

The African Rice *Oryza glaberrima* Steud: Knowledge Distribution and Prospects

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Abstract

This paper presents a consolidated balance-sheet on the botanical and historical evidence for the role of the cultivated African rice species (*Oryza glaberrima* Steud) in West and Central Africa as well as its geographical distribution. Because *Oryza glaberrima* has survived without the help and interference from human, it has developed adaptive and protective mechanisms for resisting major biotic and abiotic stresses. *Oryza glaberrima* is also very plastic with two major ecotypes: the floating and the non floating, and presents natural hybridization and admixture with its wild parents and the Asian cultivated rice *Oryza sativa*. Several ecotypes showed good aptitude in response to climatic change effects such as drought, flood, pests and diseases. This review presents several phenotypic diversity aspects on *O. glaberrima* and highlights its ecological and genetic structuring as well as the management of its diversity. Even if the African rice has undergone less diversification than the Asian rice in their evolutionary process, it presents some interesting assets which are being suggested to exploit through varietal improvement programs.

Keywords: *Oryza glaberrima*, evolution, distribution, genetic diversity, ecology, prospects

1. Introduction

The origin, evolution, distribution, cultivation and diversification of the cultivated African rice species *Oryza glaberrima* Steud interest not only biological scientists but also geographers, archaeologists, anthropologists, philologists, historians and other social scientists (Chang, 1976a). *O. glaberrima* is unique to Africa (Mohapatra, 2010) and was domesticated in West Africa more than 3500 years ago (Portères, 1956; Angladette; 1966). It is recognized that, because *O. glaberrima* survived in the African harsh environment with low human interferences, it had developed some resistant characters to its predestinated environment and presents a lot of useful traits to overcome biotic and abiotic conditions (Takeoka, 1965; Second, 1984).

Several recent studies on the African rice draw attention to the potential of the indigenous cultivated rice species which presents a rich reservoir of genes for resistance to several stresses, including weeds, for improving regional and global food supplies (WARDA, 1996; Jones et al., 1997; Sarla et al., 2005; Futakuchi et al., 2009). Indeed, African rural populations have usually exploited the assets of *O. glaberrima* to survive in their civilization. In parts of West Africa (WA), the grain of the cultivated African rice is a staple food, highly appreciated for its taste and culinary qualities. It is also used in traditional and ritual ceremonies to appease the souls of the ancestors, for example in the Casamance region in southern Senegal, and the villagers of the Danyi plateau in Togo (Mohapatra, 2010). The finer parts of the bran and broken grains are given as feed to chicken and other livestock. In the Central African Republic, the root is eaten raw to treat diarrhea (www.prota.org). But as a traditional food grain *O. glaberrima* is not traded internationally. It is only distributed within the regions of production where it was estimated that its growing areas is less than 20% of the total cultivated area allocated to rice in West Africa (WARDA, 1996). Compared to the Asian species, *O. glaberrima* is characterized by its red hulls, small size, smooth glumes and tendency to break in mechanized milling (Carney, 1998). Because *O. glaberrima* does not readily cross with *O. sativa*, the African rice's greater tolerance to salinity, drought, and

flooding is receiving increasing plant breeding attention (Sano, 1989; Harlan, 1995). However, the real beginning of the valorization of *O. glaberrima* genetic potential in the varietal improvement programs with the Asian cultivated rice has started by Africa Rice Center (AfricaRice, formerly WARDA) through the development of interspecific varieties called and trademarked under the name Nerica: New Rice for Africa (Jones et al., 1997; Sie et al., 2005; Somado et al., 2008). Despite the renewed interest granted nowadays to the African rice by scientists and especially those of AfricaRice (through fields observations and farmers' testimonies on its genetic potentialities and agro-ecologic characteristic), a consolidated balance-sheet on the botanical and taxonomic knowledge of this crop as well as its geographical distribution, ecological structuring and management of its genetic diversity deserves to be elaborate. This general review tries to satisfy these various points and to locate the plant in an appropriate context for its use.

2. Presentation of the Cultivated African Rice Species *Oryza glaberrima* Steud

2.1 Description of *Oryza Glaberrima*

Usually named African rice, red rice or rice of Casamance, *Oryza glaberrima* Steud is the main and the only cultivated rice among the whole African rice species. Gramineous belonging to the tribe Oryzaea, and Genus *Oryza*, it is an annual and preferentially selfing crop with AA genome type composed of $2n = 24$ chromosomes (Besançon et al., 1984). Annual Grass (Figure 1.1) up to 120 cm tall and more in upland or irrigated conditions, it is much higher in conditions of floating culture; up to 5 m in some floating types (Besançon, 1993). The rooting system is fibrous. Dryland types possess simple culm often rooting at lower nodes and floating types are often branching and rooting at upper nodes. The stems are without ramifications, except sometimes in floating culture. Leaves are simple, alternate and attached to the stem by a leaf sheath. Leaf blade is linear with dimensions (length and width) variable and the flag sagittate at base and rugose beneath. The ligule is short (3-4 mm), truncate and membranous. The inflorescence (Figure 1.1) is a terminal, ellipsoid, stiff and compact panicle which is erect at maturity with ascendant racemose branches. The flower or spikelet, bisexual upper floret by a stipe is made up of an ovary prolonged by two plumose stigmas, and is surrounded by six stamens. Spikelets are ellipsoid, more or less persistent reduced to sterile lemmas (glumes absent or strongly rudimentary) separated from the fertile lemma of the fertile. Fruit is a laterally compressed caryopsis (grain), often reddish and tightly enveloped by lemma (glume inferior) and palea (glume superior) which is usually without apical awn and can be colored.

Cultivated rice includes two taxonomically distinct species: *Oryza sativa* L., and *Oryza glaberrima* Steud. *O. glaberrima* differs from *O. sativa* in many qualitative and quantitative traits. The two species can be distinguished in the field especially by differences in ligule shape and panicle branching (Porters, 1955; Besançon, 1993). At the maturity, lodging and seed dormancy occurred within the African rice genotypes can also make difference between the two cultivated rice species. Linguistic evidence supports an African origin of *O. glaberrima*, as rice words in several West African language families (malo, maro, mano, etc.) predate the Portuguese-derived words associated with Asian rice (Blench, 2006; Porteres, 1970). The systematic study of the two cultivated rice is different but gradual and whereas the nomination of the cultivated Asian rice species *O. sativa* by Linnaeus goes back to 1723, it was Steudel in 1855 who firstly described and named the African cultivated rice *O. glaberrima* based on samples collected in the West African coast (Portères, 1955).

The study of the evolutionary and relational diagrams between the different species of the Genus *Oryza* were proposed starting from studies carried out on a material primarily made up of species of Asian origin by Nayar (1973), Oka (1974) and Chang (1976a). On this basis, Second (1984) had developed a new hypothesis with electrophoretic data performed on a much broader sampling including the African species. This hypothesis is based on the estimate, starting from a "molecular clock"; times of divergence between species translated in parallel with the event of paleo-environment. These debates were continued (Ge, 1999) and recently, it's Vaughan et al. (2003) who stabilized the specific composition of the genus *Oryza* (Table 1). According to these authors, the genus *Oryza* contains 21 wild relatives of the domesticated rices and is divided into four species complexes: the complex *O. sativa*, *O. officinalis*, *O. ridelyi* and *O. granulata*. All of the species of these complexes (genus *Oryza*) have $n = 12$ chromosomes and while interspecific crossing is possible within each complex, it is difficult to recover fertile offspring from crosses across complexes (Vaughan et al., 2003).

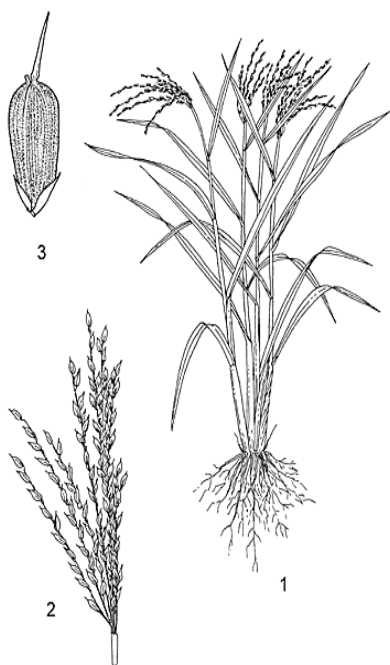


Figure 1.1. Morphological description of *O. glaberrima*

1. plant Culm; 2. inflorescence; 3. spikelet. Authors: W. Wessel-Brand, G. Bezançon and AfricaRice.



Figure 1.2. Polymorphism of panicles



Figure 1.3. Polymorphism of grains



Figure 1.4. Inflorescence of *O. glaberrima*

The two cultivated species: *O. sativa* and *O. glaberrima* belong to the *O. sativa* complex which contains five or six wild species: *O. barthii*, *Oryza longistaminata*, *Oryza meridionalis*, *Oryza glumaepatula*, *O. rufipogon*, and *O. nivara* (also considered to be an ecotype of *O. rufipogon*). All of these species are diploids. The taxonomy and usual habitat of all members of the complex *sativa* is mentioned in the table.1. Moreover, contrarily to the diagram (Figure 2.) of Chang (1976), several studies concluded the subdivision from the cultivated Asian rice *O. sativa* in two under-species: the sub-species *indica* originated from the Southeast of Asia and the sub-species *japonica* originated from China (Glaszmann, 1987; Garris et al., 2005). The intermediate under-species *javanica* is thus non-existent (Second, 1982; 1984; Lolo, 1987).

2.2 Growth and Development of *O. glaberrima*

African rice seedlings normally emerge in 4–5 days after sowing or more (6–10 days) when dormancy is higher. Vegetative growth of *O. glaberrima* is very rapid (WARDA, 1996) and this development step consists of a juvenile phase of about three weeks followed by an active tillering phase of 3–4 weeks which extends until the flowering and often towards the maturity with the appearance of youthful tillers. Vigorous tillering, high leaf area index and high specific leaf area contribute to its high competitiveness against weeds (WARDA, 1996; Rodenburg et al., 2009). However, culms tend to be weak and brittle, making African rice prone to lodging. African rice is self-fertilizing. The duration of the crop varies from 3–6 months depending on cultivar and type of culture. Some cultivars selected for rainfed conditions possess very short cycle duration. Cultivars for deep water conditions tolerate flooding up to 2.5 m deep and culms may grow up to 5 m long. At maturity, grain shattering occurs in many cultivars. The Figure 1.2 shows a polymorphism between panicles while the Figure 1.3 presents the polymorphism of grains within *O. glaberrima* genotypes.

2.3 Origin of the Cultivated Rice Species

The genus *Oryza* to which rice belongs is originated From Gondwanaland (Chang, 1976a), the ancient land mass from which India, Africa, South America and Australia drifted apart since tertiary era (ORSTOM, 1987). The two cultivated rice species, *O. sativa* L. and *O. glaberrima* are considered to have evolved later by independent but parallel evolutionary processes respectively in Asian and African continents (Figure 2). Porteres (1956) firstly postulated that the African cultigen, *O. glaberrima* is originated from the Niger River delta (Figure 3). The primary centre of diversification of *O. glaberrima* is in the swampy basin of the upper Niger River in West Africa which was probably formed around 1,500 BC (Portères, 1956; Angladette, 1966; Carney, 1998). Two secondary centres of diversification were then formed 500 years later in the southwest near the Guinean coast (Portères, 1956). The first, on the coast of Gambia, Casamance and Guinea Bissau; and the second in the Guinea forest between Sierra Leone and the western Ivory-Coast around 1,000 BC (Porteres, 1962, 1976; Chang, 1976a). According to Porteres (1970), the histories and archaeologies' researches also pointed out three centres of domestication for *O. glaberrima*, in Mali, Sene-Gambia, and Guinea and this may have contributed to the broad ecological adaptation of the African rice cultivars today. Indeed, in the absence of evidence archaeological firm, it is difficult to assess whether Porteres (1962 & 1976) is correct in suggesting that *O. glaberrima* was first domesticated in the Inland Delta of the Upper Niger River, in what is today Mali, 2,000 or 3,000 years ago (Linares, 2002). Moreover, Sweeney and McCouch (2007) reported that archaeologists have found ceramic impressions of rice grains dating from 1,800 BC to 800 BC in Ganjigana located in the north-east Nigeria. These go back to 1,800 BC and continue through to 800 BC. At the neighbouring site of Kursakata, scientists have uncovered abundant charred grains of rice dating from 1,200 BC through to AD 0 (Klee et al., 2000). However, there is no evidence that the grains from either of these sites are domesticated and not wild rices. The oldest documented domesticated *O. glaberrima* dates between 300 BC and 200 BC and comes from Jenne-Jeno, Mali on the Inland Niger Delta (McIntosh, 1995). Molecular data beginning with isozyme studies and confirmed by simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) data, unequivocally demonstrated the uniqueness of African rice and its close genetic relationship to *Oryza barthii* (Second, 1982; Semon et al., 2005). The centre of diversity for *O. glaberrima* is thought to be the upper Niger River Delta. Porteres (1970) hypothesized that *O. glaberrima* was first cultivated in the floodwaters using floating rice cultivars. Rice culture then spread to the brackish waters using non-floating cultivars and subsequently further.

Concerning the Asian rice *Oryza sativa*, Sweeney and McCouch (2007) mentioned that the oldest archaeological evidence of rice use by humans has been found in the middle and lower Yangzi River Valley region of China. Phytoliths, silicon microfossils of plant cell structures, from rice have been found at the Xianrendong and Diotonghuan sites and dated to 11,000–12,000 BC (Zhao, 1998). Scientists have uncovered other sites in this region.

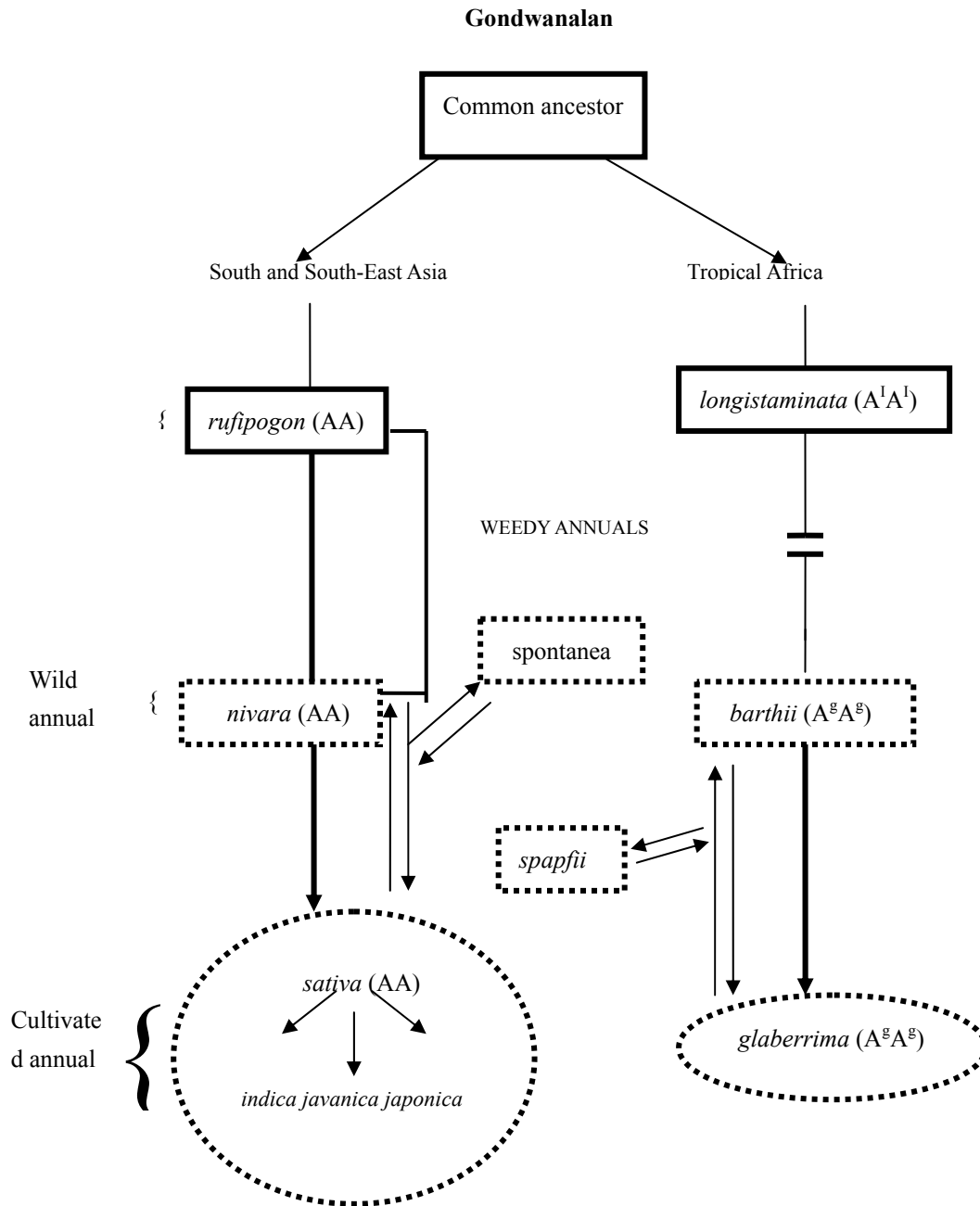


Figure 2. Evolutionary pathway of the two cultivated species of rice

Taxa boxed by solid lines are wild perennials. Taxa boxed by broken lines are annuals. Arrow with solid line indicates direct descent. Arrow with broken line indicates indirect descent. Double arrows indicate introgressive hybridization (adapted from CHANG, 1976a).

including Shangshan, and Bashidang with significant quantities of rice remains, some dating back to 8,000 BC (Higham & Lu, 1998; Pei, 1998; Jiang & Liu, 2006; Fuller, 2007). The following diagram (Figure 2.) shows the evolution of both cultivated rice species since the common ancestor.

Source Chang, 1976.

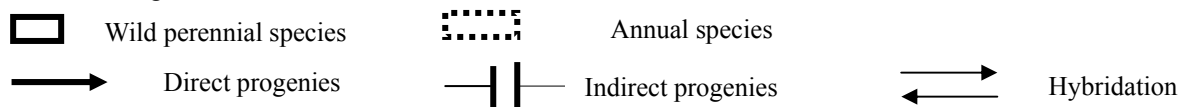


Table 1. *Oryza* species: their chromosome number, DNA content, genome group and usual habitat. (Vaughan, 2003)

Section species	Complex	Taxon	Chromosome number (DNA content [pg/2C])	Genome groupe	Usual habitat
		<i>O. sativa</i> L.	24 (0.91–0.93)	AA	Upland to deepwater; open
		<i>O. rufipogon</i> sensu lato (syn: <i>O. nivara</i> for the annual form <i>O. rufipogon</i> sensu stricto for the perennial form)	24 (0.95)	AA	(Annual) Seasonally dry; open (Perennial) Seasonally deepwater and wet year round; open
<i>O. sativa</i>		<i>O. glaberrima</i> Steud	24 (0.87)	AA	Upland to deepwater; open
		<i>O. bathii</i> A. Chev.	24	AA	Seasonally dry; open
		<i>O. longistaminata</i> Chev. et Roehr.	24 (0.81)	AA	Seasonally dry to deepwater; open
		<i>O. meridionalis</i> Ng	24 (1.02)	AA	Seasonally dry; open
		<i>O. glumaepatula</i> Steud	24 (0.99)	AA	Inundated areas that become seasonally dry; open
		<i>O. officinalis</i> Wall ex Watt	24 (1.45)	CC	Seasonally dry; open
		<i>O. minuta</i> JS Presl. ex CB Presl.	48 (2.33)	BBCC	Stream sides; semi shade
		<i>O. rhizomatis</i> Vaughan	24	CC	Seasonally dry; open
		<i>O. eichingeri</i> Peter	24 (1.47)	CC	Stream sides, forest floor; semi shade
		<i>O. malapuzhaensis</i> Krishnaswamy and Chandrasakaran	48	BBCC	Seasonally dry forest pools; shade
<i>O. officinalis</i>		<i>O. punctata</i> Kotschy ex Steud.	24 (1.11), 48	BB, BBCC	(Diploid) seasonally dry; open (Tetraploid) forest floor; semi shade
		<i>O. latifolia</i> Deav	48 (2.32)	CCDD	Seasonally dry; open
		<i>O. alta</i> Swallen	48	CCDD	Seasonally inundated; open
		<i>O. glandiglumis</i> (Doell.) Prod.	48 (1.99)	CCDD	Seasonally inundated; open
		<i>O. australiensis</i> Domin	24 (1.96)	EE	Seasonally dry; open
Ridleyanae Tateoka		<i>O. schlechteri</i> Pilger	48	Unknown	River banks; open
		<i>O. ridleyi</i> Hook	48 (1.31–1.93)	HHJJ	Seasonally inundated forest floor; shade
<i>O. ridleyi</i>		<i>O. longiglumis</i> Jansen	48	HHJJ	Seasonally inundated forest floor; shade
		<i>O. granulata</i> Nees et Arn ex Watt	24	GG	Forest floor; shade
<i>Granulata</i> Roschev.		<i>O. meyeriana</i> (Zoll. et Mor. ex Steud.) Baill.	24	GG	Forest floor; shade
Brachyantha B.R. Lu		<i>O. brachyantha</i> Chev. Et Roehr.	24 (0.72)	FF	Rock pools; open

However, there is still continuing debate over whether *Oryza rufipogon*, the perennial species, *Oryza nivara*, the annual species, or possibly both were the direct ancestors of *O. sativa*. For the purpose of this review we will reserve judgment and refer to both the annual and perennial forms as *O. rufipogon* in the following development.

According to the previous diagram, the domestication of the African rice from its direct ancestor *Oryza barthii* (= *Oryza breviligulata* A. Chev. & Roehr) in Africa was independent to that of *O. sativa* from *O. rufipogon* in Asia. Several ways of introduction of the Asian species *O. sativa* in Africa were brought back (Carpenter, 1978; Purseglove, 1976; Besançon, 1993). But the most outstanding wave of the migration, and for which there remains no doubt, was that which is addressed (end of XVe century - at the beginning of XVIe centuries) to the great navigators initially Portuguese traders, then Dutch, French and British on the way towards their European home ports to their return from Asia and which deposited rice on the East and West coasts of Africa (Portères, 1950).



Figure 3. Indigenous African rice domestication areas (Carney, 1998)

3. Genetic Evolution of the Domestication Process

Many phenotypic differences are obvious between cultivated rice and its wild relatives (Xiao et al., 1998; Cai & Morishima, 2002; Li et al., 2006). Wild rices typically display long awns and severe shattering for seed dispersal, whereas the domesticated type have short awns, if any, and reduced shattering to maximize the number of seeds that can be harvested. Domesticated type can carry larger numbers of seeds than the wild ancestors. These phenotypes are not perfectly partitioned between wild and cultivated plants. While we refer to domestication 'events' it is important to remember that domestication was a process that occurred over an extended period of time.

Genetic loci that were selected from existing genetic variation in the wild species may appear fixed within domesticated rice, but will show variation within the wild rice. Although domestication traits are not favored by natural selection, many of these traits are polygenic. A single allele promoting a more domesticated phenotype could be masked in the wild by a dominant allele at the same locus, or by alleles at other loci in the pathway, until a chance combination of different pre-existing wild alleles produces a plant with a domestication phenotype. This domesticated genotype would not survive long without artificial selection, but the parents contributing to the variation leading to the domesticated phenotype can have wild phenotypes which would not be selected against. Positive mutations that occurred later in the domestication process may be absent from the wild gene pool or early landraces, but would be ubiquitous among more recently developed cultivars. On-going gene flow between domesticated and wild rice further complicates the picture. Domestication traits is thus considered to be those that are favored by humans, occur at significantly higher frequencies in domesticated compared with wild rices, and adversely affect a plant's ability to survive and reproduce without human assistance. Genes influencing these traits and showing signs of ancient selection are considered domestication genes. Among the species which composes the complex *sativa* (Table1), the two domesticated species and cultivated in Africa are distinguished from the wild species by the following characteristics which represent the syndrome of domestication (Lolo,

1987). For example:

- Rapid disappearance of seminal dormancy
- Increase of the number of grains per panicle
- Reduction of spontaneous shattering which can also be completely avoid
- Suppression or reduction of awn length

The hypothesis of parallel lines of domestication process of the two cultivated species has been confirmed by cytological studies (Fukui et al., 1991; Ohmido et al., 1995) cited by Sweeney and McCouch (2007). The two cultivated species have been classified within the group of A-genome species but formed separate clusters within it, as shown by results from isozymes and molecular marker studies (Ge et al., 1999; Ren, 2003).

3.1 Natural Hybridizations between *O. glaberrima* and Its Wild Forms

The introgressions between cultivated and wild forms are very scarce in particular hybridizations with *Oryza longistaminata* (Chu & Oka, 1970). However, between *O. glaberrima* and *O. barthii*, hybridizations are frequent (Chu & Oka, 1970) and would be at the origin of the certain forms of *O. barthii* fertile adventitious (Second, 1982). The barriers of reproduction generally result from sterility gametic and more particularly pollinic, by the low vigor of F₁ or the degeneration of the embryo (Chu et al., 1969). The natural hybridizations are possible in the contact areas of the different species. For example, in the African rice cultivation system, introgression is frequently observed between the two cultivated species by giving sterile hybrids (Second, 1984).

3.2 Biological and Ecologic Type of *O. glaberrima*'s Wild Parents

The bio-geographical distribution of all members of the complex *Sativa* especially those of the two cultivated rice and their wild parents is presented in the Figure 4. Several biological types and modes of reproduction were distinguished among the two cultivated rice and their wild parents which are influenced by the environmental conditions and habitat (Lolo, 1987). The following Table.2 summarizes the distribution, the biological types and the reproduction systems of the two cultivated species and their wild parents in the complex *sativa*.

3.2.1 *Oryza Longistaminata* A. Chev. and Roehr

Graminaceous hardy and robust, reaching 2,5 m in height, with long rhizomes crawling and ramified, *O. longistaminata* is distinguished from the other wild species of *Oryza* by its very long and pointed ligula. Often, few seeds are formed and the natural reproduction is done by the rhizomes. *O. longistaminata* is distributed in all tropical Africa (including Madagascar). It's also found in South Africa. It's maintained in a stable and very less disturbed habitat. It colonized the African and Malagasy plains regularly flooded by the large rivers (Senegal, Niger). It also meets in the marshes, in border of the lakes Malawi and Victoria for example (Lolo, 1987). In a specific way, *O. longistaminata* is especially found in the deep water, the backwaters, the ponds, the marshes, the flooded plains and in the borders of rivers up to 1800 m of altitude. It is a harmful adventitious in flooded rice growing, because it prevents rice cultivated to push and forms hybrids with him. It can also make office of tank for significant diseases and pests of rice, like blasts (*Xanthomonas oryzae* pv. *oryzae*).

3.2.2 *Oryza Barthii* (= *O. breviligulata* A.Chev. and Roehr)

Annual grass up to 150 cm tall, growing in tufts; *O. barthii* is an selfing and annual species which is typically different from the cultivated species *O. glaberrima* on the following points: the spikelet is longer, frequently exceeding the 10 mm, the interior glume is prolonged by a very long edge (10-20 cm) strong and breakable (Besançon, 1993). *O. barthii* is not normally cultivated, but the grain is collected from the wild. The grain shatters very easily, and the panicles are usually collected before they are mature.

Oryza barthii presents a geographical distribution broader than the cultivated species *O. glaberrima*. Its natural habitat is unstable and very disturbed by the herds (Second et al., 1984). It's distributed in tropical Africa from Mauritania East to Ethiopia and South to Botswana and Zimbabwe. *O. barthii* grows in shallow water in ponds and marshes; and as weeds in rice fields, up to 1500 m altitude. It may form pure stands, but is usually found scattered with other aquatic grasses. It may become a noxious weed and may act as a reservoir for important rice diseases and pests. *O. barthii* is a short-day plant. It has a relatively narrow genetic variation and is considered as a source of resistance to various diseases affecting *O. sativa*, including bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*) and rice yellow mottle virus (RYMV).

4. Geographic Distribution of the African Rice Species

4.1 Geographic Distribution of the Cultivated African Rice Species *Oryza Glaberrima*

The distribution areas of the cultivated African rice are mainly spread in West Africa. *O. glaberrima* is grown in a zone extending from the delta of the River Senegal in the West to Lake Chad in the East. To the southeast, its range is bordered by the river basins of the Benue, Logone and Chari, but it has also been recorded from the islands of Pemba and Zanzibar (Tanzania). The areas of most intensive cultivation of African rice are the floodplains of northern Nigeria, the inland delta of the Niger River in Mali, parts of Sierra Leone and the hills on the Ghana-Togo border. The Figure 5 presents the distribution areas of *O. glaberrima* in West Africa.

Table 2. Distribution, biological types and systems of reproduction of the cultivated species and their wild parents in the complex sativa

	Species	Distribution	Biological types	reproduction system
Asian rice				
Cultivated species	<i>Oryza sativa</i> (with two subsp indica and japonica)	Asia	Intermediate	Self-pollinated plant (often) and intermediate
Wild species	<i>Oryza rufipogon</i>	Asia, Australia and America	Annual, intermediate, perennial	Self-pollinated and cross-pollinated plant, intermediate and vegetative reproduction
African rice				
Cultivated species	<i>Oryza glaberrima</i>	Africa	Annual	Self-pollinated plant
Wild species	<i>Oryza barthii</i>	Africa	Annual	Self-pollinated plant
	<i>Oryza longistaminata</i>	Africa	Perennial	Cross-pollinated and vegetative reproduction

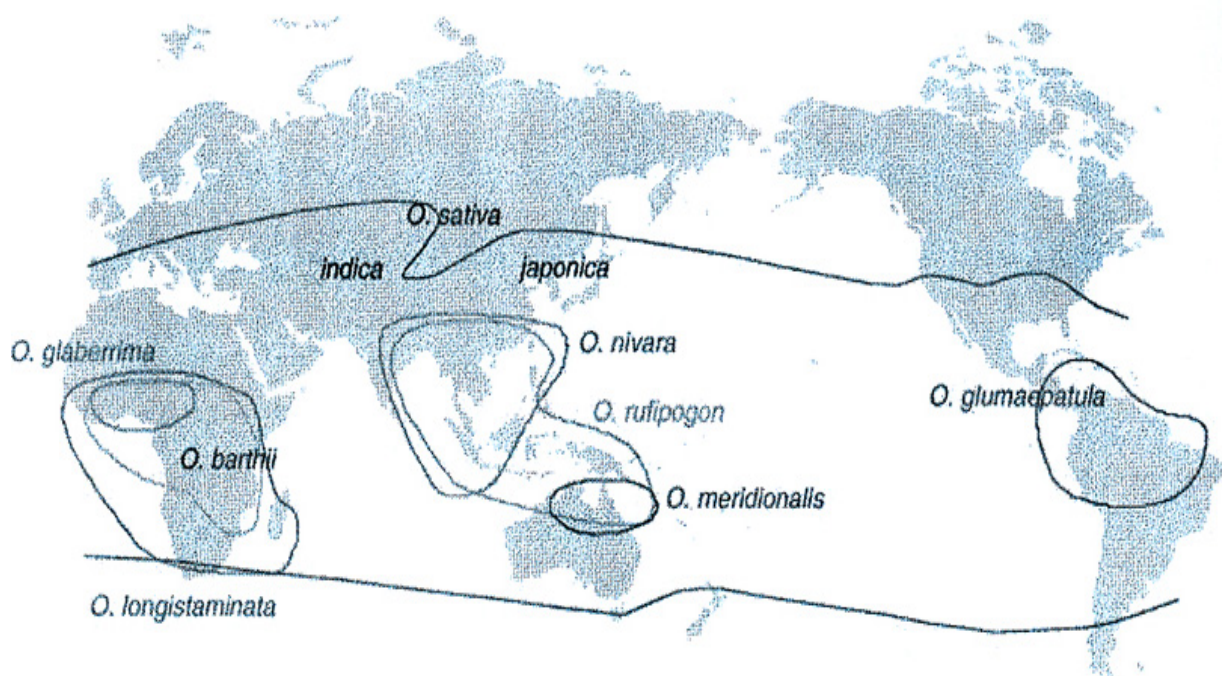


Figure 4. Geographical distribution of the genome (AA) of *Oryza* species (Ashikari et Matsuoka, 2006)

Prospection works carried out by Besançon and reported in his thesis (Besançon, 1993) pointed out the localizations (Figure 6.) of the species belonging to the complex of rice which are largely distributed in Africa. Moreover, Carney (1998) reported that *O. glaberrima* was probably introduced into the New World during the slave trade era and is still occasionally cultivated there. Example of Brazil, Guyana, El Salvador and Panama. Portères (1976) mentioned that in the past, the cultivated African rice was found in the New World (America).

He thus affirms that: "it (African rice) was transported to America and continued to exist there, either in the sub-self sown state (El Salvador), or in the cultivated state, in French Guyana and (...) as well as Panama." (Portères, 1976: 441). The presence of the African rice varieties in the New World could be explained through the event of human trade which involved the massive deportation of the Africans like slaves in America (Vido, 2007).



Figure 5. Geographic distribution zones of *O. glaberrima* in Africa (www.Prota.org)



Figure 6. Localizations of the species of the complex of rice in Africa (Besançon, 1993)

According to (Carney, 1998; 2005), *Oryza glaberrima* crossed the Atlantic during the period of the slave's trade and this is not in doubt since French botanists recovered *O. glaberrima* varieties in Cayenne (French Guyana) during the 1930s. The African slaves also introduced African cereal into the British colonies of South Carolina and Georgia and then in Bahia and Suriname (Carney, 2005).

4.2 Geographic Distribution of Others Species of the Complex Sativa

As mentioned above, the bio-geographical distribution of all members of the complex *O.* were reported by Ashikari and Matsuoka (2006) through the Figure 4. According to these authors, *O. rufipogon*, the wild parent of the cultivated Asian rice *Oryza sativa* can be found throughout Asia and Oceania. *O. meridionalis* is native to Australia and *O. glumaepatula* is endemic in Central and South America. Given these distributions, it is easy to locate the ancestral pools from which modern rice were extracted.

5. Population Structure in Complex *Sativa*

5.1 Population Structure of *O. glaberrima*

According to the methodology developed by Vavilov (1951), Portères defines associated genetic and geographical groups within the species *O. glaberrima*, according to whether the varieties come from the primary or the secondary Centre of variation (Figure 3 Above). The author connects this differentiation to associations of characters under their dominant forms in the primary Centre and recessive forms in the secondary Centre. The varieties thus met in the interior delta of Niger belong to the group *nigerica* and associate the following characters: floating type, anthocyanic pigmentation of the vegetative organs and certain floral pieces, colored caryopses and very marked deciduous of the spikelet. On the other hand, the varieties met in Casamance and Gambia belong to the group *senegambica* in which the recessive forms of the characters referred to above are associated: not-floating type, light pigmentation or completely absent on the vegetative organs, white caryopse and thinned deciduous of the spikelet. Portères explained this transformation like an evolution of the species. This led him to define the second Center of diversification in the mountainous area of Guinea, where discriminating characters with dominating and a recessive state have been met at the same time.

Concerning the geophysical structuring, the recent genetic diversity study leads by Simon et al. (2005) on 207 accessions (198 *O. glaberrima* and 09 *O. sativa*) collected from various agro-ecological zones of 12 different countries throughout West Africa showed an abundant SSR diversity observed within this collection. An average of 9.4 alleles per locus was detected among the 93 SSRs analyzed, with a range of 2–27 alleles/locus. The mean polymorphism information content (PIC) value was estimated to 0.34, with a gene-diversity (He) evaluated to 0.27 and an allele size ranging from 67 to 388 bp.

These molecular results especially the number of alleles, the gene diversity, and the PIC values offer views into how diversity is partitioned within *O. glaberrima* germplasm. This permitted to authors to identify five genetically distinct groups whose two present admixtures with the two subspecies of the Asian cultivated rice *O. sativa*, the others three groups were being characteristic of *O. glaberrima*.

The analysis of these results showed that the introgression of *O. sativa* DNA into *O. glaberrima* germplasm appears to have created intermediate types that cannot be easily distinguished at the phenotypic level from native cultivars of *O. glaberrima*. Eleven of these accessions shared significant (52%) ancestry with *O. sativa* (hereafter referred to as “*interspecific admixed accessions*”) and were collected from Guinea Conakry, Sierra Leone, and Nigeria (Figure 7). This was especially demonstrated through four accessions (YS168, YS179, YS230, and YS351) out of the six collected in Guinea Conakry which shared at least 87% ancestry with *O. sativa* while 50% of accessions from Sierra Leone (Pa DC Kono, DC Kono, and Saliforeh) shared at least 54% of their ancestry with *O. sativa* cultivars. In Nigeria, TOG5486 is identified to share 96% of ancestry with *O. sativa* (49% with the *indica*-like and 47% with the *japonica*-like group).

This is consistent with the fact that Sierra Leone and Guinea Conakry, but not Nigeria, are believed to be the primary ports of entry for *O. sativa* into West Africa. Moreover, this genetic profile of *O. glaberrima* is also entirely consistent with the cultural history of rice cultivation patterns in West Africa where *O. glaberrima* is often grown in mixtures with *O. sativa*. However, according to Futakuchi and Sié (2009), in general, a small number (4%) of *O. glaberrima* genotypes show admixture with *O. sativa*.

5.2 Population Structure in Asian Rice *O. Sativa* and Difference with *O. glaberrima*

As early as the Chinese Han dynasty in China (approx. AD100) two different types of rice, traditionally distinguished as Hsien and Keng (Matsuo et al., 1997) cited by Sweeney and McCouch (2007) have been recorded. But, Kato (1930) cited by (ORSTOM, 1987) was the first who scientifically described the two sub-groups within the Asian rice species *O. sativa* that he named “*Japonica*” and “*Indica*” subspecies. The distinctness of these groups has been confirmed by many different approaches over the course of rice research. Variation of morphological characters including leaf color, seed size and awn length etc., were used to definitively classify varieties into subspecies (Kato et al., 1928; Oka, 1988). Researchers have also observed that progeny derived from crosses between these groups exhibited sterility (Kato et al., 1928). A third group or subpopulation was identified based on morphology and was referred to as *javanica* (Figure 1. above) (Matsuo, 1952). But, this group is known today as the tropical *japonica* subpopulation (Glaszmann, 1987; Garris et al., 2005). Moreover, Isozymes were also used by Second, (1982) and Glaszmann (1987) to clarify the differentiation between *indica* and *japonica* who suggested further division within these two groups.

However, *O. glaberrima* is distinguished from *O. sativa* by glabrous glumes, short ligule with roundish tip, death after maturity, pronounced seed dormancy, susceptibility to lodging and shattering and is completely separated

from *O. sativa* by a sterility barrier (Morishima et al., 1961; Mohapatra, 2010). This is confirmed by Pham and Bougerol (1993) who explained that *O. glaberrima* is separated from *O. sativa* by a strong reproductive barrier, including pollen sterility as well as female sterility. According to Simon et al. (2005), in natural populations, geographical barriers often limit pollen dispersal, while in populations of cultivated species, both seed and pollen dispersal are often a consequence of human activity and artificial (human) selection tends to reinforce existing.

5.3 Genetic Diversity within African Rice Germplasm

The cultivated African rice presents some interesting potentialities for West and Central Africa (WCA) ecosystems. Among the eight other species indigenous to Africa, *O. glaberrima* is known to have been selected and cultivated in parts of West Africa for more than 3500 years (Bidaux, 1978; Carpenter, 1978). Because this species survived without the help or interference from human, it has developed adaptive and protective mechanisms for resisting major biotic and abiotic stresses. *O. glaberrima* is also reported by rice scientists from Africa Rice Center (AfricaRice) to represent a rich reservoir of useful genes for resistance to diseases and pests as well as tolerance to soil acidity, iron toxicity, drought, inundation and unfavourable temperatures (Jones et al., 1997). Always about phenotypical characters, *O. glaberrima* presents good ability for weed competitiveness due to its vigor and surface leaf Area that are specific traits very developed in this species. Some *O. glaberrima* varieties have been selected for their tillers number and grains supplies of their panicles and present various plant height and growth duration than *O. sativa*. In opposite, *O. glaberrima* has many undesirable traits which result in low yield potential, lodging, grain shattering, low panicles primary and secondary branches and long seed dormancy which are the major constraints to its productivity (WARDA, 1993). In large part, it is due to these agronomical undesirable characters that farmers are rapidly replacing the cultivated African rice by the productive Asian rice *O. sativa* varieties.

According to Second (1982) genetic diversity study conducted on *O. glaberrima* using isozymes markers highlighted a drastic reduction of the polymorphism which accompanies its domestication from the wild parent *O. barthii*. These molecular results showed the declining of the gene diversity from 0.14 to 0.03 and thus with no hidden variability found. According to the author, the genetic diversity of *O. glaberrima* was small but about half of that of *O. sativa* in terms of number of alleles per locus. In contrast to *O. glaberrima*, the gene (electromorph) diversity was large ($H=0.23$) in *O. sativa*. This is confirmed by Sie (1991) who supported that *O. glaberrima* present low genetic diversity than *O. sativa*. The genetic distance between *O. glaberrima* and *O. sativa* was not greater than between the presumed “ancestral” Indica and Japonica subsp. An “Africa” type of cultivated rice could probably be generated by introgression of interest genes from *O. sativa* into *O. glaberrima* (Second, 1982; Ghesquière et al., 1997).

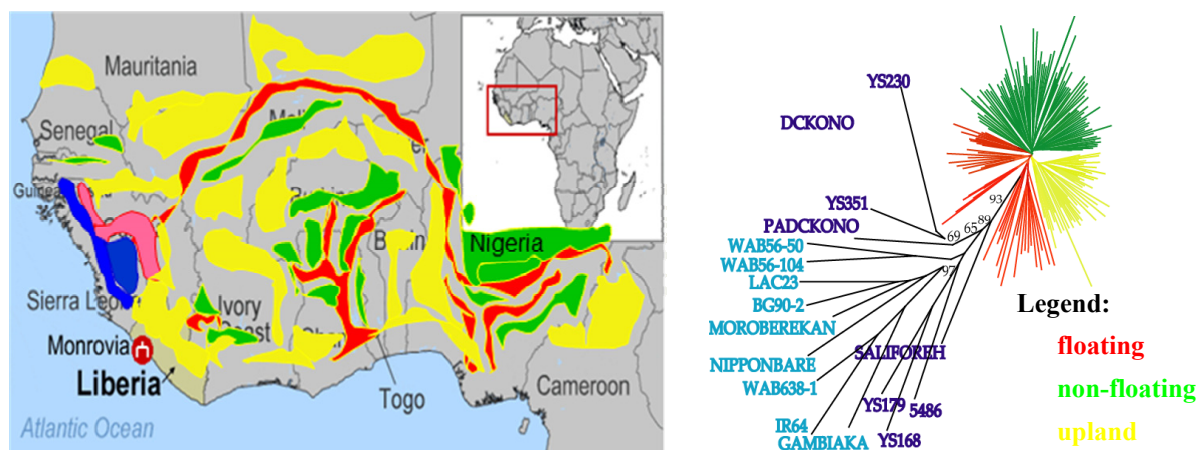


Figure 7. Geographical distribution and unrooted phylogram (based on neighbor joining) representing shared allele frequencies among 207 accessions; *O. sativa* varieties are shown in light blue; *O. glaberrima* varieties clustering with *O. sativa* are shown in dark blue. (Simon et al., 2005; Sie & Futakuchi, 2009)

6. Rice Agro-ecologies in Sub-saharan Africa

Rice cycles vary from 90 days in Sahel Zone to 270 days in Forest Zone. The Figure 8 shows that when leaving

the Sahel Zone to the Forest Zone crossing Sudan Savanna and Guinea Savanna, the growing period increases. Predominance of 90 days eco phenotypes in Sahel Zone may be easily explained by the water shortage and short rainy season of 1-3 months. Progressing to Savanna Agro ecological zone, allows rice benefit a longer rainy season. That is why the growing tends to extend itself to 90-165 and 165-210 days of growing period. Very long period over than 210 days and reaching 270 days in the case of tropical forest, can be justified by the fact that rainy season cover a big part of the year season. The total amount of sun radiation received in rainy tropical ecologies is low because of the permanently cloudy sky. The consequence is a decrease of photosynthetic activity. For the case of irrigated lowland, a negative correlation attributed to cloudy sky between yield and the sum of rainfall was found under rainy tropical ecology (Arraudeau, 1998). This weather information is very important to understand the genetic variation observed within the African rice collection and better to highlight the specific assets of each ecotype collected through African countries especially those of West-Africa.

6.1 Ecology of the Cultivated African Rice Species

O. glaberrima grows well above 30°C, but spikelet fertility is very affected over 35°C reducing yield grains. Temperatures below 25°C reduce growth and yield and below 20°C do so markedly. African rice is grown from sea-level to 1700 m altitude. It is generally a short-day plant, but photosensitivity varies between cultivars from day-neutral to strongly sensitive. African rice is grown on a wide range of soils (Doorenbos, 1987). Although preferring fertile alluvial soils, it tolerates low soil fertility. Some cultivars can produce higher yields than Asian rice on alkaline and phosphorus-deficient soils. They are also more tolerant to iron-toxicity. Floating rice may also be planted on loam or clay soils.

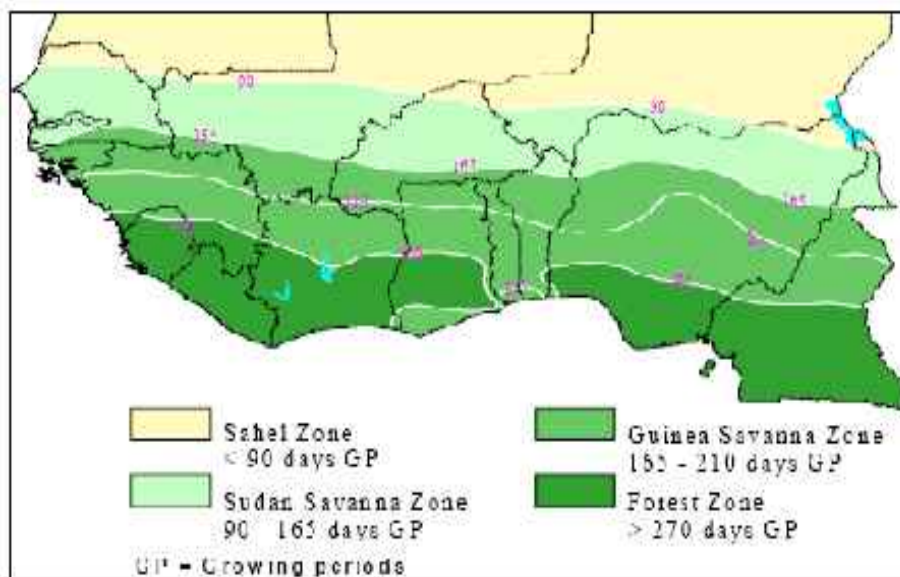


Figure 8. Agroecological zone in West and Central Africa (Defoer et al., 2004)

According to Defoer et al. (2004), five main rice ecologies are coexisting in Africa such as: Rainfed upland rice on plateau and slopes; Lowland rainfed rice in valley bottoms and flood plains with varying degrees of water control; Irrigated rice with relatively good water control in deltas and flood plains and Mangrove swamp rice in lagoons and deltas in coastal areas and Deepwater, floating rice along river beds and banks.

As mentioned above, two major agro-ecotypes were clearly identified within *O. glaberrima*: the “floating” photosensitive ecotype and the “non floating” early erect ecotype (Second, 1982, Ghesquiere et al., 1997; Sarla et al., 2005). The former is found in inundated (deep water) areas with water level up to 3 or 4 m high including coastal mangrove areas, and the latter is found in moderately inundated lowlands, irrigated fields or upland (rainfed) conditions. The cultivated areas of *O. glaberrima* are estimated at less than 20% of rice-cultivated lands in West Africa (WARDA, 1996). But, because of its susceptibility to lodging (plants fall over) and shattering (the panicle scatters seed at maturity), the cultivated areas of *O. glaberrima* is decreasing more and more in the Sub-Saharan Africa (Futakuchi et al., 2009). The Figure 9 shows rice cultivation systems and scenarios in current Africa Rice member states while Figure 10 presents the various rice ecologies in Africa.

6.2 Major Rice Production Systems in Sub-saharan Africa (SSA)

The total area under rice cultivation is currently about 4.4 million hectares (ha), with the rainfed upland and rainfed lowland ecosystems each accounting for about 1.7 million ha and irrigated rice for another 0.5 million ha, making these the high-impact ecologies (Somado et al., 2008). These various rice cultivation systems are presented as follow:

6.2.1 Rainfed Upland

Weed competition is the most important yield-reducing factor (Rodenburg et al., 2009) followed by drought, pests and diseases (especially blast, bacterial and RYMV), soil erosion and general soil acidity with P and N deficiency. Rice yields in upland systems are thus low and average about 1- 1.5 t/ha. Farmers traditionally manage these stresses through long periods of bush fallow. More recently, population growth has led to a dramatic reduction of fallow periods to extended periods of cropping in many areas, resulting of the increase of weed pressure and soil infertility. Additional weed competition further reduces labor productivity in upland rice-based production systems, which are already generally limited by labor availability during the main cropping season. Farmers also face increased risks of crop failure and generally lower productivity levels. Very early maturing varieties with tolerance to drought and rice disease are required in the dry zones where the growing season is short, while medium to late maturing, disease and acid-tolerant and weed competitiveness varieties are needed for higher rainfall areas. Desirable agronomic characters including good plant vigor at seedling and vegetative stages for weed suppression, intermediate tall stature, lodging resistance and moderate tillering ability are also need for upland varieties to grow well in this ecosystem. *Oryza glaberrima*'s collection screening may help to select ideal ecotypes in order to fill the gap of these desirable characters within the interspecific varieties through breeding programs. The Figure 10.7 presents an ideal plant type for weed competitiveness in upland rice system.

6.2.2 Rainfed Lowland

The management of rainfed lowland cultivation (flood plains and valley bottoms) depends on the degree of water control. Rice yields vary from 1 to 3 t/ha and may sometime reach 4t/ha. This rice cultivation system has a high potential for intensification, which is pushed by local land pressures and pulled by urban market demand. With improved water control, use of external inputs may become attractive and rice yields may be increased rapidly in these systems that are inherently much more stable than the upland areas. Biophysical factors affect rice growth and its nutrient supply such as: iron toxicity, blast, rice yellow mottle virus (RYMV) and African rice gall midge (AfRGM). High yield potential is the priority objective in breeding for rainfed lowlands, combined with weed competitiveness, short duration, resistances to pests and diseases, and tolerance to iron toxicity. All these rice major constraints can be surmounted through exploitation and valorization of *O. glaberrima* genetic assets.

6.2.3 Irrigated Rice

In Sub-Saharan Africa, irrigated rice-growing areas are divided into three subcategories based on temperature. Two are found in West and Central Africa characterized by favorable and low-temperature respectively in tropical irrigated zones. The latter is restricted to the mid-altitude areas of Cameroon. The former is represented by the dry-season irrigated rice that is found in all agro-ecological zones from the rainforest to the Sahel. While almost all the rice growing areas in Mauritania (Sahel) are irrigated, only 12 –14% (0.5 million ha) of the total rice area in West and Central Africa are irrigated. This includes substantial areas in Cameroon (80%), Niger (55%), Mali (30%) and Burkina Faso (20%).

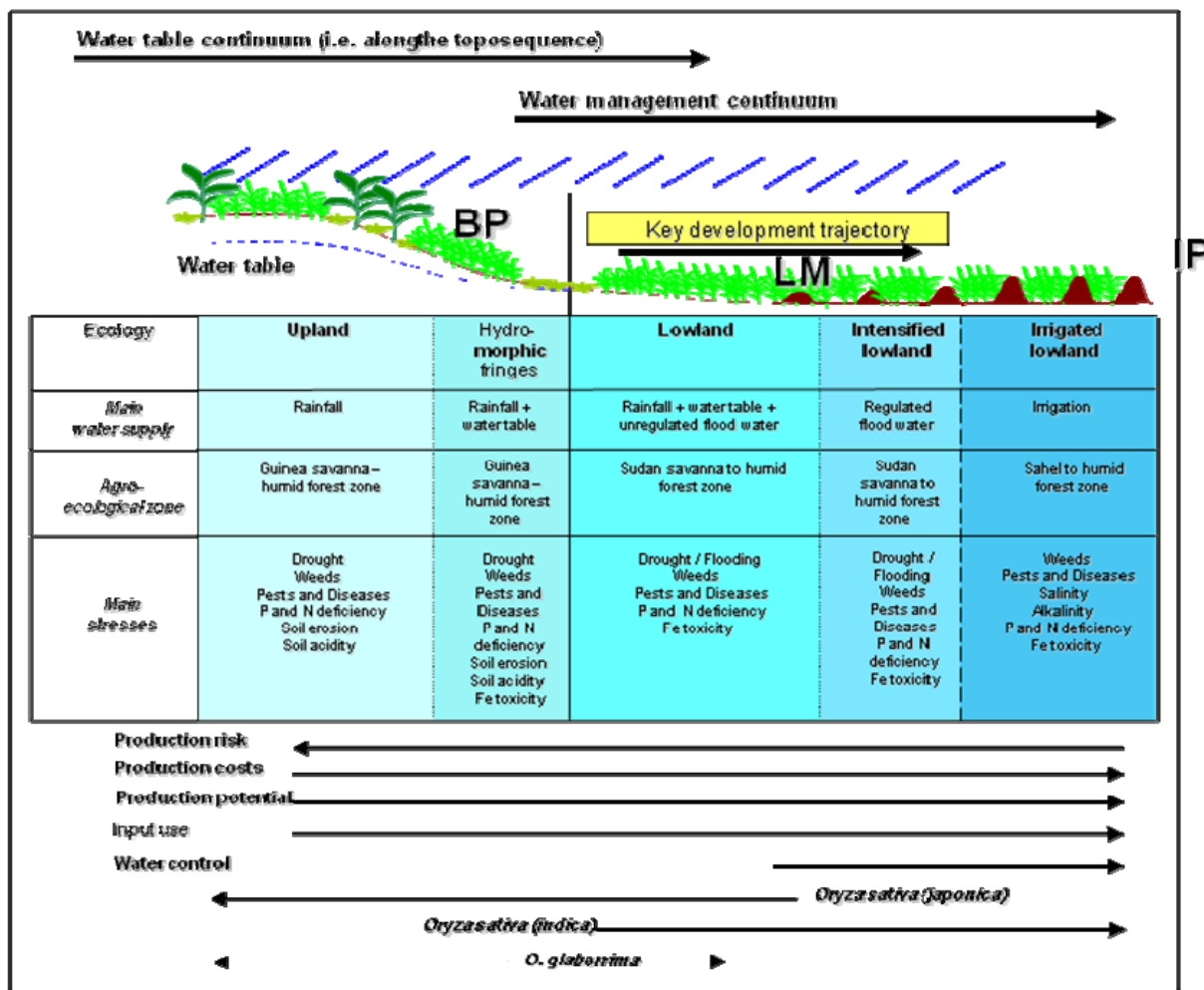


Figure 9. Rice cultivation systems and scenarios in current AfricaRice member states



Figure 10.1. *O. glaberrima* in irrigated lowland rice cultivation system. Author Agnoux, 2009



Figure 10.2. Inundated rice cultivation system
Author Courtois, 2007



Figure 10.3. *O. glaberrima* in floating rice cultivation system. Author G. Treuil cited by B.Courtois, 2007



Figure 10.4. *O. glaberrima* in floating rice cultivation system Author G. Besançon.
<http://database.prota.org/dbtw-wpd/protabase/photfile>



Figure 10.5. Mangrove swamp ecosystem. (WARDA, 2007)

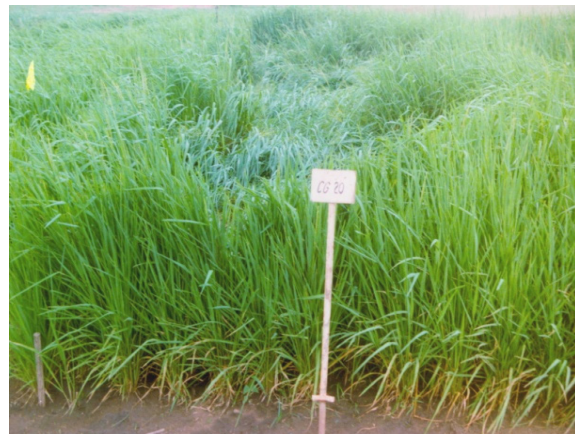


Figure 10.6. *O. glaberrima* in Upland rice cultivation system (WARDA, 2007)

Irrigated rice in these countries (except Cameroon) is mainly grown in the Sudan Savanna and Sahel, which account for nearly 60% of the irrigated rice area in West and Central Africa. In Côte d'Ivoire, about 24,500 ha (7% of total cultivated areas) are irrigated. Yield potential is higher (10 t/ha) in some of these drier zones than in others, because of high solar radiation and low disease stress. *O. glaberrima* adaptative and tolerant genotypes to major rice biotic stress and presenting good yield abilities are suitable for this rice ecology.

6.2.4 Deepwater and Mangrove Swamp Rice Area

According to Balasubramania et al., (2007), worldwide, about 11–14 million ha will come under deepwater ecosystems. In SSA, about 0.63 million ha are estimated to be affected by excess flooding, tidal submergence, saltwater intrusion, salinity and acid sulfate soils. These ecosystems cover an estimated 9% of the total rice area in SSA. Some parts of the flood plains of the Niger River, the low-lying wetlands of Madagascar, and the poorly drained inland basins of Chad, Guinea, Mali, Niger, and Nigeria have deep flooding, whereas the low-lying coastal wetlands of East and West Africa are affected by salinity and alkalinity due to seawater intrusion. Mangrove swamps constitute about 49% of the rice land in Guinea Bissau, 14% in the Gambia, and 13% in Guinea (Defoer et al., 2002). Screening and selection of *O. glaberrima* genotypes tolerant to inundation, salinity and soil acidity would be appropriated to better exploit deepwater and mangrove swamp rice areas in Sub-Saharan Africa.



Figure 10.7. *O. glaberrima* on AfricaRice experimental site of Ouedeme, Benin (Author Agnoun, 2009)

7. Management of *O. glaberrima* Genetic Resources

Several institutes like IRD (Institut de Recherche pour le Développement, formerly ORSTOM) and CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement) collected cultivated and related wild types of rice (both African and introduced) throughout their area of distribution. Between 1974 and 1983, over 3700 samples were collected in Africa and Madagascar, in which 20% are *Oryza glaberrima* and 12% related wild species (www.prota.org). These collections are kept in cold storage (4°C, 20% humidity) for medium-term conservation and partly frozen at -20°C for long-term storage at IRD in Montpellier (France). The collection is duplicated at CIRAD in France and at the International Rice Research Institute (IRRI / Philippines). The International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria keeps more than 2800 accessions of *O. glaberrima* and the Africa Rice Center (AfricaRice) through the Genetic Resources Unit (GRU) and the International Network for the Genetic Evaluation of Rice in Africa (INGER-Africa), maintains almost 2500 accessions. INGER-Africa allows for the worldwide sharing and evaluation of promising varieties, landraces, wild rices, and lines from breeding programs. To serve the national programs of Africa, it assembles nurseries for the major ecologies (upland, rainfed lowland, irrigated and mangrove) and stresses (RYMV, Blast, acidity, iron toxicity, salinity and weeds). It can also identify and supply material on specific demand from national breeders. (AfricaRice, 2010). Collections of *Oryza glaberrima* germplasm are also kept at the Bangladesh Rice Research Institute, Dhaka, and some safety backup have been made in for Collins (USA) and Svalbard (Norway). African rice shows orthodox seed storage behaviour. Currently no in-situ conservation programs of rice of African origin exist but they would be desirable.

On the contrary, the predominance of the genetic diversity of *O. sativa* on the cultivated African rice *O. glaberrima* is highlighted by Courtois (2007) who shows that the genetic diversity of *O. sativa* is considerable with more than 150.000 varieties cultivated in the world and approximately 107.000 accessions preserved in the gene bank of IRRI (including 5.000 accessions of wild species). This diversity comes from natural crossings of *O. sativa* with the wild or adventitious forms of *O. rufipogon* or crossings within-sativa combined with the natural and human selection since domestication (Khush, 1987). The structuring of this diversity is strong and particular. Its comprehension allowed a certain progress in the definition of logic strategies of rice genetic improvement.

8. Current Exploitation and Prospects for the Better Use of *O. glaberrima*

The world population is expected to increase rapidly in the recent future. Much of this human growth will be concentrated in developing countries, with sub-Saharan Africa (SSA) leading the way, as its population is estimated to double from 770 million in 2005 to 1.5 billion by 2050 (Seck, 2011). In this world area, farming, which is the principal source of livelihood for millions of poor people, suffered from several local constraints mainly due recently to climatic change whose impact is already being felt in Africa through increased incidences and severity of droughts and floods. Some of these constraints are particularly devastating to Africa's rice production since almost 80% of the region's rice area is rainfed (Mohapatra, 2009). Fortunately, rice has a significant genetic variation in traits related to local biotic stresses such as: Pests (insects, nematodes etc.), diseases (RYMV, Blast, Bacteria etc.) and abiotic stresses with mainly drought, acidity, iron toxicity, cold and salinity. Indeed, Scientists desperately look for these useful traits in plant varieties with especially short cycle

duration, root architecture, weed competitiveness and water-use efficiency which will be used in breeding programs to develop improved high-yielding and tolerant varieties. In this fact, *O. glaberrima*, the African rice species is a rich reservoir of genes for resistance against these local stresses (WARDA, 1996; Jones et al., 1997).

According to rice farmers' testimonies, AfricaRice scientists have been inspired to investigate the cultivated African rice species and tap into its rich reservoir of genes for resistance to several stresses, including weeds. Indeed, Plasticity and the capacity to regenerate quickly are the main advantages of African rice. That is why, although it is not particularly high yielding, the African rice farmers continue to grow it in pockets.

In this framework, Mohapatra, (2010), Futakuchi and Sie (2009) and Sarla et al. (2005) mentioned that CG14, one of the outstanding *O. glaberrima* varieties was proved through several studies to be weed competitive and has good resistance to iron toxicity, drought, nematodes, water logging, and major African rice diseases and pests. It seems to adapt to acid soil with low phosphorus availability. Such multiple resistances to the indigenous constraints are highly desirable characters for rice cultivation in West Africa rainfed and lowland ecologies. These useful genetic assets are also very interesting and appropriated for resource-poor farmers, who cannot afford to adopt intensive agronomic measures against such constraints (Futakuchi & Sie, 2009; Rodenburg et al, 2009, AfricaRice, 2010). That was why the AfricaRice scientist, Dr. Monty Jones and his research team selected CG14 when they decided to cross *O. glaberrima* with *O. sativa* in the 1990s to develop productive interspecific varieties adapt to upland ecosystem using WAB 56-104, the Asian rice variety as recurrent parent (Jones et al., 1997). The same study was lead by the lowland rice breeder, Dr Sie Moussa following the same concept using TOG5681 (*O. glaberrima*) and IR64 (*O. sativa*) to develop productive interspecific rice varieties for lowland ecology (Sie et al., 2005). These two senior scientists succeeded in breaking the natural barrier that made difficult interspecific cross between the two cultivated species and thus reaching the genesis of interspecific varieties trademarked as NERICA (New Rice for Africa). The best NERICA varieties combine the resistance and stress tolerance of *O. glaberrima* and its ability to thrive in harsh environment with the high yielding potential of *O. sativa*. (Somado et al., 2008; Jones et al., 1997; Sié et al., 2005). However, there are still gaps between the NERICA varieties and *O. glaberrima* in relation to resistance to some local constraints including weeds (Futakuchi et al., 2009). This remark was confirmed by Ndjiondjop et al., (2008) and Agnoun (2009) who showed through molecular profiling study of interspecific lowland rice populations derived from crossing between IR64 and TOG5681 using microsatellites markers that the estimated average rate of introgression of *O. glaberrima* genome varies from 7.2% (83.5 cM) to 8.5% (99.3 cM) and 8.7 to 13.2% respectively. These molecular results in relation with the agro-morphological traits expressed by the interspecific population showed that the interest genes of *O. glaberrima* initially targeted at the beginning of the breeding process are less introgressed thus giving priorities to the phenotypical characters of *O. sativa* within these interspecifics.

Moreover, the better exploitation of *O. glaberrima* useful assets was also reported by several scientific studies which mentioned that the African rice presents some interesting potentialities to improve rice yield and quality for food consumption in Africa (Sié et al., 2012; Futakuchi & Sié, 2009; Somado et al., 2008, Sarla et al., 2005; Linares, 2002; Jones et al., 1997; WARDA, 1996). Rice scientist researchers have therefore recommended the exploration of *O. glaberrima* genome as a source of new variability for rice genetic improvement despite the natural barriers and gene flows among *O. glaberrima*, *O. sativa* and *O. longistaminata* (Ghesquiere et al., 1997; De Kochko, 1987; Second, 1984; Takeoka, 1965). In this fact, breeding is extremely important to explore *O. glaberrima* potential and to use its genetic assets (AfricaRice, 2010).

However, about new challenges in rice genetic improvement, Sié et al., (2012) suggested that, although major advances have been made in improving rice and transfer of technology to farmer, much remains to be done to achieve food self-sufficiency and for the local African rice to be competitive in world markets. Regarding the responsibility of Program I of AfricaRice, particular emphasis will be placed on:

- A more thorough characterization of *O. glaberrima* germplasm to better exploit this reservoir of genes for tolerance / resistance to environment stresses;
- A better use of rice genetic heritage preserved in the genebank of the Center through the increasing use of local ecotypes of *O. glaberrima* and other wild materials;
- Greater use of molecular tools in breeding programs to reduce the cost of breeding; better management of the production of quality seeds and distribution to ensure a constant availability;
- The technical capacity of NARS, extension workers and farmers to take over from the breeders in national programs;
- More research efforts on improving post-harvest operations to make available to producers of alternative rice

production of better quality; and

- Strengthen work on grain quality through improving the nutritional value of new varieties (protein content, organo-leptic and culinary).

The major challenge facing SSA to achieve sustainable food self-sufficiency is to reduce the gap between actual yields and potential yields. This objective could be achieved mainly by better exploitation of lowland, rainfed and irrigated, which contain enormous potential of rice intensification. In this fact, AfricaRice scientists and their partners are currently investigating the African rice gene pools. They are integrating phenotypic screening (physical characteristics) with molecular analysis (genetic composition) to unravel the secrets of local stresses tolerance. About Phenotypical characterization, AfricaRice is screening the entire *O. glaberrima* collection (more than 2500 accessions) on the basis of their agro-morphological characters. Through molecular analysis, scientists tried to identify the genes and/or the genetic regions (quantitative trait loci or QTLs) that possess local stress tolerance traits. After identifying these specific genes for major diseases and environmental stresses such as acidity, iron toxicity, cold and salinity, Scientists can then transfer them into improved rice varieties. For this purpose, they used 3-pronged approach to improve rice varieties' tolerance to WCA constraints. This involve the characterization of biotic and abiotic stresses profiles of rainfed, irrigated and lowland rice production systems using GIS, the conventional breeding and the marker-assisted selection. Since *O. glaberrima* had been considered to have generally low yield potential, interspecific hybridization with *O. sativa*, which possess high yield potential, was a major method to better exploit the genetic assets of the two cultivated species. However, AfricaRice breeders now think that *O. glaberrima* can potentially produce yields of about 5–6 t/ha, that is sufficient for rainfed and lowland rice ecosystems in Africa. Initial results from crossing between different *O. glaberrima* genotypes also showed that completely different sets of genes are responsible for tolerance of submergence, rice yellow mottle virus, and phosphorus deficiency in soils from those found in *O. sativa*. By characterizing the *O. glaberrima* collection available in AfricaRice genebank, new *O. glaberrima* lines with better traits than the current parental lines of NERICA may be identified and used as heads of lines in the new breeding program. This will help to exploit the treasure existing within the African rice germplasm following the new concept of AfricaRice which aimed to “combine the adaptability of *O. glaberrima* to local environments with the optimal conjunction of the best traits of the two species in relation to yielding ability” (Futakuchi et al, 2009). Moreover, to better exploit the genetic assets of *O. glaberrima* without being hampered by the sterility problems of hybridization with the Asian rice species, AfricaRice scientists have begun working on the intra-specific *O. glaberrima* breeding lines and are taking steps to develop plants that are less prone to lodging and shattering. The new intra-specific varieties are expected to combine the genes of resistance from different ecotypes with optimization of the African rice yield potentials which will then be vulgarized to farmers through participatory varietal selection (PVS).

9. Conclusion

O. glaberrima is an interesting rice species that is adapted to WCA growing environments. It presents good genetic diversity but less than the Asian rice species *O. sativa*. *O. glaberrima* possesses interest genes of resistance and agro-morphological useful traits due to its domestication history. The development of NERICA was yet to be rivaling with *O. glaberrima* in some traits related to adaptability such as weed competitiveness. In addition to those *O. glaberrima* characters which were already focused in varietal improvement, introduction of new useful traits such as multiple resistances to WCA in a single variety combined with large panicle number and grain yields is targeted. For this purpose, the development of intra-specific breeding lines is suggested to be a feasible approach to exploit unique and useful characteristics of *O. glaberrima*, although a wide cross to *O. sativa* to develop interspecific varieties will still be strong tool to obtain better high yielding varieties. But the necessary yields to feed Africa can't be achieved through breeding alone. Much more attention must be granted to small-scale mechanization with good crop husbandry so as to support rice breeding with agronomic research and to enable farmers to get the best out of new varieties.

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