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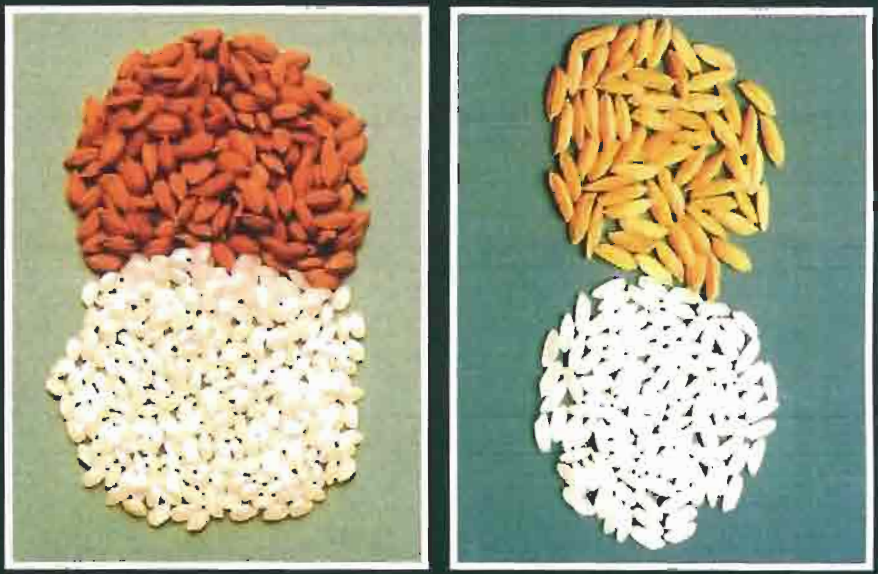
# Genetic diversity in rice production

## Case studies from Brazil, India and Nigeria



# Genetic diversity in rice production

## Case studies from Brazil, India and Nigeria

Technical editor
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# Preface

Rice provides 80 percent of the diet of half of the world's population. Most rice is produced and consumed by people in developing countries. Thanks to investment in science and technology in rice production, it has been possible to meet the global demand for rice. The adoption of high-yielding varieties (HYVs) following the release of IR 8 in the late 1960s, in addition to improved production practices, enabled rice production to meet the growing population's demand for this commodity. However, during the 1970s and 1980s, the widely planted high-yielding varieties were plagued by new pest and disease biotypes, especially brown planthopper (BPH), resulting in considerable losses in rice production in a number of major rice-producing countries in Asia. The narrow genetic background of the widely planted high-yielding varieties made rice production vulnerable to sudden disease and pest outbreaks. The management of pests in rice production remains an ongoing battle.

Broadening the genetic base of rice varieties may also help overcome the declining rate of yield increase observed in many countries in the recent past. The 19th Session of the International Rice Commission, held 7-9 September 1998 in Cairo, Egypt, recommended that FAO and Member Countries compile, analyse and disseminate information on the genetic background of the currently used varieties in order to enhance stakeholders' awareness of the genetic diversity and of the level of vulnerability of rice production. In response to this recommendation, FAO has collaborated over the last two years with national scientists in Brazil, India and Nigeria to review the genetic background of rice varieties developed through the rice improvement programmes in these important rice-producing countries.

The studies produced valuable information concerning: breeding programmes; the approaches and methods used for rice varietal improvement; and the varieties released for cultivation in these countries and their respective genetic backgrounds. Funding from the FAO-Netherlands Partnership Programme permitted research collaboration between the countries concerned and the analysis and preparation of the information collected, including the development of a database for this publication. The analysis of the information provided by the three studies confirms the narrow genetic diversity in rice production in some regions in these countries, and consequently the vulnerability of rice production to pest and disease outbreaks. This publication aims to increase awareness of and the information available on the genetic diversity of this vital commodity in important rice-producing countries.

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# List of abbreviations

| | |
|---|---|
| ADP | Agricultural Development Project |
| ICAR | Indian Council of Agricultural Research (formerly Imperial Council of Agricultural Research) |
| AFLP | amplified length polymorphism |
| AfrRGM | African rice gall midge |
| AICRIP | All India Co-ordinated Rice Improvement Project |
| AYT | advanced yield trial |
| BLB | bacterial leaf blight |
| BPH | brown planthopper |
| CENARGEN | EMBRAPA Genetic Resources and Biotechnology |
| CGIAR | Consultative Group on International Agricultural Research |
| CIAT | International Centre for Tropical Agriculture |
| CIRAD | Centre de cooperation international en recherché agronomique pour le développement (formerly IRAT) |
| CMS | cytoplasmic male sterile |
| CNPAF | EMBRAPA Rice and Beans (formerly National Rice and Beans Research Center) |
| CRET | Coordinated Rice Varieties Evaluation Trial |
| CRRI | Central Rice Research Institute (Cuttack) |
| CTArroz | Comissão técnica de arroz |
| CVRC | Central Variety Release Committee |
| DGWG | Dee-Geo-Woo-Gen |
| DH | doubled haploid |

| | |
|---|---|
| DRR | Directorate of Rice Research |
| EGMS | environment sensitive genic male sterility |
| EMBRAPA | Brazilian agricultural research enterprise/corporation |
| EMS | ethyl methane sulphonate |
| Epamig | Empresa de pesquisa agronomica de Minas Gerais |
| FAO | Food and Agriculture Organization of the United Nations |
| FDAR | Federal Department of Agricultural Research |
| GM | gall midge |
| Grumega | Grupo de mejoramiento avanzado en arroz |
| GSV | grassy stunt virus |
| GT | gelatinization temperature |
| HYV | high-yielding variety |
| IAC | Istituto agronômico de campinas |
| IAEA | International Atomic Energy Agency |
| IAPAR | Instituto agronomico do Parana |
| IAR&T | Institute of Agricultural Research and Training |
| ICAR | Indian Council for Agricultural Research |
| IFPRI | International Food Policy Research Institute |
| IITA | International Institute of Tropical Agriculture |
| INGER | International Network for Genetic Evaluation of Rice (formerly IRTP) |
| INGER-LAC | International Network for Latin America |
| IRAT | Institute for research in Tropical Agriculture and Food crops (now CIRAD) |
| IRBN | International Rice Blast Nursery |

| | |
|---|---|
| IRC | International Rice Commission |
| IRGA | Istituto Riograndese do arroz |
| IRRI | International Rice Research Institute |
| IRTP | International Rice Testing Programme |
| IRTP | International Rice Testing Program (now INGER) |
| KNARDA | Kano Agricultural and Rural Development Authority |
| MAS | marker assisted selection |
| MTA | memorandum of technical agreement |
| NAFPP | National Accelerated Food Production Program |
| NARP | National Agricultural Research Project |
| NARS | National Agricultural Research Systems |
| NCRI | National Cereals Research Institute |
| NERICA | New Rice for Africa |
| NMU | nitroso methyl urea |
| NRBN | National Rice Breeding Network |
| NSS | National Seed Service |
| OAS | Organization of American States |
| OT | observational trial |
| PGMS | photosensitive genic male sterile |
| PVS | participatory varietal selection |
| PYT | preliminary yield trial |
| QTL | quantative trait loci |
| RFLP | restriction fragment length polymorphism |
| RGA | rapid generation advance |

| | |
|---|---|
| RYMV | rice yellow mottle virus |
| SSR | simple sequence repeats |
| TGMS | thermosensitive genic male sterile |
| TRIP | Trade Related Intellectual Property Rights |
| UNDP | United Nations Development Programme |
| VNB | Viveiro nacional de brusone |
| WA | wild abortive |
| WARDA | West Africa Rice Development Association |
| WBPH | white-backed planthopper |
| WTO | World Trade Organization |

# Common terms used for rice plants and varieties

Below are the terms used for rice plants and varieties in the three reports in this book. The descriptions aim to assist readers – especially those interested in biodiversity but not familiar with rice production – in examining the reports.

## RICE PLANTS

**Cultivated rice plant:** Most of the rice plants cultivated today belong to the species, *O. sativa* L. The other rice species grown for food is *O. glaberrima* Steud. Cultivated rice plants are annual.

**Weedy rice plant:** Weedy rice plants develop phenotypic plasticity. In the cultivated field they tend to resemble a cultivated rice variety, while those grown outside the field resemble wild rice plants. The grains of weedy rice are awned and red (weedy rice is also called red rice). Weedy rice plants cannot be distinguished from cultivated rice plants before heading. The origin of weedy rice remains unknown.

**Wild rice plant:** Cultivated rice species have about 18 known wild relatives growing widely. Wild rice plants are either perennial or annual.

## RICE VARIETIES

**Aromatic:** Varieties in which the grains produce aroma when cooked.

**Bulu or *javanica*:** Varieties grown mostly on freely drained upland soils.

*Javanica* was recently renamed as *tropical japonica.*

**Deepwater:** Variety developed for growing in deepwater fields. During the growing season, rice fields are flooded for a considerable period with a layer of water more than 100 cm deep.

**Glutinous:** Varieties whose grains have very low amylose content (about 5% or less).

**High-yielding (HYV):** IR 8 and similar varieties. IR 8 has a yield potential of 10 t/ha and the following major characteristics:

1. short and sturdy culm (90-100 cm)
2. resistance to lodging
3. rather short and erect leaves of medium width
4. high tillering capacity
5. high grain-to-straw ratio or harvest index
6. photoperiod insensitivity

**Hybrid:** The discovery of the wild rice plant with abortive pollen led to the development of hybrid rice or the use of first generation seeds resulting from crossing two parent or $F_1$ seeds. The normal term for hybrid rice varieties is hybrids. Thanks to heterosis, hybrid rice has higher yielding potential than high-yielding varieties. The yielding potential of 3-line hybrid rice varieties is about 15 percent (or more) higher than that of high-yielding varieties with comparable growth duration.

***Indica*:** Varieties widely grown in lowland areas in a tropical climate.

**Irrigated:** Varieties developed for growing in irrigated fields. Water supply to rice crops is adequate throughout the growing season; it may come from both rainfall and irrigation systems during the wet (or rainy) season, but comes mainly from irrigation systems during the dry season. Rice fields are normally flooded with a layer of water 0-25 cm deep.

***Japonica*:** Varieties widely grown in temperate and subtropical climate areas.

**Modern:** Another term for high-yielding varieties.

**NERICA (New Rice for Africa):** Varieties developed from crosses between *O. sativa* and *O. glaberrima*

**Rainfed lowland:** Varieties developed for growing in rainfed lowland fields. Water supply to rice crops may come from rainfall, diverted small water courses (e.g. streams) or swollen rivers, but supply depends greatly on rainfall and its distribution. During the growing season, rice fields are submerged or flooded for a considerable period of time with a layer of water 0-100 cm deep. Rainfed lowland includes rainfed lowland, swamp, dambo, boliland, fadama and riverrine rice.

**Tidal wetland or mangrove:** Varieties developed for growing in fields which are under the influence of tidal water (saline water of the sea). Most rice fields are normally flooded with a layer of water less than 100 cm deep. Salinity in rice soils is usually high.

**Traditional:** Varieties with tall culm, long, droopy leaves and low yielding potential (<5 t/ha). It usually has a long growing period and is often photosensitive. In tropical climate areas, it was developed and released before IR 8 (the first high-yielding rice variety).

**Upland:** Varieties developed for growing mostly in freely drained upland soils. Water supply to rice crops comes mainly from rainfall. Normally, rice fields are not flooded continuously for more than 2 days at any time during the growing season.

# Genetic uniformity and vulnerability of rice production in the three countries under study

*V.N. Nguyen*[1]

In response to the recommendations of the International Rice Commission at its 19th Session held in September 1998 in Cairo, Egypt, FAO has collaborated over the last 2 years with national scientists in Brazil, India and Nigeria to initiate reviews of breeding methods used and the genetic background of rice varieties developed through the rice improvement programmes in these countries. Brazil is the largest rice-producing country in Latin America and Nigeria is the largest rice-producing country in Africa in terms of production and harvested area. India is the second largest rice-producing country in Asia in terms of production, but its rice harvested area is the world's largest.

The studies provided substantial information on the approaches and methods used in varietal improvement and on the rice varieties released for cultivation and their parents. Although, in a number of instances, the studies also provided information on varietal adoption, they did not include systematic evaluation of the genetic diversity of rice production. The following sections highlight the major achievements of the rice varietal improvement programmes in the countries under study, with emphasis on the genetic uniformity and vulnerability of rice production.

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## RICE VARIETAL IMPROVEMENT PROGRAMMES AND THEIR ACHIEVEMENTS

### Brazil

Farmers in the state of Rio Grande do Sul in Brazil introduced the first improved varieties from the United States of America in 1928/29. In 1938, the Instituto Riograndese do Arroz (IRGA) was created in Rio Grande do Sul, while in 1937 the Instituto Agronomico de Campinas (IAC) in the state of Sao Paulo began its rice breeding programme. After a few years, both institutions began crossing programmes to find good combinations between local and introduced germplasm, through pedigree selection or a combination of pedigree selection and modified bulk. The major results of these activities have been the release of EEA 404, EEA 405 and IRGA 407 for lowland irrigated systems and the release of Perola, Pratao, Dourado Precoce and Bico Ganga for upland ecosystems. In the 1960s, the local breeding programmes started looking for plants with traits such as high tillering, compact architecture, short stature, resistance to lodging and response to fertilizers. In the early days, only IR 841 and IR 22 were selected from rice lines introduced from Asia and released for cultivation in Sao Paulo (IR 841) and Para (IR 22). At a later stage, Cica 4, Cica 7, Cica 8 and Metica 1 were introduced and soon became varieties covering a significant area in the tropical climate zones in Minas Gerais, Goiás and Tocantins.

In 1976, the National Rice and Bean Research Center (CNPAF) of EMBRAPA (Brazilian Agricultural Research Corporation) was created with a mandate to coordinate research on rice and beans for the whole country. During the 1970s national institutions requested a large number of nurseries directly from IRRI, initiated rice germplasm collection and intensified the crossing programmes using rice lines from INGER-LAC, IITA and CIRAD, as well as local germplasm resources. Bulk and modified bulk in combination with pedigree breeding methods were used. Induced mutation was used only in selected cases and biotechnological tools have been used only recently. Between 1965 and 2001, breeding programmes in Brazil released for cultivation a total of 87 irrigated varieties and 43 upland varieties. The released varieties have contributed to the increase in national rice production and yield since 1961. National average yield increased from 1 698 kg/ha in 1961 to 1 880 kg/ha in 1990 and then to 3 243 kg/ha in 2001 (FAOSTAT, 2002). The rapid increase in rice yield during 1990-2001 was partially due to the reduction in the area under upland rice, where the level of input application is usually limited (Pereira *et al.*, 1999).

## India

India is one of the world's original centres of rice cultivation. The country has rich rice genetic resources and many Indian varieties have been used as parents in rice breeding both inside and outside the country. Latisail is a parent of Intan, Peta and Mas (popular varieties in Indonesia), while Peta is a parent of IR 8, the first high-yielding variety, which revolutionized rice production in tropical climate areas. An Indian wild rice plant, *O. nivara*, is the source of resistance to grassy stunt virus in several varieties released both in India and around the world. Up to 1960, 430 improved varieties were released for cultivation; among them only 27 were developed through hybridization and the rest were from pure line selection in different regions. Some of the outstanding varieties released during this period are MTU-1, MTU-15 and HR-19 in Andhra Pradesh; Chinsurah-7 in West Bengal; Kodamba in Bombay; GEB 24, CO 2, CO 25, CO 26 and ASD-1 in Tamil Nadu; T 141 and SR 26 B in Orissa; Basmati 170 in Punjab; and T 136 in Uttar Pradesh. Thanks to the *indica/japonica* project sponsored by the International Rice Commission of FAO and launched in the 1950s, ADT-27 and Mahsuri became popular in India. Subsequently, tropical *japonica* varieties from Taiwan, such as Taichung 65, Taichung Native-1 and Tainan-3, were used as donors for developing high-yielding and fertilizer-responsive genotypes.

During the three decades until 2001, the Indian rice research stations used various breeding approaches and methods to create new varieties. They undertook the introduction of promising lines and varieties from IRRI and other countries and the purification of varieties grown by local farmers to generate new varieties. These activities resulted in the release of 75 varieties. Mutation breeding using both physical and chemical mutagens was used for yield improvement, high protein content and resistance to blast and bacterial leaf blight and it led to the release of 11 varieties. The largest number of released varieties, however, came from recombination and convergent breeding methods in combination with pedigree or modified pedigree selection. The recombination breeding approach was used in breeding for yield and tolerance, while the convergent breeding approach was used in the development of varieties with multiple pest resistance. Shuttle breeding and rapid generation advance techniques were used to accelerate the breeding process. Recently, methods, such as selective diallele mating and recurrent selection, heterosis breeding and cellular and molecular breeding, have also been used. These breeding efforts resulted in the release of a total of 632 rice varieties for commercial cultivation. Of these, 374 (59%) were released for the irrigated ecosystem, 123 (19.4%) for rainfed shallow lowlands, 87 (13.7%) for rainfed uplands, 30 (4.7%) for rainfed semi-deepwater, 14 (2.2%) for deepwater conditions and 33 (5.2%) for hill ecologies. The adoption of released varieties, the development of irrigation systems, improved crop management and the increased use of input have increased the national average rice yield from 1 541 kg/ha in 1961 to 2 964 kg/ha in 2001 (FAOSTAT, 2002).

### Nigeria

*O. glaberrima* rice varieties/lines were first grown as a crop in the central Niger Delta and Sokoto basins, and they then spread into the bush fallow upland farming systems of the western forest zones of Nigeria. However, *O. glaberrima* was fast being replaced by *O. sativa*. Organized rice research activities in Nigeria began in 1953. Rice improvement efforts during this period involved collection, testing and selection from local varieties and introduced varieties. Towards the end of the 1960s (1966-1970), given the need for early-maturing and high-yielding varieties for double-cropping in irrigation schemes, some stiff-strawed, non-lodging, nitrogen-responsive, high-yielding varieties were introduced. Prominent among the introduced varieties were SML 140/10 and IR 8, later released as FARO 12 and 13, respectively. From the early 1970s, the exchange of germplasm and the development and dissemination of semi-dwarf high-yielding varieties adapted to local conditions were important rice improvement activities.

Prior to 1984, the varietal release system in Nigeria was such that rice varieties could reach farmers through many research institutes or channels. However, as of 1984, outstanding entries from all the research institutions involved in rice research in the country were nominated into a network of coordinated variety trials (CRET) coordinated by the National Cereals Research Institute (NCRI). These institutions included national institutes, such as NCRI and IAR&T (Institute of Agricultural Research and Training), as well as international centres, such as IITA (International Institute of Tropical Agriculture), IRRI (International Rice Research Institute) and WARDA (West Africa Rice Development Association). After two years, the best entries from CRET for each ecology were recommended for release to the national varietal release committee. Between 1954 and 2000, rice improvement activities led to the release of 52 varieties: 4 for deepwater ecologies, 11 for upland ecologies and 37 for swamp and irrigated ecologies. Among the released varieties, only 18 were developed by the Nigerian programme, 1 was selected from local landraces, 18 were introduced from other regions and 7 from other countries in Africa, and 8 were developed by IITA (located in Nigeria). Despite this rice varietal improvement, the increase in national rice yield was modest: from 892 kg/ha in 1961 to only 1 499 kg/ha in 2001 (FAOSTAT, 2002), due in part to the low rate of input utilization and irrigation development.

## GENETIC DIVERSITY IN RICE PRODUCTION

In general, the genetic background of the 632 rice varieties released for cultivation in India during the last three decades is diverse. However, genetic uniformity in rice production may occur in some areas. At a first glance, the reported number of rice varieties released for cultivation in the country (632) appears to be large. In reality, this number is somewhat limited, when the country's large rice area (45 Mha in 2000) and the highly variable agro-ecological conditions of rice production are taken into consideration. Moreover, a further analysis of the rice varieties released at state level shows that in Tripura, Haryana, Jammu and Kashmir, Maghalaya, Manipur and Rajsthan, the number of rice varieties released for cultivation in the last three decades is indeed limited. In Tripura, the rice area in 2000 was 250 000 ha, but the last three decades saw one variety released for cultivation. Similarly, the rice area in Haryana in 2000 was 1.08 Mha, while only eight rice varieties were released for cultivation during the last decade (Table 1). The limited number of released varieties, coupled with the high rate of adoption by farmers indicates, therefore, the possibility of genetic uniformity in rice production in several states in India. In

TABLE 1

**Harvested area (1999-2000) and number of rice varieties released for cultivation during the last three decades in different states of India**

| | Harvested area in 1999-2000 *('000 ha)* | Number of varieties released during the last three decades |
|---|---|---|
| Andhra Pradesh | 3 904.0 | 81 |
| Assam | 2 610.1 | 23 |
| Bihar | 5 086.6 | 37 |
| Gujarat | 664.4 | 23 |
| Haryana | 1 087 | 8 |
| Himachal Pradesh | 80.2 | 10 |
| Jammu and Kashmir | 250.6 | 7 |
| Karnataka | 1 447 | 32 |
| Kerala | 349.7 | 39 |
| Maharashtra | 1 508.8 | 41 |
| Meghalaya | 102.5 | 4 |
| Manipur | 157.1 | 8 |
| Madhya Pradesh | 5 354.2 | 15 |
| Orissa | 4 601.8 | 84 |
| Punjab | 2 605.0 | 16 |
| Rajasthan | 200.2 | 6 |
| Tamil Nadu | 2 204.0 | 59 |
| Tripura | 255.5 | 1 |
| Uttar Pradesh | 5 932.8 | 39 |
| West Bengal | 6 176.0 | 34 |
| Pondicherry | 25.2 | 6 |
| Other states and areas | 404.3 | 59 |
| **Total** | **45 007** | **632** |

addition, the reliance on IR 8, TN 1 and Jaya as donors for dwarf stature and high-yielding traits in rice breeding has further added to the narrowness of the genetic background of rice varieties planted in the country.

The most important factor regarding genetic uniformity in rice production in Brazil was the extensive cultivation of four irrigated rice varieties with close genetic backgrounds in Rio Grande do Sul. During the cropping season 1992/93, BR-IRGA 409 was planted on 238 000 ha, BR-IRGA 410 on 238 000 ha, BR-IRGA 414 on 145 000 ha and BR-IRGA 412 on 95 000 ha in this state, which had a total rice area of about 1 Mha. In addition, the narrow genetic diversity of irrigated rice production in Brazil may be due to the use of mostly Dee-Geo-Woo-Gen, China, Latisail, I Geo Tze, Mong Chim Vang A, Belle

Patna and Tetep as parents in the development of irrigated rice varieties. In upland ecosystems, Guarani was planted on about 52 400 ha in 1986 (1.16% of the total upland rice area) and on 350 000 ha in 1995 (12.5% of the total upland rice area). Similarly Caiapo, which was released in 1994, covered about 6.17 percent of the total upland area in 1995 and 12.04 percent (around 295 000 ha) in 1999.

Genetic uniformity in rice production in Nigeria is perhaps most common in the upland areas of the forest zone, where farmers widely adopted FARO 11 or OS6, which is well known for its tolerance to blast. Genetic uniformity may also be found in the Bende irrigation scheme, where FARO 12 and 23 are the common and popular varieties. The activities of seed multiplication and distribution of the Agricultural and Rural Development Authority in Kaduna and Kano possibly contributed to the narrowing of the genetic base of rice production in these states. In Kano, seeds of ITA 116, ITA 118 and ITA 235 were multiplied and distributed to farmers who cultivated about 40 000 ha of rice land in the state in 1988. However, due to the poor state of the extension service and seed multiplication and distribution, the level of genetic uniformity in rice production in the country may still be negligible. In fact, *O. glaberrima* rice lines and varieties are still being cultivated in the Kebbi and Sokoto states of Nigeria along the Rima Valley flood plain and as an upland crop in the Zuru area of Kebbi State. It can also be found in mixtures with *O. sativa* varieties in some farmers' fields in the shallow swamps of the Hadejia, Kano, Niger, Benue and other flood plains, and in dryland rice crops in southern parts of the country.

## GENETIC UNIFORMITY IN RICE PRODUCTION AND VULNERABILITY TO PEST OUTBREAKS

The vulnerability of rice production due to its narrow genetic diversity to pest damage and subsequent efforts in rice varietal improvement were only reported in the study on India. Rice production losses due to outbreaks of new biotypes of brown planthopper (BPH) and gall midge (GM) were reported. The BPH damage observed in the country during the late 1970s triggered an active breeding programme, which led to the release of Mansarovar in 1983 and Bhadra at a later date. Mansarovar derived its resistance to BPH from Leb Mue Nang, while Bhadra was the result of a cross between IR 8 and Ptb 20. To date, about

23 resistant varieties have been released with diverse genetic sources of resistance; they include Manoharsali, ARC 6650 and ARC 5984.

Early breeding for GM resistance at Warangal in Andhra Pradesh and Raipur in Madhya Pradesh have mainly used sources of resistance containing *Gm1* gene, while at the Directorate of Rice Research in Hyderabad, *Gm2* gene sources from Siam 29 have been extensively used. From the latter programme, varieties, such as Phalguna, Vikram and Surekha, were released for cultivation. Phalguna turned out to be very popular, covering over 80 percent of the rice area in Andhra Pradesh and Maharastra. This led to the outbreak of the new virulent GM biotype 4 in northeastern coastal regions of Andhra Pradesh in 1986 and in the Vidarbha region of Maharastra in 1989, as well as the outbreak of GM biotype 3 in the Karimnagar region of Andhra Pradesh in 1993. Subsequently, new sources of resistance, such as Ptb2, Velluthacheera and CR309, have been used in the local breeding programme.

## CONCLUSIONS

Rice improvement programmes in Brazil, India and Nigeria utilized the rich genetic resources and a variety of breeding approaches and methods to develop improved varieties for rice production. The improved rice varieties, especially the high-yielding varieties, released during the last three decades have created a basis for the increase in rice production and yield in these countries. The results of the studies, however, also indicate that development and adoption of improved rice varieties have led to narrow genetic diversity in rice production. Moreover, the study in India demonstrated that genetic uniformity in rice production led to outbreaks of pests, causing major production losses. Genetic uniformity in rice production could also lead to outbreaks of other insects and diseases. Blast is a major rice disease, especially in upland systems and in lowland areas with low temperature regimes during the cropping season. Large production losses due to blast pressures were observed in the Nile River Valley in Egypt, after the planting of a small number of varieties on a large area in the 1980s (Balal, 1994). Similar observations were reported in the Red River Valley in Viet Nam in the early 1990s (Trung, 1993). Rice production in sub-Saharan Africa is potentially vulnerable to outbreaks of rice yellow mottle virus.

Rice varietal improvement programmes should, therefore, undertake studies to analyse the status of genetic diversity in rice production to enable timely action and prevent outbreaks of pests and diseases and serious production losses. Survey of the rice varieties planted and their respective coverages could produce reliable data for the analysis of the status of genetic diversity in rice production. The lack of reliable data on planted varieties and their coverage was a major constraint to such analysis in these studies. Also, biotechnological tools, such as molecular markers and DNA printing, could also be used to provide more detailed information on the parentage of the planted varieties.

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# Genetic diversity of rice production in Brazil

*E.P. Guimarães* [1]

## INTRODUCTION

The existence of genetic diversity is the basis for progress in plant breeding. Ever since the earliest attempts to enhance plant production, quality or resistance, tools have been engineered to manage and exploit genetic diversity. Why should genetic diversity be a concern today? If we simply look around, the answer is clear. The world population increased from approximately 200 000 at the start of the first millennium to one billion in 1800 AD, whereas between 1987 and 1999 it grew from five to six billion. The rate of growth of the food supply must therefore increase rapidly in the near future. Fortunately, following the discoveries of Mendel, breeders have been able to better exploit genetic variability and increase food production to cope with the population explosion.

In-depth understanding and wise management of genetic resources and diversity is the key for increasing progress in production and sustainability in rice and other crops. The decision to base much of the calorie intake on a limited number of species, such as rice, maize and wheat, means that breeders of these crops are under great pressure to increase production. Nevertheless, plant breeders have made an excellent job of increasing several-fold the production level of these major crops, as is clear from a comparison of current production levels with those obtained at the beginning of the 20th century. It is now our responsibility to guarantee that more productive and stable varieties may be generated from the genetic resources available.

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[1] Formerly Senior Rice Breeder, EMBRAPA Rice and Beans, Goiânia, Goiás, Brazil and currently Senior Cereal Officer, Plant Production and Protection Division, FAO.

Rice improvement through the exploitation of genetic diversity began in Brazil in 1937 with the Instituto Agronômico de Campinas (IAC), and in 1938 with the Instituto Riograndense do Arroz (IRGA). The main objective of both institutions was to develop and transfer technologies for farmers in the states where the organizations were located (which is where the financial support came from). Experience shows that IAC gave priority to research for the upland ecosystem and IRGA for lowland irrigated conditions. The breeding strategy initially adopted by these institutions was selection among and within local cultivars, and only in the early 1950s were crossing and selection within the segregating population added to their programmes. In 1972, EMBRAPA (Brazilian Agricultural Research Enterprise) was created and in 1976, the National Rice and Beans Research Center (CNPAF) – now known as EMBRAPA Rice and Beans – was created with the mandate to carry out and coordinate research into rice and beans for the whole country. The backbone of the centre was and still is varietal development.

EMBRAPA played a key role in increasing germplasm collection and conservation; it was also vital to the development of a national strategy for the exploitation of local and introduced genetic resources. In 1982, it idealized the National Rice Breeding Network (NRBN) to bring together all efforts in varietal development existing in the country. This idea allowed for the development and release of 85 varieties (Guimarães, 1997a). There is no doubt that the results were very promising, but recent genetic studies have indicated that genetic diversity has been narrowing as a result of this strategy.

The principal objective of this paper is review the genetic diversity of rice in Brazil. It includes an analysis of: the rice production system used in the country; the results of the germplasm collection strategy; the exploitation of the genetic resources by the local breeding programmes; and major achievements and their impact. In conclusion, recommendations will be made for the use of genetic diversity in Brazil and the region.

## RICE PRODUCTION IN BRAZIL

In Brazil, upland and lowland ecosystems have similar importance in terms of rice production. The area planted to rice was as high as 6.6563 million ha (Mha) in the 1975/76 cropping season. This level was favoured by a combination of factors, including the yield increase in irrigated rice in the south, the economic policy favouring area expansion in the Cerrado region and the decrease in soybean prices on the international market at the time. Nevertheless, the rice area dropped drastically to its lowest level in 1997/98 (3.0733 Mha), representing a mere 2 percent of the total world rice area. In fact, since the mid-1980s the area has shown a decreasing trend. These results meant that Brazil had to import more than 2.0 million tonnes (Mt) in 1998.

The area under lowland irrigated rice is stable around 1.2 Mha, while upland rice has dropped from 4.7 to 2.4 Mha; it is believed that this may be the stabilization point, unless a clear price stimulus causes the area to increase. With the inclusion of upland rice in crop rotation systems and other alternative planting systems, such as no till, this picture may change.

The southern region remains the most important for lowland irrigated rice; the area has remained stable for several years and yields are increasing. In the near future, the area is to be maintained at just over 1 Mha a year with an average yield of around 6.5 t/ha. Nevertheless, there are possibilities for area growth in the states of Goiás, Tocantins and Mato Grosso (central tropical zone), where to date there has been only limited rice production.

In the last two decades, total production ranged from 9 to 11 Mt, with a record in 1998/99 of 11.7788 Mt. Average national yield increased by 43.6 percent from 1.349 t/ha in 1980/81 to 3.092 t/ha in 1998/99. As of 1985/86, data are available for each individual system: in 1985/86 the average yield for the lowland irrigated system was 3.992 t/ha and for the upland system it was 1.197 t/ha, while in 1999/2000 it was 5.303 t/ha (32.9% increase) and 1.904 t/ha (59.1% increase), respectively.

During the last decade, world rice consumption remained stable at around 65 kg/person/year, but in Brazil it fell from 73.1 to 67.0 kg/person/year (8.3% decrease). To cope with internal demand, the country imported around 1.2 Mt a year, reaching a level of 2.073 Mt in the 1997/98 cropping season. The Mercosul countries (Argentina and Uruguay) are the main suppliers.

The growth in world rice demand means that over the next 10 years world production must increase by 10 Mt a year (Pingali, 1995). Half will come from Asia; the other half must come from outside this macroregion. Latin America, in particular Brazil, is a strong candidate for coping with this demand, so long as policies and prices are stimulating.

## GERMPLASM COLLECTION

Although genetics-based plant breeding only began at the beginning of the 20th century, in reality it was taking place long before with the domestication of species encompassed by variability reduction. As uniformity is desirable for commercial purposes, plant breeders continued to emphasize the development and release of varieties with this characteristic, with an inevitable reduction in genetic variability. Indeed, a narrow genetic base is documented for several crops, such as soybean (Delannay *et al.*, 1983), oat (Souza and Sorrells, 1989) and rice (Dilday, 1990).

For the maintenance of Brazilian rice genetic diversity, CNPAF and CENARGEN (EMBRAPA Genetic Resources and Biotechnology) scientists devised a programme to collect and preserve the national rice germplasm. In 1978, CNPAF, aided by the extension services of the major rice-producing states, developed a project for germplasm collection. The initiative relied upon the expertise of local extension officers to collect the traditional rice varieties used by farmers. The idea was to sample as much local germplasm as possible and send it for storage and maintenance at the CNPAF germplasm bank. This effort resulted in the collection of 412 accesses nationwide.

The next step was the organization of a more structured strategy for germplasm collection and several expeditions were planned. The first, in 1979, was to Maranhao State, which had a large number of small and traditional farmers and was one of the most important producing states at the time. This expedition resulted in the acquisition of 119 accesses, 95 percent cultivated under upland and only 5 percent under lowland conditions.

In 1980, germplasm collection was concentrated in the state of Minas Gerais, a region where subsistence farming predominates. The collection added 130 entries to the CNPAF gene bank: 19 percent upland and 81 percent lowland varieties. In the same year, due to differences in cropping seasons, there was an expedition to Roraima and 59 upland accesses were gathered.

Data presented in Table 1 refer to germplasm collection accumulated between 1979 and 2000, covering 14 states nationwide. It is clear that there was greater emphasis on germplasm collection from 1978 to 1988, after which just one

TABLE 1

**Rice germplasm accesses collected in Brazilian states, 1979- 2000**

| State | Region[a] | Year | Lowland access<br>*(No.)* | Lowland access<br>*(%)* | Upland access<br>*(No.)* | Upland access<br>*(%)* | Total no. accesses |
|---|---|---|---|---|---|---|---|
| Maranhao | NE | 1979 | 6 | 5 | 113 | 95 | 119 |
| Minas Gerais | SE | 1980 | 105 | 81 | 25 | 19 | 130 |
| Roraima | N | 1980 | - | - | 59 | 100 | 59 |
| Espírito Santo | SE | 1981 | 44 | 83 | 9 | 17 | 53 |
| Amazonas | N | 1982 | - | - | 44 | 100 | 44 |
| Acre | N | 1982 | - | - | 18 | 100 | 18 |
| Rondônia | N | 1983 | - | - | 125 | 100 | 125 |
| Piauí | NE | 1984 | 44 | 24 | 140 | 76 | 184 |
| Mato Grosso do Sul | MW | 1985 | 3 | 4 | 79 | 96 | 82 |
| Goiás | MW | 1986 | 2 | 1 | 147 | 99 | 149 |
| Ceará | NE | 1987 | 2 | 8 | 22 | 92 | 24 |
| Mato Grosso | MW | 1988 | 1 | 1 | 104 | 99 | 105 |
| Tocantins | N | 1988 | 1 | 2 | 64 | 98 | 65 |
| Santa Catarina | S | 2000 | 36 | 100 | - | - | 36 |
| **Total** | **-** | **-** | **244** | **20** | **949** | **80** | **1 193** |

[a] NE = northeast; SE = southeast; N = north; MW = middle west; S = south.

collection expedition took place in 2000, privileging the only region that had not been covered previously.

In 1992 and 1993, there were two expeditions to the state of Amazonas, specifically to collect wild species, resulting in a total of 23 accesses of *Oryza glumaepatula* and 35 of *Oryza grandiglumis*. These expeditions were sponsored by the Japanese Government, which, as a counterpart, kept a replicate sample of the total germplasm collected.

Germplasm collection is no longer a priority for EMBRAPA. Nevertheless, it is certain that there are still areas where genetic variability has not been completely sampled and genetic erosion is taking place.

## EXPLOITATION OF GENETIC RESOURCES IN BRAZIL

The first rice breeding efforts made in Brazil go back to 1928 and 1929, when the farmers in the south (state of Rio Grande do Sul) introduced the first improved varieties from the United States of America. In 1938, IRGA was created, while in 1937, in the state of Sao Paulo (southeast region), IAC began its rice breeding programme. According to Germek and Banzatto (1972) activities concentrated initially on the study of the floral biology to develop hand-crossing techniques.

The initial breeding method adopted by both programmes concentrated on introducing germplasm. For lowland irrigated conditions, varieties were introduced from the United States of America; for upland conditions, local landraces were the best choice. Following the initial stage of the breeding programmes, both institutions decided to begin crossing programmes, in order to find good combinations between local and introduced germplasm. The exploitation of the genetic diversity generated by the crosses was generally managed through pedigree selection or a combination between it and modified bulk. IRGA emphasized the development of new varieties for lowland irrigated conditions, while IAC, although working under both irrigated and upland conditions, decided to concentrate its efforts on upland, as it is predominant in the state of Sao Paulo and the neighbouring states of Minas Gerais and Goiás (Germek and Banzatto, 1972).

In the early days of the breeding programmes, the major target traits were: general behaviour (adaptation to local conditions and rusticity), plant type and grain type. Examples of plant type are, for the lowland irrigated system: EEA 404, EEA 405 and IRGA 407, and for the upland irrigated system: Perola, Pratao, Dourado Precoce and Bico Ganga. Germek and Banzatto (1972) mentioned that grain types, such as cateto (short) and jaguari (medium) – inferior when compared to the irrigated long grain – were the target for upland. In general, the plant types for both systems were tall and leafy with low tillering ability. However, with the development in the 1960s of the New Plant Type at the International Rice Research Institute (IRRI), Los Baños, Philippines, local breeding programmes immediately started looking for plants with the same modern traits (high tillering, compact architecture, short stature, resistance to lodging and response to fertilizers).

To help tackle these problems, continuous and structured germplasm introduction became part of the overall breeding strategy. In the mid 1970s, the country became a member of the International Network for Genetic Evaluation of Rice (INGER, formerly International Rice Testing Program [IRTP]), coordinated by IRRI. In the early days, the most active breeding programmes (IAC and IRGA) requested nurseries, as the germplasm introduced could not be used directly; in general, they had long growth cycles and poor grain type for local standards. Exceptions included IR 841 (released in the state of Sao Paulo) and IR 22 (released in Para).

This situation changed with the creation of INGER-LAC (the International Network for Latin America) and with the increase in breeding lines in the nurseries from the International Centre for Tropical Agriculture (CIAT), Calí, Colombia. This new germplasm was more adapted to local conditions, and introductions, such as Cica 4, Cica 7, Cica 8 and Metica 1, soon covered a significant area, mainly in tropical regions in the states of Minas Gerais, Goiás and Tocantins. Unfortunately, there are no data available to estimate the impact of or the area covered by these varieties.

Following the success of the network, there was an increase in the number of nurseries tackling specific biotic (pests and diseases) and abiotic (cold, acid soil, drought, salinity and iron toxicity) stresses. Consequently, a large number of sources of tolerance or resistance to these stresses were brought to the local programmes. One good example of how the country took advantage of these introductions is the International Rice Blast Nursery (IRBN), established in Brazil in 1975, the first year of the network. The trial allowed EMBRAPA to create its national blast nursery, "Viveiro Nacional de Brusone" (VNB). Prabhu *et al.* (1997) describe how the local breeding programmes took advantage of these lines to develop blast-resistant varieties.

According to Pinheiro *et al.* (1995), during the 1970s the national institutions requested a large number of nurseries directly from IRRI. With the presence of EMBRAPA in the rice scenario and its role of coordinating research at national level, as well as the creation of a national quarantine service, all requests were channelled through this institution. The system helped to increase efficiency in nursery selection, but the quarantine requirements slowed down the introduction process. For several years this was the main source of genetic variability in most local breeding programmes.

Once the country had a mechanism for continuous introduction and distribution of germplasm, it soon realized that it was not sufficient to solve all existing problems. Therefore, EMBRAPA implemented a strong crossing programme to complement the state breeding activities and created the NRBN for better evaluation of the breeding lines developed within the country.

## CROSSING PROGRAMMES

Almost all state institutions worked on rice breeding in Brazil, but only a few allocated resources for all phases of the varietal development process. The most common method for generating genetic diversity was hand-crossing and on a few occasions induced mutation was used. Nowadays, the programmes which routinely make crosses are IRGA, IAC and EMBRAPA. Institutions, such as IAPAR (Instituto Agronomico do Parana – Parana State) and Epamig (Empresa de Pesquisa Agronomica de Minas Gerais – Minas Gerais), have also made crosses during their rice breeding history. The discussion that follows will concentrate on the three most important ones.

INGER (1991) reports all crosses made by IRGA from 1972 to 1989. There are 2 663 crosses listed: 1 567 single, 16 double, 792 triple, 164 backcrosses and 124 multiple combinations. The first crosses were made by trying to combine Japanese with local and American varieties. In 1974, the presence of breeding lines from CIAT and IRRI became very important. Of the 123 crosses made that year, 64 involved CIAT and IRRI lines; since then, however, the constant use of a limited number of lines has been observed. Of the 64 lines, IR 841-3-2-3 was used 11 times, and the 46 P lines (from CIAT) all originated from crosses between IR lines, mainly involving IR 930. Ten years on in the crossing programme, the situation worsened with regards to genetic variability: there were 125 crosses and 92 of them had sister lines (BR-IRGA 409, BR-IRGA 410 and BR-IRGA 412). These lines came from crosses between very closely related IR breeding lines. This strategy clearly shows that the breeders from IRGA combined a set of traits in improved germplasm and always went back to these sources to produce new varieties; no major concern was expressed regarding the narrowing of genetic variability.

Examination of IAC's crossing programme reveals that the 40 crosses listed in the early 1970s for upland conditions involved the combination of local developed varieties with irrigated breeding lines. IR 665 and IR 930 were used 9 and 13 times, respectively. In 1981, lines from IITA (International Institute for Tropical Agriculture, Africa) and CIRAD (Centre de cooperation internationale en recherché agronomique pour le développement - formerly IRAT [Institute for Research in Tropical Agriculture and Food Crops]) became the preferable sources for crosses. All 150 crosses involved at least one line from these programmes, showing a trend towards broadening of the genetic base of the upland germplasm. In 1987, when there were 103 crosses, 37 involved CRM 361, 8 the local line LI 84-179 and 4 other parents were used 7 times each (INGER, 1991). Similarly to what was observed with the crosses made by targeting irrigated systems, upland rice breeders have an ideotype (a set of desirable characteristics) that they aim for when choosing parents for crossing without paying too much attention to the genetic diversity or differences in origin between parental material.

EMBRAPA Rice and Beans has the largest set of rice crosses in Brazil. From 1977 to 1990, breeders made 4 560 combinations, of which 2 799 were simple and 1 442 triple crosses (INGER, 1991). The figures apply to both upland and irrigated cropping systems. In 1978, there were 239 crosses for the irrigated system. For these combinations the strategy was to combine American varieties (Labelle, Bluebelle, Dawn and Rexoro) and local cultivars (EEA 407, EEA 406, EEA 405, Barbalha, Bico Torto, Chorinho, De Abril etc.) with lines introduced from Asia (IRs and IETs). Ten years later the combinations were based on lines from its own breeding programme and germplasm developed at CIAT. Although there was wide genetic diversity available in the germplasm bank, results showed that genetic diversity in the background of the released varieties was narrow (Rangel *et al.*, 1996).

For upland varieties, in the early days crosses were made between IAC 25, IAC 47, Perola, Pratao and Bico Ganga and lines introduced from Asia (Kanan, Nunglin 24, IR 841 and Cartuna) and CIAT (Cica 4 and P 733). This strategy proved very disappointing, mainly because of the high susceptibility to diseases (in particular blast and grain discoloration) and poor grain quality.

In the early 1980s, combinations began to include lines from Africa (IITA and IRAT). In 1984, the first breeding lines produced by EMBRAPA Rice and Beans were used as parents; at this point, one cycle of selection was completed. The first important results of this programme were seen in 1986 and 1987, when EMBRAPA and its partners released several varieties, such as Araguaia, Rio Paranaiba and Guarani. The varietal release process then became routine and around one variety a year was released. Again, due to lack of information, the impact of this technology cannot be precisely assessed. Seed sales indicated that these new varieties covered more than 15 Mha in 10 years, but seed use in the upland system is very low (30-40%) (Anuário Abrasem, 1996).

With rice, as with the great majority of self-pollinated crops, the main breeding method used to develop varieties is the pedigree. In Brazil, no important variety has been developed by any other breeding method. EMBRAPA has used bulk and modified bulk in combination with pedigree to produce its breeding lines, some of which have become commercial varieties. Induced mutation as a source of variability generation has been used in very specific cases targeting highly heritable traits, but no commercial product has originated from this methodology.

Biotechnological tools have only recently been incorporated into the Brazilian breeding programmes, contributing to the understanding of genetic variability and the incorporation of desirable genes in the germplasm of interest. Thus they have not been used for the development of any commercial product.

According to EMBRAPA's strategy, all lines developed in its rice breeding programme undergo evaluation in a broad range of environments. To implement that strategy, the NRBN was created in 1982 to allow for national evaluation of rice germplasm. The section below outlines how this network operated within Brazil.

## National Rice Breeding Network (NRBN)

EMBRAPA, assuming its responsibility as national coordinator for rice research, carried out careful analysis of the breeding activities and genetic resources available in the country. The conclusion was that there were several actions which could be more efficient if organized under a network structure. Thus, in 1982, activity breeding institutions met and decided to create the "Comissão Técnica de Arroz" (CTArroz). The main goals of this network were to:

- organize different trials covering all phases of the breeding lines evaluation process;
- facilitate annual meetings to discuss past results and plan for the future;
- exchange technical information and experiences; and
- act as a forum for decisions concerning variety release.

CTArroz worked very efficiently until 2000, when the new scenario of property rights forced internal adjustment and the group structure broke down. Guimarães (1997a) describes the commission's major achievements. By 1997, 85 varieties had been released by its members. The strategy was based on the exploitation of genetic diversity generated by the local breeding programmes and the introductions from international centres. A key factor contributing to its success was the involvement in decision-making concerning the best breeding lines to be kept in the trials. There were three major trials: observational (OT), preliminary yield (PYT) and advanced yield (AYT).

The observational trial was the starting point for common breeding activities. It brought together between 150 and 300 breeding lines (in general $F_6$ lines) both from local programmes and introduced (mainly from CIAT, IRRI and CIRAD – see Table 2 for an example of the number of lines distributed by the irrigated network). The nursery was planted in five to ten key sites and general information regarding adaptation, response to disease, grain quality etc. was collected and used as parameters for decision-making. The lines with the best overall behaviour were chosen for further evaluation and, in general, around 35 to 50 materials were selected at this first stage.

According to the strategy, the second point for joint activities was the PYT. This nursery was composed of lines selected in the OT. The number of trials increased significantly during this phase, with around 50 to 60 trials planted in the country every year. The main purpose was to assess the yield potential of these lines and select the best ones for the final stage of evaluation.

The AYT was the final step for large-scale evaluation. Trials normally included around 15 to 20 entries chosen from the PYT. At this stage, all lines included in the trials needed all major agronomic traits of interest at their best.

TABLE 2
**Number of breeding lines offered by each institution to be included in the OT of NBRN**

| Institution | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | Total | % |
|---|---|---|---|---|---|---|---|---|
| CNPAF | 44 | 65 | 51 | 92 | 47 | 82 | 381 | 47 |
| IRGA | 9 | 12 | 34 | 58 | 30 | 30 | 173 | 21 |
| IAPAR | 38 | 24 | 15 | 13 | 18 | 18 | 126 | 15 |
| EPAGRI | 21 | 5 | 26 | 10 | 9 | 5 | 76 | 10 |
| CIAT | 7 | 13 | 18 | - | - | - | 38 | 5 |
| CPAF-RR | - | 21 | - | - | - | - | 21 | 2 |
| **Total** | **119** | **140** | **144** | **173** | **104** | **135** | **815** | **100** |

TABLE 3

**An example for upland rice of the number of lines distributed for evaluation within NBRN**

| Trial | 1996/97 | 1997/98 | 1998/99 | % |
|---|---|---|---|---|
| OT | 16 | 18 | 13 | 14 |
| PYT | 21 | 28 | 22 | 21 |
| AYT | 75 | 69 | 65 | 65 |
| **Total** | **112** | **115** | **110** | **100** |

The trials were distributed across the target region and were conducted over at least two consecutive years prior to varietal release.

All local breeding programmes and partners had a major role to play in these trials; their participation was also very important during the meeting where the results of all trials were discussed and lines were selected to move from one stage to the next.

Table 3 provides an example of the number of trials distributed and evaluated every year by the members of CTArroz. From now on EMBRAPA will continue to follow a similar strategy, but the only partners will be EMBRAPA's units across the country and selected institutions, which will have to sign a "memorandum of technical agreement" (MTA) for germplasm evaluation.

## MAJOR ACHIEVEMENTS AND IMPACT OF THE PROGRAMME

The major achievements of a breeding programme are evaluated in terms of: the number of varieties released and the area planted under them. The first parameter is relatively simple: all varieties released in Brazil between 1965 and 2001 are listed in Appendix 1 (87 for lowland irrigated conditions and 43 for upland conditions); more than 200 varieties released by other national programmes in Latin America are also included. The second parameter is more difficult to assess, because there are no statistics to support it. As mentioned before, seed use for the rice crop is very low (around 30-40%) (Anuário Abrasem, 1996).

The latest and most relevant information available regarding varietal impact is a study carried out by the International Food Policy Research Institute (IFPRI), Washington, in collaboration with the University of California, Davis, requested by EMBRAPA. The study analysed 35 upland rice varieties released from 1976 to 1999. It considered three groups: EMBRAPA, the cooperative system (all institutions involved in breeding activities in Brazil) and IAC, with variety shares of 77.1, 17.1 and 5.7 percent, respectively.

This report shows that varietal improvement research investments have been very profitable for upland rice, with the benefit-cost ratio varying between 59 and 81, depending on the basis used for calculations. This means that for every dollar invested by EMBRAPA in varietal development, there was a benefit of between US$59 and 81 accrued to the country.

On the basis of the IFPRI study, it can be estimated that an important upland rice variety, such as Guarani, was planted on around 52 400 ha in 1986 (1.16 percent of the total upland area planted to rice in Brazil) and grew to 350 000 ha in 1995 (12.5 percent). Another variety, Caiapo, was released in 1994; it covered 6.17 percent of the area planted in 1995 and increased to 12.04 percent in 1999, i.e. around 295 000 ha.

Pinheiro *et al.* (1993) reported that, for the cropping season 1992/93, the BR-IRGA varieties were planted on more than 700 000 ha (BR-IRGA 409 on 238 000 ha, BR-IRGA 410 on 238 000 ha, BR-IRGA 414 on 145 000 ha and BR-IRGA 412 on 95 000 ha) considering only the state of Rio Grande do Sul (the most important region for lowland irrigated rice in Brazil).

It is thus clear that breeding programmes in Brazil have contributed significantly to the increase in rice production, as well as being very profitable. Unfortunately, only recently has there been an awareness of the need to generate data to determine the impact of such technology.

## GENETIC DIVERSITY STATUS

Genetic diversity has recently been a constant issue in the field of varietal improvement. As shown, rice in Brazil is no exception, but since the early 1990s there has been concern regarding the narrowing of this diversity. The reasons for and consequences of this change are analysed below.

### Brazil

As in any other rice-growing country in the world, Brazil has taken advantage of the Green Revolution, with the introduction and commercial release of semi-dwarf varieties. The substitution of traditional tall varieties in the states of Rio Grande do Sul and Santa Catarina (the main rice-growing region in Brazil) with so-called modern varieties resulted in yield increases of 30 percent (Carmona *et al.*, 1994) and 66 percent (Ishiy, 1985), respectively. Crop management also played a significant role in this process.

Although a great number of crosses were performed every year (Soares, 1992; Rangel *et al.*, 1992), the yield increases of the 1970s were followed by limited genetic gain in the subsequent two decades. In general, changes were introduced in terms of shortening growth duration, increasing disease resistance and improving quality, but very little, if anything, was gained in terms of yield potential.

Rangel *et al.* (1996) analysed the genetic base of the main varieties sown under lowland irrigated conditions in Brazil and concluded that seven ancestors (Deo-Geo-Woo-Gen, Cina, Lati Sail, I Geo Tze, Mong Chim Vang A, Belle Patna and Tetep) were responsible for more than 70 percent of the background of these varieties. In Rio Grande do Sul, the contribution was as high as 86 percent.

Under upland conditions, studies reveal a narrow genetic base for most cultivated varieties. Guimarães (1993) concluded that there are six native varieties which comprise the base for the upland varieties released up to 1992. Montalván *et al.* (1998) examined the varieties released between 1971 and 1993 and found that 40 ancestors were involved in crossing to originate the varieties, but only 11 of them accounted for 81 percent of the genes.

Hanson (1959) mentioned that one of the main drawbacks of working with narrow genetic diversity is that there is a reduction in possible genetic gains through selection when breeders manage a limited gene pool.

Pedigree selection has been the main breeding method used to improve rice, not only in Brazil, but all over the world. Morais (1995) conducted a study which showed the consequences of this traditional way of improving autogamous species. He emphasized the negative effect on the genetic recombination level, the liberation of new genetic variability and the restricted genetic base under exploitation. Breeders have the tendency to use the same limited group of parents several times in the crossing programme, resulting in populations with few differences, thus contributing to the narrowing of the genetic diversity used in the programmes.

The consequences of this narrow genetic diversity can be easily observed in the difficulties experienced in developing varieties resistant to diseases. Prabhu *et al.* (2002) reported that in the 1998/99 cropping season in the tropical lowland irrigated rice-growing area of Brazil (State of Tocantins), there was a blast outbreak in the varieties, Epagri 108 and Epagri 109. The outbreak was due to the fact that the area planted to these varieties increased from a few hectares to over 20 000 ha in just one year, and the compatible blast races were present as a result of previous planting (no genetic diversity in resistance sources).

Another related event was the release and breakage of the resistance of Rio Formoso. This variety was developed and released in 1997 by EMBRAPA for the State of Tocantins. As soon as the variety reached the farmers' fields, the resistance was broken down. The reason was simple: although Epagri and EMBRAPA are two different institutions located in different regions, the varieties released (Epagri 108, Epagri 109 and Rio Formoso) come from the same combination or same parents. This is a clear example of the trend of using the same germplasm to develop varieties for completely different regions and of the ensuing consequences.

In general, under lowland or upland conditions in Brazil, released varieties do not last more than 2 years before disease resistance breaks down, particularly to blast. The main reason for this is the limited genetic base used by the local breeding programmes.

EMBRAPA became aware of the problem in the late 1980s and began looking for alternatives. The most attractive was the use of broad-base populations created by the help of a male-sterile gene induced in the IR 36 variety by Singh and Ikehashi (1981). Several populations were developed for irrigated (Rangel and Neves, 1997) and upland (Morais *et al.*, 1997) conditions. Their management was based on population improvement through recurrent selection. There is currently no variety developed from this strategy, only some breeding lines being tested in regional advanced yield trials.

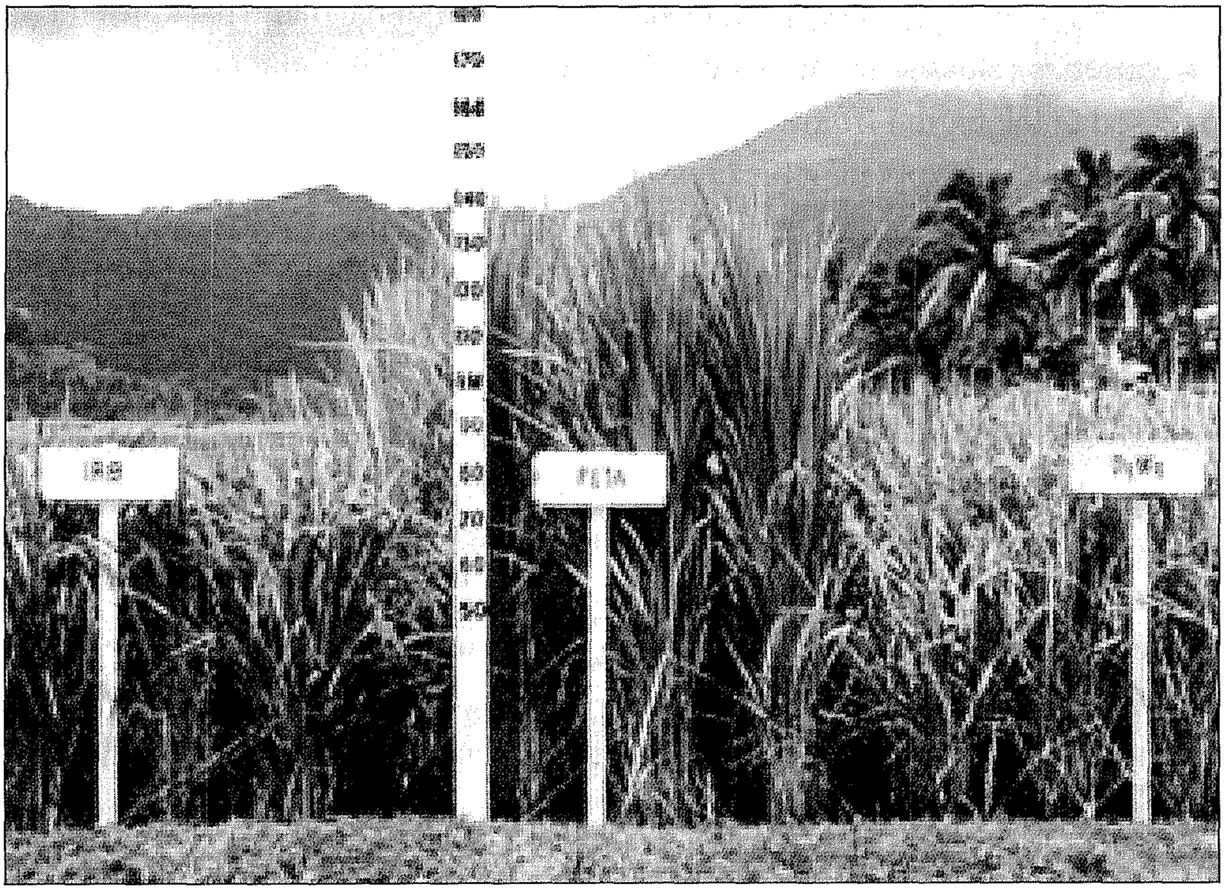
Even though EMBRAPA decided to add this strategy to its breeding programme, there is no study indicating that the potential new varieties coming from this alternative strategy will have a different genetic background. Studies

PLATE 1

**Wild rice found in Latin America**

PLATE 2

**IR first High Yielding Variety for tropical climate area and its parents**



*Source:* Darymple, 1986.

using the new molecular tools are underway to prove that this alternative will lead to broadening the genetic base of future releases in the country. This is one area where biotechnological tools are useful, since the traditional pedigree analyses are difficult to make.

### Latin America

The limited use of the genetic diversity available worldwide has been of concern in Latin America since the late 1980s. Cuevas-Perez *et al.* (1992a) analysed the situation and published a paper showing the limited genetic background of the varieties released in the region. They examined 143 commercial varieties released in the region from 1971 to 1989. The authors found that 101 different landraces were involved in the crosses that produced the varieties, but only 14 ancient cultivars contributed to 70 percent of the genes. Similar results were found in the United States of America by Dilday (1990) and in Japan by Kaneda (1985).

Cuevas-Perez *et al.* (1992b) identified seven breeding programmes making crosses and developing fixed lines. Today, a similar analysis would show the number to have increased to ten, but sizeable programmes (such as Mexico's) have all but disappeared, and others (such as Venezuela's and Bolivia's) have become substantially larger.

These findings also made the national programmes in the region look for alternative solutions to the problem. The Brazilian experience was important for population improvement through recurrent selection. Initially CIAT-developed broad-base populations targeted blast resistance (Guimarães *et al.*, 1995); a joint project between CIRAD and CIAT then had the responsibility of helping national programmes to develop their own populations and use the methodology. Nevertheless, the factor that pushed the idea forward was the training course on the subject that took place in Calí, Colombia, in 1996 under the sponsorship of the Organization of American States (OAS).

Argentina, Bolivia, Brazil, Chile, Colombia, El Salvador, Venezuela and Uruguay have been informally working together on population improvement since 1996. CIRAD, through its joint project with CIAT, has been the international partner in this initiative, and FAO, with less emphasis, has also helped to keep the group together. Nevertheless, financial support for all activities has come from national projects at the expense of reducing investments in the traditional and proven method of variety production. Further work is required for full implementation.

The history of this group's work is well documented in Guimarães (1997b, 2000), both published in Spanish. In 2000, representatives of FAO participated in a group meeting, during which it was attempted to formally organize the group into a network called "Grupo de mejoramiento avanzado en arroz" (Grumega). The idea was to take advantage of the ongoing activities and add the use of biotechnological tools in the breeding strategies followed by the national programmes.

Even though such initiatives take place, positive results are not evident, since the methodology is new and requires time to mature and produce cultivars. This strategy is doubtless an additional tool for breeding programmes to better exploit genetic diversity towards increasing productivity and sustainability in the region. An effort must be made to motivate donors to support such projects in the region and make them aware of the use of this powerful strategy for generating and exploiting genetic diversity.

## POTENTIAL AND CONSTRAINTS OF THE USE OF GENETIC DIVERSITY

Genetic diversity in rice species is high and has been sufficient for breeders for centuries. Nevertheless, because of the specific requirements of industry and consumers, breeders have throughout the history of rice improvement devoted efforts to a limited number of parents contributing directly to the characters of interest. Classical breeding methods allowed for tremendous progress a few decades ago; nowadays growth in demand requires faster progress for yield potential and more specialized products.

Biotechnological tools are opening up new frontiers in the exploitation of genes present in wild species. McCouch and Doerge (1995) reported that QTLs (quantitative trait loci) found in chromosome one and two of *Oryza rufipogon* are responsible for yield increase. Xiao *et al.* (1996) obtained similar results with the same wild species. Martínez *et al.* (1998) describe the use of wild species at CIAT. The Brazilian irrigated rice breeding programme has been using *Oryza glumaepatula* (a species native to Brazil) and an approach developed by Brondani *et al.* (2002) targeting QTL for yield increase. Studies have been done on the upland environment: Moncada *et al.* (2001) recorded yield increases in crosses between Caiapo (a commercial cultivar in Brazil) and *O. rufipogon*.

As mentioned above, Latin America found an alternative method for helping national programmes deal with the narrow genetic base in their breeding strategies. The use of population improvement through recurrent selection appears to be the right approach. The potential of this methodology has not yet been completely proved, but the initial results are positive. Ospina *et al.* (2000) in Colombia present results showing progress for blast resistance in three populations submitted to phenotypic mass selection under acid soil conditions in Colombia; Rangel and Zimmermann (1998) report genetic gains ranging from 3.1 to 8.8 per cycle for grain yield for three irrigated rice populations managed in Brazil. Castro *et al.* (2000), working with populations developed for Brazilian upland environment, indicated that after only one cycle of recurrent selection it was possible to increase the gene frequency for grain yield in two CG populations.

The major advantages mentioned by the rice breeders in those countries using the methodology are: the possibility to create and manage broad-base populations; the presence of a continuous source of genetic diversity for line development; the existence of technical support from international programmes, such as CIRAD-CIAT and EMBRAPA; the possibility to exploit genes present in wild relatives through their incorporation in the background of the populations; and the ownership of the locally developed populations.

The two new alternatives described above give an idea of the potential for exploiting genetic diversity from a different angle. It is clear that there are also constraints related to these processes. The biotechnological tools are very useful, but the high costs are still a limiting factor; very few national programmes in Latin America can take advantage of this technique. Population improvement also has drawbacks that can be summarized as follows:

- It was designed to produce results in the medium and long term, when gene frequency becomes substantially high.
- For the creation of a new population, several years are required to evaluate and study the parents and recombine their genes.

- The presence of the male-sterile gene in the constitution of the populations requires additional work during line extraction, evaluation and development.

## RECOMMENDATIONS FOR ENHANCING THE USE OF GENETIC DIVERSITY

On the basis of the information described herein, the following recommendations can be made at national, regional and international level:

- Stimulate new programmes for germplasm collection covering areas where there are still possibilities for new genetic diversity findings.
- Help look for a support mechanism for breeding programmes at national and regional level using strategies that allow better exploitation of genetic diversity.
- Create a network to organize the existing regional initiatives using alternatives to better exploit genetic variability (e.g. Grumega).
- Look for mechanisms (conferences, working groups) that put together successful experiences elsewhere in the world related to use of genetic diversity in rice.
- Stimulate the international centres, CIAT, IRRI and WARDA (West Africa Rice Development Association), to develop mechanisms to quickly transfer to national programmes finds made in the field of genetic diversity aimed at productivity gains, mainly in the biotechnological aspects.
- Develop donors' awareness of the subject and of the initiatives present in Latin America.

## CONCLUSIONS

The ideas and results presented and discussed in this document point to the following conclusions concerning the genetic diversity of rice production:

- Breeding programmes have made a tremendous impact on rice production in Latin America.
- There are still areas where germplasm collection needs to continue, not only in Brazil, but in other countries in the region.
- Brazil has been working on population improvement to better exploit genetic diversity in its breeding programmes.

- Latin America is beginning to use a population improvement method that will allow for better use of genetic diversity.
- Biotechnological tools can be very helpful for understanding and broadening the genetic base of Latin American varieties.
- Financial support is the major limiting factor to speeding up the process of more intensive exploitation of genetic diversity in the region.
- There is a need for donors' awareness in relation to the genetic diversity problem in Latin America and the alternatives being used.

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