New Breeding Directions at AfricaRice: Beyond NERICA

Contents

New Breeding Directions at AfricaRice: Beyond NERICA

Africa Rice Center (AfricaRice)
01 B.P. 2031 Cotonou, Benin
Tel: (229) 21 35 01 88
Fax: (229) 21 35 05 56
Email: AfricaRice@cgiar.org
www.AfricaRice.org

2010

Citation

Africa Rice Center (AfricaRice) 2010. *New Breeding Directions at AfricaRice: Beyond NERICA.* Cotonou, Benin: 24 pp.

ISBN

978-92-9113-340-6 (print)

978-92-9113-339-0 (pdf)

Text:
Guy Manners

Design:
BluePencil Infodesign, Hyderabad, India

Printing:
Pragati Offset Pvt. Ltd., Hyderabad, India

Photo credits

Cover photo and those on pages 9 (top) and 14 are by Guy Manners
All other photos are by AfricaRice staff members

NERICA…

To many, NERICA is synonymous with the work that earned the Africa Rice Center (ex-WARDA) the King Baudouin award in 2000 and Dr Monty Jones the prestigious World Food Prize in 2004

'NERICA'[1] is now a household name in Africa – a name that stands for good rice. In fact, the NERICA name is better known than that of the organization that developed it! To many, however, NERICA is synonymous with the work that earned the Africa Rice Center (ex-WARDA[2]) the King Baudouin award in 2000 and Dr Monty Jones the prestigious World Food Prize in 2004. In fact, there are two types of NERICA varieties: 18 upland NERICAs, pioneered by Monty Jones, and 60 lowland NERICAs (NERICA-L), adapted for both rain-fed and irrigated lowlands, which were developed later by Dr Moussa Sié and national (NARS) partners, and which earned Sié the Fukui International Koshihikari Rice Prize from Japan in 2006.

'African' rice, 'Asian' rice and NERICA

Oryza glaberrima is a cultivated species that is found only in Africa. Rice farmers throughout the rest of the world grow only *O. sativa*, which is known as 'Asian rice' in Africa. Back in colonial times, farmers could not pay off their debts with *O. glaberrima*, and in the mid-1960s, some researchers even advised breeders to throw it away! However, where *O. sativa* has the yield potential to feed the masses, *O. glaberrima* is the rice of choice for many African farmers because of its adaptability and ceremonial and cultural importance. Moreover, *O. glaberrima* has characteristics derived from its origins on the continent, such as resistance to local diseases and pests. *Oryza barthii* is a wild rice native to Africa – in fact it is the ancestor of cultivated *O. glaberrima*.

The NERICA varieties were the first wide-scale success of crossing of the two cultivated species. The upland varieties are derived from *O. sativa* subsp. *japonica* (known in Africa as 'upland rice') and the lowland varieties from subsp. *indica* ('lowland rice').

During the period 2000–2006, AfricaRice designated 18 upland NERICA and 60 lowland NERICA-L varieties.

Most African countries consume far more rice than they produce. In 2008, an estimated US$ 3.6 billion was spent on imports. With most African countries running up huge trade deficits, the 2008–2009 global food-price crisis was a major incentive to increase domestic rice production. Consequently, rice production in Sub-Saharan Africa rose by 16–18% in 2008 and a further 4.5% in 2009 (FAO data). Statistics for specific ecologies and countries are even more impressive – for example, a 44% increase in rice production across the Sahel, and 241% in Burkina Faso (2007–2008, FAO data). Advocacy work by AfricaRice during the earlier years of the decade[3] had generated renewed governmental interest in rice throughout the region, and many member states had rice-development strategies in place before the crisis struck.[4] Thus, the unprecedented increase in rice production can be attributed in part to successful policy advocacy, in part to the success of the NERICA and other improved varieties, and in part to the motivation of the global food-price crisis, leading to government subsidies for inputs (seed, fertilizer, agricultural equipment).

NERICAs have brought specific benefits to African rice growers, in particular shorter growth duration and tolerance to specific biotic and abiotic stresses, while giving them yield that is generally as good as the high-yield-potential *O. sativa* varieties. For example, in the field NERICAs 1, 2, 4, 5, 7 and 14 have all proven tolerant of stem-borer attack. NERICA 1 is also tolerant of termite attack – in both cases producing extra tillers in response to the insect's presence so as to still yield grain. In the lowlands, NERICA-L19 tolerates iron toxicity, NERICA-L25 tolerates African Rice Gall Midge, and NERICA-L49 tolerates both!

The success of the NERICA varieties cannot be denied. Particular highlights include Nigeria with close to 200,000 ha of NERICA 1 and NERICA 2, and Uganda, where 35,000 ha of NERICAs were grown in 2007 alone, and the country was able to halve its imports of rice in the five years from 2002 to 2007. Similar successes have been reported in other countries, such as Burkina Faso, Ethiopia, Guinea, Mali, Sierra Leone and Togo. The impact of NERICA adoption on poverty reduction has also been documented in Benin and Uganda.

… and far more besides

The Africa Rice Center (known as AfricaRice) has a long history and has achieved far more than just bringing the NERICAs to 'life' and into Africa.

Improved *Oryza sativa* varieties

On the breeding side, the testing of newly introduced material and conventional (*O. sativa* x *O. sativa*) crosses has been ongoing since AfricaRice's beginnings in Liberia in 1971. These continued for upland and lowland rice at the M'bé headquarters near Bouaké, Côte d'Ivoire, and for irrigated and lowland rice at Ibadan, Nigeria (where AfricaRice has facilities on the campus of the International Institute of Tropical Agriculture, IITA) and then at the Sahel Station, N'Diaye, near St Louis, Senegal. Each of these has generated varieties that have improved farmers' production. For example, Sahel 108 was released for irrigated systems in the Senegal River valley in Senegal and Mauritania in the mid-1990s. Originally a line from the International Rice Research

PVS worked well throughout West and Central Africa as part of the NERICA project – giving farmers the varieties they wanted, and generating valuable feedback for the breeders

Institute (IRRI), Sahel 108 is now the most widely grown variety in the Senegal River valley![5]

Participatory varietal selection

When the time came to test the NERICAs, it was felt necessary to get the material into farmers' hands as soon as possible. Consequently, AfricaRice adopted participatory varietal selection (PVS), in which a large selection of rice lines was presented to farmers in the form of a village-based demonstration plot. Farmers were then asked to select their favorite lines at various points during the crop season, and to indicate the reasons for their choices. Over the following two seasons, farmers took increasing control of the 'varieties' they chose. Special attention was paid to getting feedback from women. The majority of Africa's rice farmers are women, and their preferences often turned out to be quite different from those of men.

PVS trials were linked to varietal release mechanisms where possible and seed production projects and schemes to speed up adoption. PVS worked well throughout West and Central Africa as part of the NERICA project – giving farmers the varieties they wanted, and generating valuable feedback for the breeders. PVS is still being used by AfricaRice throughout Africa for the same reasons.

Getting varieties into farmers' hands

'Seed' is what the farmer plants in the field, while 'grain' is what people eat. Essentially they are the same, but the qualities required for good seed are more stringent than those for good grain. Tadashi Takita is a Japan International Cooperation Agency (JICA) rice-seed specialist working for the African Rice Initiative (ARI), based at AfricaRice. Working with national partners, ARI helps establish national seed systems. Farmers are identified and trained in good seed management, organization, and small-enterprise management. ARI and partners also try to link the newly established groups/enterprises with microfinance providers and traders, so that they can purchase inputs (fertilizer and agro-chemicals). Takita emphasizes the need to have good-quality seed, from breeder seed all the way to foundation, registered and certified seed. He is instrumental in the regular training courses ARI organizes in seed production.

ARI has also become involved in emergency and post-conflict situations. For example, it has been working to restore old varieties to Liberia and to expose rice farmers there to new material. Popular varieties LAC 23 and Suakoko 8 have already been repatriated as breeder seed saved through the AfricaRice genebank. At the same time, ARI has been training technicians from the Central Agricultural Research Institute (CARI), extension agents and NGOs in seed production; assisting with the local production of foundation seed; and assisting farmers' groups to produce certified seed.

In response to the global food crisis in 2008–09, the Government of Japan funded an emergency seed program to 20 countries in West, Central and East Africa. Similarly, USAID funded an emergency relief project in four countries in West Africa, partly

> The African Rice Initiative, based at AfricaRice, has also become involved in emergency and post-conflict situations. For example, it has been working to restore old varieties to Liberia and to expose rice farmers there to new material

Moussa Sié observes a rice field along with farmers

focusing on seed. These projects aim to boost rice production in 2010 and beyond through improved farmer access to quality foundation seed, thereby reducing rice imports and averting the need for costly food-relief actions.

Demand for breeder seed far outstripped AfricaRice's capacity (through its Genetic Resources Unit, GRU), so ARI has conducted seed multiplication for the Republic of Congo, the Democratic Republic of Congo, Côte d'Ivoire, Kenya, Liberia, Nigeria, Sudan, Uganda and Zambia, among others.

Integrated crop management and participatory learning and action-research

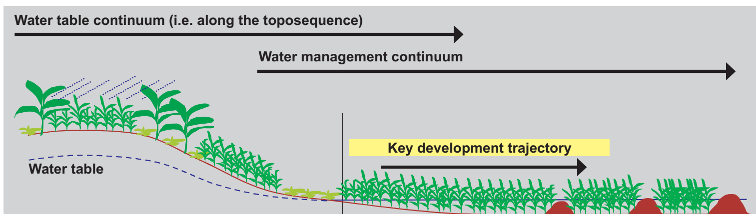
Just having a 'good' crop variety is never enough to maximize farmers' benefits, the way the field is managed and the crop is handled after harvest are equally important. Thus, AfricaRice introduced integrated crop management (ICM) for rice, first in the irrigated systems and then in the lowlands, accompanied by a participatory learning and action-research (PLAR) approach. As the second decade of the 21st century begins, ICM and PLAR have already moved beyond the borders of AfricaRice's traditional 'home' into East Africa. More attention is also being paid to harvest and post-harvest processes. AfricaRice adapted a thresher–cleaner from the Philippines to reduce post-harvest losses (in quantity and quality) and tackle labor constraints. The thresher–cleaner (or 'ASI',[6] as it is better known) has been a great success, especially in irrigated areas, and continues to multiply across the region.

New breeding directions

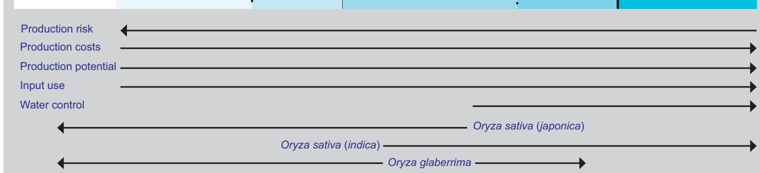
> With climate change a reality, the work of developing crop varieties adapted to the changing environment is going to keep plant breeders busy for decades

"It is very important to distinguish the various ecosystems in which rice is grown in Africa," explains AfricaRice program leader for Genetic Diversity and Improvement Moussa Sié. "Rice is an incredibly versatile crop and is grown in deep water (up to 6m!), mangrove swamps, hilly areas (upland), and rain-fed and irrigated lowlands." These environments determine, to a large extent, the yield level that can be obtained by a farmer. Lots of abiotic and biotic stresses intervene in these environments and the job of the breeder is to develop varieties that do well under such conditions. In fact, breeders look for plants that fit a certain 'target population of environments' (TPE), which also needs to include socio-economic factors, such as consumers' preference for a certain quality of rice. Moreover, with climate change a reality, the work of developing crop varieties adapted to the changing environment is going to keep plant breeders busy for decades.

Rice-growing systems and scenarios in current AfricaRice member states



Ecology	Upland	Hydro morphic fringes	Lowland	Intensified lowland	Irrigated lowland
Main water supply	Rainfall	Rainfall + water table	Rainfall + water table + unregulated flood water	Regulated flood water	Irrigation
Agro-ecological zone	Guinea savanna–humid forest zone	Guinea savanna–humid forest zone	Sudan savanna to humid forest zone	Sudan savanna to humid forest zone	Sahel to humid forest zone
Main stresses	Drought Weeds Pests and Diseases P and N deficiency Soil erosion Soil acidity	Drought Weeds Pests and Diseases P and N deficiency Soil erosion Soil acidity Fe toxicity	Drought / Flooding Weeds Pests and Diseases P and N deficiency Fe toxicity	Drought / Flooding Weeds Pests and Diseases P and N deficiency Fe toxicity	Weeds Pests and Diseases Salinity Alkalinity P and N deficiency Fe toxicity



New-generation inter-specific rice

"African rice varieties still need improvement," says Sié, who is also the AfricaRice lowland-rice breeder. "As a breeder, my life goal is that the variety I breed today is better than the one I bred before, but I know that it will not be as good as the next one."

"One important issue remains weed competitiveness, especially for the upland NERICA varieties," says agro-physiologist Kazuki Saito, who has been with AfricaRice since 2006. In fact, the NERICA varieties were developed from just a handful of *O. sativa* and *O. glaberrima* parents. AfricaRice's genebank contains more than 2300 *O. glaberrima* accessions! So in terms of making use of genetic diversity, breeders have only scratched the surface.

With so much potential in both parents and progenies, it makes sense to continue to improve the NERICAs and develop new material. But how to overcome the age-old problem of hybrid sterility of progenies derived from inter-specific crossing?

In the past, inter-specific (*O. sativa* x *O. glaberrima*) rice breeding at AfricaRice relied on anther-culture to accelerate the production of fertile fixed lines, all generated from back-crosses to their *O. sativa* parent over two or more generations. So far, the goal of inter-specific breeding had therefore been to improve *O. sativa* by incorporating *O. glaberrima* genes through a back-crossing approach, and that goal was achieved. But, this approach reduced the proportion of the *O. glaberrima* genome in the final NERICA varieties.

Upland-rice breeder Mandè Semon looked into reversing the situation: "What if we were to increase the proportion of *O. glaberrima* genes – would we get better varieties?" His idea was essentially to try to reverse the 'route' and bring the desirable genes from *O. sativa* into *O. glaberrima*. However, sterility of the inter-specific hybrids was still going to be a problem. "We needed a breeding protocol to enhance the content of *O. glaberrima*," explains Semon, "so we decided to use 'bridging material' that we developed by crossing *O. glaberrima* with *O. sativa*."

Moreover, thanks to 'transgressive segregation' – a phenomenon by which some progenies will express characteristics that are not present in either parent – it was possible to select lines with good crossing compatibility to *O. glaberrima* or *O. barthii* that were called 'bridging lines.'

Kazuki Saito studies the weed competitiveness of different rice varieties

The TGS breeding lines

The bridging lines used in the AfricaRice breeding program are transgressive-segregant (TGS) lines that exhibit semi-dwarf stature (up to 80 cm tall), many tillers (up to about 40) per plant, and *O. sativa*-like panicles. Two lines that are showing great promise are: TGS3, which is a product of *O. glaberrima* CG14 x *O. sativa* Moroberekan, back-crossed to Moroberekan; and TGS25, which is *O. glaberrima* RAM90 x Moroberekan, again back-crossed to Moroberekan. CG14 is a popular *O. glaberrima* breeding line, while Moroberekan is used for its drought tolerance (deep roots) and durable blast resistance. Upland-rice breeder Mandè Semon uses a broad definition of 'transgressive segregant' that includes "anything that looks different from its parents."

A lot of the skill in the successful 'creation' of the bridging lines lies in generating enough second-generation (F_2) seeds from the first-generation (F_1) progeny to compose the F_2 population to select from. "Inter-specific sterility is still an issue," explains Semon, "but we do have some knowledge of how it works and how to overcome it." The first generation of plants from the inter-specific cross is completely sterile because of failure of pollen development. In the past, the 'trick' has been to use fertile pollen from the male parent (usually *O. sativa*) to make a back-cross. "Although the progenies from the back-crosses are not fully fertile," Semon explains, "currently, we generate hundreds of segregating progenies to give us enough fertile plants to select from."

By using molecular markers, Semon and his team have been able to demonstrate that the fully fertile *O. glaberrima*-based bridging lines are one-quarter *O. glaberrima* – that is, 25% of their genetic makeup is from the *O. glaberrima* parent. This compares with only 5–10% in the NERICAs. "Moreover," enthuses Semon, "all of the bridging lines developed so far are inter-fertile with *O. sativa*, *O. glaberrima* and *O. barthii*." In other words, a bridging line can be crossed with any other line of interest. This bridging-line technique is forming the basis for much of Semon's work in breeding rice for the African rice-growing ecologies.

These bridging lines (TGS lines) displayed high tillering (over 40 tillers per plant), were semi-dwarf in stature (about 80 cm tall) and were fully fertile; these characteristics were combined with *O. sativa*-like panicles (valuable for yield).

"We need to exploit the treasure-trove that is in African rice germplasm," says Semon. The main problems with both *O. glaberrima* and *O. barthii* are lodging and shattering. 'Lodging' is when the plants fall over at, or just before, maturity, and 'shattering' is when the panicle scatters the seed at maturity – a good trait for a wild plant like *O. barthii*, but obviously a drawback in a crop that is to be harvested. By crossing *O. glaberrima* with the transgressive bridging lines (see box), AfricaRice has developed shorter *O. glaberrima*-type plants that are less prone to lodging and also do not shatter.

The sixth generation (F_6) from the cross of CG14 x TGS6 will be tested on-farm in 2010. For *O. barthii*, some progenies derived from single and double back-crosses of *O. barthii*-based bridging lines are showing *O. sativa*-like plant type (about 30 tillers per plant), *O. barthii*'s weed competitiveness, and good yield.

In fact, the *O. barthii*-based inter-specific lines have themselves

Fourth-generation progeny of O. glaberrima *(AC103549) x TGS 25 showing wide variation in growth habit and maturity*

proved successful in on-farm trials, as they have inherited earliness, tillering ability, large, long and slender grains, and stem-borer resistance from the *O. barthii* parent, which have helped increase yield and grain-weight over the *O. sativa* parent. By 2010, over 1300 lines possessing these attributes had been developed for multi-location evaluation by NARS collaborators. Bridging lines are also used to improve the existing NERICAs in terms of drought tolerance, plasticity, yield, and grain quality and type.

Improving *O. glaberrima*

In 1980, Moussa Sié was recalled from his doctoral studies to establish the national rice program in his home country of Burkina Faso. “Two experiences sparked my interest in African rice (*O. glaberrima*),” he says. “The first was at Gagnoa in Côte d’Ivoire, where I had my first taste of *O. glaberrima* rice in the company of the late Dr Yoboué N’Guessan – I liked the taste so much that I didn’t wait for the sauce! The second was during trips I took to collect various rice varieties from farmers’ fields in 1982. Farmers told me, ‘*glaberrima* is farmers’ rice, *sativa* is for office workers.’ So, why shouldn’t we try to improve *O. glaberrima* itself?” This is exactly what eco-physiologist Koichi Futakuchi and Sié have embarked upon. Futakuchi’s work showed that under unfavorable growth conditions, yield of *O. glaberrima* was not lower than that of *O. sativa*. For example, yield of *O. glaberrima* (CG14) was 2.8 tonnes per hectare in the rainy season in iron-toxic fields without nutrient application, while that of iron-tolerant and iron-susceptible *O. sativa* varieties was 2.9 and 2.4 t/ha, respectively. However, it

Upland-rice breeder Mandè Semon evaluates progeny of O. glaberrima *x TGS*

is well known that *O. glaberrima* does not respond to inputs. Futakuchi's work showed that the number of spikelets before shattering in *O. glaberrima* is not lower than in *O. sativa* at any fertilizer input level. "If problems of grain shattering and lodging can be removed, the development of *O. glaberrima* varieties with acceptable yield potential for rain-fed rice ecosystems (5–6 t/ha) will be possible," says Futakuchi. One concern is whether such improved *O. glaberrima* plants will be able to fill all their spikelets and form grains. "Because of the typical dense canopy of *O. glaberrima*, mutual shading and high canopy respiration may arise, and that may lead to incomplete filling of spikelets," says Futakuchi. However, improving *O. glaberrima* may one day turn out to be an elegant short-cut to getting varieties in farmers' hands that have high yield potential and that are very well armed against Africa's multiple abiotic and biotic stresses.

Improving *Oryza sativa*

With the general dismissal of *O. glaberrima* from rice-breeding programs for so many years, a lot of resources have been invested by many organizations in finding and developing better rice for Africa in and from the *O. sativa* genepool. For a long time, crosses were made at AfricaRice's headquarters (then at M'bé, Bouaké, Côte d'Ivoire) and Nigeria station (at Ibadan). Particular successes included the release of varieties for the rain-fed and irrigated lowland ecologies in Côte d'Ivoire and Senegal (the WITA and Sahel series of varieties).

Koichi Futakuchi examines rice plants in an AfricaRice field

Upland-rice farmers in Africa grow mainly *japonica* varieties; however, elsewhere in the world, *indica* varieties are also grown in the uplands. Agro-physiologist Kazuki Saito brought some modern *indica* varieties from IRRI to test under African upland conditions. "These varieties were noted for their performance in soils with poor fertility, which is also typical of the African uplands," he says. In trials under various weed-management regimes, the Asian *indicas* out-performed NERICA 1, *O. glaberrima* and local check varieties, and also displayed the bushy growth habit typical of weed-competitive rice. Moreover, farmers liked the *indicas*. This not only shows promise for direct use of *indicas* in the uplands, but also as a source of weed-competitiveness in future inter-specific crosses. Meanwhile, Asian *indicas* tested in the lowlands showed wide adaptation to hydrology (degree of water control). According to irrigated-rice breeder Baboucarr Manneh, the majority of breeding for the irrigated ecology will continue to be based on *indica* x *indica* crosses, while advances in tolerance to biotic and abiotic stresses are expected from *japonica* x *indica* crosses.

The field results achieved with inter-specifics, *O. sativa* subspecies *indica* and *japonica*, and *O. glaberrima* highlight the value of evaluating a diverse range of plant materials in the diversity of ecologies in which rice is grown.

Hybrid rice

AfricaRice has recently established a hybrid-rice program, and experienced Egyptian hybrid-rice breeder Raafat El-Namaky joined the AfricaRice Sahel Station in late 2009.

Hybrid-rice technology exploits the phenomenon of 'heterosis,' or hybrid vigor, and involves raising F_1 hybrid seeds.

The most common method of hybrid-seed production is the three-line method, which requires careful seed production (see box). It is widely used in China, and has been championed in Africa by the Chinese, with various exchange visits for African researchers to learn hybrid-rice *growing* techniques in China or on their home soil. The advantage of hybrid rice is that it almost guarantees a 20–30% yield increase over the parent varieties (as a result of heterosis). There are two major disadvantages, however: *seed* yields (as opposed to grain yields) are only about 70% of 'regular' varieties; and farmers have to buy fresh seed every year because hybrid grain will not breed true if saved as seed.

Meanwhile, there is still a lot of room for increasing the yield potential of conventional non-hybrid rice and the yields of existing varieties in farmers' fields

Hybrid rice – the mechanics

The commonest form of hybrid-rice technology involves three lines. The key to the system is the cytoplasmic male sterile, or CMS, line, in which the fertility of the nucleus (the major player in sexual reproduction) is suppressed by factors in the cytoplasm of the cell. Thus, the CMS line cannot pollinate itself – i.e., it is sterile. The two other lines required to make the system work are the Maintainer and the Restorer. The Maintainer is genetically identical to the CMS, except that it does not have the cytoplasmic sterility factors. Crossing CMS (as female) with Maintainer generates CMS seed. The Restorer may or may not have cytoplasmic sterility factors, but these are not dominant over the 'normal' fertility factors of the nucleus; however, the Restorer is genetically dissimilar to the CMS, so that seed from the resulting cross (F_1) has as much heterosis as possible.

Both Maintainer and Restorer lines can be self-pollinated and breed true. However, the CMS must be crossed with either the Maintainer, to maintain the CMS line, or the Restorer, to generate the F_1 seed that is grown by farmers. The hybrid (F_1) seeds typically grow into plants with vigorous roots, strong tillering, large panicles and heavy grains.

Certain characteristics are required of good CMS lines: good agronomic characters; stable male sterility (100%); floral structure; and flowering habits. CMS lines must maximize their reception of pollen (e.g., by having a large stigma). Meanwhile, the Restorer line needs: strong restorer ability; good agronomic characters; to be taller than the CMS line (to maximize dispersal of pollen over recipient CMS rows in the field); and appropriate flower structure and habit (e.g., large anthers with much pollen, long filament to exsert the anthers, closed floret to protect it from self-pollination).

Crossing-plots typically consist of two rows of male parent and 15 of the female (CMS) parent, and need to be isolated from other plots (to avoid out-crossing) by distance (100–500 m), a barrier (taller than 2 m) or timing.

typically falls well short of their potential. For example, lowland NERICAs typically yield 2–3 tonnes per hectare, against their potential of 6 t/ha. According to Moussa Sié, it makes more sense therefore for AfricaRice to concentrate its efforts on increasing the yield potential of conventional (non-hybrid) rice and helping farmers achieve yields closer to the varieties' potential in the foreseeable future than resorting to hybrid-rice technology. However, with the technology already gaining ground on the continent, it seemed appropriate for AfricaRice to establish its own hybrid-rice program, albeit on a small scale. "Moreover," says Sié, "this will help build capacity in hybrid-rice *breeding techniques* at AfricaRice and in the national programs, rather than simply how to grow the varieties."

El-Namaky believes that the technology has something to offer African farmers in the areas of yield, grain quality (especially amylose content), earliness and tolerance to stresses.

A successful indigenous hybrid-rice program for Africa will involve:

- Multiplication of foundation seed of parental lines
- Multiplication of CMS lines (see box)
- Production of hybrid seed.

Short-term goals of the new program are to field test and establish seed production for six hybrid varieties imported from Egypt. At the same time, imported CMS lines will be crossed with local varieties (e.g., NERICA-L and Sahel varieties) to determine the potential for using hybrid technology with these varieties and to start the process of developing new CMS lines based on the local material. In the longer term, El-Namaky hopes to develop new F_1 lines (based on local varieties) and look at using hybrid technology to overcome the sterility issues in *indica* x *japonica* crosses.

Hybrid rice also offers potential in other areas. Screening of 122 hybrid varieties from China against African Rice Gall Midge revealed four that showed some level of tolerance to the insect's attack – this is being verified on farm in 2010. AfricaRice is also collaborating with the Chinese Academy of Agricultural Sciences (CAAS) to test hybrid rice lines from China for their adaptability to Africa within the Green Super Rice (GSR) project.

Making greater use of molecular biology

"Conventional breeding approaches have been hugely successful in developing new varieties for humankind," says AfricaRice molecular biologist Marie-Noëlle Ndjiondjop. "However, screening for different abiotic and biotic stresses and selecting for good plant traits is time-consuming and expensive." Most of the traits that are selected in this way are complex traits that are controlled by several genes.

Molecular genetic information can be used to enhance breeding strategies through techniques broadly referred to as marker-assisted selection (MAS). Breeders at AfricaRice are using MAS to improve (upgrade) 'mega-varieties.' Such upgraded mega-varieties are effectively identical to the original variety but carry the new gene.

This requires close interaction between the molecular biologist and the breeder, because genetic analysis needs to be communicated to the breeder almost in real time to guide the breeding process.

Working with Institut de recherches pour le développement (IRD) and NARS partners, AfricaRice has developed 'upgraded' mega-variety lines with resistance to Rice Yellow Mottle Virus (RYMV), and these are being evaluated in four countries in West Africa in 2010.

Baboucarr Manneh believes that 'upgrading' can be achieved in just two or three back-crosses to

Molecular genetic information can be used to enhance breeding strategies through techniques broadly referred to as marker-assisted selection (MAS). Breeders at AfricaRice are using MAS to improve (upgrade) 'mega-varieties,' which are effectively identical to the original variety but carry the new gene

the mega-variety. He hopes that African countries will allow quick one-year validation screening for such upgraded mega-varieties prior to release because of their similarity to the original mega-variety. This is already the case in parts of Asia where the *sub1* gene was introduced by IRRI into Swarna and other mega-varieties to increase short-term flooding (submergence) tolerance.

AfricaRice is also using biotechnology tools to work on the step prior to MAS, that is, discovering genes that convey resistance to key stresses for rice in Africa, such as RYMV, Blast, Bacterial Blight and African Rice Gall Midge. This work is done in partnership with advanced research institutions in Europe (IRD; Centre de coopération internationale en recherche agronomique pour le développement, CIRAD; Georg-August University Göttingen) and Japan (Japan International Research Center for Agricultural Sciences, JIRCAS). A special effort to genetically characterize a core collection of African germplasm (*O. glaberrima* and *O. barthii*) using state-of-the-art biotechnology is ongoing with Cornell University.

A variation on MAS – known as marker-assisted recurrent selection (MARS) – is used to increase the efficiency of the


Irrigated-rice breeder Baboucarr Manneh assessing rice plants in a salinity-tolerance screening tank

exploitation of the genes that are present in different parents and ensure that as many of those genes as possible are transferred to the progenies in the shortest possible time. AfricaRice will be using this method for drought-tolerance, but it also has great potential for generating 'durable' resistance to diseases and pests.

Improved phenotyping

'Phenotyping' is measuring observable traits of the rice plants that are affected by genotype, environment and their interaction. Traits typically phenotyped include plant morphology, development, growth and physiological characteristics.

AfricaRice is placing great emphasis on improving its phenotyping facilities. A great boost to this effort was obtained through the STRASA (Stress tolerant rice for poor farmers in Africa and South Asia) project jointly executed with 14 NARS partners and IRRI in Africa. Protocols for screening for abiotic stresses (most notably drought, iron toxicity, salinity and cold) were thoroughly reviewed and streamlined with IRRI. Through another joint project with IRRI and the CAAS, the Green Super Rice project, phenotyping facilities for biotic stresses have been upgraded at AfricaRice's temporary headquarters in Cotonou, Benin. Protocols for screening for weed-competitiveness, including for parasitic weeds, have also been improved.

Grain quality

The importance of grain quality in rice breeding has been increasingly recognized since the turn of the millennium – locally produced rice needs to rival imports if domestic production is to stem the flow of (previously cheap) imported rice into the region. Overall, grain quality is a product of variety characteristics, environmental conditions during growth, and the quality of post-harvest handling.

In the early days, many of the upland NERICAs were praised for their high protein content; however, "there is far more to grain quality than protein content," says grain-quality specialist John Manful, who joined AfricaRice in 2009. Although many of the NERICAs have some other good grain-quality attributes, they have also inherited some not-so-good traits from their parents, in particular chalkiness.

"A major lesson in all this," explains Manful, "is for breeders to broaden their choice of parents, not only in original crosses, but at subsequent stages as well."

Grain-quality testing was formerly conducted on an *ad hoc* basis, whenever breeders requested it; however, from 2010, the grain quality of breeding lines will be routinely evaluated in the fourth and fifth generations, before they are placed in 'observation nurseries.' Facilities at the Sahel and Tanzania stations will enable lines to be tested for such characteristics as head-rice ratio (a measure of the wholeness of the grains), percentage recovery (the yield of clean milled grain in comparison with either brown rice or paddy), grain appearance and cooking characteristics (time, digestibility, etc.). Additional facilities at headquarters in Cotonou will enable determination of protein and amylose contents (amylose is the most important determinant of the quality of cooked rice), and viscosity (a measure of rice texture after cooking).

AfricaRice is also working with the HarvestPlus Challenge Program to screen breeding lines for the micronutrients iron and zinc in collaboration with the University of Adelaide in Australia. In 2006, some 299 lines were screened (177 upland and 122 lowland), and in 2007 some 325 (mostly *O. glaberrima*) lines were screened for these micronutrients.

One grain quality that has been overlooked for the most part in Africa is aroma. Gambiaka is 'the' long-standing aromatic variety in the region, especially in Mali, where it is grown over vast areas. The fact that it is a favorite among consumers – despite being more expensive than other varieties – indicates the potential for aromatic rice. Successful aromatic rice has a specific shape, good milling characteristics, taste, cooking qualities and nutritional value. Breeders from AfricaRice and Togo developed the ORYLUX series of aromatic rices by crossing their own WITA 1 with Pusa Basmati. These varieties combine a grain type (size and shape) that consumers appreciate, with aroma and early maturity. Two of the six varieties have been adopted in Togo, and are also proving popular in Uganda, where AfricaRice is linking them with the private-sector company Tilda Uganda Ltd.

Quality seed

"One of the biggest constraints to the successful use of improved varieties is the availability of seed," says AfricaRice director general Papa Abdoulaye Seck. A study in Nigeria showed that some farmers were abandoning NERICA because of lack of seeds. The main reason for seed shortage is that national seed systems lack the staff, equipment and funding to assure farmers an adequate supply of quality seeds on a regular basis. Only a quarter of African countries have passed a seed act on specific seed regulations. But even in these countries enforcement mechanisms and resources for implementation are inadequate.

In its role as an association of states, AfricaRice therefore recommended to its Council of Ministers (of agriculture) that:

- "Every country should establish standard seed laws, seed quality-control mechanism and seed certification systems for rice and should ensure their application;
- Seed legislation should encourage the involvement of the private sector in seed supply and trade;
- NARS should be strengthened to produce breeder and foundation seeds;
- The informal seed sector must be recognized and helped to improve the quality of seed."

To that end, a regional workshop was organized in September 2008 by the West Africa Seed Alliance to initiate the process of standardizing variety-release procedures across the sub-region and establishing a regional catalog for varieties of maize, millets, rice and sorghum. The idea is that any variety accepted into the national catalog of any of the 17 participating states would be considered automatically released in all the other states. In effect, this means that any variety that is added to the regional catalog may be grown by farmers anywhere in the sub-region.

Meanwhile, the variety release committee in Senegal has accepted PVS trials as part of the prerelease process for new varieties, and this was a contributory factor in the release of 16 AfricaRice varieties in 2009.

Partnerships and capacity-building

Partnerships are natural to AfricaRice. Since its inception in the early 1970s, AfricaRice has always been an association of member states. From an original membership of 11 countries, AfricaRice now has 24 member countries distributed all over the continent.

"Perhaps what we have been missing most of all in recent years is the 'task force' structure of ROCARIZ," muses deputy director general and director of research for development Marco Wopereis. ROCARIZ – the West and Central Africa Rice Research and Development Network (in its French acronym) – built on AfricaRice's highly successful Task Forces collaborative mechanism of the 1990s. The arrangement enabled researchers from the same fields of study to meet regularly to discuss their work and share experiences. Unfortunately, the funding for ROCARIZ expired in 2006. "The good news," continues Wopereis, "is that we have a new grant for breeding coming on line from Japan in 2010." This funding will allow AfricaRice, IRRI, the International Center for Tropical Agriculture (CIAT) and NARS partners to jointly set priorities for rice breeding for the continent, divide tasks and discuss results. The expectation is that this new rice-breeding task force will result in faster, better documented and better targeted release of new varieties.

The role of AfricaRice and the new breeding task force is heightened because of the state of many of the national programs with which it works. "Africa's researcher population has been aging," says Wopereis. "As older crop breeders retire, for the most part they are not being replaced by younger researchers." Not only is the population of rice breeders being slowly eroded, but institutional memory is lost every time another breeder retires. Moreover, younger researchers are often schooled in biotechnology, but are less experienced with classical breeding approaches and hands-on field selection. "There is an urgent need to improve the capacity of the national programs to conduct crop breeding," says Wopereis.

Another very important development is the global rice science partnership that has been forged between AfricaRice, IRRI and CIAT, and will become operational in 2011. In terms of

Germplasm exchange between breeders

The International Network for the Genetic Evaluation of Rice in Africa (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, INGER-Africa assembles nurseries for the major ecologies (upland, rain-fed 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. Over the five years 2005–2009, INGER-Africa supplied over 20,000 seed samples of almost 17,500 lines to scientists in 38 countries, including 26 African countries (13 each in West and Central Africa, and East and Southern Africa). The supply of such materials has been growing annually from just 171 samples in 2005 to nearly 10,000 in 2009. INGER-Africa thus provides an invaluable service to AfricaRice partner breeders in the national programs – material for them to evaluate under their own field conditions.

View from Mali

Mamadou M'Baré Coulibaly is rice breeder and head of the irrigated-rice program of Institut d'Economie Rurale (IER) in Mali. He has been collaborating with AfricaRice since 1985, when he conducted yield trials and observation nurseries with AfricaRice-supplied lines. In 1990, he became actively involved in the Task Forces and their successor, ROCARIZ, initially as national correspondent and president of the breeding task force. From 2004, he was chairman of the steering committee until ROCARIZ funding dried up in 2006.

"I have conducted collaborative activities with AfricaRice in the selection of the lowland NERICAs, screening [for] resistance to RYMV and Bacterial Blight," he says. "As a result some inter-specific and intra-specific lines of AfricaRice are released in Mali, including the most popular variety cultivated in the dry season in the irrigated ecology (WAT 310-WAS-B-28-3-3-2, occupying 75% of the total area) and the most popular variety in the uplands (NERICA 1, occupying 70% of the area)."

Coulibaly appreciated the contribution of AfricaRice to capacity-building at IER through training and purchase of equipment as part of collaborative projects. Several researchers of the irrigated and lowland rice program of Mali benefitted from training on breeding, agronomy, and biotechnology and crop protection. AfricaRice also helped equip a biotechnology laboratory at the Agronomic Research Station in Niono.

Coulibaly has worked alongside AfricaRice lowland-rice breeder Moussa Sié in Benin and Togo, selecting "promising lines descended from the crossings of AfricaRice and my own program." He has also been involved in participatory plant breeding, PVS and MAS.

Coulibaly indicates that he found the task-force mechanism of collaboration extremely helpful, and is fully supportive of the plans to re-launch a task-force mechanism to link rice researchers across the continent. He wants to see AfricaRice build on the achievements of ROCARIZ, while retaining (or re-instituting) the task-force connection between AfricaRice and the NARS.

View from Nigeria

Alhassan Tswako Maji is a rice breeder with the National Cereals Research Institute, Badeggi, Nigeria. He has benefitted from AfricaRice training and as a member of the former breeding task force of ROCARIZ. He appreciated the germplasm exchange that occurred within the task-force context, which brought valuable material into the country and his own breeding program. For example, WITA 4 was released in Nigeria for its iron-toxicity tolerance, yield under low inputs, and yield potential, and is now widely grown in the country. He and his colleagues have benefitted from short training courses run by AfricaRice on seed production, rice agronomy, plant breeding, and statistics in agriculture.

Thanks to the AfricaRice and task-force collaborations, he has been able to make crosses for Nigeria, including *O. sativa* x *O. glaberrima* (TOG 6542), some progenies of which have been shared with AfricaRice

Contd...

View from Nigeria...Contd from Page 17

and evaluated in other countries. His own interspecific cross of WITA 4 x TOG 7442 has generated six lines that are to be shared with AfricaRice and regional partners.

Also as a result of the collaborations, Nigeria has released NERICAs 1 and 2, and is in the process of releasing NERICAs 7 and 8, and locally bred NCRO 49. Maji notes that NERICA-L19 is also likely to be released in the country in due course.

He is very happy with the collaboration with AfricaRice, not least for the personal professional development – he obtained his Master's degree on drought and *O. glaberrima* work (evaluating almost 1200 lines) at AfricaRice under African Development Bank (AfDB) sponsorship, and his doctorate involves crosses for resistance to African Rice Gall Midge and MAS at IRRI, supported by AfricaRice and with Rockefeller Foundation funding.

Maji is inspired by the level of collaboration he has experienced, especially with respect to varietal dissemination (PVS), exchange of material among countries, and information dissemination. He looks forward to a strengthened collaborative partnership that will bring even greater benefit to 'ordinary' rice farmers in Nigeria – through appropriate use of research results, and availability of additional varieties. He also sees great promise in further inter-specific exploitation.

breeding, AfricaRice has already established a strong bond with IRRI since 2008, to the extent that nearly all breeding-related projects are now executed jointly by the two centers. This new partnership allows joint research priority-setting and sharing of techniques and resources.

Breeding in perspective

"We also need to pay much more attention to small-scale mechanization. Too many farmers – many of them women – still have to farm with their bare hands, from land preparation to harvest and post-harvest activities. That has to change"

"Breeding is extremely important," says Wopereis, "but we won't achieve the yields necessary to feed Africa through breeding alone." A well-respected and competent agronomist in his own right, Wopereis recognizes the need to support rice breeding with agronomic research to enable farmers to get the best out of new varieties. "We hope that we will be able to close yield gaps and break yield barriers through breeding," he says, "but for farmers to get to a new yield ceiling and to maintain yields will require good crop husbandry. We also need to pay much more attention to small-scale mechanization. Too many farmers – many of them women – still have to farm with their bare hands, from land preparation to harvest and post-harvest activities. That has to change."

Looking at the new inter-specific rice plants in the field around him, he reflects, "The NERICA varieties are a huge success – but breeding never stops! It is good to know that we have new products in the pipeline for Africa's rice farmers."

Notes

1. The term 'NERICA' was coined in 1999 from 'New Rice for Africa.'
2. WARDA (West Africa Rice Development Association) is the former name of the Africa Rice Center.
3. AfricaRice has the unique opportunity to influence rice policy because of its structure as an association of member states, with direct links to ministers of agriculture.
4. For example, Senegal published its rice self-sufficiency strategy in January 2007.
5. Each crop season, an average of about 50 farmers are surveyed for their use of varieties (and certified seed). In the 2009 dry season, 100% of farmers surveyed in the Senegal River valley were cultivating Sahel varieties (Sahel 108, 201 and 202, along with the newer Sahel varieties released in 2007 and 2009), of these Sahel 108 was the most widely grown.
6. 'ASI' is derived from the combination of partners that originally developed the thresher–cleaner in West Africa – ADRAO (French of WARDA), SAED (Société d'aménagement ed d'exploitation des terres du Delta du Fleuve Sénégal et des vallées du Flueve Sénégal et de la Falémé) and ISRA (Institut sénégalais de recherches agricoles).
7. 'Hybrid rice' should not be confused with the technology used to generate the NERICAs and other inter-specific lines. The NERICAs are pure breeding lines or varieties derived from the hybridization of the two species of rice – they breed true-to-type in the field, and farmers can re-use high-quality grain as seed. Hybrid rice is the first generation (F_1) seed from a cross – although it grows true-to-type for the first season, the resulting grain is not homogeneous, and therefore cannot be used as seed.

Without whom…

AfricaRice would never be able to conduct any of its research-for-development activities without the financial and moral support of its donors. AfricaRice wishes to sincerely thank all those who have generously contributed to its budget since 2000:

- AfricaRice Member countries
- African Development Bank (AfDB)
- Arab Bank for Economic Development in Africa (BADEA)
- Belgium: Federal Public Service (FPS) Foreign Affairs, Foreign Trade and Development Cooperation, Belgium Directorate General for Development Cooperation (DGDC)
- Canada (CIDA)
- CGIAR Challenge Programs: Generation, HarvestPlus, Water and Food
- Republic of China (Taiwan)
- Chinese Academy of Agricultural Sciences (CAAS)
- Common Fund for Commodities (CFC)
- Conservation, Food & Health Fund (CFH)
- Denmark
- ENI Congo S.A.
- European Union (EU)
- Food and Agriculture Organization of the United Nations (FAO)
- France
- Gatsby Foundation
- Germany (BMZ/GTZ)
- International Fund for Agricultural Development (IFAD)
- International Rice Research Institute (IRRI)
- Japan International Cooperation Agency (JICA)
- Japan International Research Center for Agricultural Sciences (JIRCAS)

- Japan (MOFA, MAFF)
- Netherlands
- Norway
- Rockefeller Foundation
- Sweden (SIDA)
- United Kingdom (DFID)
- United Nations Development Programme (UNDP)
- United Nations Environment Programme (UNEP)
- USA (USAID)
- World Bank

About Africa Rice Center (AfricaRice)

The Africa Rice Center (AfricaRice) is a leading pan-African research organization working to contribute to poverty alleviation and food security in Africa through research, development and partnership activities. It is one of the 15 international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). It is also an autonomous intergovernmental research association of African member countries.

The Center was created in 1971 by 11 African countries. Its membership comprises 24 countries, covering West, Central, East and North African regions, namely Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, Democratic Republic of Congo, Egypt, Gabon, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Madagascar, Mali, Mauritania, Niger, Nigeria, Republic of Congo, Senegal, Sierra Leone, Togo and Uganda.

AfricaRice temporary headquarters is based in Cotonou, Benin. Research staff are also based in Senegal, Nigeria, Tanzania and Côte d' Ivoire.

For more information, visit www.AfricaRice.org

AfricaRice is known for the NERICA varieties that have helped reverse the downward trend in rice production across the African continent. However, the work didn't stop there.

Rice is now a key staple in the diet of many Africans, making up almost 20% of the average diet in West Africa, and over 8% for Sub-Saharan Africa as a whole.

This booklet looks at what AfricaRice is doing to breed new and better-adapted rice varieties for the diversity of African rice-growing environments. From the simplicity of introducing Asian varieties for the African uplands to inter-specific 'bridging lines' based on African rices, AfricaRice is leaving no stone unturned in its quest for better-yielding and better-quality rice for the farmers and consumers of the continent.

The text explains the work of the AfricaRice breeders and their colleagues, the challenges they face and the successes they're achieving. If you've ever asked "what can they do after NERICA?", here's your answer…

Africa Rice Center · Centre du riz pour l'Afrique

AfricaRice

Africa Rice Center (AfricaRice)
01 B.P. 2031 Cotonou, Benin
Tel: (229) 21 35 01 88
Fax: (229) 21 35 05 56
Email: AfricaRice@cgiar.org
www.AfricaRice.org