain shattering (Jones et al., 1997) and lodging (Futakuchi et al., 2008). Dingkuhn et al. (1998) measured number of spikelets before the occurrence of shattering for an *O. glaberrima* accession (CG 14) and *O. sativa* and interspecific varieties in upland with several nitrogen application levels, and showed that the number of spikelets per unit ground area was not low in *O. glaberrima* compared to *O. sativa* and interspecific varieties, suggesting low yield of *O. glaberrima* could be due to grain shattering and its yield potential is not inferior to *O. sativa*. To assure the prospects for intraspecific breeding, more information on the relationship between grain shattering and yield using a larger number of *O. glaberrima* accessions is necessary.

Therefore, the objectives of this study were: to evaluate the yield of *O. glaberrima* accessions if no incidence of grain shattering occurs (hereafter we call it potential yield); to know the range of yield loss from grain shattering within *O. glaberrima* (evaluation for the varietal difference of yield loss); and to identify *O. glaberrima* accessions which show resistance to grain shattering.

## MATERIALS AND METHODS

The trial was conducted in 2010 and 2011 under upland conditions at the AfricaRice (Africa Rice Center) experimental site at Ouedeme (6°42'46"N, 1°41'07"E, altitude 21 m), Benin. The experimental site is located in the Guinea savannah zone in Benin, with 986.3 and 1202 mm of total annual rainfall in 2010 and 2011, respectively. The genetic material used comprised 21 accessions of *O. glaberrima* selected for their origins from throughout West Africa and four *O. sativa* varieties as checks from an *O. sativa* core collection compiled by the National Institute of Agrobiological Sciences (NIAS), Japan (Kojima et al., 2005) (Table 1). Of these four checks, Nipponbare was known to have strong resistance to grain shattering (Konishi et al., 2006; Goto et al., 2009). The other three varieties were randomly selected from the remaining 68 varieties and there was no information in relation to their resistance to grain shattering.

The experiment was conducted during the wet season from June to December in 2010 and repeated in 2011. The site was in rainfed upland and no additional irrigation water was supplied during the experiments. Two treatments were made for the incidence of grain shattering. One treatment was to cover panicles on each hill by paper sacks at the heading stage to avoid grain shattering and the second one was a control without coverage by paper sack. An alpha-lattice design with three replications was adopted. The size of each plot was 1 m × 2 m for each accession/variety and the plot was divided into two sub-plots (1 m × 1 m each): the non-grain shattering and control treatments. Hills were arranged by square planting 0.25 m apart. Three seeds were sown in each hill. All plots received compound N-P-K (15-15-15) fertilizer at the rate of 200 kg ha<sup>-1</sup> at 25 days after seeding (DAS) and urea (46% nitrogen) at the rate of 50 kg ha<sup>-1</sup> at 45 DAS. The field was manually weeded regularly to maintain all plots weed-free and bird damage was avoided by hiring bird scarers during maturity.

When 85% of grains matured, all hills except one border row were harvested. The samples were manually threshed and threshed paddy was air-dried. The paddy was winnowed manually and weighed. Grain moisture content was determined by moisture meter (AE 36093, Kett) and yield was expressed at 14% grain moisture content. Yield in the treatment to avoid grain shattering was considered as potential yield, while that in the control (no treatment to avoid grain shattering) gave control yield. Yield loss was therefore obtained by subtracting the control yield from the potential yield, and the percentage ratio of the lost yield to the potential yield was calculated for every accession/variety in each replication.

A linear mixed model procedure and a generalized linear mixed model procedure,

both using a restricted maximum likelihood method (REML), were used to estimate the variance between the years. Further analysis was dependent on the interactive effect of Year  $\times$  Genotype in the results of the REML; if the interactive Year  $\times$  Genotype effect was significant, analysis of variance (ANOVA) was performed in each year separately. If not, ANOVA was done combining the results of the two years. Potential yield and control yield were subjected to the linear mixed model while percentage of lost yield by grain shattering to the potential yield was subjected to the generalized linear mixed model. To evaluate a difference between potential and control yields in each accession/variety, a t-test was used combining the data of the two years. Statistical analysis were performed using GenStat Discovery software (2003).

**Table 1:** Rice genotypes used and their origins.

Accessions/Varieties	Species	Origins
Nipponbare	<i>O. sativa</i>	Japan
Davao 1	<i>O. sativa</i>	Philippines
Vary Futsi	<i>O. sativa</i>	Madagascar
Calotoc	<i>O. sativa</i>	Philippines
CG 14	<i>O. glaberrima</i>	Senegal
CG 17	<i>O. glaberrima</i>	Senegal
CG 20	<i>O. glaberrima</i>	Senegal
Saliforeh	<i>O. glaberrima</i>	Sierra Leone
TOG 12303	<i>O. glaberrima</i>	Cote d'Ivoire
TOG 5473	<i>O. glaberrima</i>	Nigeria
TOG 5641	<i>O. glaberrima</i>	Nigeria
TOG 5681	<i>O. glaberrima</i>	Nigeria
TOG 5775	<i>O. glaberrima</i>	Liberia
TOG 5829	<i>O. glaberrima</i>	Liberia
TOG 6740	<i>O. glaberrima</i>	Liberia
TOG 6748	<i>O. glaberrima</i>	Liberia
TOG 6804	<i>O. glaberrima</i>	Nigeria
TOG 7206	<i>O. glaberrima</i>	Cote d'Ivoire
TOG 7420	<i>O. glaberrima</i>	Sierra Leone
TOG 7442	<i>O. glaberrima</i>	Nigeria
TOG 9066	<i>O. glaberrima</i>	Nigeria
TOG 9276	<i>O. glaberrima</i>	Nigeria
TOG 9280	<i>O. glaberrima</i>	Nigeria
TOG 9281	<i>O. glaberrima</i>	Nigeria
TOG 9300	<i>O. glaberrima</i>	Nigeria

## RESULTS

The linear mixed model indicated highly significant interaction for potential yield ( $P < 0.001$ ) and significant interaction for control yield ( $P = 0.0267$ ) between year and genotype (Year  $\times$  Genotype) in both 2010 and 2011. The generalized linear mixed model also indicated a highly significant interaction for percentage of lost yield ( $P < 0.001$ ) between year and genotype (Year  $\times$  Genotype) in both 2010 and 2011. Therefore, a single factor ANOVA for potential yield, control yield or percentage of lost yield was adopted separately for each year. All data of potential and control yields and percentage of lost yield are shown in Table 2.

Potential yield was generally higher in 2011 than in 2010 for both *O. glaberrima* and *O. sativa*, probably due to higher precipitation in 2011. Correlation coefficient of percentage of lost yield (the check varieties were included) between 2010 and 2011 was 0.853, which was highly significant ( $P < 0.001$ ), so that the incidence of grain shattering seemed to be a varietal characteristic. There were highly significant varietal differences ( $P < 0.01$  or  $P < 0.001$ ) in potential yield, control yield and percentage of lost yield in both 2010 and 2011.

The average of potential yield in *O. glaberrima* was 2.42 t ha<sup>-1</sup> in 2010 and 3.65 t ha<sup>-1</sup> in 2011; these values are comparable to the average potential yield of the *O. sativa* checks (2.99 t ha<sup>-1</sup> in 2010 and 3.49 t ha<sup>-1</sup> in 2011). In particular, one *O. glaberrima* accession, Saliforeh, depicted the highest yield (5.91 t ha<sup>-1</sup>) in 2011 and the second highest (4.09 t ha<sup>-1</sup>) after Nipponbare (*O. sativa*) in 2010. In addition to that accession, six *O. glaberrima* accessions had yields of more than 4 t ha<sup>-1</sup> under rainfed upland conditions in 2011. Therefore, if resistance to grain shattering is improved, (potential) yield of *O. glaberrima* will not be inferior to that of *O. sativa*.

In the *O. sativa* check varieties, potential and control yields were not significantly different in the t-test combining

the two year results, and percentage of lost yield was 3.48% in 2010 and 21.12% in 2011 on average, suggesting the effect of grain shattering on yield is small but incidence of grain shattering was a little bit higher in the condition where yields of the checks were higher. In contrast, potential and control yields were significantly different in most *O. glaberrima* accession except two (TOG 12303 and TOG 9300). The percentage of lost yield by shattering in *O. glaberrima* was, on average, 55.84 and 66.67% in 2010 and 2011, respectively. These values are much higher than the averages for *O. sativa*; all accessions other than TOG 12303 and TOG 9300 had significantly higher values than the *O. sativa* variety (Calotoc), thereby showing the highest percentage of lost yield. It was confirmed that grain shattering is a characteristic generally observed in *O. glaberrima*. On the other hand, clear varietal differences were also observed in the percentage of lost yield in *O. glaberrima*: its range was 3.71 – 85.21% in 2010 and 15.53 – 87.49% in 2011. However, the coefficient of variations (CVs) of the percentage of lost yield in *O. glaberrima*—0.35 in 2010 and 0.25 in 2011—were low compared to those of *O. sativa*—0.48 in 2010 and 0.45 in 2011. The varietal difference of the percentage of lost yield in *O. glaberrima* could be small compared to *O. sativa*.

Two *O. glaberrima* accessions, TOG 12303 and TOG 9300, did not show a significant difference between potential and control yields. Over the two years TOG 12303 and TOG 9300 constantly had as low percentages of lost yield (3.71 and 6.36% in 2010, respectively; 15.53 and 27.18% in 2011, respectively) as did the *O. sativa* check varieties (3.48% in 2010 and 21.12% in 2011, on average). Percentages of lost yield in these *O. glaberrima* accessions did not differ significantly from the percentage in the *O. sativa* check (Vary Futsi) possessing the lowest value. These two *O. glaberrima* accessions can be suitable genetic material to improve resistance to grain shattering in the intraspecific breeding of *O. glaberrima*.

**Table 2:** Potential yield by avoiding grain shattering, yield loss by grain shattering and percentage (%) of lost yield to the potential yield in 2010 and 2011.

Accessions /varieties	2010			2011			t-test
	Potential yield (t ha <sup>-1</sup> )	Control yield (t ha <sup>-1</sup> )	% of lost yield	Potential yield (t ha <sup>-1</sup> )	Control yield (t ha <sup>-1</sup> )	% of lost yield	
<i>O. glaberrima</i>							
CG 14	2.53	0.98	60.75	3.87	1.43	62.57	***
CG 17	3.42	2.05	40.42	6.66	1.16	67.55	***
CG 20	1.98	0.68	64.41	3.86	1.59	64.14	**
Saliforeh	4.09	2.15	46.95	5.91	2.32	62.52	**
TOG 12303	2.13	2.05	3.71	2.98	2.51	15.53	ns
TOG 5473	1.66	0.53	68.04	2.39	0.31	87.49	***
TOG 5641	3.34	0.50	85.21	2.80	0.68	76.66	***
TOG 5681	2.30	1.04	58.40	4.69	1.97	62.98	*
TOG 5775	2.45	1.17	52.09	3.81	1.10	71.92	**
TOG 5829	2.64	1.16	55.37	4.04	1.79	56.94	**
TOG 6740	2.80	1.10	60.72	2.82	0.83	70.88	***
TOG 6748	2.98	1.05	64.93	4.55	1.31	70.74	***
TOG 6804	1.60	0.32	81.29	4.52	1.08	77.09	*
TOG 7206	2.30	0.74	70.47	4.70	1.89	64.96	*
TOG 7420	3.19	1.37	57	2.79	0.77	72.82	***
TOG 7442	1.56	0.45	73.13	3.09	0.36	82.87	**
TOG 9066	2.73	1.07	59.92	4.54	1.57	65.81	**
TOG 9276	1.63	0.36	77.32	3.48	0.77	84.88	**
TOG 9280	1.89	0.72	63.18	3.11	0.68	77.74	***

TOG 9281	1.83	0.62	65.90	3.29	0.74	78.77	***
TOG 9300	1.72	1.61	6.36	1.73	1.14	27.18	ns
Average	2.42	1.03	57.88	3.65	1.24	66.76	
CV	0.28	0.52	0.35	0.25	0.48	0.25	
<hr/>							
<i>O. sativa</i>							
Nipponbare	5.72	5.52	3.46	4.44	0.56	13.36	ns
Vary Futsi	2.71	2.66	1.91	4.19	0.52	11.64	ns
Calotoc	1.34	1.26	6.15	1.65	0.63	35.66	ns
Davao1	2.17	2.13	2.25	3.68	0.74	23.43	ns
Average	2.99	2.89	3.48	3.49	0.61	21.12	
CV	0.5	0.55	0.48	0.28	0.14	0.45	
Significance	***	***	***	**	***	***	
LSD	0.99	0.53	13.30	1.49	1.24	17.24	

ns, not significant; \*, P < 0.05; \*\*, P < 0.01; \*\*\*, P < 0.001; CV: Coefficient of variation;

LSD: Least Significant Difference; t-test for each accession/variety as to whether the potential yield is significantly higher than the control yield combining the two years data.

## DISCUSSION

Using the data on number of spikelets per unit ground area before shattering, Dingkuhn et al. (1998) have shown that potential yield of the *O. glaberrima* accession, CG 14, is comparable to that of a high yielding *O. sativa* variety, WAB56-104, and suggested that low yield of *O. glaberrima* is caused by grain shattering. This study, with the larger number of *O. glaberrima* accessions tested, confirmed that yield without grain shattering (potential yield) was not lower in *O. glaberrima* than in *O. sativa*.

Wild plant species demonstrate seed shattering, which is a useful trait to secure and disperse individuals of the next generation; in the process of domestication of wild species, grains that had reduced the shattering habit were selected to diminish grain yield loss by seed shattering (Zhou et al., 2012) and non-seed shattering is one of the most important characteristics in cultivated crops (Fuller, 2007). In this experiment, almost all *O. glaberrima* accessions tested were susceptible to grain shattering. The ease of grain shattering seems to be a character of *O. glaberrima* and this may come from its short history of domestication compared to *O. sativa*.

From observation of an abscission layer between the grain and the apical end of a pedicel during the maturing stages of 159 *O. sativa* varieties, Jin et al. (1982) have reported that the order of varieties for easiness of grain shattering is as follows: varieties possessing abscission layers cracked, varieties possessing abscission layers non-cracked and varieties possessing no abscission layers. In the evaluation of 42 *O. glaberrima* accessions, all accessions possessed abscission layers but some *O. glaberrima* accessions produced incomplete abscission layers, which cannot be seen in *O. sativa* (Jin et al., 1990); these accessions had some resistance to shattering compared to those with complete abscission layers but they are still classified as “easily shattering” (Jin et al., 1990). In this study, TOG 12303 showed the lowest values of the

percentage of lost yield, which was 3.71% in 2010 and 15.53% in 2011. These values are slightly not significantly higher than, but comparable to, those of Nipponbare, which has strong resistance to grain shattering (Konishi et al., 2006; Goto et al., 2009). Further morphological studies on the abscission layers of this accession and of TOG 9300 possessing similar values of percentage of lost yield with TOG 12303 will be necessary.

Nineteen of the 21 *O. glaberrima* accessions tested were highly susceptible to grain shattering in the current study. These accessions would be expected to have complete abscission layers, but there was still a varietal difference within these 19 accessions the difference between the highest and lowest values was greater than the LSD (5%) in both 2010 (44.79 vs. 13.30) and 2011 (30.55 vs. 17.24). Lodging is also a negative characteristic of *O. glaberrima* but there is a varietal difference within the species in the susceptibility to lodging (Futakuchi et al., 2008). The difference in lodging incidence might cause the varietal differences in the percentage of lost yield in these 19 accessions. Although *O. glaberrima* has been considered as low yield and this was a cause of its decreasing cultivation area in favor of *O. sativa* in Africa (Linares, 2002), the low yield could be the result of grain shattering, which can obviously be seen in this species. With grain shattering eliminated, potential yield is not low. Therefore, identification of genotypes to provide resistance to grain shattering is a crucial element to the intraspecific breeding of *O. glaberrima*, and two accessions, TOG 12303 and TOG 9300, possessing the requisite resistance were identified in this study.

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