RICE

Interspecific Hybridization Project

Research Highlights 2000

WARDA ADRAO™

CGIAR

What's in a name?*

The interspecifics have gone through several 'incarnations' in terms of naming since the first lines were fixed in 1994. However, the decision to use 'New Rice for Africa,' first in 1998, then as the standard from early 1999 was crucial. "After all," explains Dr Tatsuo Fujimura of UNDP-TCDC, New York, "WAB 450-bla-bla really doesn't mean very much to a farmer, it's simply too long."

In late 1999, the decision was taken to standardize on 'NERICA.' This will serve not only as a general label for the *glaberrima–sativa* interspecifics, but also as a numbered series for the released varieties.

In 2000, the first seven varieties were released on a wide scale in Côte d'Ivoire and Guinea. For those who have an interest in details, here they are:

NERICA 1 = WAB 450-I-B-P-38-HB

NERICA 2 = WAB 450-11-1-P31-1-HB

NERICA 3 = WAB 450-I-B-P-28-HB

NERICA 4 = WAB 450-I-B-P-91-HB

NERICA 5 = WAB 450-11-1-1-P31-HB

NERICA 6 = WAB 450-I-B-P-160-HB

NERICA 7 = WAB 450-I-B-P-20-HB

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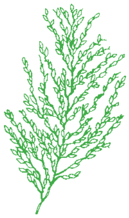
* Adapted from *WARDA Annual Report 1999*, page13



RICE

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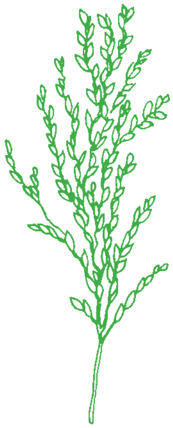
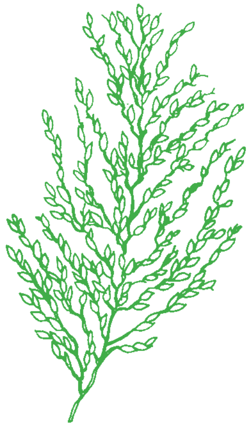
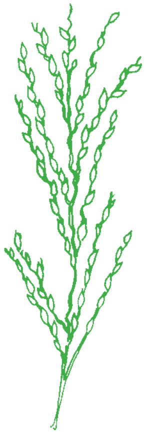
Africa/Asia joint research on
interspecific hybridization
between African and Asian rice species
Oryza glaberrima Steud. and *Oryza sativa* L.



Oryza sativa



Progeny



Oryza glaberrima

WARDA's mission

To contribute to food security and poverty alleviation in poor rural and urban populations, particularly in West and Central Africa, through research, partnerships, capacity strengthening and policy support on rice-based systems, and in ways that promote sustainable agricultural development based on environmentally sound management of natural resources.

WARDA (West Africa Rice Development Association). 2001.
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Acknowledgments

The year 2000 was one of transition for the Interspecific Hybridization Project (IHP), with the completion of phase 1 and the seamless start of phase 2.

Our thanks, as ever, go to our loyal donors, for their committed support to the second phase of the IHP:

- Japanese Ministry of Foreign Affairs (MOFA)
- United Nations Development Programme's Technical Cooperation among Developing Countries (UNDP-TCDC)
- Rockefeller Foundation
- CGIAR Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation (PRGA)

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- Department for International Development (DFID, UK) Plant Sciences Division
- *Institut de recherche pour le développement* (IRD, France)
- International Center for Tropical Agriculture (CIAT, Colombia)
- International Rice Research Institute (IRRI, The Philippines)
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- University of Tokyo (Japan)
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- *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD, France)
- Japan International Cooperation Agency (JICA)
- Japan International Research Center for Agricultural Sciences (JIRCAS)
- Natural Resources Institute (NRI, UK)
- United Nations (UN Volunteers)

Our thanks to all!

Summary

Farmers' enthusiasm for the participatory varietal selection (PVS) in general, and the interspecific hybrid progenies (now dubbed NERICA lines for *Ne*w *Ric*e for *A*frica) in particular, remained high. Sixty-one PVS trials were conducted in the 17 WARDA member countries during 2000, including evaluation of NERICA lines in upland, rainfed and irrigated lowland ecologies. Through the PVS process, five NERICA varieties were released in Guinea and were grown on 8000 ha in 2000, four years after they were first introduced into that country. Guinea is expected to be self-sufficient in seed by 2002, and to export seed to neighboring countries. Two NERICA varieties were released in Côte d'Ivoire in December 2000. Already, farmers, farmers' organizations and the national seed service in Côte d'Ivoire have produced Foundation Seed, Basic Seed, and Seed of Acceptable Quality, and 500 tonnes of seed are expected to be available for use in 2001.

During 2000, considerable progress was made in developing new methodologies to accelerate the development of interspecific progenies with desirable characteristics. Molecular markers were used for more rapid characterization of *Oryza glaberrima* germplasm, with the prospect of hastening the identification and utilization of yet untapped valuable genes from this species. An improved tillering medium enhanced the efficiency of the anther-culture method, which is currently being used to overcome the infertility of crosses between *O. sativa* and *O. glaberrima*. A simpler and cheaper method was developed to select drought-tolerant rice varieties. Similarly, a criterion to identify varieties with good adaptation to lowland conditions was identified. A weed-competition model was adapted to identify key characteristics required for superior competitiveness against weeds in rainfed rice systems, and to identify the desired plant type. Using this

method, two NERICA lines were identified as representing this plant type.

Field tests confirmed earlier findings that NERICA lines combine high yields with resistance/tolerance to the important stresses. Their yields were stable in both low-input (up to 3 t/ha) and high-input (up to 5 t/ha) cropping under upland conditions. They responded to high levels of input in the same way as *O. sativa* cultivars did, but showed superior adaptation to low-input conditions. They were as tolerant of high soil acidity as the local checks, but performed better than the latter under mild acidity. Under mild acidic upland conditions, NERICA lines yielded more than local checks with no phosphorus (P) application, but responded positively to application of fertilizer P or rock-phosphate. NERICA lines suffered less than the intraspecific varieties under drought stress.

Tests in West and Central Africa (WCA) identified several NERICA lines with resistance to one or more of the following diseases: rice yellow mottle virus (RYMV), neck rot, brown spot, and blast. Almost 80% of NERICA lines tested had less stem-borer attack than the local check variety. In mixed stands of rice and maize, the major rice stem borers preferred maize to rice, raising the possibility of using maize as a trap crop in rice integrated pest management (IPM).

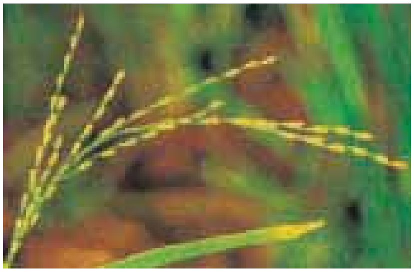
Through the joint Interspecific Hybridization Project (IHP), NERICA lines developed at WARDA were tested for adaptation in Asia and Latin America. In Columbia, several of the NERICA lines were highly tolerant of leaf and neck blast, leaf scald, brown spot, grain discoloration, and soil acidity. In France, efforts were made to transfer RYMV resistance into three popular lowland rice cultivars for use in WCA. Of 18 progenies evaluated in China, one was well adapted in three provinces, while four were well adapted in two provinces. The prospects for considerable spill-over to areas outside WCA have therefore been demonstrated.

A farmer and his family show the earliness of a NERICA variety (left) in comparison with their traditional variety (right).

What is it all about?

Oryza sativa

NERICA



Oryza glaberrima

African rice (*Oryza glaberrima)* possesses many useful attributes, such as earliness, ability to compete effectively with weeds, tolerance of prevailing diseases and insect pests (including blast, rice yellow mottle virus and African rice gall midge), tolerance of adverse environmental and soil stresses (including drought, acidity, low fertility, and iron toxicity in the lowlands), and acceptable grain qualities. WARDA developed the concept of crossing African rice with Asian rice (*O. sativa*) to produce rice types for rainfed ecologies with stable high yields (inherited from *O. sativa*) and resistance/tolerance to biotic and abiotic stresses. The first sets of fertile interspecific progenies (NERICA lines) were developed in 1994 through conventional and modern breeding techniques, which successfully broke the genetic barrier between the two species. They combined the high yield potentials of *O. sativa* with several useful traits acquired from *O. glaberrima.*

The joint Interspecific Hybridization Project, initiated and coordinated by WARDA, started in 1997 and the first phase ended in 2000. The purpose was to solicit international support and to establish a formal mechanism for collaboration among the various institutions world-wide involved in transferring genes from African rice species into elite breeding lines. The vision that created the project has been vindicated by the enormous progress made towards realizing the ultimate goal of developing appropriate rice production technology that would greatly alleviate production constraints of resource-poor farmers, while preserving the natural-resource base.

Why farmers in Africa are excited about NERICA lines

Characteristics of NERICA lines

- The NERICA lines have wide, droopy lower leaves, which smother out weeds in early growth. In the reproductive stage, however, the leaves become erect, to capture more sunlight and consequently increase grain production. Their weed-competitiveness reduces the cost of producing rice and enables farmers to use the same land for one or two more seasons before moving on to new plots.
- Their stems are strong and can thus support heavy heads of grain without lodging.
- They produce more tillers, with longer grain-bearing panicles than either parent.
- Panicles have more primary and secondary branches, and thus carry up to 400 grains, compared with up to 116 in *O. glaberrima* and 250 in *O. sativa*.
- As in *O. sativa*, their grains do not shatter.
- NERICA lines mature 30–50 days earlier than the currently grown cultivars; this allows inclusion of high-value crops or nutritious crops such as vegetables and legumes in the rice-based cropping systems.
- They are taller than the traditional *O. glaberrima*, making harvesting of panicles easier.
- NERICA lines tolerate drought better than the Asian rices, a characteristic that is vitally important for half of West and Central Africa's farmers who depend entirely on rainfall to water their crops.
- They have better resistance to Africa's most serious insect pests and diseases, such as African rice gall midge (AfRGM), rice yellow mottle virus (RYMV) and blast (*Magnaporthe grisea*).
- They grow well in acidic soils and respond to limited application of organic and inorganic fertilizers.
- NERICA lines could help farmers grow upland rice on 17 million hectares in Asia and more than 4 million hectares in Latin America. Exploiting the *O. glaberrima* genes in breeding programs could significantly increase global biodiversity in rice and minimize damage to the natural-resource base.

Bright prospects for more useful genes from African rice

Over 348 crosses have now been made between *O. glaberrima*—and wild rices having desirable traits—and improved *O. sativa.* In order to enhance the tolerance of improved upland rice cultivars to drought and perenniality, more interspecific crosses between *O. sativa* and *O. longistaminata* were made in 2000. Seeds of these crosses are now being used for population generation of F_2 and backcrosses. Embryo-rescue and anther-culture (AC) techniques are used to overcome genetic incompatibility problems between the species.

The improvement of the presently cultivated high-yielding *O. glaberrima* cultivars with good grain qualities, aimed at introgressing genes for lodging and shattering resistance into these varieties, was continued. Advanced populations and backcrosses of the interspecific progenies of six *O. glaberrima* lines were produced, and more crosses were made. In order to enhance drought tolerance, blast resistance, multiple resistance to RYMV and AfRGM, and to enhance tillering ability, bridging materials (*O. sativa/O. glaberrima* fertile progenies) were used as females and crossed with either the *O. glaberrima* or the *O. sativa* parent as donor.

Improved efficiency of anther-culture to produce fertile interspecific progenies

A number of doubled-haploid NERICA lines with high fertility from the first (BC_1F_1) and second (BC_2F_1) backcross generations of NERICA lines were generated through AC. WAB 56-50, WAB 181-18 and WAB 56-104, all *japonica* upland rice cultivars, were identified as cultivars with high efficiency of callus induction and green-plantlet regeneration. WAB 56-104, CG 14 and CG 20 are being used as sample cultivars in the AC program. Studies to assess culturability in African *japonica*, *indica* and *O. glaberrima* germplasm continued. Parental lines and the progenies of 576 *japonica* × *indica*, *japonica* × *O. glaberrima,* and interspecific progeny (bridging materials) × *O. sativa* or *O. glaberrima* F_1, F_2 and BC_2F_1 crosses were subjected to AC.

High callus induction of the different genotypes was obtained by using liquid or semi-solid N_6 medium to which was added 0.5 mg 2,4-D/L, 5% maltose and 150 ml coconut milk/L, which was incubated in the dark at $25 \pm 1^{\circ}C$. Calli obtained were regenerated in an MS (Murashige and Skoog) medium, supplemented with 4 mg kinetin/L, 1 mg naphthalene acetic acid (NAA)/L, 100 mg Myoinositol/L and 3% sucrose, under light intensity of 2500 lux and photoperiod of 16 h per day. In addition to these ingredients, the rooting and hardening medium used had Multi-Effect Triazole and 3% more sucrose. A tillering medium, which gives 10–35 tillers from a single plantlet, has also been developed. This improves the efficiency of the AC method since more plants can now be obtained from a given cross.

The frequency of callusing anthers ranged from 10.8 to 115.6%, while the regenerating capacities of the microspore-derived calli varied from 0 to 32.3% (Tables 1a and b).

Anther-culture response (green plants per anther) ranged from 0 to 16.5% (Tables 1a and b). The modified N_6 medium produced a large number of fast-growing, white, compact and lobed calli with fairly high regenerability. Response to callus induction and green-plantlet regeneration depended on the genetic origin of the crosses. The green and albino plant regenerating capacities of the microspore calli increased slightly at 6 and 5 weeks after inoculation of the anthers, respectively, then decreased gradually. Forty-three percent of the plantlets were green, and were used in the next stage of the process. Among the green plants, 57% were haploids with 12 chromosomes; 36.5% were spontaneous doubled-haploids; and 6.5% were polyploids.

Table 1. Anther-culture responses for first- and second-generation hybrids.

Hybrids[1]	No. of crosses	Anthers plated	Callus production		No. of calli transferred	Green plants regeneration		Anther-culture (AC) response[2]
			No.	%		No.	%	
(a) First generation (F_1)								
G × G	4	4,900	2,457	50.1	2,244	23	1.0	0.5
G × I	2	2,000	502	25.1	459	0	0.0	0.0
G × J	6	12,300	1,765	14.3	1,598	30	1.9	0.2
I × G	2	900	516	57.3	437	0	0.0	0.0
I × J	3	7,500	7,731	103.1	6,771	54	0.8	0.7
J × G	4	11,900	2,343	19.7	2,111	260	12.3	2.2
J × I	5	16,700	9,702	58.1	8,415	97	1.2	0.6
J × J	2	2,200	2,543	115.6	2,277	78	3.4	3.5
(b) Second generation (F_2)								
G × I	2	900	97	10.8	90	0	0.0	0.0
I × G	2	1,500	689	45.9	654	35	5.4	2.3
I × J	2	3,600	866	24.1	819	140	17.1	3.9
J × B	3	12,300	12,922	105.1	11,669	346	3.0	2.8
J × G	18	27,400	6,580	24.0	6,097	875	14.4	3.2
J × I	4	11,400	3,061	26.9	2,825	490	17.3	4.3
J × J	2	4,200	1,249	29.7	1,162	59	5.1	1.4
J × I × J	2	1,700	911	53.6	866	280	32.3	16.5
J × J × J	2	1,600	563	35.2	529	105	19.8	6.6

1. J = *Japonica*, I = *Indica*, G = *O. glaberrima*, B = Bridging material (*japonica* × *O. glaberrima* progeny)
2. Green plants/anthers plated (%)

Progress in molecular-marker gene technology and marker-assisted breeding

The level of interspecific polymorphism for all the *O. sativa*/*O. glaberrima* combinations was assessed, using the complete set of selected microsatellites. Concurrently, molecular-marker data concerning intraspecific polymorphism were analyzed, especially for *O. glaberrima* lines, before using informative microsatellites on a collection of *O. glaberrima* accessions in order to assess its allelic diversity.

One hundred and thirty-two markers were scored on the set of parental material. Marker data were recorded in the form of frequency distribution for 15 interspecific *O. sativa*/*O. glaberrima* combinations. Figure 1 summarizes the selected lines and the different levels of polymorphism. The level of interspecific polymorphism was high with values ranging from 87% to 96%. The mean polymorphism value of 90% is higher than the 56% recorded on the same kind of interspecific material using restriction fragment length polymorphism (RFLP) markers. *Indica/O. glaberrima* combinations were more polymorphic than the *japonica/O. glaberrima* combinations. This result confirms that almost all the genome is covered with informative microsatellites, irrespective of the interspecific combination being considered.

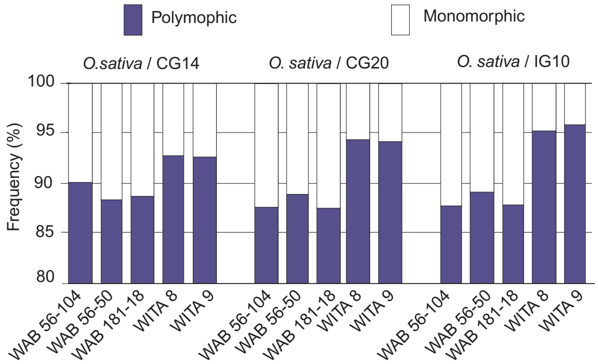


Figure 1. Polymorphism frequencies based on pooled marker data for 15 interspecific cross combinations (data on 132 microsatellite markers).

Six *indica*/*japonica* combinations compared with interspecific combinations revealed similar values of polymorphism (mean = 87.7%). Conversely, intra-specific combinations (*japonica*/*japonica*, *indica*/*indica* and *O. glaberrima*/*O. glaberrima*) revealed significantly lower levels of polymorphism compared with interspecific and *indica*/*japonica* combinations. Polymorphism varied from 52% from WITA 8/WITA 9 combination to 3.4% from WAB 56-104/WAB 56-50 combination. Polymorphism was also detected among the three *O. glaberrima* varieties CG 14, CG 20 and IG 10 in 12 of 17 marker comparisons. This confirms the strong variability characteristic of microsatellites compared with other markers (isozyme and RFLP).

Segregation of microsatellite marker OSM25 in NERICA lines

By using the silver-staining method, the NERICA lines were shown to carry multiple introgressions of *O. glaberrima* in *O. sativa* background.

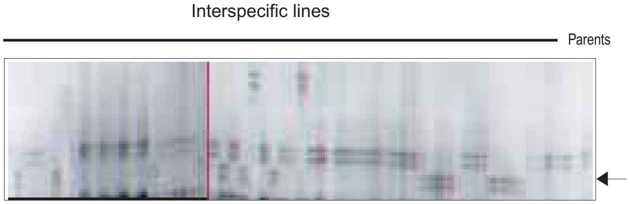


Figure 2. Segregation of microsatellite marker OSM25 in interspecific progenies.

The two methods—silver staining and fluorescent detection—of simple sequence repeat (SSR) used in this study also showed the new non-parental alleles in most of the lines tested (Figure 2).

Allelic frequencies in NERICA lines

The frequency of *O. glaberrima* alleles in the NERICA lines was up to 20% (Table 2). The level of heterozygosity is very low across the NERICA lines. Some lines had more introgressed alleles from *O. glaberrima* than others, but in general *O. glaberrima* alleles were found across the NERICA lines. The level of non-parental

Table 2. Allelic frequencies in NERICA lines.

	Allele frequencies (%)				
NERICA line	*O. glaberrima* allele	*O. japonica* allele	Extra allele	Hetero-zygote	Missing data
WAB 450-I-B-P-138-HB	9	73	6	0	12
WAB 450-I-B-P-160-HB	12	52	13	1.5	20
WAB 450-I-B-P-33-HB	5	71	10	1.5	12.5
WAB 450-11-1-1-P31-HB	12	70	10	1.5	6.5
WAB 450-24-3-2-P18-HB	12	67	12	3	6
WAB 450-I-B-P-153-HB	18	58	9	1.5	13
WAB 450-5-1-BL1-DV6	10	49	16	0	24
WAB 450-B-16A1.4	15	52	24	0	9
WAB 450-4A2	14	46	7.5	3	29.5
WAB 450-4-1-A16	20	38	7.5	6	28
WAB 450-B-16A2.7	12	37.3	18	1.5	31.5
WAB 450-B-16A1.8	14	43	22.4	3.6	17

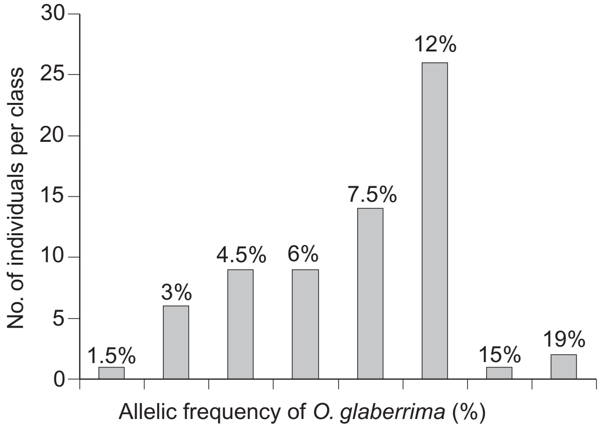


Figure 3. Distribution of O. glaberrima alleles across NERICA lines.

(extra) alleles (6–24%) seems high (Table 2), but the crosses were made in the field, where it would be difficult to avoid out-crossing. Other factors that could explain the level of non-parental alleles are (i) residual heterozygosity in either parent when crosses were made, and (ii) the parent stock could have changed genetically (by mutation, contamination by out-crossing of pollen or by physical mixing of the seed from another genotype) after being used for the crosses.

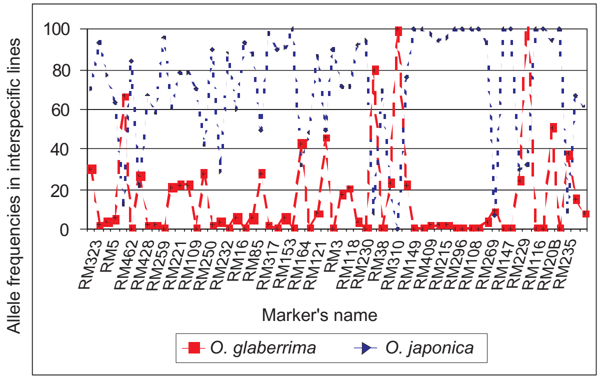


Figure 4. Segregation of each locus marker across interspecific lines.

Distribution of *Oryza glaberrima* alleles across NERICA lines

The modal frequency of alleles from CG 14 (an *O. glaberrima* cultivar) was 12% (Figure 3). This and the observed low level of heterozygosity fit what would be expected in theory, since the test genotypes were from the BC_2F_8 generation.

Markers with potential use for fingerprinting

The microsatellite markers RM284(chr1), RM435(chr6), RM164(chr5) and RM462(chr8) showed preferential selection for *O. glaberrima* genome across the lines (Figure 4). RM435 is located on chromosome 6 near a gamete killer gene in *O. glaberrima* that is responsible for sterility in F_1 hybrids between *O. sativa* and *O. glaberrima*. Earlier studies on progenies of *O. glaberrima* × *O. sativa* also showed a strong segregation distortion on chromosome 6 close to the microsatellite markers OSR19 and OSR25, both of which are found in the 'waxy' gene. This could be due to the presence of a sporogametophytic sterility factor, *s10*, which was found to be tightly linked to the 'waxy' character. The main effect of this factor is that, in the heterozygous genotypes, male gametes are systematically eliminated and female gametes carry the *O. sativa* alleles. In our study, some of the markers that showed preferential selection of the CG 14 alleles were not on chromosome 6, indicating that mechanisms other than *s10* are probably involved.

Graphical genotyping of NERICA lines

The graphical genotyping of the NERICA line WAB 450-I-B-P-153-HB (Figure 5) showed it has inherited CG 14 alleles in almost all parts of the genome. Recombination

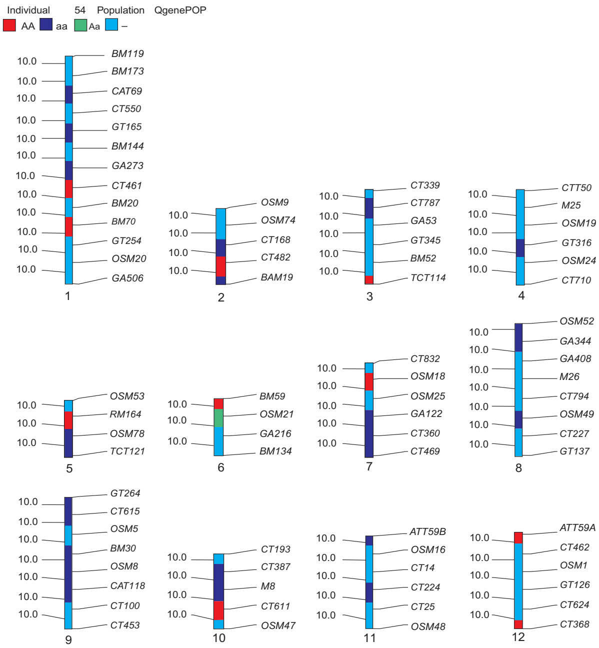


Figure 5. Graphical genotype of WAB 450-I-B-P-153-HB line. Red indicates the O. glaberrima allele; dark blue is for the O. sativa allele, and green represents the heterozygote; light blue indicates missing data.

occurred frequently, suggesting that there is no barrier to recombination during meiosis. Among individuals derived from the classical breeding process, the level of heterozygosity was low and close to theoretical expectations. Since the number of introgressions from the *O. glaberrima* parent was small in this study, NERICA lines could be used to develop near-isogenic material, which are necessary for determining the functions of specific regions that are associated with certain agronomic traits. Single or multiple introgressions of *O. glaberrima* in an *O. sativa* background would be invaluable as parents in future breeding efforts.

The phenotyping of these lines is continuing at WARDA to identify quantitative trait loci (QTLs) associated with traits of interest, e.g. wide droopy leaves, number of tillers, number of grains per panicle, panicle size and number of secondary branches. A poster summarizing these results was presented at the 4th Rice Genetics Symposium held at the International Rice Research Institute, the Philippines, in 2000.

Transferring rice yellow mottle virus (RYMV) resistance into lowland rice varieties

The fine mapping of an RYMV resistance gene has detected new microsatellites close to it, which are polymorphic between the three recurrent parents (BG 90-2, Bouaké 189 and Jaya) and Gigante. Resistant BC_2F_2 individuals of each combination were developed at the *Institut de recherche pour le développement* (IRD), Montpellier, France. Polymorphic microsatellite markers will be used to select resistant BC_3 progenies by evaluating them against the range of RYMV isolates available at WARDA.

Use of molecular markers to evaluate genetic diversity in *Oryza glaberrima*

A study was undertaken using 81 microsatellite markers to evaluate diversity of 200 accessions of *O. glaberrima* collected from 12 countries within its center of diversity in WCA. Eight accessions of *O. sativa,* representing both the *indica* and *japonica* subspecies, were used as an outgroup. The 81 single-strand length polymorphism (SSLP) markers were distributed throughout the genome (Figure 6). A mean polymorphism information content (PIC) value of 0.65 and allele size range of 57 to 388 bp were obtained. An average of 16 alleles per locus was detected in *O. glaberrima,* ranging from 4 to 67 alleles per locus, and demonstrating abundant genetic variation in *O. glaberrima.*

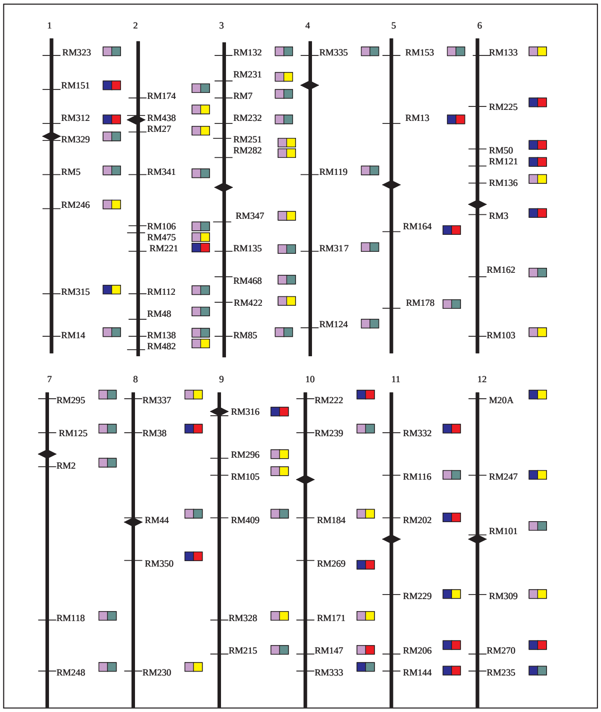


Figure 6. Position of the 81 SSLP markers along the 12 chromosomes of rice. The color code indicates the number of alleles (🟪 = low for number of alleles fewer or equal to the mean, and 🟦 = high if more than the mean), and PIC values based on a categorization of low (🟩 = less than 0.6), medium (🟨 = equal to or more than 0.6 and less than 0.8), or high (🟥 = more than 0.8).

Oryza glaberrima accessions can be uniquely identified using microsatellites, and potential duplicates can also be recognized. Genetic similarity of germplasm is shown in Figure 7, demonstrating that samples collected in the same geographic area are not always the most closely related genetically. For the first time, the WARDA germplasm collection can be characterized based on shared allele frequencies rather than simply on the geographic location where the samples were obtained. Correlation between genotype and phenotype can also be identified and targeted for further study.

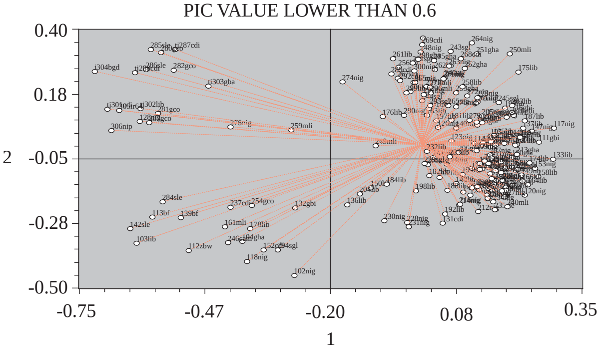


Figure 7. PCA of relationship among 170 O. glaberrima accessions and O. sativa varietes based on 36 microsatellite markers with PIC values less than 0.6.

Reciprocal crosses between WAB 56-104 and CG 14 were made at Cornell University to generate the required populations for mapping and QTL analysis. Very few (0–4) seeds were produced, suggesting low pollen viability of interspecific F_1 hybrid. Despite extensive bagging of single F_1 panicles and their regular shaking to optimize self-pollination, no F_2 seeds were obtained. However, when F_1 panicles were bagged with panicles from either parent, BC_1 seeds were produced. These results indicate that interspecific F_1 panicles can be used as females to produce BC_1 seed.

We found that pericarp color could be a good morphological marker for QTL identification. The *O. sativa* and *O. glaberrima* parents have white and red pericarps, respectively. When the two parents were crossed, the F_1 seed pericarp colors were the same as those of the mother plants. However, the BC_1 seeds were all red, regardless of the BC_1 cross combination. We deduced that pericarp color was at least partially controlled by a cytoplasmic (maternal) effect, interacting with one or more nuclear gene(s).

Overcoming the yield gap in rainfed rice production systems

Response of NERICA lines to different management levels

In low-input conditions (20 kg N/ha with one hoe-weeding at 21 days after seeding [DAS]), 25 NERICA lines out-yielded the best performing *O. sativa* check WAB 56-50 by 6–68%. The highest yielders were WAB 878-6-3-5-4-P1-HB, WAB 881-10-37-18-8-P1-HB, WAB 881-10-37-18-5-P1-HB, WAB 881-10-37-18-12-P3-HB and WAB 881-10-37-18-13-P1-HB with yields of 2.8–3.2 t/ha. Under high-input conditions (good land preparation, 100-40-40 kg NPK/ha, and weeding as and when necessary), 21 NERICA lines out-yielded WAB 56-50, with WAB 878-6-37-8-3-P1-HB, WAB 878-6-37-5-6-P1-HB and WAB 881-10-37-18-1-P2-HB yielding above 5 t/ha.

In another experiment, NERICA lines responded positively to fertilizer in the same way as the *O. sativa* cultivars did (Figure 8). Under high-input conditions, 28 of 73 NERICA lines yielded 2.0–4.9 t/ha. Under low-management conditions, 18 NERICA lines out-yielded *O. sativa* cultivars and gave yields similar to or higher than *O. glaberrima*, indicating superior adaptation to low-input conditions.

Screening and breeding for acidity tolerance

In acidic forest soils at Man in western Côte d'Ivoire, NERICA lines yielded 0.4–2.8 t/ha with P and 0–0.9 t/ha without P. Only WAB 495-30-4, WAB 495-142-1, WAB 495-28-2 and WAB 495-30-3 out-yielded the check, IDSA 5. With the application of 100 kg N/ha followed by 40 kg N/ha in two equal splits, 15 NERICA lines yielded more than 2 t/ha, with WAB 704-76-4-HB and WAB 569-36-2-1-1-HB giving 2.8 t/ha. In the mildly acidic soils at M'bé, both NERICA lines and intraspecific progenies out-performed IDSA 6, but the anther-culture (AC) derived lines behaved similarly to the check. At Man with higher acidity, the AC-derived lines and the intraspecific lines out-yielded IDSA 6, while the NERICA lines gave yields similar to IDSA 6 (Figure 9).

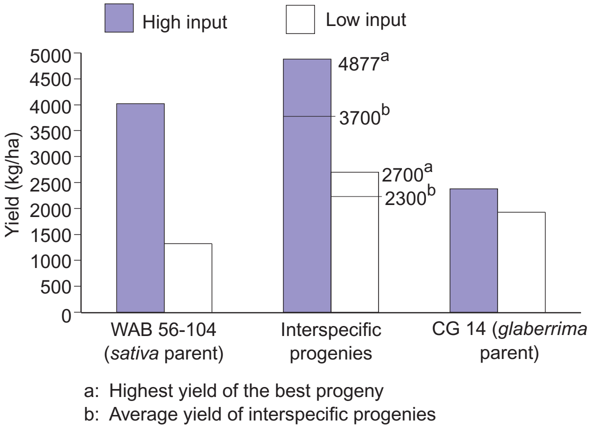


Figure 8. Grain yield of interspecific hybrid progenies and parents in replicated yield trials under high and low levels of management.

On-station acidity tolerance trial: susceptible (left) and tolerant (right).

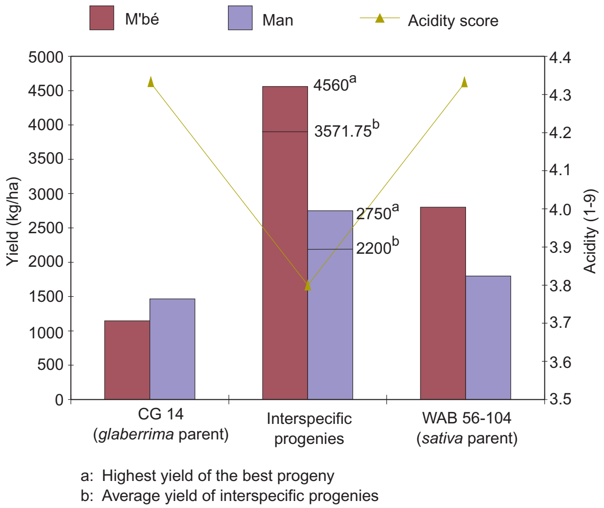


Figure 9. Performance of parents and their progenies in replicated yield trials for acidity tolerance.

Response of NERICA lines to fertilizer and Mali rock-phosphates

Insufficiency of soluble phosphorus (P) in the low-activity, acid soils of the humid forest zones of West Africa constrains upland rice production and productivity. Upland rice cultivars differ in their P efficiency and adaptation to acid soil conditions.

In the wet seasons of 1999 and 2000, we studied the response of promising NERICA lines to direct and residual fertilizer P in an Ultisol at Man in the humid forest zone of Côte d'Ivoire. Phosphorus was applied at the rate of 0, 30, 60, 90 and 120 kg/ha as triple superphosphate (TSP). The direct (1999) and residual (2000) effects of applied P were evaluated in WAB 450-I-B-P-38-HB, WAB 450-11-1-P31-1-HB and WAB 450-I-B-P-160-HB (NERICA lines), CG 14 (*O. glaberrima* cultivar) and WAB 570-10-B-1A1.15 (*O. sativa*). The entries differed in their responses to freshly applied P in 1999 and residual P in 2000. With zero P, WAB 450-11-1-P31-1-HB gave the highest grain yield (1.73 t/ha), followed by WAB 450-I-B-P-160-HB (1.29 t/ha), WAB 450-I-B-P-38-HB (1.22 t/ha) and WAB 570-10-B-1A1.15 (1.03 t/ha).

In 1999, the NERICA lines gave a better response to freshly applied P than did the *O. sativa* and *O. glaberrima* cultivars. WAB 450-11-1-P31-1-HB gave a linear response and the highest yield (3.09 t/ha). CG 14 did not respond significantly to applied P, while the other entries were intermediate in their responses (Figure 10). Grain yield responses of all entries to residual P in 2000 were considerably lower than they were to direct P in 1999. Responses were highest in WAB 450-I-B-P-160-HB and lowest in CG 14. As with direct P, the response of CG 14 was not significant. The considerably reduced yields in 2000 confirm our earlier findings that residual effects of applied P are reduced due to the reversion of soluble P into an insoluble form, leading to reduced availability of applied P. On the basis of these results, WAB 450-11-1-P31-1-HB and WAB 450-I-B-P-160-HB appear to be promising.

Rock-phosphates, which are produced in several countries in West Africa (Burkina Faso, Mali, Niger, Nigeria, Senegal and Togo), are cheaper than imported soluble P. Mali produces the best rock-phosphate in the sub-region. As in 1999, an experiment was conducted in a humid forest acid soil at Man to determine the response of NERICA lines to Mali rock-phosphates.

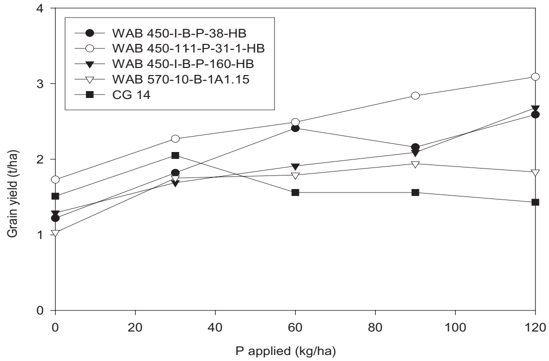


Figure 10. Relationship between grain yield and direct response to different rates of fertilizer P of five rice cultivars in an Ultisol in 1999.

During 2000, WAB 56-104 (an *O. sativa* subsp. *japonica* cultivar) (V1), and four NERICA lines—WAB 450-I-B-P-38-1-HB (V2), WAB 450-11-1-HB (V3), WAB 450-11-1-P40-1-HB (V4) and WAB 450-24-3-2-P18-HB (V5)—were evaluated for their response to the residual effect of Mali rock-phosphate applied at four doses in 1998 (0, 150, 300 and 450 kg P/ha). Basal potassium (K) was applied at planting and N was split-applied at planting and booting stages.

All five genotypes responded positively to Mali rock-phosphate applied two years earlier, indicating that phosphorus is essential for crop production in this humid forest acid soil. Grain yield at 300 kg P/ha varied from 0.47 t/ha for WAB 56-104 to 1.04 t/ha for WAB 450-11-1-P40-1-HB. Rock-phosphate application significantly increased grain yield. As was observed in 1998 and 1999, the optimum dose was 300 kg P/ha. Figure 11 shows the direct effect of Mali rock-phosphate application in 1998 and residual effects in 1999 and 2000. Mali rock-phosphate gave high yields one year after application, but yields decreased significantly in the second year. WAB 450-11-1-HB and WAB 450-11-1-P40-1-HB gave the highest yields in 1999, while WAB 450-I-B-P-38-1-HB and WAB 450-11-1-P40-1-HB did so in 2000.

Overall, NERICA lines responded significantly to direct and residual rock-phosphate application, and WAB 450-11-1-HB and WAB 450-11-1-P40-1-HB yielded more than the check *O. sativa* cultivar.

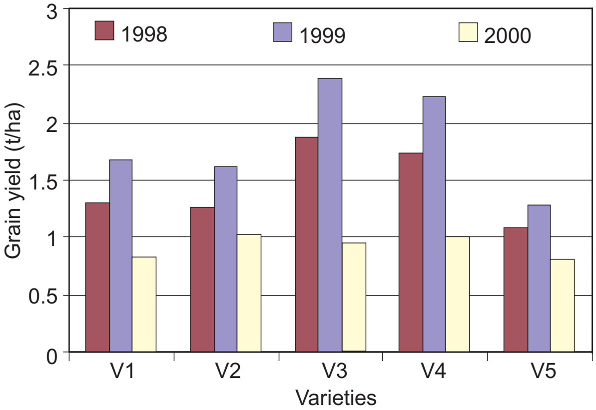


Figure 11. Direct (1998) and residual (1999, 2000) effects of Mali rock phosphates at 300 kg/ha P on five upland rice cultivars in a humid forest acid soil. V1 = WAB 56-104; V2 = WAB 450-I-B-P-38-1-HB; V3 = WAB 450-11-1-HB; V4 = WAB 450-11-1-P40-1-HB; V5 = WAB 450-24-3-2-P18-HB.

Selection for weed competitiveness

Weed competition is a major cause of low yields in rice in WCA, and farmers spend more time in weeding than in any other farm operation. Weed-competitive cultivars can increase rice yields and save labor for other operations. Tools for rapid identification of rice cultivars possessing traits for superior competitiveness against weeds can accelerate the process of developing varieties for the less-favorable production environments in WCA. The INTERCOM crop–weed

competition model—developed by IRRI and Wageningen Agricultural University, and adapted by WARDA—was used to evaluate the competitiveness of hypothetical rice types that were formulated, based on the observed characteristics of CG 14 (*O. glaberrima*) and WAB 56-104 (*O. sativa*). All hypothetical rice types were made to compete with the strongly competitive weed *Echinochloa crus-pavonis.* By using specific leaf area (SLA) measurements, we determined that the most competitive type was one that maintained a high SLA up to near panicle initiation and switched to a low level SLA at flowering (Figure 12).

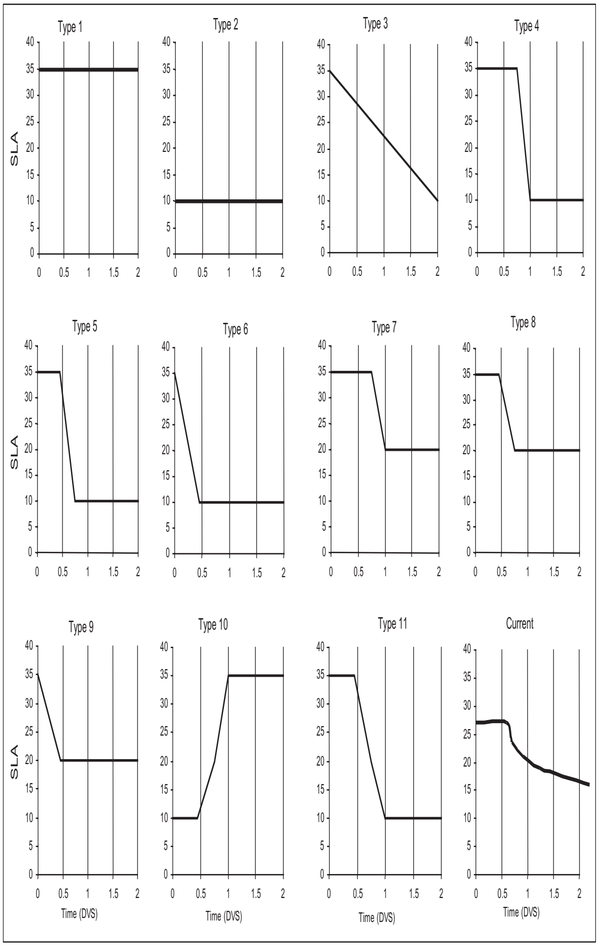


Figure 12. Hypothetical SLA prototypes used for sensitivity analysis to determine traits for competitiveness against weeds. SLA = specific leaf area; DVS = developmental stage.

The above, and earlier work at WARDA, described a desirable plant type for low-input conditions: it should have rapid early vegetative growth characteristic of *O. glaberrima*, followed by the more upright architecture of the improved *O. sativa* cultivars in the reproductive phase. This was intended to combine the weed- competitiveness imparted by high leaf area index in the early stages, followed by the higher yield potential imparted by better light penetration into the canopy from erect leaves in later growth. Expressed in terms of SLA, this corresponds to high values in the early stages of growth and low values in the reproductive phase. SLA tends to fall with age in all cultivars, but a plant with high early values that fall rapidly as the plant ages would be likely to fit the above criteria.

Figure 13 shows that the mean of SLA values for the 160 screened cultivars was 28 m^2/kg (range = 24–38 m^2/kg). The highest values were from the *O. glaberrima* cultivars and the lowest were from *O. sativa* checks, while the majority of those with intermediate values were NERICA lines. Of particular interest are WAB 881-10-37-18-14-P1-HB and WAB 880-1-38-18-2-P2-HB. The latter has early SLA values which are intermediate between *O. glaberrima* and *O. sativa,* but the values fall to become similar to those of the *O. sativa* cultivar at 80 days after seeding (DAS). The former is perhaps of more interest as the SLA values fall rapidly, so that by 50 DAS, the values are lower than those of the *O. sativa* cultivar. These results show that the objective of producing a plant type that resembles one species in early growth and the other species in the reproductive phase has been achieved.

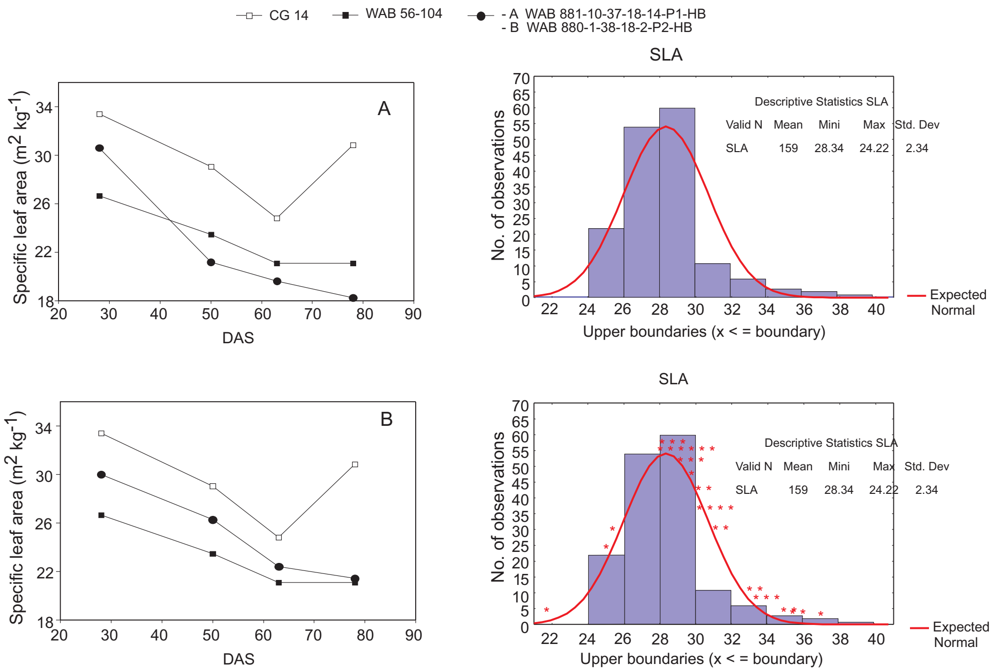


Figure 13. Specific leaf area of upland rice cultivars in observational yield trials, M'bé 1999, with values over time for WAB 881-10-37-18-14-P1-HB and WAB 880-1-38-18-2-P2-HB. DAS = days after seeding.

Morpho-physiological characteristics related to drought adaptation mechanisms in *O. glaberrima* and *O. sativa*

We reported in 1998 and 1999 that some NERICA lines produced stable high yields in drought-prone areas. A trial was conducted to explore the use of morpho-physiological characteristics to select rice cultivars that are adapted to drought-prone conditions. We also attempted to identify morpho-physiological characteristics that are associated with drought-avoidance mechanisms in rice. Morpho-physiological characteristics of 24 rice genotypes, including *O. sativa* subsp. *indica*, *O. sativa* subsp. *japonica*, *O. glaberrima*, and NERICA lines, were measured at the flowering stage. For each group, a released improved cultivar was included for comparison. Root and plant water status was recorded after 35 days of water deficit imposed during the vegetative stage. The materials were grown under irrigation at M'bé in a well-drained Alfisol following five years of fallow.

With greater total dry matter, *O. glaberrima* had better growth than *O. sativa*. This was confirmed by greater tiller production and larger SLA (longer and thinner leaves that provide a greater surface area) for *O. glaberrima*. *Oryza glaberrima* also produced more roots and had higher root length density than the other groups tested (Figure 14). Plant growth characteristics were greatest in *O. glaberrima*, high in *O. sativa* subsp. *indica*, lowest in *O. sativa* subsp. *japonica*, and intermediate in NERICA lines. Conversely, physiological

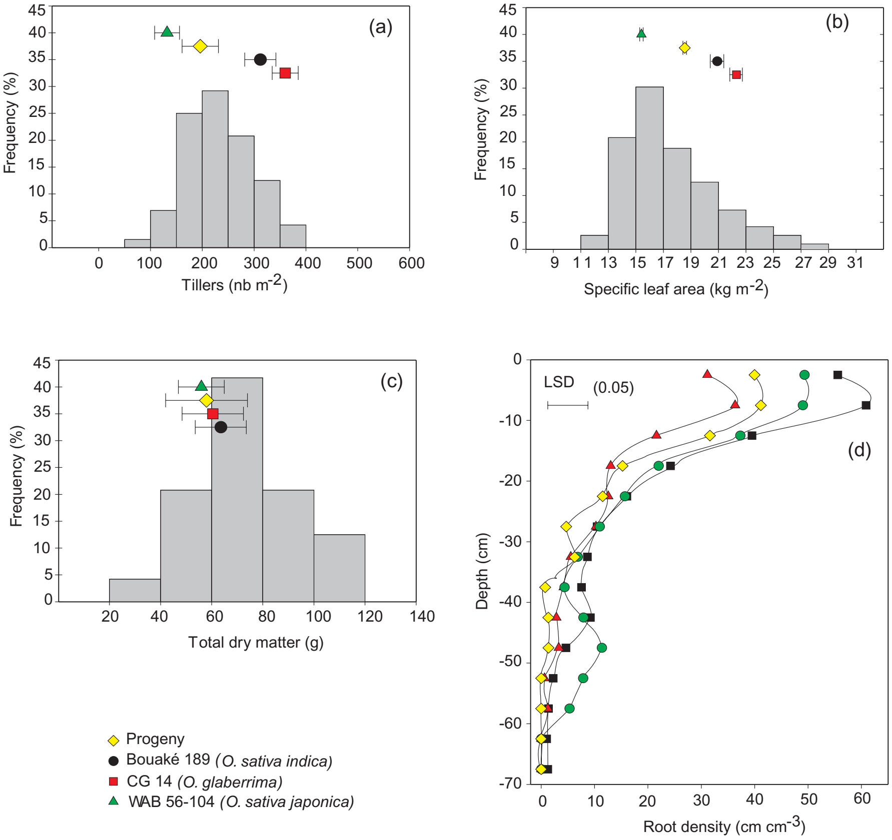


Figure 14. Morphology traits among genotypes of O. sativa, O. glaberrima *and NERICA lines. (a) frequency distribution of number of tillers, (b) frequency distribution of SLA, (c) frequency distribution of total dry matter and (d) root length density for representative cultivars of each group.*

plant characteristics, such as chlorophyll content, stomatal density, photosynthetic rate, and water use efficiency were highest in *O. sativa* subsp. *japonica*, lowest in *O. glaberrima*, and intermediate in the NERICA lines (Figure 15). These combined morphological and physiological characteristics induced good drought adaptation in *O. glaberrima*. Leaf rolling, which is used by rice as an avoidance mechanism during drought periods, was also more rapid in *O. glaberrima* than in *O. sativa* subsp. *indica*, because of the difference in leaf thickness (SLA). However, the *O. sativa* subsp. *indica* cultivar Bouaké 189 had good leaf rolling for a specific relative leaf water content, and this could explain its good adaptation to drought.

A quantitative screening and evaluation method for drought tolerance in rice

For quantitative trait locus (QTL) analysis, several mapping populations, each comprising 100 or more individuals, are normally evaluated. A quicker, but still reliable screening method is needed to map genes responsible for drought tolerance in rice. By comparing

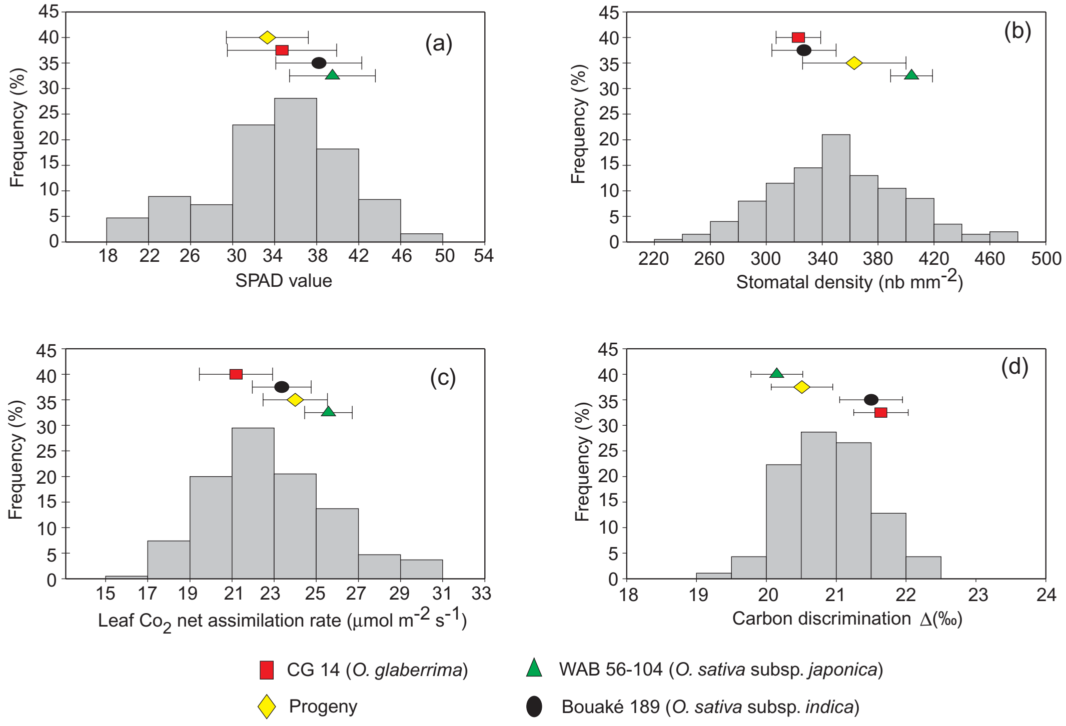


Figure 15. Leaf activity characteristics among genotypes of O. sativa, O. glaberrima *and NERICA lines: (a) frequency distribution of chlorophyll content, (b) frequency distribution of stomatal density, (c) frequency distribution of photosynthetic rate, and (d) frequency distribution of carbon isotope discrimination.*

the performance of drought-tolerant African and susceptible Asian varieties, we attempted to find good phenotypic and physiological characters that are closely associated with drought tolerance.

During early vegetative growth (15–45 DAS), 14 Asian rice (*O. sativa*) and African rice (*O. glaberrima*) cultivars, and 5 NERICA lines were subjected to drought stress in an upland rice field. Growth analysis revealed that upland rice (*O. sativa* subsp. *japonica*) had higher drought tolerance than lowland rice (*O. sativa* subsp. *indica*). There were two types among upland cultivars: WAB 56-50 and WAB 56-104 maintained higher net assimilation rate (NAR), while Morobérékan and Bala compensated for the reduced NAR by increasing leaf area ratio (LAR).

On-station screening for drought tolerance.

Table 3. Xylem exudation rate and osmotic potential in different rice varieties.

	Control		Drought	
Cultivar	Xylem exudation rate (mg/h)	Osmotic potential (MPa)	Xylem exudation rate (mg/h)	Osmotic potential (MPa)
WITA 9	24.6± 7.4	-0.102±0.030	19.8± 5.8	-0.048±0.016
WAB 56-50	62.7±14.7	-0.114±0.030	35.9± 6.9	-0.116±0.022
Azucena	69.7±14.5	-0.104±0.030	43.7±13.5	-0.099±0.016
CG 20	31.4± 3.6	-0.112±0.019	22.7± 5.7	-0.107±0.013

Physiological characters were investigated under drought stress in four cultivars (WAB 56-50, Azucena, WITA 9 and CG 20). Photosynthetic rate was reduced by drought stress for all cultivars. The reduction was most in WITA 9 (36%) and least in WAB 56-50 (8%), which was consistent with higher NAR in the latter. Stomatal conductance (transpiration) was also reduced by drought stress. CG 20 (*O. glaberrima)* reduced its transpiration rate (54%) more than its photosynthetic rate (18%), indicating a drought-tolerance mechanism that is associated with the prompt closure of stomata and a restriction of transpiring water.

Although drought reduced leaf xylem water potential for all cultivars tested (Figure 16), WAB 56-50 kept a higher water potential (-0.86 MPa compared with -1.61 for WITA 9 and -1.43 for CG 20). Osmotic potentials of WITA 9 (-3.3 MPa) and CG 20 (-3.0 MPa) were slightly lower than that of the two upland cultivars (-2.5 MPa). Pressure potential did not vary significantly among rice cultivars, and was not affected by drought.

Upland cultivars had a higher rate of xylem exudation (rate of water exudation from the cut stem) than did WITA 9 and CG 20 (Table 3). The rate was positively correlated

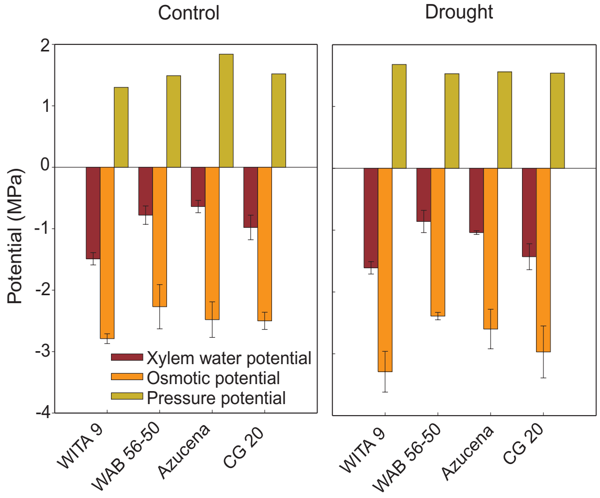


Figure 16. Parameters of water relations in seedlings of rice varieties with and without drought stress.

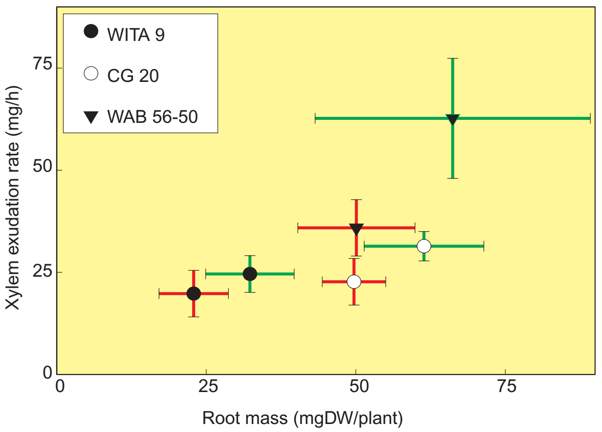


Figure 17. Relationship between xylem exudation rate and root mass of seedlings of rice varieties with (red error bars) and without (green error bars) drought stress.

with root mass in Asian rices. However, although CG 20 had a relatively higher root mass, its exudation rate was as low as that of a lowland cultivar (Figure 17). This indicates that the passive water uptake ability of plants is governed not only by root mass, but also by root activity. Osmotic potential of the exudates was similar for all the cultivars. We conclude that xylem exudation rate would be a better quantitative criterion than root mass for screening individuals in a mapping population for QTL analysis of drought tolerance—it is simple and cheap.

Screening for tolerance to drought stress

After 35 days of exposure to drought, most NERICA lines were rated as tolerant (scores of 1–3 on a scale of 1–9) at the vegetative phase (Figure 18). Compared with the control, seedling vigor, seedling height and tillering ability of the NERICA lines were reduced by 18%, 26% and 12%, respectively, and by 46%, 50% and 57%, respectively, in intraspecific progenies.

At the reproductive phase, 3.2% of the NERICA lines, compared with 0.4% of intraspecific lines, were rated as tolerant (Figure 19). The following NERICA lines had a score of 3: WAB 450-I-B-P-65-4-1, WAB 450-I-B-P-91-HB, WAB 878-4-2-2-7-P1-HB, WAB 880-1-38-15-2-P2-HB and WAB 891-1-1-10-5-2-15-P1-14P. Entries with moderate resistance at the reproductive stage generally had good seedling vigor and high leaf-rolling ability under stress conditions. Among the 239 drought-tolerant lines and checks tested at M'bé, 9 entries yielded more than 4 t/ha. The best 20 lines out of 112 tested at Ponondougou, a drier site, yielded more than 3 t/ha.

Identifying new lines resistant to major diseases and insect pests

Rice yellow mottle virus (RYMV)

Sixteen NERICA lines were tested for their resistance to RYMV. Given the existence of a differential interaction between the isolates of RYMV and rice varieties, we wanted to know the reactions of these lines to the different isolates. Three isolates (Rym-r-6, Rym-r-37a and Rym-r-35) were thus inoculated into the 16 lines, which were compared with three resistant and three susceptible checks. The results showed that:

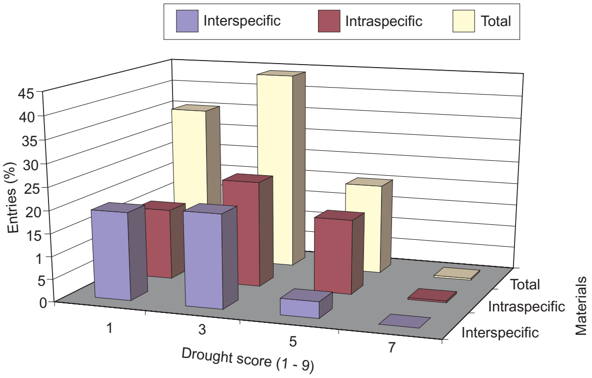


Figure 18. Reaction of interspecific and intraspecific rice progenies to drought: vegetative phase.

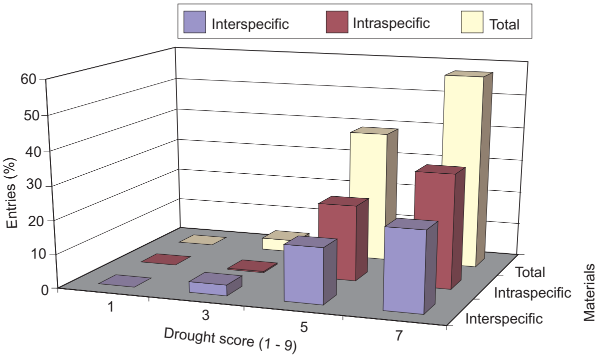


Figure 19. Reaction of interspecific and intraspecific rice progenies to drought: reproductive phase.

Table 4. Reaction of 16 NERICA lines, 3 resistant and 3 susceptible checks to 3 RYMV isolates.

	ISOLATE (ORIGIN)								
	Rym-r-6 (Danané)			**Rym-r-37a** (Gagnoa)			**Rym-r-35** (M'bé)		
Entry	Chlorosis	ELISA	Conclusion	Chlorosis	ELISA	Conclusion	Chlorosis	ELISA	Conclusion
WAB 450-15-3-2-P8-HB	–	–	Healthy	–	–	Healthy	+	+	Attacked
WAB 450-8-3-3-MB-HB	+	+	Attacked	+	–	Healthy	+	–	Healthy
WAB 450-9-2-13-1-HB	–	–	Healthy	–	–	Healthy	–	–	Healthy
WAB 450-I-B-P-103-HB	+	+	Attacked	–	–	Healthy	–	–	Healthy
WAB 450-11-2-BL1-DR1	+	+	Attacked	+	–	Healthy	+	–	Healthy
WAB 450-11-1-2-P41-HB	+	+	Attacked	+	–	Healthy	–	–	Healthy
WAB 450-15-2-BL1-DR5	–	+	Attacked	–	–	Healthy	+	–	Healthy
WAB 450-I-B-P-26-2-1	+	–	Healthy	+	–	Healthy	NT	NT	NT
WAB 450-I-B-P-51-2-1	+	–	Healthy	–	+	Attacked	+	+	Attacked
WAB 450-B-1A1.1	–	–	Healthy	–	–	Healthy	–	–	Healthy
WAB 450-16-2-BL1-DR3	+	–	Healthy	–	–	Healthy	NT	NT	NT
WAB 450-I-B-P-121-4-1	–	–	Healthy	–	–	Healthy	NT	NT	NT
WAB 450-B-9A2.1	NT	NT	NT	+	+	Attacked	+	+	Attacked
WAB 450-11-1-1-P31-HB	–	+	Attacked	+	–	Healthy	+	+	Attacked
WAB 450-I-B-P-167-1-1	+	+	Attacked	+	–	Healthy	+	+	Attacked
WAB 450-I-B-P-65-4-1	+	–	Healthy	–	–	Healthy	+	–	Healthy
RCK1 Gigante	–	–	Healthy	NT	NT	NT	–	–	Healthy
RCK2 IR 47686-15-1-1	–	–	Healthy	NT	NT	NT	–	–	Healthy
RCK3 Morobérékan	–	–	Healthy	NT	NT	NT	–	–	Healthy
SCK1 Bouaké 189	+	+	Attacked	NT	NT	NT	+	+	Attacked
SCK2 BG 90-2	+	+	Attacked	NT	NT	NT	+	+	Attacked
SCK3 IR 1529-680-3	+	+	Attacked	NT	NT	NT	+	+	Attacked

+ Positive chlorosis or ELISA
– Negative chlorosis or ELISA
NT Not tested

- Three NERICA lines (WAB 450-9-2-13-1-HB, WAB 450-B-1A.1, WAB 450-I-B-P-65-4-1), as well as the control resistant lines (Gigante, IR 47686-15-1-1 and Morobérékan), were resistant to all isolates tested (Table 4).
- Five lines were resistant to the isolates from Gagnoa and M'bé.
- The Rym-r-6 isolate from Danané exhibited a wide spectrum of severity since it attacked almost 50% of the NERICA lines. On the contrary, Rym-r-37a from Gagnoa had a narrow spectrum of severity.

Neck rot and brown spot

A high level of neck rot provoked by *Magnaporthe grisea* in Danané and brown spot caused by *Dreschlera oryzae* in Man, gave us the opportunity of evaluating WARDA's elite material under natural infection. Six NERICA lines — WAB 450-I-B-P-153-HB, WAB 450-11-1-P40-HB, WAB 450-I-B-P-138-HB, WAB 450-11-13-P40-HB, WAB 450-I-B-P-91-HB and WAB 488-161-2 — were resistant to neck rot. Many lines showed good levels of resistance to brown spot (5–10% severity), but lines of the WAB 878 series are highly susceptible.

Blast

The screening strategy for blast resistance consists in looking for, among varieties having no vertical resistance to *M. grisea* pathotype, those having horizontal resistance to the epidemic. Such a resistance seems to be a sign of durable resistance. NERICA lines identified in earlier screening schemes and not having vertical resistance were tested at M'bé and Man. Among these, 11 lines (5 at M'bé and 6 at Man) showed good levels of resistance to blast, but only WAB 450-I-B-P-152-1-1 was resistant at both sites.

Rice stem borers

In 1999, the NERICA line WAB 450-I-B-P-181-22-1-HB was reported to have some resistance to African rice gall midge (AfRGM). Species of the stem-borer complex are the most important rice pests in West Africa. Stem-borer larvae feed on the growing points of seedlings, and cause severe crop damage (deadheart) that reduces grain yield. In 2000, we observed stem-borer attack on 19 NERICA lines, and also investigated the possibility of using maize as a trap crop to protect rice against stem borers.

Effect of strip cropping maize with rice on stem-borer attack

In a rainfed upland rice field at WARDA, M'bé, maize (cv EVDT97STRC$_1$) was strip-cropped with 19 NERICA lines (4 rows of maize after 4 rows of each variety). At 84 days after sowing (DAS), 10 randomly chosen maize plants or rice hills per plot were examined and records were taken of the number of stem-borer larvae and the percentage of plants/hills with deadheart symptoms.

There were fewer stem-borer larvae and deadhearts on rice than on maize (Figure 20), indicating that maize may have diverted some stem borers from attacking rice. Among the 19 NERICA lines, WAB 450-I-B-P-91-HB had

NERICA with maize in a typical upland farmer's field.

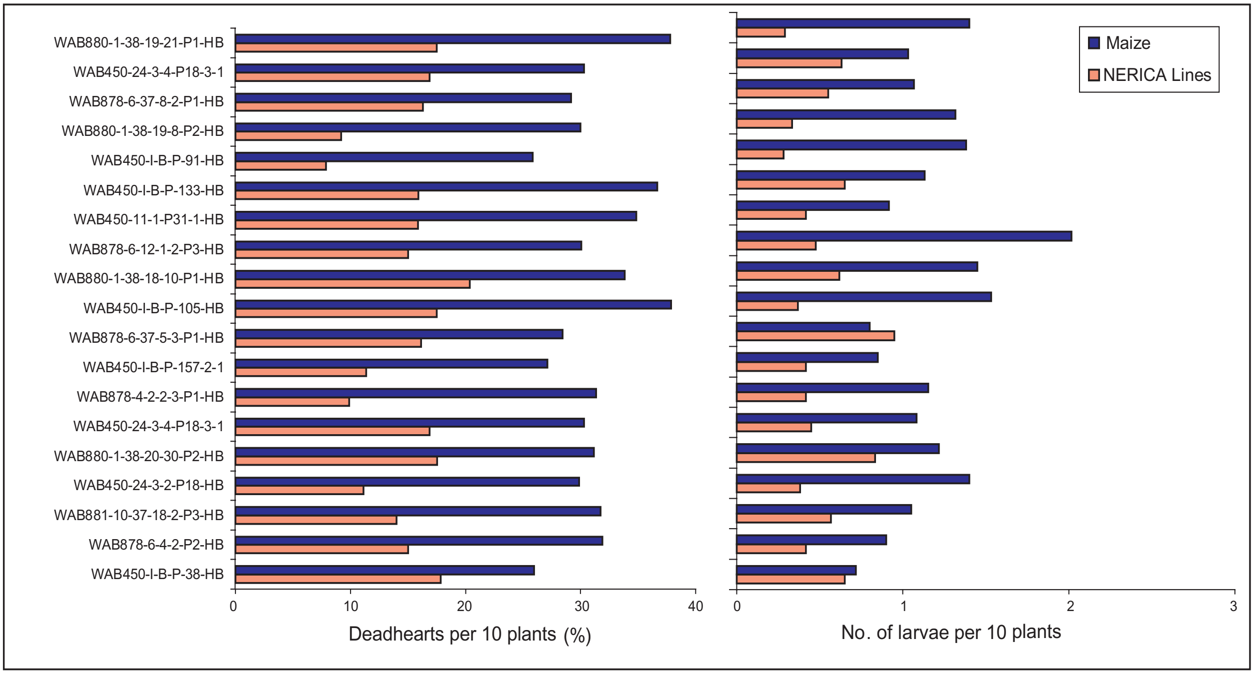


Figure 20. Stem-borer infestation and damage on NERICA lines grown with maize in alternate rows, M'bé, Côte d'Ivoire, wet season 2000.

the fewest larvae per plant, followed by WAB 880-1-38-19-8-P2-HB and WAB 450-I-B-P-105-HB.

Eldana saccharina was the predominant stem borer on maize (90%), followed by *Maliarpha separatella* (5%), *Sesamia calamistis* (3%), *Chilo zacconius* (1%) and *Busseola fusca* (1%). Stem borers on rice were *E. saccharina* (58%), *M. separatella* (26%), *S. calamistis* (6%), *C. zacconius* (5%), *Diopsis longicornis* (4%) and *B. fusca* (1%).

Relative incidence of stem borers on 19 NERICA lines

Stem-borer damage was observed on 19 NERICA lines under natural infestation at M'bé in the wet season (June–October). The improved *O. sativa* variety IDSA 6 was used as a susceptible check. At 28, 56 and 84 DAS, 10 hills of rice were chosen randomly per plot and the percentage of tillers with stem-borer deadhearts was determined and transformed using a 0–9 scale to estimate the level of infestation.

Maliarpha separatella was the dominant stem-borer species. All 19 NERICA lines, except WAB 450-24-3-2-P18-HB, WAB 881-10-37-18-2-P3-HB, WAB 878-6-4-2-P2-HB and WAB 450-I-B-P-38-HB, had fewer stem-borer deadhearts than the susceptible check, WAB 880-1-38-19-21-P1-HB had fewest deadhearts. These results need to be confirmed under artificial infestation in a screenhouse.

NERICA Lines for Lowland Systems

The first generation of crosses between *O. glaberrima* and *O. sativa* were targeted for production in upland systems. In view of their desirable qualities, however, we also evaluated them for adaptability to lowland conditions.

Adaptability of NERICA lines to lowlands

Growth and root characteristics of three NERICA lines — WAB 450-B-9A2.1, WAB 450-11-1-1-P31-HB and WAB 450-I-B-P-65-4-1 — their parents, CG 14 (*O. glaberrima*) and WAB 56-104 (*O. sativa*), and a leading lowland *O. sativa* cultivar in Côte d'Ivoire (Bouaké 189) were compared in a solution culture that simulated lowland conditions. In addition, exudation from stems of the six entries was measured in potted plants grown in lowland soil that was flooded continuously. CG 14 grew much more vigorously than the *O. sativa* and NERICA lines (Table 5). Up to 17 DAS, the NERICA lines were inferior to the *O. sativa* cultivars, but became superior thereafter. Rapid seedling growth is important to suppress weeds in lowland systems where direct-seeding is popular.

Table 5. Crop growth rate (CGR) of seedlings in a crowded nursery bed in water culture.

	CGR (mg/day)		
Line/variety	Seed–12 DAS[1]	12–17 DAS	17–26 DAS
WAB 450-B-9A2.1 (P1)	–0.19	0.74	3.66
WAB 450-11-1-1-P31-HB (P2)	–0.20	1.60	7.28
WAB 450-I-B-P-65-4-1 (P3)	–0.35	1.06	8.03
Bouaké 189	–0.49	2.11	6.99
CG 14	–0.52	2.84	13.16
WAB 56-104	–0.47	1.10	5.58

1. DAS = days after seeding.

CG 14 was outstanding in top growth, compared with the other entries (Figure 21), but root growth was similar in CG 14, Bouaké 189 and WAB 450-I-B-P-65-4-1. CG 14 was much more vigorous than Bouaké 189 in oxygen consumption and root respiration. The performances of Bouaké 189 and WAB 450-I-B-P-65-4-1 were similar for all the parameters measured. Results in soil and solution culture were similar. Respiration rate of submerged roots could be a good indicator of performance in lowland conditions because it is significantly correlated with total plant dry weight. Exudation rate per root dry weight had no correlation with total plant dry weight, and was inadequate as a physiological indicator. We conclude that although CG 14 is classified as an upland variety, it is highly adaptable to lowland conditions and this may explain why one of its progenies, WAB 450-I-B-P-65-4-1, performed as well as Bouaké 189 in the simulated lowland environment.

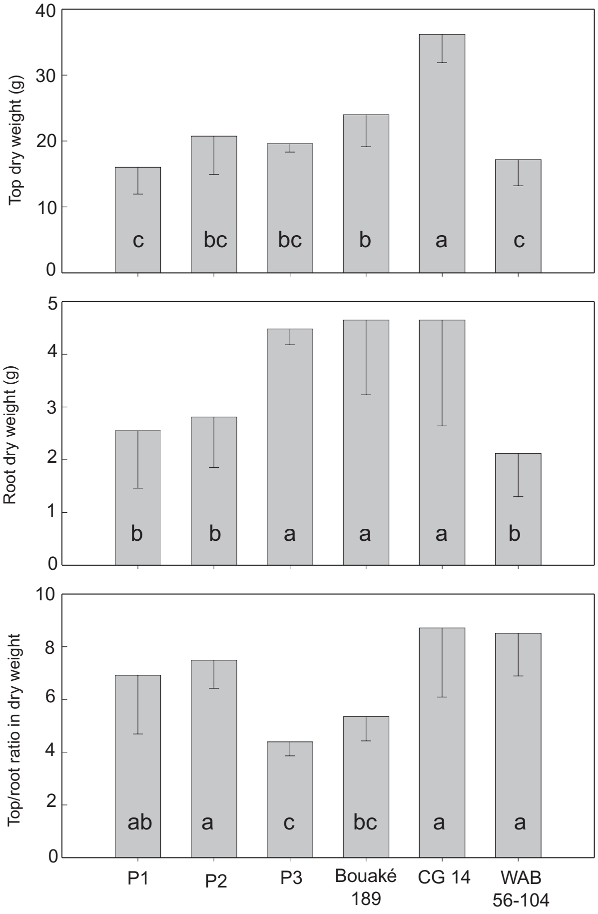


Figure 21. Top dry weight, root dry weight and top/root ratio in the soil. Columns with the same letters are not different at the 0.05 level of probability. P1 = WAB 450-B-9A2-1; P2 = WAB 450-11-1-1-P31-HB; P3 = WAB 450-I-B-P-65-4-1.

Effects of nitrogen fertilizer application and flooding on protein content of NERICA lines

Some NERICA lines have higher protein content than the check *O. sativa* cultivars. We examined the effects of nitrogen-fertilizer application and flooding on the protein content of four NERICA lines with various levels of protein content, and on two *O. glaberrima* and two *O. sativa* cultivars. There were three levels of nitrogen—0, 80 and 120 kg/ha. Rice was transplanted in the flooded plots and direct-seeded in the non-flooded plots.

Grain protein content and yield were generally higher with flooding, almost irrespective of entry (Table 6). Under flooding, protein content increased with the level of applied nitrogen, more so in the high-protein NERICA lines WAB 450-B-1A.1 and WAB 450-I-B-P-167-1-1. In the non-flooded plots, high nitrogen application gave higher yields in all entries, and higher protein content in *O. glaberrima*, but not in the NERICA lines and *O. sativa* (Table 6). WAB 450-B-1A.1 had a high protein content, even when nitrogen was not applied, and is therefore promising as a high-protein lowland variety.

Table 6. Effects of nitrogen application and flooding on grain protein content (dry matter basis) of rice.

	Line[1]		
	N rate[2]	Flooded	Non-flooded
CG14 (G)[1]	High	8.64±0.39	7.28±0.57
	Medium	8.28±0.97	6.48±0.20
	None	8.28±0.52	6.80±0.06
TOG 6642 (G)	High	9.28±0.05	7.73±0.84
	Medium	8.15±0.19	7.00±0.39
	None	7.28±0.65	6.88±0.20
WAB 56-104 (S)	High	9.35±0.77	7.02±0.33
	Medium	8.98±0.38	8.12±0.62
	None	8.52±0.32	Not available[3]
Bouaké 189 (S)	High	7.72±0.39	6.54±0.06
	Medium	7.37±0.16	6.39±0.13
	None	7.53±0.30	6.99±0.23
WAB 450-B-1A.1 (I)	High	10.27±0.42	9.24±0.54
	Medium	9.89±0.37	9.16±0.17
	None	8.94±0.28	9.20±0.03
WAB 450-I-B-P-37-1-1 (I)	High	7.84±0.19	6.06±0.14
	Medium	7.75±0.21	6.13±0.01
	None	7.34±0.26	6.49±0.19
WAB 450-I-B-P-167-1-1 (I)	High	9.32±0.69	7.66±0.28
	Medium	9.11±0.49	7.18±0.11
	None	8.18±0.22	7.67±0.06
WAB 450-I-B-P-65-4-1 (I)	High	8.25±0.16	6.71±0.15
	Medium	7.82±0.64	6.28±0.14
	None	7.81±0.26	6.95±0.27

1. G = *Oryza glaberrima*; S = *O. sativa*; I = Interspecific.
2. High = 120 kg N/ha, Medium = 80 kg N/ha.
3. There were no data due to poor germination.

Progress in farmer participatory varietal selection research in West and Central Africa

The ultimate goal of the participatory varietal selection (PVS) research is to assist in the early and broad dissemination and adoption of NERICA lines by the national agricultural research and extension systems (NARES), development agencies and farmers in WCA, through farmer participation.

Country reports for 1999 trials were submitted during the PRIGA (Participatory Rice Improvement and Gender/User Analysis) 2000 workshop on 17–21 April 2000 at WARDA headquarters, M'bé, Côte d'Ivoire. There were 62 participants from WARDA's NARES partners and several donor representatives. Major issues and concerns were discussed during the workshop and presented in the workshop proceedings, which were published as *Participatory Varietal Selection: The Flame Spreads into 2000.* Of the 90 rice varieties chosen by farmers in 1999, twenty-four were NERICA lines, which were chosen 65 times in 13 countries, with a range of 2–9 times per country (Table 7).

During 2000, PVS trials were continued in all 17 countries, which were at different stages of the PVS process (Table 8). Sixty-one trials were conducted over a range of ecologies (rainfed upland, rainfed lowland, irrigated lowland and mangrove swamp) and topics (varietal evaluation, seed priming, seed preservation and seed multiplication).

A monitoring tour was conducted to Benin, Burkina Faso, The Gambia, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal and Togo, and the trip report was shared with all participating countries. The WARDA team and their NARES counterparts visited the PVS field trials. The quality of the trials visited varied across countries, depending on the environment and the capacity of the NARES. Upland-rice farmers were more concerned with germination and crop establishment, weed competitiveness, grain quality and yield, while irrigated-rice producers were more keen on grain yield and crop duration. Discussions on how to improve future trials were held with the NARES staff. Of particular importance was the need for the NARES to use better criteria for choosing trial sites and participating farmers, and to multiply seed of varieties selected by farmers to ensure that sufficient seed was available at the right time. There are new opportunities for training farmers on seed production. Farmers were generally impressed by the performances of NERICA lines and showed keen interest in participating in future trials.

Table 7. NERICA lines selected by farmers in 13 WARDA member countries after PVS trials on their own farms in 1999[1].

Designation	Benin	Cameroon	Côte d'Ivoire	The Gambia	Ghana	Guinea	Guinea Bissau	Liberia	Mali	Nigeria	Senegal	Sierra Leone	Togo	Total
WAB 450-11-1-1-P31-HB			1	1		1	1		1			1		6
WAB 450-11-1-1-P50-HB									1					1
WAB 450-11-1-2-P41-HB						1	1							2
WAB 450-24-2-3-P33-HB		1					1		1	1	1			5
WAB 450-24-2-3-P38-HB						1		1						2
WAB 450-24-3-4-P18-3-1									1					1
WAB 450-4-1A1.6							1			1				2
WAB 450-I-B-P-91-HB			1											1
WAB 450-I-B-P-105-HB			1	1		1			1	1				5
WAB 450-I-B-P-133-HB					1									1
WAB 450-I-B-P-135-HB			1				1	1		1			1	5
WAB 450-I-B-P-153-HB							1			1				2
WAB 450-I-B-P-157-1-1	1	1												2
WAB 450-I-B-P-160-HB	1				1			1	1	1		1		6
WAB 450-I-B-P-163-4-1		1				1	1			1				4
WAB 450-I-B-P-163-HB						1					1			2
WAB 450-I-B-P-147-HB			1											1
WAB 450-I-B-P-20-HB			1											1
WAB 450-I-B-P-24-HB		1		1		1				1				4
WAB 450-I-B-P-26-HB					1									1
WAB 450-I-B-P-28-HB			1										1	2
WAB 450-I-B-P-33-HB		1					1		1					3
WAB 450-I-B-P-38-HB			1			1						1		3
WAB 450-I-B-P-62-HB		1		1		1								3
Total	2	6	8	4	3	9	8	3	7	8	2	3	2	65

1. Burkina Faso, Chad, Mauritania, and Niger did not participate.

Table 8. PVS activities conducted in 17 WARDA member countries during 2000.

Type of trial	Year 1	Year 2	Year 3	Total
Upland rainfed	4	14	8	26
Lowland rainfed	3	3	0	6
Irrigated lowland	8	7	0	15
Mangrove swamp	1	0	0	1
Seed priming	9	0	0	9
Seed multiplication	3	0	0	3
Seed preservation	1	0	0	1
Total	29	24	8	61

NERICAs spread through community-based seed production system in Guinea and Côte d'Ivoire

Guinea

The spread of NERICA lines in Guinea is an excellent example of rapid technology transfer. The use of a participatory approach involving farmers' indigenous knowledge and seed-exchange pathways has resulted in the planting of five NERICA lines—WAB 450-11-1-1-P31-HB (NERICA 5), WAB 450-I-B-P-28-HB (NERICA 3), WAB 450-I-B-P-91-HB (NERICA 4), WAB 450-I-B-P-20-HB (NERICA 7) and WAB 450-I-B-P-160-HB (NERICA 6)—on 8000 ha within four years of their introduction into the country.

Guinea's national extension agency (*Service national de la promotion rurale et de la vulgarisation*, SNPRV) and research institute (*Institut de recherche agronomique de Guinée*, IRAG) worked closely with farmers to identify the major constraints to the adoption and dissemination of rice varieties. Farmers were involved in farmer-managed trials, participatory varietal selection (PVS) trials, and the community-based seed production system (CBSS). These methodologies allowed farmers to select varieties that were best suited to their localities, and to start seed multiplication and wider dissemination through farmer-to-farmer seed exchange.

The Guinean seed production system is currently being reorganized around the CBSS through the improvement of farmers' seed-saving practices. Yattiah and Kilissi stations of IRAG produce Breeder Seed from which Foundation Seed is multiplied and distributed to Basic-Seed producers located in Upper and Coastal regions of Guinea. In the 1999/2000 dry season, seed of NERICA lines was produced to meet farmers' demand. Figure 22 shows the seed program designed by Guinea with farmers' collaboration. From seed introduced by WARDA and IRAG in 1998, some 130 ha were covered in 1999 (10 ha for Foundation Seed, 20 ha for Basic Seed, and 100 ha for Seed of Acceptable Quality). In 2000, the total coverage was 8000 ha, including 3000 ha spillover into non-project areas. The high multiplication rate was a result of the use of fertilizers and dry-season seed production by farmers. In 2001, Guinean farmers will be able to deliver, to the local communities, sufficient seed for at least 100,000 ha. In 2002, this is expected to increase to more than 200,000 ha—by that time Guinea is expected not only to produce enough seed to meet its own farmers' requirements, but also to export to neighboring countries, where the demand for seed of NERICA lines is also increasing rapidly.

Figure 22. Seed program projection for 1998–2002 in Guinea (ha).

			Seeds of Acceptable Quality		
	Foundation	Basic	1st generation	2nd generation	3rd generation
1998	Introduction from WARDA and IRAG				
1999	**12.5**	**20**	**100**		
2000	**10**	**750**	**1,000**	**3,000**	
2001	**10**	**600**	**10,000**	**20,000**	**60,000**
2002	**10**	**600**	**30,000**	**200,000**	**Paddy**

Côte d'Ivoire

Table 9 shows progress made in seed production in Côte d'Ivoire during 2000. The National Varietal Release Committee in Côte d'Ivoire formally released two NERICA lines (WAB 450-11-1-P31-1-HB [NERICA 2] and WAB 450-I-B-P-38-HB [NERICA 1]) on 20 December 2000 and named them *Keah* (old man) and *Bonfani* (good taste), respectively. Foundation Seed, Basic Seed and Seed of Acceptable Quality of the two NERICA lines were produced. About 438 farmers also produced grain of these progenies on 68.18 ha. About 500 tonnes of the NERICA lines will be available in the following targeted areas: Daloa (Saïoua, Bonon, Zaguiguia, Prikro), Gagnoa (Guessihio, Bogregnoa, Attoniyo), Danané (Mahapleu, Zouampleu, Kassiapleu), and Korhogo (N'Goran, Niofouin). In addition, the national rice project (*Projet national riz*) produced Foundation Seed, innovative farmers and farmers' organizations produced Basic Seed, while farmers produced Seed of Acceptable Quality of four popular varieties (WAB 56-50, Bouaké 189, WITA 1 and WITA 3) and the two NERICA lines. The advantages of the CBSS are:

- the resources of the national seed service are not overstretched, trying to meet the whole country's seed requirements;
- seed can reach farmers within four years from the release of a variety;
- good-quality material is readily available at the community level;
- it allows farmers to share good-quality seed with neighboring farmers who are also producing good-quality seed;
- it facilitates the rapid dissemination of improved varieties as well as local traditional varieties, and can thus foster the conservation of landraces that may otherwise be at risk of extinction;
- it provides savings for farmers in terms of having access to cheaper seed;
- farmers' earlier access to good-quality rice results in better yields, and therefore more income;
- it enables senior technicians, local development agents and farmers to work closely together to solve seed problems;
- it fits well into the system already practised by farmers, and does not therefore require many additional resources;
- it permits the renewal of seed after 3–5 years.

Table 9. Rice seed and paddy produced through community-based seed production system in Côte d'Ivoire during 2000.

	NERICAs		Other varieties			
	WAB 450-11-1-P31-1-HB	WAB 450-I-B-P-38-HB	WAB 56-50	Bouaké 189	WITA 1	WITA 3
Foundation Seed	3.0 ha	10.0 ha	2.2 ha	0	0	0
Basic Seed	1.4 ha	6.2 ha	7.0 ha	0	0	0
No. of farmers	6	6	5	0	0	0
Seed of Acceptable Quality	16.5 ha	51.75 ha	2.3 ha	0.1 ha	0.1 ha	2.1 ha
No. of farmers	428	428	0	1	1	9
Paddy production	16.48 ha	51.70 ha	0	0	0	0
No. of farmers	438	438	0	0	0	0

Contributions from Collaborating Institutions

Institut de recherche pour le développement (IRD), Montpellier, France

Genotyping data showed that, except for the extremity of chromosome 10, the entire *O. glaberrima* genome was conserved in a subset of 50 BC_3F_1 and 2 BC_2F_2 plants. The fragment size was normally distributed between 5 and 50 cM. Several morphological traits were also measured in the glasshouse and QTL analysis, based on a special model using the QGene software, confirmed several loci detected in BC_1F_1 analysis.

Additional mapping and extension of the IR64 × Gigante F_2 population were conducted in order to prepare the high RYMV resistance locus as a candidate for positional cloning. The conversion of PCR resistance marker was used to initiate the transfer of RYMV resistance into three popular but RYMV-susceptible cultivars (BG 90-2, Bouaké 189 and Jaya). At Montpellier, microsatellite markers RM 241 and RM 252 were found to be polymorphic between the three recurrent parents and Gigante. These markers were used to develop BC_2 progenies and BC_2F_2 resistant individuals were selected. BC_3 generations are now being studied for the release of resistant isogenic lines of the three varieties.

International Rice Research Institute (IRRI), Los Baños, The Philippines

Hybrids produced during 1999 between 10 elite breeding lines/varieties of *O. sativa* (3 new plant type lines, 3 upland, and 4 rainfed-lowland cultivars), and 18 accessions of *O. glaberrima* were backcrossed with *O. sativa* as recurrent parent. BC_1F_1 and BC_2F_1 progenies were produced from these cross-combinations. The selfed progenies from BC_2 were grown to select fertile lines with good agronomic characteristics. These materials will now be evaluated for tolerance to biotic and abiotic stresses, and weed competitiveness.

Seeds of 800 advanced backcross progenies (BC_3F_3, BC_4F_2) derived from crosses of *O. sativa* (IR 64, BG 90-2) with *O. glaberrima* accessions were shared with WARDA for evaluation for tolerance to various stresses. Another set of 600 advanced lines was sent to Yunnan Academy of Agricultural Sciences, Kunming, China, for evaluation. In addition, selections were made for high seed fertility and improved plant types from these advanced progenies. IRRI has initiated screening of introgression lines under controlled phytotron conditions for tolerance to abiotic stresses.

IRRI produced a large number of advanced backcross progenies from the crosses of elite breeding lines of *O. sativa* with different accessions of *O. glaberrima*. A subset of 95 mapped microsatellite markers was used for polymorphism survey of two *O. sativa* and 14 accessions of *O. glaberrima*. A high degree of polymorphism was observed: 70% of the markers were polymorphic between *O. sativa* and *O. glaberrima*, while 30% showed polymorphism among *O. glaberrima* accessions. Advanced backcross lines, with *O. sativa* as recurrent parent (BC_2F_3 and BC_4F_3), were characterized for introgression. Of the 67 polymorphic markers, 31 detected introgression from *O. glaberrima* into *O. sativa*. The introgressed segments of *O. glaberrima* were found in homozygous as well as in heterozygous forms in these lines.

No calli were obtained from culture of 45,400 anthers from 75 F_1s from 34 crosses. The other 41 F_1s showed an average of 1.3% callus formation from 144,160 cultured anthers. Plant regeneration ranged from 0 to 77%. Five hundred and sixty-two doubled-haploid (DH) lines were produced and were characterized

Table 10. Callus induction and plant regeneration from anther culture of the F$_1$s of *O. sativa* × *O. glaberrima*.

O. sativa x *O. glaberrima* F$_1$	No. of anthers cultured	No. calli produced/plated	Callus formation (%)	No. of plants regenerated	Plant regeneration (%)[1]
IR 68552-5-3-2 x CG 14	8920	27	0.3	12	44.4
IR 68552-5-3-2 x CG 17	1480	40	2.7	15	37.5
IR 68552-5-3-2 x CG 20	11880	50	0.4	22	44.0
IR 68552-5-3-2 x TOG 5675	6960	46	0.7	18	39.1
IR 68552-5-3-2 x TOG 6472	1960	39	2.0	21	53.8
IR 68552-5-3-2 x TOG 6589	2880	178	6.2	137	77.0
IR 68552-5-3-2 x TOG 7235	2840	6	0.2	-	-
IR 68552-5-3-2 x TOG 7291	4640	56	1.2	23	41.1
IR 68703-AC -24-1 x CG 14	2160	401	18.6	138	34.4
IR 68703-AC-24-1 x CG 17	1520	120	7.9	16	13.3
IR 68703-AC-24-1 x TOG 6472	2240	8	0.4	-	-
IR 68703-AC-24-1 x TOG 7235	1800	60	3.3	10	16.7
IR 60080-46A x IG 10	2080	66	3.2	26	39.4
IR 60080-46A x CG 14	2960	162	5.5	65	40.1
IR 60080-46A x TOG 6631	1760	90	5.1	26	28.9
IR 55423-01 x IG 10	1760	37	2.1	-	-
IR 55423-01 x TOG 5860	920	76	8.3	12	15.8
BG 90-2 x CG 20	1920	55	2.9	10	18.2
BG 90-2 x TOG 7442	2120	8	0.4	-	-
IR 68544-29-2-1-3-1-2 x IG 10	10600	3	0.03	-	-
IR 68544-29-2-1-3-1-2 x CG 14	6320	20	0.3	-	-
IR 68544-29-2-1-3-1-2 x TOG 7442	1240	4	0.3	-	-
IR 65600-81-5-3-2 x TOG 6589	1280	13	1.01	-	-
IR 65600-81-5-3-2 x TOG 5674	4880	4	0.08	-	-
IR 64 x TOG 5860	1000	20	2.0	-	-

1. Plant regeneration (%) $\frac{\text{No. of plants regenerated}}{\text{No. of calli plated}} \times 100$

based on plant morphology. One hundred and thirty-seven plants were obtained from IR 68552-5-3-2 × TOG 6589 and 138 plants from IR 68037-AC-24-1 CG 14, and 65 plants were obtained from IR 60080-46-A × CG 14. The DH lines showed very high seed sterility (56.2–100%). The results indicate strong genotypic differences for anther culturability both for callus induction and plant regeneration. Furthermore, callus induction and plant regeneration from anther-culture were found to be independent of each other (Table 10).

International Center for Tropical Agriculture (CIAT), Cali, Colombia

Thirty-three breeding populations are being developed for use in the upland, rainfed lowland, and irrigated production systems in West Africa. The parent material comprises: BG 90-2 (high-yielding irrigated cultivar with good grain quality and tolerance to RYMV), Lemont (leading long-grain variety from USA with excellent grain and milling quality), Oryzica 3 (long-grain, high-yielding variety from Colombia), Progresso and Caiapo (upland cultivars from Brazil, resistant to several diseases and tolerant of acidic soil conditions), and other improved breeding lines with tolerance to many diseases, high yield potential, and good grain quality.

Reciprocal crosses between CG 14 and WAB 56-104 were made to develop mapping populations for genetic studies on genome introgression.

BG 90-2 was crossed with *O. rufipogon, O. barthii* and *O. glaberrima.* BC_2 populations were developed and seeds of 300 BC_2F_2 families were sent to WARDA. High sterility was observed in the BC_1 and BC_2 populations in crosses involving *O. glaberrima* and *O. barthii.* Although embryo-rescue successfully recovered fertile hybrid plants, the development of improved populations with these two wild species has been slower than with *O. rufipogon.* Only 8 of the 12 new *O. glaberrima* accessions sent by WARDA germinated and IG 10, CG 14 and TOG 5980 were selected for crossing.

Evaluations in the greenhouse showed that *O. barthii* and the *O. glaberrima*s TOG 5486, CG 20, TOG 6405, CG 14, IG 10, TOG 5810, TOG 5980 and TOG 6331 are highly resistant to rice stripe necrosis virus, vectored by *Polymyxa graminis.* Several interspecific populations have been developed from crosses involving *O. glaberrima* and *O. barthii*, and will be screened for tolerance to this virus.

Of 100 NERICA lines received from WARDA, 60% were susceptible to blast, but most were tolerant of leaf scald and *Dreschlera.* Based on field performance and yield potential, 36 lines were selected for further evaluation.

Several NERICA lines showed high levels of resistance to major diseases such as leaf and neck blast (*Magnaporthe grisea*), leaf scald (*Gerlachia oryzae*), brown spot (*Dreschlera oryzae*), and grain discoloration. They also showed tolerance to acidic soil conditions. Some of them had better seedling vigor and earliness than local checks. The lines WAB 450-I-B-P-82-2-1, WAB 450-I-B-P-91-HB, WAB 450-I-B-P-133-HB, WAB 450-I-B-P-6-2-1 and WAB 450-I-B-P-92-3-1 yielded as well as local checks (2 t/ha). However, in terms of grain quality, these NERICA lines do not meet regional consumer preferences for long/slender and translucent grain type. The line WAB-16-2-BL1-DU1-3M- was selected as progenitor in CIAT's crossing program.

Over 300 BC_2F_2 families were derived per cross combination of two improved rice cultivars (BG 90-2 and Caiapo) with *O. rufipogon* and were field-tested. Transgressive segregation was observed for grain yield and yield components. In the cross BG 90-2 × *O. rufipogon*, 16% of the BC_2F_2 families gave higher grain yield than BG 90-2, twenty-two percent had higher 1000-grain weight, 48% showed higher total grain yield per plant, 43% had longer panicles, and 26% had longer grains than BG 90-2.

Molecular markers RM13 and RM242 located on chromosomes 5 and 9, respectively, were associated with alleles derived from *O. rufipogon* that positively affected grain yield.

Of 89 QTLs identified in the cross BG 90-2 × *O. rufipogon*, 18 (26%) were trait-improving alleles derived from *O. rufipogon*, and showed no detectable negative effect on any measured trait. These QTLs can be used immediately for breeding purposes. BC_2F_5 lines, having either consistent yield advantage through several generations or longer/slender translucent grain type than any of the parents, have been selected for testing in national programs. Several BC_2F_6 lines resistant to rice blast were also selected.

In conclusion, parallel studies using the advanced-backcross analysis provide strong evidence that certain regions of the rice genome are likely to harbor genes of interest for the improvement of cultivated rice in multiple environments.

Cornell University, Ithaca, USA

The aim of the interspecific hybridization study at Cornell University is to: (1) investigate the possibility of using microsatellites or SSLPs to characterize the diversity of *O. glaberrima*; and (2) use these markers in a molecular breeding strategy aimed at developing improved rice varieties for WCA. During the year, Mr Semon Mandé, a PhD student from WARDA, was trained at the laboratory of Dr Susan McCouch. A summary of his findings is presented under "Use of molecular markers to evaluate genetic diversity in *Oryza glaberrima*" above (page 9).

Yunnan Academy of Agricultural Sciences (YAAS), Kunming, China

Eighteen of WARDA's NERICA lines introduced in 1998 were evaluated in Beijing, Shandong and Henan provinces. WAB 450-11-1-2-P61-HB performed well in all three provinces, while WAB 450-11-2-BL1-DR, WAB 450-11-1-3-P40-HB, WAB 450-I-B-P-91-HB and WAB 450-I-B-P-160-HB performed well in two provinces.

Based on pollen grain and spikelet fertility of test-crosses, the ability of WAB 450-11-1-3-P40-HB, WAB 450-11-1-2-P61-HB, WAB 450-I-B-P-91-HB, IRAT 216, and IRAT 359 to restore Dian 1 type cytoplasm male-sterile (CMS) Dianyu 1A (cms-D), and BT type CMS Qiuguang A (cms-boro) was confirmed (Table 11).

Dianyu 1A/WAB 450-11-1-2-P61-HB//Dianyu 1B (BC_1F_1) pollen-grain fertility had a continuous bimodal distribution. Sterility and fertility fit a 1:1 segregation ratio (highly significant); Dianyu 1A.IRAT216//Dianyu 1B (BC_1F_1) pollen grain fertility showed a discontinuous bimodal distribution. Sterility and fertility fit a 1:1 segregation ratio. The results of both crosses indicated that a single dominant gene controlled the restoring ability of WAB 450-11-1-2-P61-HB and IRAT 216. Since F_1 and BC_1F_1 fertile plants had about 50% pollen-grain fertility, and F_1 plants had normal spikelet fertility, sterility of Dianyu 1A and Qiuguang A was gametophytic.

Restoring ability of WAB 450-11-1-3-P40-HB, WAB 450-11-1-2-P61-HB, WAB 450-I-B-P-91-HB, IRAT 216 and IRAT 359 was transferred to Dianyu 1A background, using Dianyu

Table 11. Pollen grain and spikelet fertility of hybrids between progenies of interspecific hybridization and cytoplasm male-sterile lines.

	Qiuguang A/		Dianyu 1A/	
Male parent	Pollen grain fertility (%)	Spikelet fertility (%)	Pollen grain fertility (%)	Spikelet fertility(%)
WAB 450-11-1-3-P40-HB	29.92	80.38	41.98	82.24
WAB 450-11-1-2-P61-HB	49.40	76.51	44.69	79.96
WAB 450-I-B-P-91-HB	31.38	82.35	41.23	79.61
WAB 56-104	12.02		3.96	
IRAT 104	29.71	73.93	15.80	2.49
IRAT 216	21.96	75.01	49.18	75.01
IRAT 359	63.34	80.18	58.77	83.17
C 57(Rf-1)			35.92	90.71

Table 12. Pollen grain fertility (%) of hybrids between interspecific hybridization progenies and their parents.

	Parents	
Interspecific progeny	WAB 56-104	CG 14
WAB 450-I-B-P-135-HB	59.87	2.65
WAB 450-11-1-1-P50-HB	54.58	7.41
WAB 450-I-B-P-153-HB	66.05	1.72
WAB 450-11-2-BL1-DR1	55.19	3.47
WAB 450-I-B-51-1-1	91.18	0.97
WAB 450-24-2-3-P33-HB	48.95	2.61
WAB 450-24-3-2-P18-HB	79.72	0.00
WAB 450-I-B-P-160-HB	51.60	3.17
WAB 450-11-1-3-P40-HB	96.21	0.33
WAB 450-I-B-P-28-HB	53.17	2.70
WAB 450-24-2-5-P4-HB	53.24	1.33
WAB 450-I-B-P-38-HB	74.36	1.86
WAB 450-11-1-2-P61-HB	97.59	1.22
WAB 450-I-B-P-91-HB	97.07	1.49
WAB 450-I-B-P-24-HB	62.65	0.39

1A as maternal parent and advanced to BC$_3$F$_1$ generation. WAB 450-11-1-1-P50-HB and WAB 450-24-3-3-P37-HB maintained the sterility of Dianyu 1A.

Pollen-grain fertility of 17 interspecific crosses between *O. glaberrima* and *O. sativa* subsp. *japonica* cultivars was zero. Typical abortion and empty abortion averaged about 50%. Pollen-grain fertility for interspecific BC$_1$F$_1$ was usually low.

Eleven of 20 crosses between WAB 56-104 and progenies of WAB 56-104/CG14//WAB 56-104///WAB 56-104 were semi-sterile, indicating that some progenies had sterile gene(s) introgressed from *O. glaberrima* cultivar CG 14.

When 15 progenies of WAB 450 were backcrossed to their two parents, WAB 56-104 and CG 14, most F$_1$ hybrids with the Asian cultivated rice parent WAB 56-104 were semi-sterile. All F$_1$ hybrids with the African cultivated rice parent CG 14 had very low pollen grain fertility, but they usually gave some fertile pollen grains (Table 12).

Figure 23 indicates that pollen-grain fertility of progenies with WAB 56-104 was significantly negatively related to pollen fertility of progenies with CG 14.

Some crosses combined the high yield potential of Yunnan *japonica* rice and the strong vegetative vigor and resistance of wild or African cultivated rice species. In 2001, these materials will be selected under Yunnan conditions.

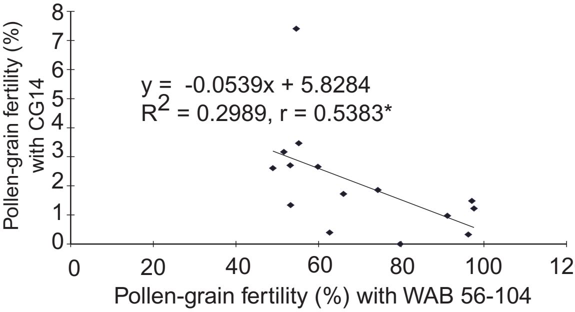


Figure 23. Relationship between pollen-grain fertility of hybrids with CG14 and WAB 56-104.

About WARDA

The West Africa Rice Development Association (WARDA) was formed as an autonomous intergovernmental research association in 1971 by 11 countries, with the assistance of the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO), and the Economic Commission for Africa (ECA). Today, the Association comprises 17 member states: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo. Since 1987, WARDA has also been a member of the Consultative Group on International Agricultural Research (CGIAR), a network of 16 international research centers supported by more than 50 public- and private-sector donors.

WARDA's mission is: to contribute to food security and poverty alleviation in poor rural and urban populations, particularly in West and Central Africa, through research, partnerships, capacity strengthening and policy support on rice-based systems, and in ways that promote sustainable agricultural development based on environmentally sound management of natural resources.

WARDA's research and development activities are carried out in collaboration with the national agricultural research systems of members states, academic institutions, international donors and other organizations, to the ultimate benefit of West and Central African farmers—mostly small-scale producers—who cultivate rice, as well as the millions of African families who eat rice as a staple food.

WARDA Headquarters are at M'bé, 25 km north of Bouaké, a major commercial center in Côte d'Ivoire. WARDA also operates research stations at N'Diaye, near Saint Louis, Senegal, and at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Donors to WARDA in 2000 were: the African Development Bank, Belgium, Canada, CGIAR (Finance Committee), Common Fund for Commodities (CFC), Côte d'Ivoire, Denmark, the Food and Agriculture Organization of the United Nations (FAO), France, the Gatsby Foundation (UK), Germany, the International Development Research Centre (Canada), the International Fund for Agricultural Development, Japan, the Netherlands, Norway, the Rockefeller Foundation (USA), Sweden, the United Kingdom, UNDP, the United States of America, the World Bank and WARDA member states.

About CGIAR

The Consultative Group on International Agricultural Research (CGIAR) was founded in 1971 as a global endeavor of cooperation and goodwill. The CGIAR's mission is to contribute to food security and poverty eradication in developing countries through research, partnership, capacity building and policy support, promoting sustainable agricultural development based on the environmentally sound management of natural resources. The CGIAR works to help ensure food security for the twenty-first century through its network of 16 international and autonomous research centers, including WARDA. Together, the centers conduct research on crops, livestock, fisheries and forests, develop policy initiatives, strengthen national agricultural organizations, and promote sustainable resource management practices that help provide people world-wide with better livelihoods.

The CGIAR works in partnership with national governmental and non-governmental organizations, universities and private industry. The United Nations Development Programme, the United Nations Environment Programme, the World Bank, and the Food and Agriculture Organization of the United Nations sponsor the CGIAR. The CGIAR's 57 members include developing and developed countries, private foundations, and international and regional organizations. Developing world participation has doubled in recent years. All members of the OECD (Organisation for Economic Co-operation and Development) Development Assistance Committee belong to the CGIAR.

The CGIAR is actively planning for the world's food needs well into the twenty-first century. It will continue to do so with its mission always in mind and with its constant allegiance to scientific excellence.

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