

Part 2:
**Workshop full papers on Breeding for
blast resistance and the process of
varietal diffusion**

Selection of intra-specific (*Oryza sativa* × *O. sativa*) and inter-specific (*O. sativa* × *O. glaberrima*) lines for their tolerance to blast in Burkina Faso

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Abstract

Three types of rice cropping systems are practiced in Burkina Faso: rain-fed upland, irrigated lowland and rain-fed lowland. This last type is practiced over 70% of the cultivated land and provides 48% of the country's rice production. However farmers are progressively abandoning some inland valleys because of the poor spatio-temporal distribution of rains and the high disease pressure, particularly blast and Rice Yellow Mottle Virus (RYMV).

Blast (*Magnaporthe grisea*) is one of the most damaging constraints for rice-growers in West Africa in general and in Burkina Faso in particular because of the ever-increasing yield losses. This is why finding donors with long-lasting resistance or cultivars with a good tolerance level in field conditions is a priority.

This study was designed to identify ideotypes adapted to inland valleys. It was based on the agromorphological characterisation of 76 intraspecific (*O. sativa* × *O. sativa*) lines and 493 interspecific (*O. sativa* × *O. glaberrima*) lines obtained after 18 crosses in 2000. They were tested in the Banfora rain-fed lowland during the 2000, 2001 and 2002 rainy seasons. At the end of the first season, 96 lines were selected (14 intra- and 77 interspecific) and were grown under the same conditions in 2001. Fifteen lines were then selected (6 intraspecific from 6 crosses, and 9 interspecific from 4 crosses). These lines were tested under rain-fed lowland and irrigated conditions in the irrigated plain of Karfiguéla during the 2002 rainy season. The design used was a modified DITER as described by Notteghem (1977), using IR 50 as the susceptible control for blast, BG 90-2 for RYMV, and ITA 306 for gall midge.

The lines showed low susceptibility to disease and insect attacks. The scores obtained with these lines were well below 5 for blast and RYMV for the 2000 rainy season. The individual crosses that seemed to be most susceptible to blast during this first year were WAS 127 and WAS 131 (*O. glaberrima* × *O. sativa*) and WAS 115 (*O. sativa japonica* × *O. sativa indica*).

At the end of the 2001 rainy season, 15 lines (6 intraspecific and 9 interspecific) obtained from 10 crosses were selected. This selection was based on the genotypes with a good resistance level to diseases such as blast and RYMV, to insects (stem borers and gall midge), and which also had the following agronomic characteristics: short cycle duration, resistance to lodging, good yield potential, and good grain quality.

This study dealt with the adaptability of the different genotypes to inland valley rice cropping (as based on the evaluation of the agronomic characteristics), and with the tolerance to diseases (blast and RYMV) and insects (stem borers and gall midge), which involves a number of genes controlling these complex characters. Marker-assisted selection opens new ways to identify, select and transfer the genes that are linked to blast resistance. This will be a convenient way to save time and money in the implementation of our objectives.

Résumé

Trois types de riziculture sont pratiqués au Burkina Faso : la riziculture pluviale stricte, la riziculture irriguée avec maîtrise de l'eau et la riziculture de bas-fond. Cette dernière occupe 70 % des superficies cultivées et assure 48 % de la production rizicole du pays. Cependant, la mauvaise répartition spatio-temporelle des pluies et la forte pression parasitaire notamment la pyriculariose et la virose contraignent les populations rurales à abandonner progressivement certains bas-fonds.

La pyriculariose (*Magnaporthe grisea*) est une des plus importantes contraintes pour les riziculteurs ouest-africains en général et burkinabé en particulier en raison de l'importance sans cesse croissante des

peres occasionnées. C'est pour cette raison que la recherche de donneurs pour la résistance durable ou de cultivars dotés d'un bon niveau de tolérance en milieu réel se révèle comme une priorité.

L'étude a eu à identifier des idéotypes capables de s'adapter aux conditions de bas-fond à partir d'une caractérisation agromorphologique de 76 lignées intraspécifiques (*O. sativa* × *O. sativa*) et 493 lignées interspécifiques (*O. glaberrima* × *O. sativa*) issues de 18 croisements. Elles ont été testées en condition de bas-fond à Banfora durant les saisons humides 2000, 2001 et 2002. A l'issue de la première campagne, 96 lignées ont été retenues (14 intra et 77 inter) et ont été conduites dans les mêmes conditions en saison humide 2001 ; 15 lignées ont été retenues (6 intraspécifiques issues de 6 croisements, et 9 interspécifiques issues de 4 croisements). Ces lignées ont été testées en condition de bas-fond et en condition irriguée (plaine irriguée de Karfiguéla) en hivernage 2002. Le dispositif utilisé est le DITER modifié mis au point par Notteghem en 1977 avec IR 50 comme témoin sensible à la pyriculariose, BG 90-2 pour la RYMV et ITA 306 pour la cécidomyie.

Les lignées ont manifesté une faible sensibilité vis-à-vis des maladies et des attaques d'insectes. Les notes obtenues sur les lignées ont été largement inférieures à 5 pour la pyriculariose et la panachure jaune en saison humide 2000. Les individus *O. glaberrima* × *O. sativa indica* (croisement WAS 127, WAS 131) et *O. sativa japonica* × *O. sativa indica* (WAS 115) paraissent les plus sensibles à la pyriculariose lors de la première campagne.

A l'issue de la campagne hivernale 2001, 15 lignées issues de 10 croisements dont 6 intraspécifiques et 9 interspécifiques ont été retenues. Cette sélection a porté sur les génotypes dotés d'un bon niveau de résistance aux maladies que sont la pyriculariose et la virose, aux insectes (foreurs de tiges et cécidomyie) et présentant les caractères agronomiques souhaités : précocité, résistance à la verse, bonne aptitude au rendement et bonne qualité de grain.

Cette étude a abordé à la fois l'adaptabilité des différents génotypes à la riziculture de bas-fond (sur la base de l'évaluation des caractères agronomiques), la tolérance aux maladies (pyriculariose et panachure jaune) et aux insectes (foreurs de tiges et cécidomyie), ce qui met en jeu un ensemble de gènes contrôlant ces caractères complexes. La sélection assistée par marqueurs moléculaires qui fera appel à la biologie moléculaire offre de nouvelles voies pour identifier, sélectionner et transférer les gènes impliqués dans la résistance à la pyriculariose. Ainsi l'on pourra gagner du temps et sauver de l'argent pour la réalisation de nos objectifs.

Introduction

In Burkina Faso, rice cropping has been showing an unforeseen expansion in the last two decades, although its development has remained relatively low compared with other cereals. In fact, the area grown in rice is only 1.8% of the total area grown in cereals. Rice ranks fourth after sorghum, millet and maize in both cropping area and production (PSSA 1999). In Burkina Faso, the consumption per inhabitant, which was estimated at 4.5 kg/year in 1960, reached 8.5 kg/year in 1980 and 18.5 kg/year in 2000 (GBIKPI 1996, cited in Causse *et al.* 1997).

Rice production reached 97 000 tons in 1996–98; and will need to yield 305 000 tons of paddy in 2010 to meet a 10% yearly increase (Ministère de l'Agriculture 1999).

In the last 10 years, imports have reached 851 130 tons, corresponding to 130 385 million Fcfa. The mean yields increased from 0.8 t/ha in 1970 to 2.2 t/ha in 1998 (Traoré 2000).

Three types of rice cropping systems are practiced in Burkina Faso: rain-fed upland, irrigated lowland and rain-fed lowland. This last type is practiced over 70% of the cultivated land and provides 48% of the country's rice production (Sié 1999). The country has a high potential in rain-fed lowlands, especially in the south where annual rainfalls reach and often exceed 1000 mm.

The country's low rice yield is mainly due to socioeconomic, climatic and biotic constraints, but diseases also cause high yield losses. This is why the instability of resistance to blast is the main flaw in the introduced material as it leads to discarding of varieties a few years after their release. In addition, some new diseases such as Rice Yellow Mottle Virus (RYMV) have recently appeared and become a threat for the varieties currently cultivated under irrigated and rain-fed lowland conditions.

Within the scope of biodiversity extension, WARDA has implemented a number of interspecific crosses: *O. glaberrima* × *O. sativa japonica* for rain-fed upland conditions and *O. glaberrima* × *O. sativa*

indica for irrigated conditions. The new lines will have to be tested in the rain-fed lowland rice-cropping system in Burkina Faso.

The objective of this study was the testing of intra- and interspecific lines to identify the ideotypes adapted to rain-fed lowland rice-cropping; evaluation was based on their agromorphological characteristics and their resistance to diseases and insect attacks.

Material and methods

The experiment was held in the irrigated part of the Banfora rain-fed lowland in the Comoé area. It is a rudimentary system with buried compacted bunds.

The Comoé area has a climate of the south-sudanian type (Guinko 1984) tending to sudanian-guinean in the far south. Two seasons can be distinguished: a rainy season from April to October, and a dry season from November to March.

As it is situated between the 1000 and 1200 mm isohyets (CRPA 1994) the Comoé area is in the better-watered zone in Burkina Faso. From 1951 to 2000, the mean rainfalls in the Banfora area reached 1030 mm, and in the 2000 rainy season, 1200 mm. Most of the precipitation falls between June and September over 50 to 70 days of rain.

The rain-fed lowland soils are hydromorphic to pseudogley. Their texture is of a clay-loam type and the pH is between 3.5 and 5.4.

Vegetal material

The study aimed at testing these lines under rain-fed lowland conditions and at identifying the ideotypes adapted to that cropping system; it was based on the agromorphological characterisation of 76 intraspecific lines (*O. sativa* × *O. sativa*) and 493 interspecific lines (*O. glaberrima* × *O. sativa*) descended from 18 crosses. Their susceptibility to the main rice diseases, including blast and RYMV, was observed.

At the end of the 2000 rainy season, 91 lines (14 intraspecific and 77 interspecific) were selected. These lines were grown under the same conditions in 2001 after which 15 lines (6 intraspecific and 9 interspecific) descended from 10 crosses were selected. The 15 lines were tested in the Banfora valley in 2002. Tables 1 and 2 show the different crosses performed.

From the beginning, the lines originating in Saint-Louis (Senegal) were screened in semi-artificial conditions for RYMV susceptibility. The infesting border was made with a mixture of IR 50 and WITA 8, which are respectively susceptible to blast and RYMV.

Experiment management

Sowing was performed on two 2.4 m-long rows for each line. Sowing was direct using three seeds per planting hill separated by interspaces of 0.25 m × 0.25 m.

Sowing was implemented after a fertilisation of 200 kg/ha of NPK. Later 150 kg/ha of NPK were supplied in three 50 kg/ha applications: (1) just after the first weeding, (2) at the panicle initiation stage at 65–70 days after sowing (DAS), and (3) at booting stage. The infesting border was fertilised with 300 kg/ha of urea spread in three applications of 100 kg/ha each.

Experimental design

The experiment was run in a minor riverbed in the Banfora rain-fed lowland following a DITER design (Decreasing Inoculum Test for the Evaluation of Resistance) as fine-tuned by Notteghem in 1977. The lines to be tested and the controls were transplanted on two rows each, perpendicular to the infesting border in order to homogenise the spread of the disease and to assess the resistance level of the different lines. Controls were sown every 50 lines in order to assess the pressure level of the disease.

Table 1. Interspecific crosses.

| Designation of cross | Type of cross [†] | Parents | No.of lines | Generation |
|----------------------|---|---|----------------|--|
| WAB 878 | <i>O. glaberrima</i> × <i>O. sj</i> | CG 14/IRAT 144 | 3 14 | F ₅ F ₆ |
| WAB 880 | <i>O. glaberrima</i> × <i>O. sj</i> | CG 14/WAB 56-50 | 18 46 | F ₅ F ₆ |
| WAB 881 | <i>O. glaberrima</i> × <i>O. sj</i> | CG 20/IRAT144 / | 2 16 | F ₅ F ₆ |
| WAS 122 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/3* IR 64 | 2 24 111 | F ₃ F ₄ F ₅ |
| WAS 124 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/3* IR 1529-680-3-2 | 25 8 | F ₄ F ₅ |
| WAS 126 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/2* IR 64 // IR 31785-58-1-2-3-3 | 41 | F ₅ |
| WAS 127 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/2* IR 64 // IR 31851-96-2-3-2-1 | 2 21 43 | F ₃ F ₄ F ₅ |
| WAS 131 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5674/3* IR 31785-58-1-2-3-3 | 16 4 | F ₄ F ₅ |
| WAS 161 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/ 4* IR 64 | 2 18 | F ₃ F ₄ |
| WAS 162 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/ 4* IR 1529 | 1 8 | F ₃ F ₄ |
| WAS 163 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5674/ 4* IR 31785 | 4 | F ₄ |
| WAS 164 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5675/ 3* IR 28 | 22 | F ₃ |
| WAS 186 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/ 5* IR 64 | 1 7 | F ₃ F ₄ |
| WAS 187 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5681/ 5* IR 1529 | 4 | F ₄ |
| WAS 189 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 5675/ 4* IR 28 | 5 | F ₄ |
| WAS 190 | <i>O. glaberrima</i> × <i>O. si</i> | TOG 7291/ 3* ITA123 | 6 | F ₄ |
| WAS 191 | (<i>O. si</i> × <i>glaberrima</i>) × <i>O. si</i> | IR 64 / TOG 5681 // 4* IR 64 | 16 | F ₄ |
| WAS 192 | (<i>O. si</i> × <i>glaberrima</i>) × <i>O. si</i> | IR 31785 / TOG 5674 // 4* IR 31785-58-1-2-3-3 | 3 | F ₄ |

† *O. si* = *Oryza sativa indica*; *O. sj* = *Oryza sativa japonica*.

Table 2. Intraspecific crosses.

| Designation of cross [†] | Type of cross | Parents | No. of lines | Generation |
|-----------------------------------|-----------------------------|--|--------------|----------------|
| WAT 1174 -B | <i>O. sj</i> × <i>O. si</i> | ITA 123 / TOX 3226-5-2-2-2 | 1 | F ₄ |
| WAT 1176 -B | <i>O. sj</i> × <i>O. si</i> | ITA 123 / ITA 414 | 1 | F ₄ |
| WAT 1181 -B | <i>O. si</i> × <i>O. si</i> | ITA 416 / TOX 3226-5-2-2-2 | 1 | F ₄ |
| WAT 1184 -B | <i>O. si</i> × <i>O. si</i> | TOX 3093-35-2-3-3 / ITA 414 | 13 | F ₄ |
| WAT 1187-B | <i>O. si</i> × <i>O. si</i> | TOX 3058-52-2-2-3-2 / ITA 414 | 1 | F ₄ |
| WAT 1189 -B | <i>O. si</i> × <i>O. si</i> | TOX 3093-35-2-3-3 / TOX 3226-5-2-2-2 | 1 | F ₄ |
| WAT 1191 -B | <i>O. si</i> × <i>O. si</i> | TOX 3093-35-2-3-3 / ITA 414 | 1 | F ₄ |
| WAT 1193 -B | <i>O. si</i> × <i>O. si</i> | TOX 3093-35-2-3-3 / TOX 3876-56-1-4 | 1 | F ₄ |
| WAT 1123 | <i>O. si</i> × <i>O. si</i> | TOX 3090-135-1-3-2-2 / CISADANE// CK 73 / MATCANDU | 1 | F ₄ |
| WAT1223 -B | <i>O. si</i> × <i>O. si</i> | TOX 3399-108-3-3-2 / SPT 7106-2-3-3-1 | 1 | F ₄ |
| WAT 1224 -B | <i>O. si</i> × <i>O. si</i> | TOX 3399-108-3-3-2 / IR 48028-B-B-126-3 | 1 | F ₄ |
| WAT 1249 -B | <i>O. si</i> × <i>O. si</i> | TOX 3093-4-5-1-1 / TOX 3162-11-1-2-1-1 | 1 | F ₄ |
| WAT 1273 -B | <i>O. si</i> × <i>O. si</i> | BW 348-1 / TOX 3233-46-3-3-4-2-2 | 1 | F ₄ |
| WAT 1275 -B | <i>O. si</i> × <i>O. si</i> | SURASHA / TOX 3233-46-3-3-4-2-2 | 1 | F ₄ |
| WAT 1281 -B | <i>O. si</i> × <i>O. si</i> | PHALGUNA / TOX 3876-58-1-2 | 1 | F ₄ |
| WAS 97 | <i>O. sj</i> × <i>O. sj</i> | LAC 23 / ITA 123 | 4 | F ₄ |
| WAS 99 | <i>O. sj</i> × <i>O. si</i> | FOFIFA 62 / IR 64 | 1 | F ₆ |
| WAS 105 | <i>O. sj</i> × <i>O. si</i> | IR 47686-15-1-1 / BG 90-2 | 3 | F ₆ |
| WAS 106 | <i>O. sj</i> × <i>O. si</i> | ITA 305 / IR 32307-107-3-2-2 | 1 | F ₃ |
| WAS 107 | <i>O. sj</i> × <i>O. si</i> | ITA 305 / BG 90-2 | 4 | F ₆ |
| WAS 108 | <i>O. sj</i> × <i>O. si</i> | FOFIFA 62 / IR 1529-680-2-3 | 1 | F ₃ |
| WAS 110 | <i>O. sj</i> × <i>O. si</i> | FOFIFA 62 / JAYA | 5 | F ₆ |

| | | | | |
|---------|---|---|---|----------------|
| WAS 112 | <i>O. sj</i> × <i>O. si</i> | LAC 23 / BG90-2 | 1 | F ₃ |
| WAS 114 | <i>O. sj</i> × <i>O. si</i> | ITA 305 / IR 13240-2-2-3 | 8 | F ₅ |
| WAS 115 | <i>O. si</i> × <i>O. sj</i> | BG 90-2 / ITA 305 | 1 | F ₃ |
| WAS 116 | <i>O. si</i> × <i>O. si</i> | GIGANTE / BG 380-2 | 1 | F ₃ |
| WAS 117 | <i>O. si</i> × <i>O. si</i> | JAYA / GIGANTE | 1 | F ₃ |
| WAS 121 | <i>O. sj</i> × <i>O. si</i> | ITA 305 / BG 380-2 | 4 | F ₅ |
| WAS 129 | (<i>O. sj</i> × <i>O. si</i>) × <i>O. si</i> | FOFIFA 62/BG90-2 // IR 13240-108-2-2-3 | 6 | F ₅ |
| WAS 137 | <i>O. sj</i> × <i>O. si</i> | LAC 23/BG 90-2 // IR 28 | 1 | F ₃ |
| WAS 138 | <i>O. sj</i> × <i>O. si</i> | LAC 23/BG 90-2 // IR 64 | 1 | F ₃ |
| WAS 140 | <i>O. sj</i> × <i>O. si</i> | FOFIFA 62// 2*IR 1529-680-3-2 | 1 | F ₃ |
| WAS 141 | <i>O. sj</i> × <i>O. si</i> | ITA 305 / BG 380-2 // IR 32307-107-3-2-2 | 1 | F ₃ |
| WAS 142 | (<i>O. sj</i> × <i>O. si</i>) × <i>O. si</i> | ITA 305 / IR 13240-108-2-2-3 // IR 31785-58-1-2-3-3 | 1 | F ₅ |
| WAS 146 | (<i>O. si</i> × <i>O. sj</i>) × <i>O. si</i> | BG 90-2 / ITA 305 // ITA 306 | 1 | F ₅ |
| WAS 151 | (<i>O. sj</i> × <i>O. sj</i>) × <i>O. si</i> | LAC 23/ITA 123 // IR 1529-680-3-2 | 1 | F ₅ |

† *O. si* = *Oryza sativa indica*; *O. sj* = *Oryza sativa japonica*.

The infesting border, sown along four continuous rows, was composed of a mixture of two varieties, one susceptible to blast (IR 50) and the other susceptible to RYMV (BG 90-2). The infesting border was sown 1 week before the varieties to be tested.

Observations

The agromorphological parameters observed were:

- mean number of tillers per seedling 60 days after sowing (T60)
- mean height of the mature plants (MH)
- sowing to heading duration (SHD)
- sowing to maturity duration (SMD)
- number of panicles per meter (P/M)
- panicle length (PL)
- panicle weight (PW)
- yield (Y)
- sterility level (St)
- number of dead hearts (DH)
- number of onion tubes (OT).

The assessment of the diseases was implemented as follows:

Rice blast

In order to assess blast in this study, we considered the 12 planting hills that made a row while the lines were distributed in two distinct batches of six seedlings each:

- Batch 1 of the row was set on the alleyway side and covered the first to the sixth planting hills.
- Batch 2 was set on the infesting border side and covered all the other rice plants, from the seventh to the twelfth hills.

The scoring was made from the tenth day after the outbreak of the first lesions (DAO) on the infesting border for leaf blast (corresponding to 30 DAS) and from the fifteenth day after heading (DAH) for neck blast (corresponding to 95 DAS). The INGER–IRRI (1996) Standard Evaluation System (SES) was used.

RYMV

To determine the RYMV level of infestation on the intra- and interspecific lines, the severity of the disease was scored at 30 DAS and 95 DAS with the evaluation system of varietal resistance to RYMV developed by IITA.

Measurement of the water table fluctuations

Two piezometers placed next to the two adjacent plots were used to measure the water table level every day during the entire vegetative cycle

Data analysis

Statistical analysis of the agromorphological and entomological data was performed with Genstat and Statistica. Excel was used for the phytopathological data and the fluctuations of the water table.

Results and discussion

Fluctuation of the water table

In the Banfora area, the rainy season is well under way in June, which is when its effects on the water table become perceptible. However, in our study, the follow-up of the water table was possible only from 19 July 2001. The results obtained show firstly, that the variations of the water table are dependent on the inland valley topological sequence (minor riverbed, slope bottom). The observations also show that the fluctuations of the water table during the rainy season can be schematised into three successive phases both at the level of the minor riverbed and at the bottom of the hill: a rising phase, a flooding phase, and a drying up phase.

Agromorphological evaluation of the lines

The projection of the individuals shows a distribution of the intra- and interspecific lines on axes 1 and 2 of the Principal Component Analysis (Figure 1). On axis 1, two line groups can be distinguished: there is a high concentration of lines on the positive side of axis 1 close to 0 and over the first centimeters on the negative side. Thus, two groups of lines can be distinguished on axis 1.

Group I is situated in the positive part and in the first centimeters of the negative side of the axis: it groups most of the vegetal material studied. This group contains lines with average to high levels of tillering, short compact and heavy panicles, with a seeding–heading cycle of average length.

Group II is situated at the negative end part of axis 1. The lines in this group are characterised by a low level of tillering, relatively long and meager panicles with a short seeding–heading cycle.

On the basis of their agromorphological characters and of their reaction to diseases and pests, 15 lines were selected and assessed in the third year (2002 rainy season).

The analysis of variance of the yields showed a non-significant difference with a coefficient of variance of 18.59 and a mean of 2937 kg/ha. The best variety was WAS 129-B-IDS-A-B-WAS 1-1-FKR B-B, which yielded 3912 kg/ha.

Line screening for blast and RYMV

The parasite pressure was moderate over the three years. The IR 50 used in the infesting border showed very strong signs of neck blast, scored up to 7.

For the families from the crosses WAB 880 and WAB 881, the leaf blast scores (at 30 DAS) were identical for the two areas of observation: 0.11 on the alley side (B1) and 0.13 on the infesting border side (B2); the neck blast scores (at 95 DAS) were 0 for both B1 and B2. For the lines from the WAB 878 crossing, the leaf blast scores (at 30 DAS) were 0.35 (B1) and 0.59 (B2) and 0 at 95 DAS. This shows that the WAB 878 lines were slightly more susceptible to leaf blast than the controls and WAS 880 and 881. No individual presented any visual symptoms of neck blast or RYMV. These crosses took advantage of the high level of tolerance coming from their *japonica* (IRAT 144 or WAB 56-50) and *glaberrima* parents.

The *O. glaberrima* × *O. sativa indica* lines (crosses WAS 127, WAS 131) and the *O. sativa indica* × *O. sativa japonica* (from the 2000 selection) (WAS 115) were the most susceptible to blast during the first season (Tables 3 and 4). Eighteen intraspecific families among 36 (50%) presented no symptom of blast, all types being put together, whereas only one interspecific family (191) showed the same result (Tables 3 and 4).

Through these three seasons, RYMV pressure was low over the whole vegetative cycle of the rice plants. BG90-2, a particularly susceptible variety, did not present severe signs of RYMV. Twenty-five lines showed some susceptibility to the virus.

Table 4. Blast and RYMV incidence on intraspecific progenies from *O. sativa* × *O. sativa* (Banfora rain-fed lowland, wet season 2000).

| Designation of cross | Blast disease | | | | RYMV | |
|----------------------|-------------------|------|------------------|-----|--------|--------|
| | On leaves (30DAS) | | On necks (95DAS) | | 30 DAS | 95 DAS |
| | B1† | B2† | B1 | B2 | | |
| WAS 97 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 99 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 105 | 0.33 | 0.67 | 0 | 0 | 0 | 0 |
| WAS 106 | 0 | 0 | 1 | 1 | 0 | 0 |
| WAS 107 | 0.62 | 0 | 0 | 0 | 0 | 0 |
| WAS 108 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 110 | 0.87 | 1 | 0 | 0 | 0 | 0 |
| WAS 112 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAS 114 | 0 | 0.07 | 0.5 | 0.5 | 0 | 0 |
| WAS 115 | 0 | 0 | 5 | 3 | 0 | 0 |
| WAS 116 | 1 | 1 | 0 | 0 | 0 | 0 |
| WAS 117 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAS 121 | 0 | 0 | 0.16 | 0.5 | 0 | 0 |
| WAS 129 | 0.17 | 0.5 | 0.5 | 0 | 0 | 0 |
| WAS 137 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 138 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 140 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 141 | 0.67 | 0 | 0.33 | 0 | 0 | 0 |
| WAS 142 | 1 | 0 | 0.5 | 0.5 | 0 | 0 |
| WAS 146 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAS 151 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1174 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1176 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1181 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1184 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1189 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAT 1191 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAT 1193 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1223 | 0 | 1 | 0 | 0 | 0 | 0 |
| WAT 1242 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1244 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAT 1249 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1273 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1275 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAT 1281 | 1 | 0 | 0 | 0 | 0 | 0 |
| WAT 1282 | 0 | 0 | 0 | 0 | 0 | 0 |

† B1 = Batch 1 of the row setting on the alleyway side. B2 = Batch 2 of the row setting on the alleyway side.

Table 5. Evaluation of the 15 best interspecific and intraspecific lines in the Banfora rain-fed lowland (in 2000, 2001 and 2002).

| Variety | 2000 | | | | | | | | | | 2001 | | | | | | | | | | 2002 | | | | | | | | | |
|-------------------------------|------|-----|-----|-----|----|----|----|----|----|-----|------|-----|-----|----|----|----|----|----|-----|----|------|-----|------|-------|----|------|------|----|---|--|
| | T60 | P/m | SHD | MH | St | LB | NB | DH | OT | Y | T60 | P/m | SHD | MH | St | LB | NB | DH | OT | Y | T60 | P/m | SHD | MH | LB | NB* | DH | OT | Y | |
| WAT 1176-B-FKR-B-B | 79 | 74 | 90 | 103 | 3 | 0 | 0 | 1 | 5 | 59 | 57 | 86 | 133 | 0 | 1 | 0 | 0 | 54 | 90 | 55 | 88 | 135 | 2 | 3.48 | 1 | 24 | 3256 | | | |
| WAT 1184-B-FKR-B-B | 58 | 54 | 84 | 147 | 3 | 0 | 0 | 1 | 5 | 72 | 55 | 93 | 124 | 5 | 3 | 0 | 5 | 41 | 115 | 59 | 86 | 114 | 2 | 3.8 | 1 | 15 | 3291 | | | |
| WAT 1191-B-FKR-B-B | 73 | 72 | 86 | 113 | 5 | 0 | 0 | 1 | 7 | 71 | 48 | 88 | 90 | 0 | 1 | 0 | 0 | 22 | 135 | 47 | 87 | 102 | 2 | 4.37 | 2 | 20 | 3309 | | | |
| WAS 105-B-I-B-WAS-2-1-FKR-B-B | 102 | 96 | 86 | 112 | 3 | 0 | 0 | 1 | 2 | 75 | 48 | 88 | 88 | 0 | 3 | 0 | 0 | 27 | 125 | 55 | 90 | 100 | 2 | 8.08 | 1 | 24 | 3251 | | | |
| WAS 114-B-I-B-WAS-1-5-FKR-B-B | 77 | 65 | 86 | 115 | 3 | 0 | 7 | 1 | 5 | 90 | 50 | 88 | 103 | 0 | 1 | 0 | 7 | 27 | 122 | 54 | 86 | 111 | 2 | 5.16 | 1 | 15 | 3589 | | | |
| WAS 129-B-I-B-WAS-1-1-FKR-B-B | 96 | 95 | 84 | 130 | 5 | 0 | 0 | 3 | 2 | 76 | 63 | 86 | 121 | 4 | 1 | 1 | 3 | 26 | 133 | 60 | 85 | 107 | 2 | 6.56 | 1 | 18 | 3912 | | | |
| WAS 122-1-1-WAS-6-1-FKR-B-B | 44 | 41 | 86 | 114 | 1 | 0 | 0 | 0 | 14 | 73 | 54 | 91 | 116 | 0 | 3 | 0 | 0 | 29 | 132 | 49 | 85 | 113 | 2 | 4.95 | 1 | 30 | 3357 | | | |
| WAS 122-1-1-WAS-2-V-FKR-B-B | 89 | 73 | 86 | 117 | 3 | 0 | 0 | 5 | 12 | 77 | 44 | 88 | 94 | 0 | 1 | 0 | 5 | 11 | 99 | 43 | 85 | 106 | 2 | 4.27 | 1 | 23 | 3035 | | | |
| WAS 122-1-1-WAS-B-FKR-B-B | 65 | 53 | 87 | 122 | 3 | 0 | 0 | 0 | 61 | 47 | 92 | 112 | 0 | 1 | 0 | 0 | 29 | 97 | 43 | 85 | 106 | 2 | 3.54 | 1 | 24 | 2173 | | | | |
| WAS 161-6-4-FKR-B-B | 55 | 52 | 72 | 103 | 1 | 0 | 0 | 0 | 0 | 79 | 58 | 86 | 88 | 0 | 5 | 0 | 0 | 48 | 118 | 48 | 84 | 103 | 2 | 38.27 | 1 | 19 | 2277 | | | |
| WAS 161-8-9-3-FKR-B-B | 94 | 86 | 87 | 106 | 3 | 0 | 0 | 0 | 13 | 112 | 55 | 88 | 85 | 0 | 2 | 0 | 3 | 55 | 126 | 50 | 83 | 91 | 2 | 6.05 | 1 | 19 | 2157 | | | |
| WAS 161-6-3-FKR-B-B | 84 | 81 | 81 | 102 | 3 | 0 | 0 | 0 | 8 | 97 | 58 | 82 | 94 | 0 | 3 | 1 | 0 | 33 | 123 | 65 | 80 | 97 | 3 | 7.88 | 2 | 21 | 2128 | | | |
| WAS 163-B-5-3-FKR-B-B | 66 | 52 | 93 | 89 | 3 | 1 | 0 | 0 | 10 | 65 | 50 | 88 | 91 | 0 | 3 | 0 | 0 | 58 | 115 | 38 | 89 | 94 | 2 | 8.36 | 1 | 22 | 3000 | | | |
| WAS 191-8-3-FKR-B-B | 71 | 69 | 93 | 88 | 3 | 0 | 0 | 3 | 11 | 75 | 62 | 85 | 96 | 5 | 5 | 0 | 0 | 45 | 130 | 55 | 82 | 100 | 3 | 3.03 | 1 | 16 | 2261 | | | |
| WAS 191-9-3-FKR-B-B | 35 | 30 | 101 | 92 | 3 | 0 | 0 | 3 | 0 | 76 | 76 | 86 | 97 | 5 | 3 | 1 | 5 | 41 | 104 | 61 | 82 | 107 | 2 | 3.38 | 1 | 16 | 3053 | | | |

T60 = mean number of tillers per seedling 60 days after sowing
 SHD = sowing to heading duration
 St = sterility level
 LB = leaf blast score
 DH = number of dead hearts
 Y = Yield in kg per hectare
 P/m = number of panicles per meter
 MH = mean height of the mature plants
 NB = Neck blast score (* = incidence in %)
 OT = number of onion tubes

Concerning the onion tube variable, among the intraspecific lines (*O. sativa indica* × *O. sativa indica*, *O. sativa indica* × *O. sativa japonica*, and *O. sativa japonica* × *O. sativa japonica*), 16 crosses among 36 showed an average of 5 to 15% attack.

All the intra- and interspecific lines were susceptible to gall midge with scores from 4 to 58% in 2000. Such a source of damage therefore remains a serious problem in the inland valley ecology in Burkina Faso for which an adequate solution should be found.

Behaviour of the lines selected during the three rain seasons

Table 5 presents the behaviour of the 15 lines selected in 2001 over the three years considered: 2000, 2001 and 2002. The data show that during the first season the lines displayed some resistance to leaf blast as all the observations recorded were between 0 and 1. For neck blast, only the line WAS 114-B-IDSA-WAS 1-5-FKR-B-B reached the score 7.

During the second season, all lines showed signs of leaf blast with scores from 0 to 5. Two lines were scored 5. The neck blast attacks were low. During the third season, all the lines performed well for both leaf and neck blast except WAS 161-6-4-FKR-B-B which is susceptible to neck blast. Such data show that line susceptibility to blast changes according to seasons. Under such conditions, assessing the severity of the symptoms requires a wide approach in time (over years) and in space (in different environments) in order to ensure the selection of varieties with a stable resistance to blast.

Table 6 shows the weekly evolution of 15 lines as concerns leaf and neck blast. All lines presented a low score at the first evaluation date, 35 DAS. One week later, the score rose from 1 to 2 for two lines (WAS 122-1-1-WAS-2-V-FKR-B-B and WAS 161-8-9-3-FKR-B-B); the susceptibility to blast of the last line showed a steady increase.

At the fourth scoring, the lines WAS 161-6-3-FKR-B-B, WAS 163-B-5-3-FKR-B-B and WAS 191-8-3-FKR-B-B increased their susceptibility score from 1 or 2 to 3. All the other lines scored 2.

The susceptible control confirmed its susceptibility to the two forms of blast. For neck blast, WAS 161-6-4-FKR-B-B showed the highest susceptibility with an incidence score of 38.27.

Table 6. Blast disease score on 15 interspecific and intraspecific varieties in the Banfora rain-fed low-land during the wet season 2000.

| Variety | Leaf blast score at different dates | | | | Neck blast score (%) | |
|-------------------------------|-------------------------------------|--------|--------|---------|----------------------|-------|
| | 22 Aug | 29 Aug | 3 Sept | 10 Sept | | |
| WAT 1176-B-FKR-B-B | 1 | 1 | 2 | 2 | 0.20 | 3.48 |
| WAT 1184-B-FKR-B-B | 1 | 1 | 1 | 2 | 0.19 | 3.80 |
| WAT 1191-B-FKR-B-B | 1 | 1 | 2 | 2 | 0.18 | 4.37 |
| WAS 105-B-I-B-WAS-2-1-FKR-B-B | 1 | 1 | 2 | 2 | 0.23 | 8.08 |
| WAS 114-B-I-B-WAS-1-5-FKR-B-B | 1 | 1 | 2 | 2 | 0.19 | 5.16 |
| WAS 129-B-I-B-WAS-1-1-FKR-B-B | 1 | 1 | 1 | 2 | 0.16 | 6.56 |
| WAS 122-1-1-WAS-6-1-FKR-B-B | 1 | 1 | 1 | 2 | 0.22 | 4.95 |
| WAS 122-1-1-WAS-2-V-FKR-B-B | 1 | 2 | 2 | 2 | 0.22 | 4.27 |
| WAS 122-1-1-WAS-B-FKR-B-B | 1 | 1 | 1 | 2 | 0.26 | 3.54 |
| WAS 161-6-4-FKR-B-B | 1 | 1 | 2 | 2 | 0.20 | 38.27 |
| WAS 161-8-9-3-FKR-B-B | 1 | 2 | 3 | 2 | 0.16 | 6.05 |
| WAS 161-6-3-FKR-B-B | 1 | 1 | 1 | 3 | 0.18 | 7.88 |
| WAS 163-B-5-3-FKR-B-B | 1 | 1 | 2 | 3 | 0.19 | 8.36 |
| WAS 191-8-3-FKR-B-B | 1 | 1 | 2 | 3 | 0.15 | 3.03 |
| WAS 191-9-3-FKR-B-B | 1 | 1 | 1 | 2 | 0.19 | 3.38 |
| Control (TOX 30555-10-1-1) | 4 | 6 | 8 | 8 | 1.22 | 70.25 |

Conclusion

During the 2000, 2001 and 2002 rainy seasons, intra- and interspecific lines were assessed. After an agromorphological assessment based on their susceptibility to insects, diseases and water table variations, a number of lines were selected for their adaptability to rain-fed lowland rice cropping systems.

In 2000, 15.06% of the intra- and interspecific lines were selected: 91 among 569 intra- and interspecific lines were selected, totaling 92. In 2001 rainy season, these 91 lines were grown, allowing a further selection of 15 lines that were re-evaluated in the Banfora inland valley in 2002. Among these, 14 were not too susceptible to leaf and neck blast (Table 6).

Intraspecific lines

| | | |
|----|--------------------|--|
| 1. | WAT 1176-B-FKR-B-B | <i>ITA 123/ITA 414</i> |
| 2. | WAT 1184-B-FKR-B-B | <i>FAROX 308-35-1-2/TOX 3226-5-2-2-2</i> |
| 3. | WAT 1191-B-FKR-B-B | <i>TOX 3093-35-2-3-3/TOX 3226-5-2-2-2</i> |
| 4. | WAS 114-B-FKR-B-B | <i>ITA 305/IR 13240-2-2-3</i> |
| 5. | WAS 129-B-FKR-B-B | <i>FOFIFA 62/BG 90-2//IR 13240-108-2-2-3</i> |

Interspecific lines

| | | |
|-----|--------------------------------|----------------------------------|
| 6. | WAS 122-IDSA-1-B-FKR-B-B | <i>TOG 5681/3*IR 64</i> |
| 7. | WAS 122-IDSA-1-2-FKR-B-B | <i>TOG 5681/3*IR 64</i> |
| 8. | WAS 122-IDSA-1-WAS-6-1-FKR-B-B | <i>TOG 5681/3*IR 64</i> |
| 9. | WAS 191-8-3-FKR-B-B | <i>IR 64 // TOG 5681/4*IR 64</i> |
| 10. | WAS 191-9-3-FKR-B-B. | <i>IR 64 // TOG 5681/4*IR 64</i> |

The weekly scores for blast confirmed the good tolerance level of the lines selected in 2002.

The joint work of many breeders from Mali, Burkina Faso, Togo and the ARI coordinator confirmed the good behaviour of the following jointly selected lines: WAS 122-IDSA-1-B-FKR-B-B, WAS 122-IDSA-1-2-FKR-B-B, WAS 122-IDSA-1-WAS-6-1-FKR-B-B and WAT 1176-B-FKR-B-B.

Prospect

These lines could be incorporated in a regional study within the breeders' network. They would benefit from the contribution of pathologists and entomologists before being selected as material with a stable selection level and thereafter become available to producers in PVS studies.

Potential use of molecular markers in rice breeding

Until now this study dealt with the adaptability of different genotypes to rain-fed lowland rice systems (by measurement of the agronomic characters), the tolerance to diseases (blast and RYMV) and to insects (stem borers and gall midge) that involve several genes controlling these complex characters. Marker-assisted selection, using molecular biology, offers new ways to identify, select and transfer the genes implied in blast resistance. The studies in quantitative genetics are now facilitated by the use of molecular markers (Sié 1997). The markers derived from Restriction Fragment Length Polymorphism (RFLP) present numerous qualities that make them the favourite markers for the creation of genetic linkage maps and for the follow-up of characters after crosses and backcrosses (Paszek 1996). Indeed the main genes for resistance to diseases and insects are mostly a group of genes controlling complex characters such as yield and quality (Young *et al.* 1992). The genes of disease resistance were the first gene categories to be mapped using RFLP. This could be explained because most of the resistance genes that were characterised

are controlled by alleles localised on a single locus and most are dominant genes easy to identify. The use of such markers is easy as their number is almost limitless, they are neutral, i.e. their allelic status has no influence on the phenotype, they are co-dominant (the allelic differences in a heterozygotic individual can be detected and are detectable whatever the origin of the tissue analysed or the development stage of the individual). Saturated maps have recently been built for a number of plants (Kurata *et al.* 1994; Causse *et al.* 1996).

The RFLP method can be used in plant breeding as the desired combination of genes can be obtained faster than with the classical methods, thus allowing a quicker selection of new varieties. Such an approach is particularly useful in the production system using a low level of input in which the problems due to insects, diseases and weeds are the main constraints.

Analysis of genetic diversity

The use of molecular markers has allowed characterisation of the diversity in the disease-causing populations as is the case for the strains of the fungus provoking blast. This is how Levy (1997, cited in Causse *et al.* 1997) obtained the genetic fingerprints of the profiles of a highly repeated sequence, *MGR 586*.

Romain *et al.* (1997) cited by Courtois (2001) were able, using molecular markers, to build a dendrogram of the genetically linked groups. When inoculated, strains from the same line display very similar behaviour, and some resistance genes are effective against all strains belonging to the same line.

QTL use

Numerous characters show a continuous quantitative variation in segregating populations and are under the dependence of many loci that can interact among themselves and with the environment. The genetic mapping of segregating populations for these characters allows localisation of these loci or QTLs (Quantitative Trait Loci). Most maps use populations descending from backcrosses (F2) which are difficult to reproduce and do not provide good phenotypic values (de Vienne *et al.* 1999). Recent studies mostly used doubled haploids (DH) in order to establish genetic maps and to localise QTLs as, in particular for rice, the lines are genetically homozygotic after one single generation and can therefore be multiplied without segregation).

When QTLs have been identified for a group of qualitative characters, it is then possible to use their linked markers for breeding. According to de Vienne *et al.* (1999), using QTLs could allow researchers to attain the following objectives:

- improving performances by accumulating alleles favourable to yield, resistance to lodging and to pests.
- improving the stability of varieties by accumulating general QTLs in order to create high-yielding varieties for a large range of environments.
- improving the adaptation to a given environment, by accumulating QTLs specific to that environment.

Another interesting aspect in the use of QTLs is getting rid of the unfavourable breeding correlations. One of the correlations that could be improved is the unfavourable correlation between cycle duration and yield (de Vienne *et al.* 1999).

By limiting the use of QTL-based mapping to the evaluation of phenotypes in a single environment, the genotype \times environment interaction could be neglected although it is an essential component influencing the expression of quantitative characters. The expression of alleles to QTLs throughout seasons and locations is an acute problem in plant breeding. Because of the cost of analysing different parameters for adaptability, the early use of the corresponding QTLs and of their genotype \times environment interaction could be extremely helpful in plant breeding. It is therefore becoming evident that, with molecular biology, the use of information will favour a tighter collaboration between breeders, pathologists and molecular biologists (Robertson 1968).

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Screening Strategy for Durable Resistance to Rice Blast Disease at WARDA

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Résumé

La pyriculariose du riz est une des plus importantes maladies du riz dans la plupart des écosystèmes rizicoles d'Afrique de l'Ouest. La recherche de variétés dotées d'une résistance efficace fait l'objet d'une préoccupation constante des phytopathologistes comme des sélectionneurs. L'ADRAO s'est donc investie à mettre au point une stratégie visant à identifier du matériel résistant et utilisable directement par les producteurs, ou pouvant servir de donneurs dans les programmes de création variétale. La présente communication décrit cette stratégie après avoir fait le point sur les connaissances des relations hôte parasites qui ont servi de trame à la mise au point de cette technique d'identification de variétés dotées d'une résistance durable. Cette stratégie consiste à évaluer la résistance horizontale des variétés dont la résistance verticale a été surmontée.

Abstract

Rice blast is one of the most important diseases in most of the rice ecosystems of West Africa. The development of rice varieties with an effective resistance is an ongoing objective of plant pathologists and breeders. WARDA has thus developed a strategy aiming to identify resistant material to be used either directly by the producers, or as donors in the breeding programmes. The present communication describes this methodology, following a progress report on knowledge of the host-parasite relationships that were used to develop the screening strategy for durable resistance. This strategy consists of analysing the parameters of horizontal resistance for varieties on which vertical resistance is not operating.

Introduction

Rice blast is the most widespread disease of rice in the world. Caused by the pathogenic fungus *Magnaporthe grisea*, it is found in most of the rice ecosystems of West Africa. Particularly dangerous in upland rice, it also causes serious damage in rain-fed lowland and irrigated systems, mainly when farmers seek to intensify the production by the use of improved varieties and fertilisers. Unexpected epidemic explosions still appear such as those observed within farmers' fields in the west of Côte d'Ivoire in 2002 (pers. comm., Bouet, Plant Pathologist, National Center of Agronomic Research).

One of the principal components of an integrated management system for this disease is varietal resistance. However, this can be unstable in space and in time according to the structure of the pathogen population. It is thus important to take this fact into account when wishing either to diffuse material to farmers or to provide donors to the breeders. In Japan, when the vertical resistance to blast fungus became ineffective for a variety, the variety proved even more sensitive than the sensitive local cultivars (Ezuka 1979).

The present communication aims to describe the strategy developed by WARDA to identify varieties with durable resistance. Before that, however, we summarise the knowledge of the host-pathogen relationship that was used in the conception of this screening technique.

Host-pathogen relationship within the couple *Oryza sativa*/*Magnaporthe grisea*

In genetic control of plant diseases, plant pathologists distinguish a specific or vertical resistance and a non-specific or horizontal resistance. The relations between rice and blast fungus conform so well to the principles governing the host-pathogen relationship that plant pathologists use to regard this couple as a model. The two kinds of resistance have been described for the couple *O. sativa*/*M. grisea*.

Vertical resistance is characterised by the existence of a differential interaction between the pathogen isolates confronted with the host varieties. It is qualitative, i.e. it results in an all-or-nothing reaction. Since it is controlled, in general, by a few genes of major effect, breeders frequently use it to create resistant materials. Unfortunately, it is not durable, since new pathogen races are able, in a relatively short time, to overcome it and destroy the efforts of many years of labour.

The existence of a monogenic (or oligogenic) resistance to the blast fungus has been largely confirmed by many studies (Wang *et al.* 1994; Naqvi *et al.* 1995; Pan *et al.* 1996; Yu *et al.* 1996; Liu *et al.* 2002). This oligogenic system is responsible for a qualitative, complete and non-durable resistance.

The position of each gene on the various chromosomes of rice was specified. For example, Yu *et al.* (1996) reported Pi-2(t) and Pi-4 on chromosomes 6 and 12 respectively, while Zu *et al.* (quoted by Pan *et al.* 1996) described Pi-zh(t) on chromosome 8. By the use of isogenic lines, Inukai *et al.* (1994) identified Pi-1 and Pi-2(t), which are allelic or strongly linked to Pi-z, then Pi-3 and Pi-4a(t) allelic or strongly linked to Pi-ta. Wang *et al.* (1994), through molecular analysis, discovered Pi-5(t) and Pi-7(t) respectively on chromosomes 4 and 11. Pi-8 is noted by Pan *et al.* (1996) on chromosome 8. More recently, Liu *et al.* (2002) showed that Pi-2(t) and Pi-9(t), two resistance genes efficient against many strains of *M. grisea*, are linked genes located on chromosome 6.

The host-pathogen relationships proceed according to the gene-for-gene principle illustrated in Table 7.

Table 7. Relationship between *M. grisea* avirulence gene and *Oryza sativa* resistance genes, according to the gene-for-gene theory.

| Pathogen avirulence gene | Host resistance genes | Reactions [†] |
|--------------------------|----------------------------|------------------------|
| av-a+ & av-b | Without any resistant gene | + |
| | Pi-a only | + |
| | Pi-b only | - |
| | Pi-a and Pi-b | - |
| av-a & av-b+ | Without any resistant gene | + |
| | Pi-a only | - |
| | Pi-b only | + |
| | Pi-a and Pi-b | - |
| av-a+ & av-b+ | Without any resistant gene | + |
| | Pi-a only | + |
| | Pi-b only | + |
| | Pi-a and Pi-b | + |

† + = compatible reaction (susceptibility); - = incompatible reaction (resistance).

By artificial inoculation of pathogen isolates to a range of suitable differential varieties, it is possible to identify avirulence genes which these isolates carry and thus to identify the races present within a given population.

Horizontal resistance is characterised by the absence of differential interaction. It is quantitative and stable. Its genetic determinism is polygenic. From the epidemiological point of view, it acts by slowing down the progression of the disease.

Such a system has been clearly shown in rice under different denominations: Field Resistance, Slow blasting, Quantitative Resistance, Non-specific Resistance and Partial Resistance. Scientists agree that this system is stable and durable, and that its genetic determinism is polygenic (Bonman 1992; Notteghem 1993; Wang *et al.* 1994).

An interesting variety in its behaviour with respect to the diseases (with durable resistance) is that it must not only be slightly attacked, but more especially, needs to express this aptitude on a broad geographical surface and/or during several cultural cycles. The stability of resistance is almost as important as the weakness of the attacks. This is why horizontal resistance is preferred to vertical resistance.

Various techniques have been used to characterise horizontal resistance. Evaluation of the infection rate of the epidemics is one method. While proceeding, for example, by evaluating the amount of disease over the time, it is possible to draw an exponential curve ($x = x_0 e^{rt}$), and define the epidemiological parameters related to the varieties and, in particular, to calculate the infection rate (r). However this rate is defined only during the logarithmic phase of the disease-progression curve. It can thus prove to be insufficient to characterise the aptitude of the varieties to slow down the progression of the epidemics for the adult plant resistance. Some prefer to use the value of the Area Under the Disease Progress Curve (AUDPC). Others take as a starting point the model by Eberhart and Russel (1966) developed for yield stability, in order to characterise the relationships between rice varieties and the blast pathogen.

Application to the screening for resistance

The strategy developed by WARDA is based on the principle that the two types of resistance (vertical and horizontal) can coexist within the same variety. For example, Moroberekan, a local variety of Côte d'Ivoire that is well known for the durability of its resistance to the blast fungus, has two dominant genes associated with a qualitative resistance and a polygenic system, quantitative trait loci (Qtl), affecting partial resistance (Wang *et al.* 1994).

It is then clear that differences in disease severity can come from different resistance mechanisms. Consequently, it is a mistake to base the choice of variety only on the disease score. Indeed, the small quantity of disease observed can be quite simply related to the fact that vertical resistance is effective against a large proportion of races of the pathogenic population (Chen and Line 1995).

The strategy (illustrated in Figure 2) consists of initially evaluating the vertical resistance of the material within blast nurseries. Each year, WARDA tests a few hundred varieties or lines provided by its Genetic Resources Unit and/or by the breeders.

The attacks are evaluated weekly according to the international scale (IRRI 1976). The varieties selected are those that receive a score of 3. As stated above, such a score can be for either horizontal resistance or effective vertical resistance against a part of the pathogen population.

The immune varieties are not selected because they could represent material having escaped the attack owing to the effectiveness of their vertical resistance against all the pathogenic population. They will be integrated in the nurseries of following years.

The tolerant material is then characterised for horizontal resistance by analysing the progression of the epidemic. They are tested in statistical trials led in Fisher blocks in the presence of the Moroberekan, the check for horizontal resistance.

Three epidemiological parameters are used: infection rate (r), the area under disease progress curve (AUDPC) and the maximum disease severity (x_{max}).

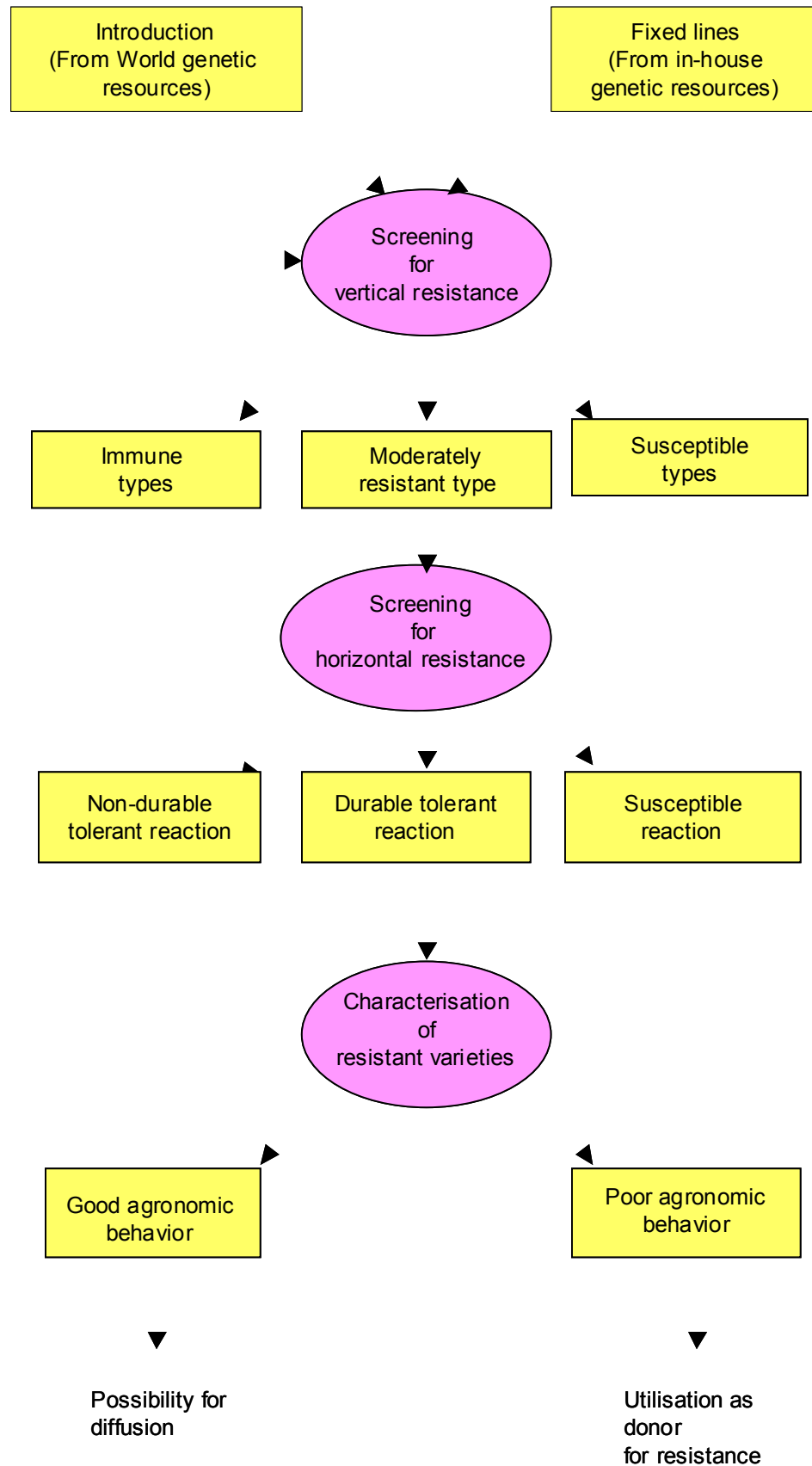


Figure 2. Steps of the screening strategy for durable blast resistance at WARDA

For example, in 2001, the comparative analysis of a hundred interspecific varieties and their parents (Table 8) led to the following results:

- 34 entries have a good level of horizontal resistance, including the interspecific varieties NERICA 1, NERICA 2, NERICA 3, NERICA 5 and their *sativa* parent (WAB 56-104), as well as the resistant check Moroberekan
- 72 entries, including NERICA 6, NERICA 7, the susceptible check and the *glaberrima* parent of interspecific, have a low level of horizontal resistance.

Table 8. Utilization of three epidemiological parameters to characterize the level of horizontal resistance of some rice varieties.

| Parameters [†] | | | Conclusions | | |
|-------------------------|----------------|-------|-------------|--------|---|
| x (max) | Infection rate | AUDPC | Type | Number | Example [‡] |
| + | + | + | Resistant | 34 | N1, N2, N3, N5 Moroberekan WAB 56-104 |
| + | + | - | | | |
| + | - | + | | | |
| - | + | + | | | |
| - | - | - | Susceptible | 72 | CG 20, CG14 Gigante WAB 96-13-1 N6, N7 |
| - | - | + | | | |
| - | + | - | | | |
| + | - | - | | | |

† % = as resistant as (or more resistant than) Moroberekan; & = less resistant than Moroberekan.

‡ N1 ... N6 = NERICA1 ... NERICA6.

Conclusion

The examination of the relationship between rice and the blast pathogen shows that unstable resistance and durable resistance can coexist within the same variety. If the plant does not have a specific resistance to the race with which it is confronted, the infection process proceeds normally until the production of the conidia enables the initiation of new lesions. The quantity of the disease obtained will then depend on the non-specific resistance. One can thus say that resistance during the first stages of the infectious process concerns resistance of the vertical type. When that it is overcome, the plant has a certain level of horizontal resistance with which to oppose the disease progression.

It is thus important to keep these facts in mind in the screening process for durable resistance. This is why the technique that we developed initially makes it possible to make sure that vertical resistance is overcome, before better determining the effects of horizontal resistance.

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Impact assessment of agricultural technology: Concept, methodology and application to rice pests and diseases

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Abstract

Once disparate approaches to impact assessment encompassing various sub-disciplines of economics and statistics are now converging to provide a single unified methodological framework within which the impact of various types of programmes, policy changes, and technologies on various behavioural, environmental and welfare outcomes can be assessed with a level of rigour satisfactory from both economic and statistical perspectives. A synthesis of some recent methodological developments is presented within one single coherent conceptual and methodological framework, including an application to the assessment of the adoption impact of disease resistance varietal technologies.