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Better Exploitation of African Rice (*Oryza glaberrima* Steud.) in Varietal Development for Resource-Poor Farmers in West and Central Africa

Koichi Futakuchi and Moussa Sié
Africa Rice Center (WARDA), 01 B.P. 2031 Cotonou, Benin

Abstract: Inter specific breeding between *Oryza sativa* and *Oryza glaberrima* was started at WARDA with the basic concept of combining the resistance of *O. glaberrima* to local constraints in West and Central Africa (WCA) with the high yielding ability of *O. sativa*. Developed interspecific progeny is now called as NERICA, which was named after New Rice for Africa and 18 upland NERICA varieties and eleven lowland NERICA varieties have been released or widely disseminated in several WCA countries. Some of them were beyond WCA and released in other sub-Saharan Africa countries such as Uganda. However, a gap is still existing between current NERICA varieties and *O. glaberrima* lines with special reference to resistance to local constraints in WCA. In this study, published data and also some additional unpublished data on the performance of NERICA and *O. glaberrima* were critically reviewed and possible improvements and further directions in rice breeding with better exploitation of *O. glaberrima* were proposed.

Key words: Backcrossing, interspecific breeding, *Oryza glaberrima* Steud., *Oryza sativa* L., West and Central Africa

INTRODUCTION

Oryza glaberrima Steud., which is the cultivated *Oryza* species different from *Oryza sativa* L., was domesticated in West Africa >3500 years ago (Jones *et al*., 1997b) and is still cultivated in this sub-region (Singh *et al*., 1997). Since the yield level of *O. glaberrima* is regarded as generally low compared to that of *O. sativa* due to grain shattering and poor resistance to lodging, its growing area has been decreasing (Linares, 2002). However, *O. glaberrima* is considered to have resistance to various local constraints in West and Central Africa (WCA) because of its domestication history and be important as genetic resources to develop rice suitable for resource-poor farmers in WCA, who are suffering from low yielding due to multiple stresses in their fields. Therefore, Africa Rice Center (WARDA) commenced a new breeding program to use only assets of this species by crossing it to *O. sativa*, although a commercial variety had never been developed from this wide cross before in spite of a number of attempts.

In 1990 and 1991, WARDA screened 1130 accessions of *O. glaberrima* in upland conditions at the experimental field of its headquarters in M'bé, near Bouaké, Côte d'Ivoire in terms of early maturity, high tillering ability and rapid seedling growth and nominated 8 lines for wide hybridization. These 8 *O. glaberrima* lines selected were expected to compete with weeds (high tillering and rapid seedling growth) and escape drought and late-season fungal disease (early maturity). As *O. sativa* parents for the wide crosses, 5 high yielding elite japonica type upland lines developed by WARDA, all of which were officially released in Côte d'Ivoire and/or other WCA countries later on, were nominated. In 1992, interspecific crosses between those lines were made. After 2 backcrossings to the respective *O. sativa* parents, BC_2F_1 progenies were subjected pedigree selection and the 1st fixed fertile upland interspecific progenies (WAB450 series) were obtained from the cross of WAB56-106 (*O. sativa*) and CG 14 (*O. glaberrima*) in 1994.

The development of the 1st interspecific progeny are described in Jones *et al*. (1997a). All fixed interspecific lines are now called as NERICA, which was named after New Rice for Africa. The original basic concept of the interspecific breeding was to develop NERICAs possessing the adaptability of *O. glaberrima* to local rice growing conditions in WCA and the characteristics of *O. sativa* associated with high yielding. A number of promising upland NERICA lines were developed under this basic concept and seven NERICA varieties were released in Côte d'Ivoire and/or Guinea in 2000. Eighteen upland NERICA varieties were adopted by several Sub-Sahara African (SSA) countries beyond WCA as of 2007 (Futakuchi, 2008).

Corresponding Author: Koichi Futakuchi, Africa Rice Center (WARDA), 01 B.P. 2031 Cotonou, Benin

NERICAs for lowland (WAS122, 161 and 191 series) have been developed under the same breeding concept with the upland NERICA. Resistance to Rice Yellow Mottle Virus (RYMV), which is a crucial indigenous disease in Africa, is especially an expected trait from *O. glaberrima* and some of the lowland NERICA lines have been released in Burkina Faso, Cameroon, Gambia, Mali, Niger, Sierra Leone and Togo (Futakuchi, 2008). Several prototypes of lowland NERICA lines have also been developed from another cross such as WAB1159 series (Futakuchi *et al*., 2004).

NERICA varieties have already had impacts on farmers' livelihoods and poverty reduction in SSA (Obilana and Okumu, 2005). However, Obilana and Okumu (2005) have also pointed out that there are still gaps in WARDA's interspecific breeding program and *O. glaberrima* has not been fully utilized despite the current success of NERICA. The objective of this study is to propose several ways to better exploit *O. glaberrima* as breeding materials than the current interspecific breeding program through the critical review of published data and new additional data on the performance of NERICA lines, especially upland ones and *O. glaberrima*.

MATERIALS AND METHODS

Published data and some additional unpublished data on the performance of NERICA lines and *O. glaberrima* were critically reviewed. As a result, possible improvement and further directions in rice breeding with better use of *O. glaberrima* were suggested in the following 4 categories: Filling gaps between NERICA and *O. glaberrima* lines in relation to adaptability to local environments in WCA and other traits expected from the *O. glaberrima*, Using characteristics of *O. glaberrima* which are not focused in current varietal improvement, seeking better *O. glaberrima* in terms of important traits and feasibility of intra-specific breeding of *O. glaberrima*.

RESULTS AND DISCUSSION

Gaps between NERICA lines and *O. glaberrima*: A weed problem is one of the major constraints for rainfed rice production in WCA. According to a yield gap study conducted by Backer and Johnson (2001) in Côte d'Ivoire, yield gaps were attributed to weed and nitrogen; especially in the forest zone, weed was the dominant factor of the yield gap since it explained 65% of the yield reduction. *O. glaberrima* is know to be highly weed competitive compared to *O. sativa* due to its growth

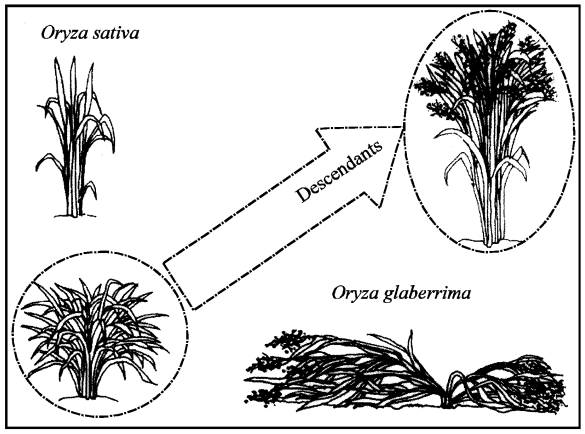

Fig. 1: Diagram of the ideal plant type of high yielding weed competitive rice (Jones *et al*., 1997a). The ideal descendant should have *O. glaberrima*-like vegetative growth and *O. sativa*-like reproductive growth

characteristics at the vegetative stage such as vigorous initial growth, high tillering ability, large leaf area and droopy leaves (Johnson *et al*., 1998; Dingkuhn *et al*., 1999). An ideal plant type of high yielding weed competitive rice (Fig. 1) was developed according to the basic concept of the interspecific breeding mentioned in the introduction (Jones *et al*., 1997a). The ideal plant type may have the vegetative growth of *O. glaberrima* (vigorous growth, high tillering, large leaf area and droopy leaves) and the reproductive growth of *O. sativa* (erect leaves, no lodging, no grain shattering and large panicles). Current NERICAs had an intermediate value of leaf area between *O. sativa* and *O. glaberrima* and the same tiller number with *O. sativa* at vegetative growth (Dingkuhn *et al*., 1998). On the other hand, NERICA did not lodge and its yield level was higher than *O. glaberrima's*, especially with fertilizer inputs and as same as *O. sativa's* (Jones *et al*., 1997a; Dingkuhn *et al*., 1998). In general, the current NERICA lines were more similar with *O. sativa* than *O. glaberrima* in relation to morphological characteristics in both the vegetative and reproductive growth stages. Judging from their morphology at vegetative growth, therefore, there is a gap between the current NERICAs and *O. glaberrima* in terms of weed competitiveness. All upland NERICA varieties have been developed through 2 time backcrossings to the respective *O. sativa* parents and genetically more similar with *O. sativa*. In 70 upland NERICA lines (WAB450 series), the average proportion of the *O. sativa* parent genome was 87.4%, while that of *O. glaberrima* was 6.3% (Semagn *et al*., 2007).

Table 1: Growth characteristics of seedlings of NERICA lines in a crowded nursery

Line	Plant height (cm)	SPAD	TDW[1] (mg)	LDW[2]/ TDW (%)
NERICA line				
WAB1159-2-12-11-5-1	29.6	17.8	30.3	54.1
WAB1159-4-10-15-1-3	32.9	25.8	55.5	43.8
WAB1159-4-10-15-1-4	32.9	28.0	57.8	44.4
WAB1159-4-10-15-1-5	28.9	25.5	37.8	44.9
WAB1159-2-12-11-2-1	29.9	21.6	37.4	54.5
WAB1159-2-12-11-2-10	30.3	16.5	38.0	52.1
WAB1159-4-7-1-4-1	24.9	23.1	35.4	54.1
WAB1159-2-12-11-6-7	28.3	22.4	41.3	54.9
WAB1159-2-12-11-6-8	43.0	20.0	73.4	53.8
WAB1159-2-12-11-6-10	37.0	20.5	76.0	50.2
WAB1031-1-6-4-1-1	33.0	20.7	55.6	55.3
WAB1031-1-6-4-1-2	32.1	23.2	53.4	53.7
Check				
CG 14 (*O. glaberrima*)	46.4	17.2	54.3	49.3
Bouake 189 (*O. sativa*)	30.4	21.8	38.0	45.3
Level of significance in a single factor ANOVA	**	**	**	**
LSD (p = 0.05)	1.2	0.9	5.5	1.7

1, TDW = Total Dry Weight; 2, LDW = Leaf Dry Weight. **Indicates significant difference at p<0.01, Seedlings were sampled on 22 days after seeding. This table is cited from Futakuchi *et al.* (2004)

To develop high yielding weed competitive rice, the ideal plant type already supposed does not have to be changed. Better NERICAs in relation to weed competitiveness should be more similar with *O. glaberrima* than the existing ones so that the less number of backcrossings to *O. sativa* may be desirable during their development. Fertile interspecific progeny was obtained from BC_1F_1 anther explants (Jones *et al.*, 1997a). Anther culture therefore could help the development of such weed competitive NERICA lines similar with *O. glaberrima*. Even by the same backcross breeding procedure with the existing NERICA lines, however, several prototypes possessing *O. glaberrima*-like vegetative growth have already been developed from a different parental combination. Table 1, which is cited from Futakuchi *et al.* (2004), depicts that seedlings of *O. glaberrima*, CG 14, showed larger plant height, greater dry matter production and larger portion of dry matter to leaves, which are photosynthetic organs, than those of *O. sativa*, Bouake 189 and some new NERICA lines had even better early vigor in plant height and dry matter production than *O. glaberrima*. Anyway, weed competitiveness comprises various traits such as early vigor, high tillering ability, large leaf area and droopy leaves etc. and will concern a large number of genes; backcross breeding with segregating populations of a sufficient size will continue to be a useful method.

Characteristics of *O. glaberrima* which have not been focused: *O. glaberrima* is a rich genetic source to provide resistant genes for growth constraints in WCA, some of which cannot be found easily in the variation of *O. sativa* such as resistance to RYMV. Another noteworthy character of this species, which has not been clearly described, is that a single line can have multiple resistance to various local constraints although certain *O. sativa* varieties with stronger resistance for individual constraints can de found. For example, CG 14, a parent of all upland NERICA varieties released in WCA and other sub-regions of SSA, has weed competitiveness (Jones *et al.*, 1997a; Dingkuhn *et al.*, 1999), strong resistance to iron toxicity (Sahrawat and Sika, 2002), drought resistance (Jones *et al.*, 1997a), drought recovery (Audebert, 2006), resistance to nematode (Coyne *et al.*, 1995), resistance to water logging (Futakuchi *et al.*, 2001), adaptability to acid soil with low phosphorus availability (Tobita *et al.*, 2003). Such resistance to multiple constraints is a highly desirable character for rice cultivated by resource-poor farmers in rainfed ecology in WCA, who cannot afford to adopt intensive agronomic measures against such constraints. The number of backcrosses to an *O. sativa* variety would be limited when combining such a comprehensive trait as multiple resistance of *O. glaberrima* to the high yielding ability of *O. sativa*. Therefore, the assistance of anther culture and other biotechnology tools will become more important in order to overcome the sterility problem and develop a desirable NERICA variety. Another possibility to develop such a NERICA variety may be backcrossing to an *O. glaberrima* parent.

In the current basic concept of the interspecific breeding, characteristics associated with yield generation are expected only from *O. sativa* and present upland NERICA lines (WAB450 series) have the same yielding type with the *O. sativa* parent on average, which can be classified into the panicle size type, according to the principal component analysis with yield component (Futakuchi and Jones, 2005). There was no influence of the *O. glaberrima* parent on the yielding type of those NERICA lines. The *O. glaberrima* parent, CG 14, showed a much larger number of panicles even than *O. sativa* varieties of the panicle number type, although its individual panicle is smaller (Futakuchi and Jones, 2005). The introduction of such an extraordinary trait, which cannot be seen in *O. sativa*, may increase yield potential of NERICA lines. Therefore, the additional new concept of the interspecific breeding is to combine the adaptability of *O. glaberrima* to local environments with the optimal conjunction of the best traits of the 2 species in relation to yield generation. For instance, the schematic diagram to develop higher yielding weed competitive NERICA therefore becomes like Fig. 2, where the promising interspecific progeny possesses vegetative growth of

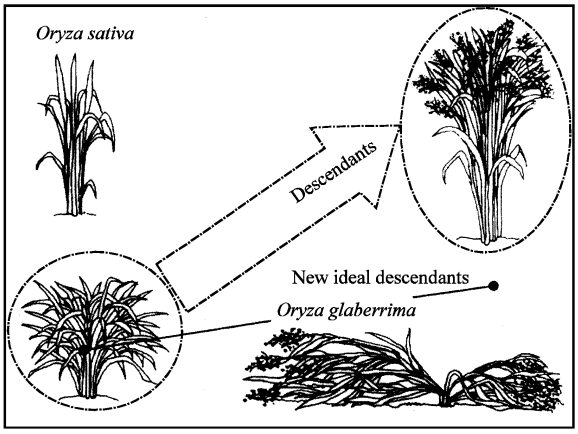

Fig. 2: Diagram of the new ideal plant type of higher yielding weed competitive rice. The new ideal descendant should have the traits of *O. glaberrima* at vegetative growth and the optimal conjunction of the best traits of the 2 species favourable to yield generation at reproductive growth

O. glaberrima and reproductive growth of the combination of *O. glaberrima* and *O. sativa*. Several new NERICA lines, which may have some promise, have already been developed. Those new lines were included in WARDA's field trial in rainfed upland at Ikenne, Nigeria in the 2003 wet season (the seeding date was 25 May 2003), the entry of which was thirteen existing NERICA varieties, 12 *O. sativa* varieties and 4 new NERICA lines. The best yielder without fertilizer was WAB880-1-32-1-1-P2-HB (1.2 tonne ha^{-1}), WAB375-B-4-H2-HB (1.2 tonne ha^{-1}) and WAB1159-4-10-15-1-3 (2.2 tonne ha^{-1}) for existing NERICA, *O. sativa* and new NERICA, respectively.

Regarding panicle length, no difference was observed among WAB880-1-32-1-1-P2-HB (19.2 cm), WAB375-B-4-H2-HB (17.7 cm) and WAB1159-4-10-15-1-3 (19.3 cm), whereas their panicle number per square meter was like this: WAB880-1-32-1-1-P2-HB, 150; WAB375-B-4-H2-HB, 140; and WAB1159-4-10-15-1-3, 260 (unpublished data). Although the yield level was generally low due to drought and low fertility in that trial, the new NERICA had much more panicles than the others with retaining the same panicle size (length). Those new NERICA lines were developed from 2 backcrosses to the *O. sativa* parent (Futakuchi *et al*., 2004) and this conventional method will continue to be a strong tool for varietal development under the new concept of the interspecific breeding. However, since the new concept shows that promising NERICA lines should have more similar morphological characteristics with *O. glaberrima* than the old one, less or no number of backcrosses to *O. sativa* with assistance of anther culture and some other biotechnology tools or backcrossing to *O. glaberrima* as mentioned above could be possible approaches too.

Grain quality traits were not included in the initial selection criteria. After the completion of the selection with segregating populations, NERICA lines (WAB450 series), their parents and other *O. glaberrima* lines were evaluated in relation to grain quality inclusive of protein content with some *O. sativa* check varieties in WCA. The parents had as low protein content as did the *O. sativa* check varieties used. Out of the NERICAs, however, some high protein content lines have been identified due to transgressive segregation (Watanabe *et al*., 2006). Furthermore, the *O. glaberrima* parent, CG 14, showed an exceptionally low protein content as *O. glaberrima* and some *O. glaberrima* lines possessing higher protein content even than high protein NERICA lines were identified (Watanabe *et al*., 2004). If those *O. glaberrima* lines are used in the wide cross with *O. sativa*, new NERICA lines with higher protein content than the existing ones could be developed. Although association of protein content with other quality and agronomic traits was sometimes observed in rice, development of high protein NERICA varieties seemed to be feasible without sacrificing yield (Watanabe *et al*., 2006) and other grain quality traits (Futakuchi *et al*., 2008b) in the interspecific breeding of the 2 species.

Seeking better *O. glaberrima*: *O. sativa* is one of the major staple food crops and a huge number of basic and applied studies have been made with this species, e.g., its whole base sequence was already determined. On the other hand, *O. glaberrima* is much less explored in a scientific manner. WARDA is still seeking better *O. glaberrima* lines for important traits in rainfed rice cultivation in WCA such as drought resistance and short duration etc. IRCG Accession No. 104038 is one of the examples of such better *O. glaberrima* lines newly identified. The line apparently showed better initial growth than CG 14 (unpublished data) and its growth duration was 19 and 6 days shorter than CG 14 and NERICA 8 possessing the earliest maturity among the eighteen upland NERICA varieties, respectively, with the same seeding date of 22nd May 2006.

In future the following traits could be paid attention in screening: resistance to lowland constraints since relatively less information is available for lowland than for upland in relation to adaptability of *O. glaberrima* and traits with which little information is available such as micronutrients. When improved screening tools are developed for important traits, re-screening of the germplasm already tested should be made too.

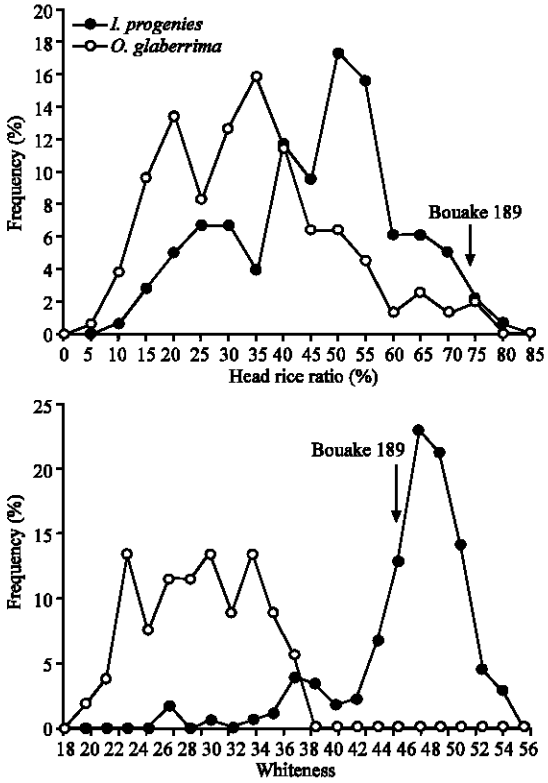

Fig. 3: Frequency distributions of head rice ratio and whiteness in *O. glaberrima* and NERICA lines (*I. progenies*). Bouake 189 is a leading *O. sativa* variety in Côte d'Ivoire (Watanabe *et al*., 2002b)

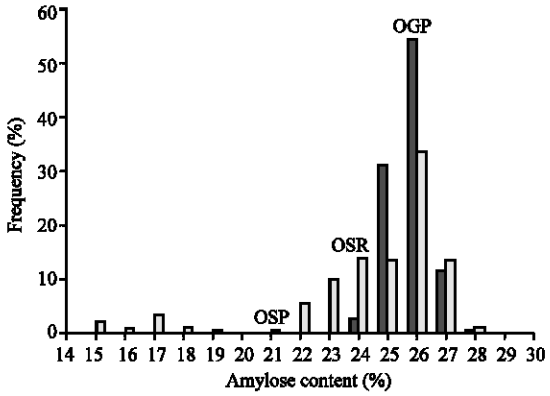

Fig. 4: Frequency distribution of amylose content in *O. glaberrima* (filled columns) and NERICA (open columns) lines. OSP, OSR and OGP mean the *O. sativa* parent (WAB56-104) of NERICA, *O. sativa* reference variety (Bouake 189) and *O. glaberrima* parent (CG 14) of NERICA, respectively (Watanabe *et al*., 2002a)

Feasibility of intra-specific breeding of *O. glaberrima*: Intra-specific breeding of *O. glaberrima* will be the best way to exploit its unique assets such as multiple resistance to major constraints in WCA and high protein content etc., because fixed fertile progeny can be obtained without suffering from a sterility barrier always cropping out in interspecific breeding. However, *O. glaberrima* seems to have several drawbacks when we attempt to develop a commercial variety acceptable in WCA. For instance, grains of *O. glaberrima* easily crack after milling (low head rice ratio of milled rice) and whiteness of its milled grains is low compared to *O. sativa* because of red pericarp of all *O. glaberrima* lines tested (Watanabe *et al*., 2002b) (Fig. 3). Those are considered as low quality in the market in general. Genetic variation of content is very narrow; most of *O. glaberrima* lines showed content in between 25 and 27% (Watanabe *et al*., 2002a) (Fig. 4). Amylose content is a major factor to determine rice texture and consequently taste. Preference for texture is ranging in WCA; for example, people in Côte d'Ivoire may like rice with around 20% or a little bit higher content judging from the content of released varieties in the country (Ministere de l'Agriculture et des Ressources Animales, 1998), whereas Nigerian people may prefer hard texture rice of the content above 25% since many of the released varieties have that range of content. Therefore, it could be difficult to develop *O. glaberrima* varieties, of which taste is acceptable in Côte d'Ivoire. The number of *O. glaberrima* lines tested in the screening for grain quality was 157 (Watanabe *et al*., 2002a, b) and a few *O. glaberrima* lines possessing as high head rice ratio as a high quality *O. sativa* variety have already been identified in our past screening (Watanabe *et al*., 2002b) (Fig. 3). To identify *O. glaberrima* lines with the content beyond the range of 25-27%, however, a larger number of lines will have to be screened. Narrow genetic variation of content might become a bottleneck in its intra-specific breeding in *O. glaberrima*.

Low yield is sometimes listed up as a cause of the decline of *O. glaberrima's* cultivated area in the sub-region (Linares, 2002). Low yield of *O. glaberrima* is caused by grain shattering and lodging enhancing grain shattering; the sink capacity of *O. glaberrima* estimated by the spikelet number is not inferior to that of *O. sativa* (Dingkuhn *et al*., 1998). We obtained yield of >5 ha^{-1} in irrigated lowland in the dry season cropping at WARDA's experimental field in Côte d'Ivoire (Futakuchi and Jones, 2005). Yield potential of this species will not become an obstacle to develop acceptable varieties by farmers. To achieve it, however, we should identify *O. glaberrima* lines resistant to lodging and grain shattering. The screening of *O. glaberrima* lines in this regard has already been commenced. However, lines possessing strong resistance to lodging have not yet been identified (Futakuchi *et al*., 2008a).

CONCLUSION

Characteristics of *O. glaberrima* and NERICA were critically reviewed using published data as well as additional unpublished data collected by WARDA in order to seek the way to enhance the exploitation of genetic reservoirs of *O. glaberrima*. In the concept of the interspecific breeding of WARDA, what was expected from *O. glaberrima* was adaptability to rice growing environments in WCA. However, NERICA was yet to be rivalling with *O. glaberrima* in some traits related to the adaptability such as weed competitiveness. In addition to those traits of *O. glaberrima* which were already focused in varietal development, attention was paid to new characteristics of *O. glaberrima*, introduction of which could improve the performance of existing NERICA varieties; such examples were multiple resistance of a single line to various local constraints in WCA and an extremely large number of panicles compared to *O. sativa*. As seen in the latter example, *O. glaberrima* also possessed advantageous characteristics to yield generation as well as adaptability to local environments in spite of the initial concept of the interspecific breeding at WARDA.

Intra-specific breeding of *O. glaberrima* is also a feasible approach to exploit unique and useful characteristics of this species, although a wide cross to *O. sativa* to develop NERICA will still be a strong tool to obtain better varieties. Low yielding ability of *O. glaberrima*, which has sometimes been regarded as the character of this species, will not be an obstacle in the intra-specific breeding since its yield potential estimated from the spikelet number was not inferior to that of *O. sativa*. However, some grain quality characteristics of *O. glaberrima*, especially its narrow genetic variation in content, may hinder the development of commercial varieties in *O. glaberrima*.

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