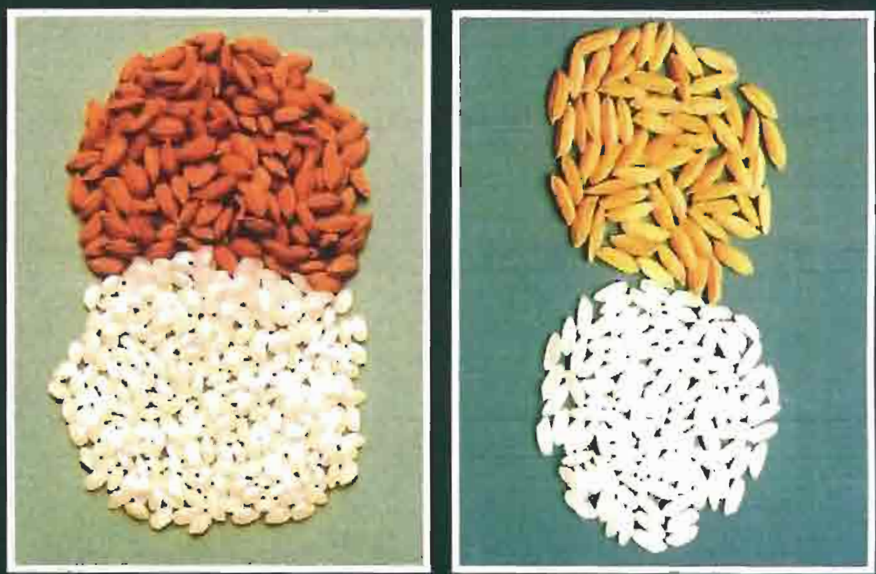
Genetic diversity in rice production

Case studies from Brazil, India and Nigeria



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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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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.

REFERENCES

Balal, M.S. 1994. Overview of rice production and research in Egypt. Paper presented at the 18th Session of the IRC.

FAOSTAT. 2002. FAOSTAT Database Records.

Pereira, P.A.A., Guimaraes, E.P. & Martins, J.F. da S. 1999. Rice production in Brazil: achievements and policies. In *Proceedings of the 19th Session of the IRC*, 7-9 Sept. 1998, Cairo, Egypt, p. 174-180. FAO, Rome, Italy.

Trung, H.M. 1993. Present status of rice diseases and their control with emphasis on the use of resistant varieties in Vietnam. In *INGER report on disease resistant monitoring visit*, p. 44-49. IRRI.

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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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 (*No.*)	Lowland access (*%*)	Upland access (*No.*)	Upland access (*%*)	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.

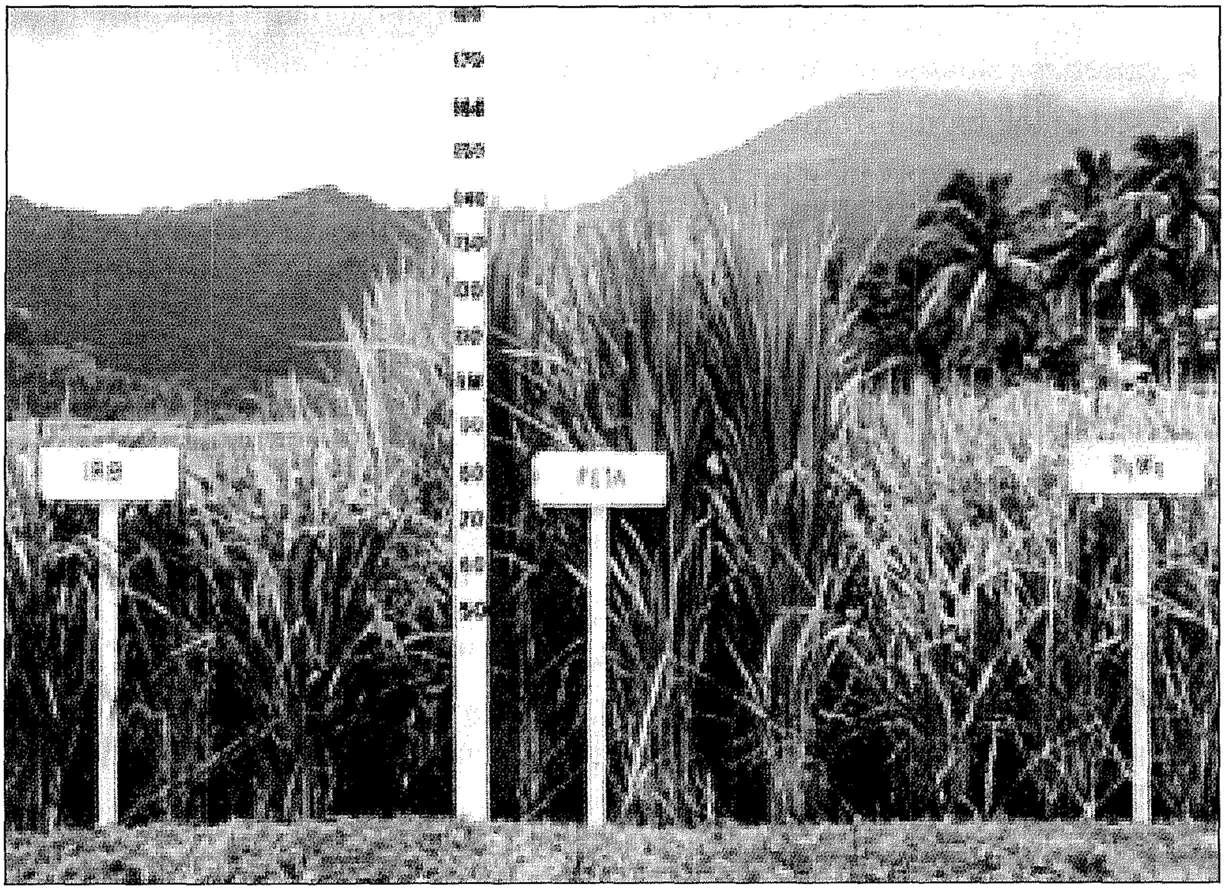
In general, under lowland or upland conditions in Brazil, released varieties do not last more than 2 years before disease resistance breaks down, particularly to blast. The main reason for this is the limited genetic base used by the local breeding programmes.

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.

REFERENCES

Anuário Abrasem. 1996. *Seed directory, Anuário Abrasem.* 178 pp.

Brondani, C., Rangel, P.H.N. & Ferreira, M.E. 2002. QTL mapping and introgression of yield related traits from *Oryza glumaepatula* to cultivated rice *(O. sativa)* using microsatellite markers. *Theor. Appl. Genet.* (in press)

Castro, E. da M., Morais, O.P. de, Sant'Ana, E.P., Breseghello, F. & Neto, F. de M. 2000. Mejoramiento poblacional de arroz de tierras altas en Brazil. *In* Guimarães, E.P. (ed.) *Avances en el mejoramiento poblacional en arroz*, p. 221-240. Calí, Colombia, CIAT.

Carmona, P.S., Terres, A.L. & Schiocchet, M. 1994. Avaliação crítica dos projetos do PNP-Arroz na área de melhoramento genético no período de 1980 a 1990: Estados do Rio Grande do Sul e Santa Catarina. In *A pesquisa de arroz no Brazil nos anos 80, avaliação crítica dos principais resultados*. Documento 40. Goiânia, Brazil, EMBRAPA/CNPAF.

Cuevas-Perez, F.E., Guimarães, E.P., Berrio, L.E. & Gonzales, D.I. 1992a. Genetic base of irrigated rice in Latin America and the Caribbean. *Crop Sci.*, 32: 1054-1058.

Cuevas-Perez, F.E., Guimarães, E.P. & Martínez, C.P. 1992b. Estado actual de las actividades de fitomejoramiento del arroz en América Latina y el Caribe. In *Arroz em América Latina: Mejoramiento, manejo y comercialización*, p. 15-30.

Darymple, D.G. 1986. *Development and spread of high-yielding rice varieties in developing countries*. USAID. 117 pp.

Delannay, X., Rodgers, D.M. & Palmer, R.G. 1983. Relative genetic contribution among ancestral lines to North American soybean cultivars.

Crop Sci., 23: 944-949.

Dilday, R.H. 1990. Contribution of ancestral lines in the development of new cultivars of rice. *Crop Sci.*, 30: 905-911.

Germek, E. & Banzatto, N.V. 1972. *Melhoramento do arroz no Instituto Agronômico.* Boletim No. 202. Campinas, São Paulo, Brazil, Instituto Agronômico de Campinas. 56 pp.

Guimarães, E.P. 1993. Genealogy of Brazilian upland rice varieties. *Intl Rice Res. Newsl.*, 18(1): 6.

Guimarães, E.P., Correa-Victoria, F.J. & Tuland, E. 1995. GC-91, a broad-based rice synthetic population for blast (*Pyricularia grisea* Sacc.) resistance. *Rev. Bras. Gen.*, 18(4): 553-561.

Guimarães, E.P. 1997a. *Embrapa e parceiros lançam 85 cultivares de arroz em 15 anos de pesquisa.* Pesquisa em Foco No. 4. Goiânia, Goiás, Brazil, Embrapa Arroz e Feijão.

Guimarães, E.P. (ed.). 1997b. *Selección recurrente en arroz.* Publicacion CIAT No. 267. Calí, Colombia, CIAT. 240 pp.

Guimarães, E.P. (ed.). 2000. *Avances en el mejoramiento en arroz.* Santo Antonio de Goiás, Goiás, Brazil, Embrapa Arroz e Feijão. 311 pp.

Hanson, W.D. 1959. Theoretical distribution of the initial linkage block lengths intact in the gametes of a population intermated for generations. *Genetics*, 44: 839-846.

INGER. 1991. *Cruzamientos de arroz América Latina.* Volume 1. 426 pp.

Ishyi, T. 1985. O impacto das cultivares modernas de arroz irrigado em Santa Catarina. *Lavoura Arrozeira*, 38(359): 10-14.

Kaneda, C. 1985. Development of very high-yielding rice varieties. *Farming Japan*, 19: 25-29.

Martínez, C.P., Tohme, J., Borrero, J., McCouch, S.R., Roca, W., Chatel, M. & Guimarães, E.P. 1998. Estado actual del mejoramiento del arroz mediante la utilización de especies silvestres de arroz en CIAT. *Agronomia Mesoamericana*, 9(1): 10-17.

McCouch, S.R. & Doerge, R.W. 1995. QTL mapping in rice. *Trends in Genet.*, 11: 482-487.

Moncada, P., Martínez, C.P., Borrero, J., Chatel, M., Gauch Jr, H., Guimarães, E.P., Tohme, J. & McCouch, S.R. 2001. Quantitative trait loci for yield and yield components in an *Oryza sativa* × *Oryza rufipogon* BC_2F_2 population evaluated in an upland environment. *Theor. Appl. Genet.*, 102: 41-52.

Montalván, R., Destro, D., Silva, E.F. da & Montaño, J.C. 1998. Genetic base of Brazilian upland rice cultivars. *J. Genet. & Breed.*, 52: 203-209.

Morais, O.P. de. 1995. Fatores ecofisiológicos e genéticos que afetam o melhoramento do arroz para maior rendimento. *In* Pinheiro, B. da S. & Guimarães, E.P. (eds) *Arroz na América Latina: Perspectivas para o incremento da produção e do potencial produtivo.* IX Conferência Internacional de Arroz para a América Latina e o Caribe and V Reunião Nacional de Pesquisa de Arroz, Goiânia, Goiás, Brazil, 21-25 de março de 1994. Documento 60, p. 83-91. Goiânia, Brazil, Embrapa-CNPAF.

Morais O.P. de, Castro, E. da M. de & Sant'Ana, E.P. 1997. Selección recurrente en arroz de secano en Brazil. *In* Guimarães, E.P. (ed.) *Selección recurrente en arroz*, p. 99-115. Calí, Colombia, CIAT.

Ospina, Y., Chatel, M. & Guimarães, E.P. 2000. Mejoramiento poblacional del arroz de sabanas. *In* Guimarães, E.P. (ed.) *Avances en el mejoramiento poblacional en arroz*, p. 241-254. Calí, Colombia, CIAT.

Pingali, P.L. 1995. GATT and rice: do we have our research priorities right? In *Fragile lives in fragile ecosystems*. Proceedings of the International Rice Research Conference, 13-17 Feb. 1995, p. 25-38. Los Baños, Philippines, IRRI.

Pinheiro, B. da S., Prabhu, A.S. & Rangel, P.H.N. 1993. INGER Network activities in Brazil: Benefits and constraints. *In* Proceedings of the Advisory Committee Meeting of the International Network for Genetic Evaluation of Rice (16th Meeting), p. 52-61. Los Baños, Philippines, IRRI.

Pinheiro, B. da S., Prabhu, A.S. & Rangel, P.H.N. 1995. Twenty years of INGER Network activities in Brazil. *In* Proceedings of the Advisory Committee Meeting of the International Network for Genetic Evaluation of Rice (18th Meeting), p. 139-158. Los Baños, Philippines, IRRI.

Prabhu, A.S., Ribeiro, A.S., Soave, J., Souza, N.S., Kempf, D., Filippi, M.C., Rangel, P.H.N. & Zimmermann, F.J.P. 1997. Vivero nacional de Piricularia: Progreso, perspectivas y utilización como fuente de progenitors para la selección recurrente. *In* Guimarães, E.P. (ed.) *Selección recurrente* *en arroz*, p. 217-226. Calí, Colombia, CIAT.

Prabhu, A.S., Filippi, M.C., Araujo, L.G. & Faria, J.C. 2002. Genetic and phenotypic characterization of isolates of *Pyricularia grisea* from the rice cultivar Epagri 108 and Epagri 109 in the state of Tocantins. *Fitopatologia Brazileira*. (in press)

Rangel, P.H.N., Zimmermann, F.J.P. & Neves, P.C.F. 1992. El CNPAF investiga? Decrece en Brazil el rendimiento del arroz de riego? *Arroz en las Américas*, 13(1): 2-4.

Rangel, P.H.N., Guimarães, E.P. & Neves, P.C.F. 1996. Base genética das cultivares de arroz (*Oryza sativa* L.) irrigado do Brazil. *Pesq. Agropec. Bras*., 31(5): 349-357.

Rangel, P.H.N. & Neves, P.C.F. 1997. Selección recurrente aplicada al arroz de riego de Brazil. *In* Guimarães, E.P. (ed.) *Selección recurrente en arroz*, p. 79-97. Calí, Colombia, CIAT.

Rangel, P.H.N. & Zimmermann, F.J.P. 1998. Ganhos de produtividade de grãos no melhoramento populacional do arroz de várzeas. *In* Pinheiro, B. da S. & Guimarães, E.P. (eds) *Arroz na América Latina: Perspectivas para o incremento da produção e do potencial produtivo*. IX Conferência Internacional de Arroz para América Latina e o Caribe and V Reunião Nacional de Pesquisa de Arroz, Goiânia, Goiás, 21-25 de marzo de 1994, p. 174-177. Goiânia, Brazil, EMBRAPA-CNPAF.

Singh, R.J. & Ikehashi, H.I. 1981. Monogenic male sterility in rice: Introduction, identification and inheritance. *Crop Sci.*, 21: 286-289.

Soares, A.A. 1992. Desempenho do melhoramento genético do arroz de sequeiro e irrigado na década de oitenta em Minas Gerais. Lavras, Brazil, Escola Superior de Agricultura de Lavras. 188 pp. (Doc.Thesis)

Souza, E. & Sorells, M.E. 1989. Pedigree analysis of North American oat cultivars released from 1951 to 1985. *Crop Sci.*, 29: 595-601.

Xiao, J., Grandillo, S., Ahn, S.N., McCouch, J.R. & Tanksley, S.D. 1996. Genes from wild rice improve yield. *Nature*, 184: 223-224.

Varietal improvement for rice production in India

B. Mishra [1]

INTRODUCTION

Rice is the most important tropical cereal and it supplies a quarter of the entire calorie intake of the human race. South and Southeast Asia, which support a major part of the world population, account for about 90 percent of rice area and consumption. Rice belongs to the genus *Oryza* and there are two main cultivated species: *sativa* in Asia and *glaberrima* in Africa. The predominant *O. sativa* subspecies grown in Asia are *japonica* (grown mostly in Japan, Korea and northern China), *indica* (mostly in the rest of Asia) and *javanica* (in Indonesia). Rice is a semi-aquatic graminaceous crop with great diversity as it is grown in a complex range of very different environments, from uplands at altitudes of 3 000 m to rainfed lowland, irrigated, tidal swamp and deepwater areas.

Globally, India is first in terms of rice area, second after China in terms of production and it accounts for 24.8 percent of world rice production. Within the country rice occupies 22.8 percent of the total cropped area and 46.3 percent of the area under cereals; it contributes 42 percent of total food grain production and continues to play a vital role in national food security, as it constitutes the staple food for two-thirds of the population supplying about 33 percent of food energy. Despite the low protein content of brown rice, the net protein utilization value of rice is 73.8 percent – the highest amongst cereals. Rice cultivation and processing also form the basic economic activities, either directly or indirectly, for the vast majority of rural households in India.

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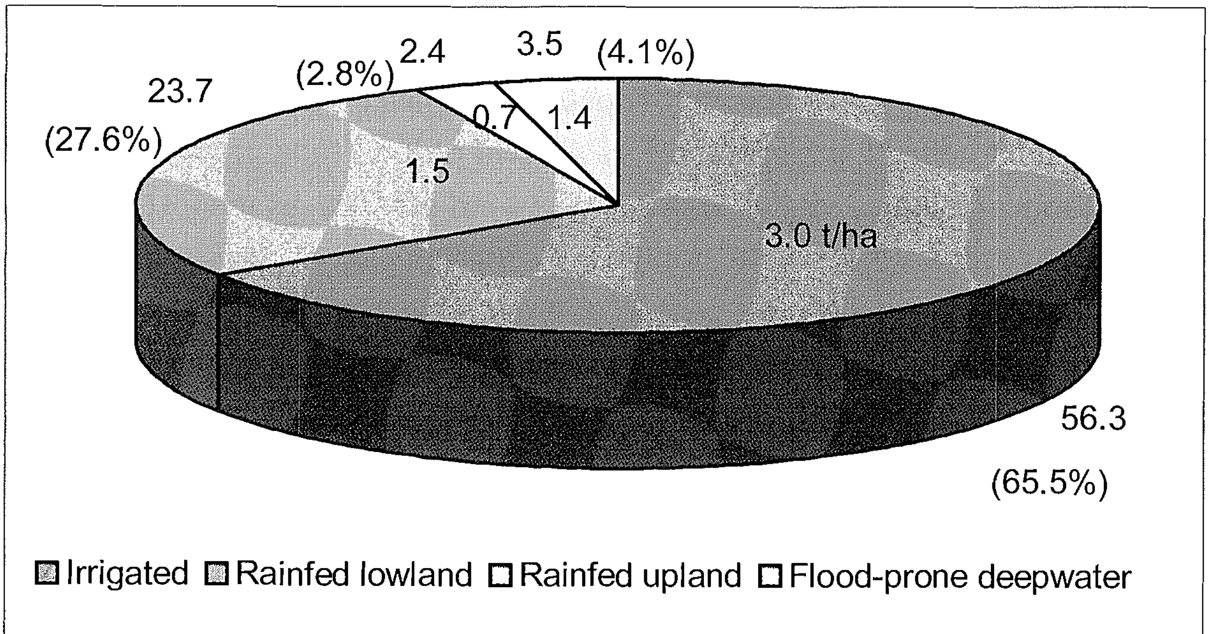
Despite the high production growth rate achieved over the years, rice productivity in the country still remains low at around 2.0 t/ha of milled rice (1999-2000), which is much less than many other rice-producing countries, such as China (3.9 t/ha), Japan (4.1 t/ha), Republic of Korea (4.6 t/ha) and Indonesia (2.7 t/ha). This is mainly because rice in India is grown in many different ecosystems and seasons which are not uniformly favourable for high productivity. Irrigated rice is grown on 50 percent of the rice area, contributing 63.5 percent of the total yield with a highest average level of productivity of about 3.0 t/ha. Rainfed shallow water lands (representing about 30 percent of the area) contribute 26.7 percent of production with an average productivity of 1.5 t/ha. Rainfed uplands occupy 15 percent of the area but contribute only 5.8 percent of total production with a least productivity rate of 0.7 t/ha. Flood-prone and deepwater rice occupy 5 percent of the total area, contributing 4 percent of production with a productivity of 1.4 t/ha. Ecosystem-wise production and productivity levels are presented in Figure 1. As each of these ecosystems requires a different set of genetic attributes, varietal improvement strategies need to be deployed accordingly. Regional disparity also prevails in terms of productivity (Fig. 2). Southern India – representing predominantly the irrigated

FIGURE 1
Rice production and productivity in different ecologies in India



ecosystem – has the highest productivity (3.7 t/ha). The northern and northwestern region, covering the states of Punjab, Haryana and Himachal Pradesh, has an average productivity of 3.1 t/ha. The predominantly rainfed shallow, semi-deep and deepwater, as well as rainfed, uplands in the eastern region record productivity of 2.4 t/ha. The western region with its hostile environment has the lowest productivity (1.9 t/ha).

RICE IMPROVEMENT IN THE PAST

As a historical backdrop, rice breeding in India began in 1911 in Dacca (now in Bangladesh) and the following year in Coimbatore in the old Madras Province. Recognizing the importance of rice to India's economy, the Imperial (now Indian) Council of Agricultural Research (ICAR) - founded in 1929 - sponsored rice breeding projects in all the major rice-growing states and as a result by 1950 the country had as many as 82 research stations exclusively for rice research. However, rice research in the country was revamped in the late 1940s in the aftermath of the now forgotten holocaust – the famous Bengal Famine of 1943-44, in which an estimated 3.5 to 3.8 million people perished due to starvation. The Indian Government rose to the occasion and set up the National Commission on

FIGURE 2
Rice production and productivity in different regions of India

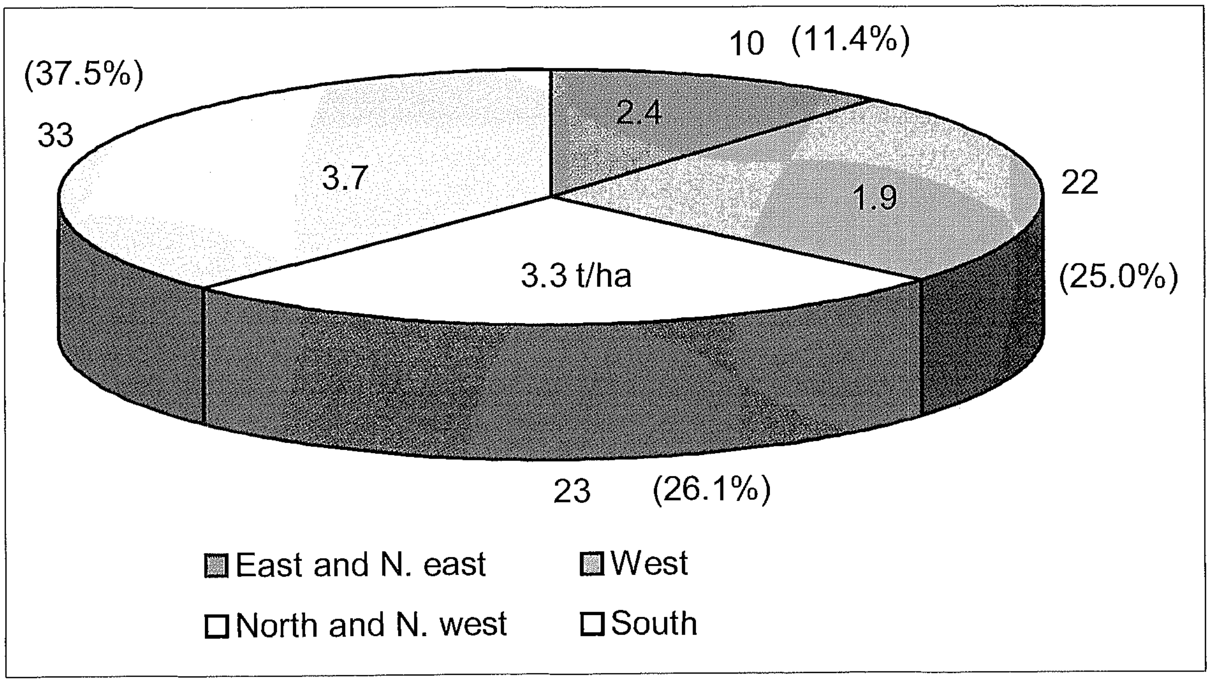


PLATE 3

Irrigated rice field planted with a High Yielding Variety

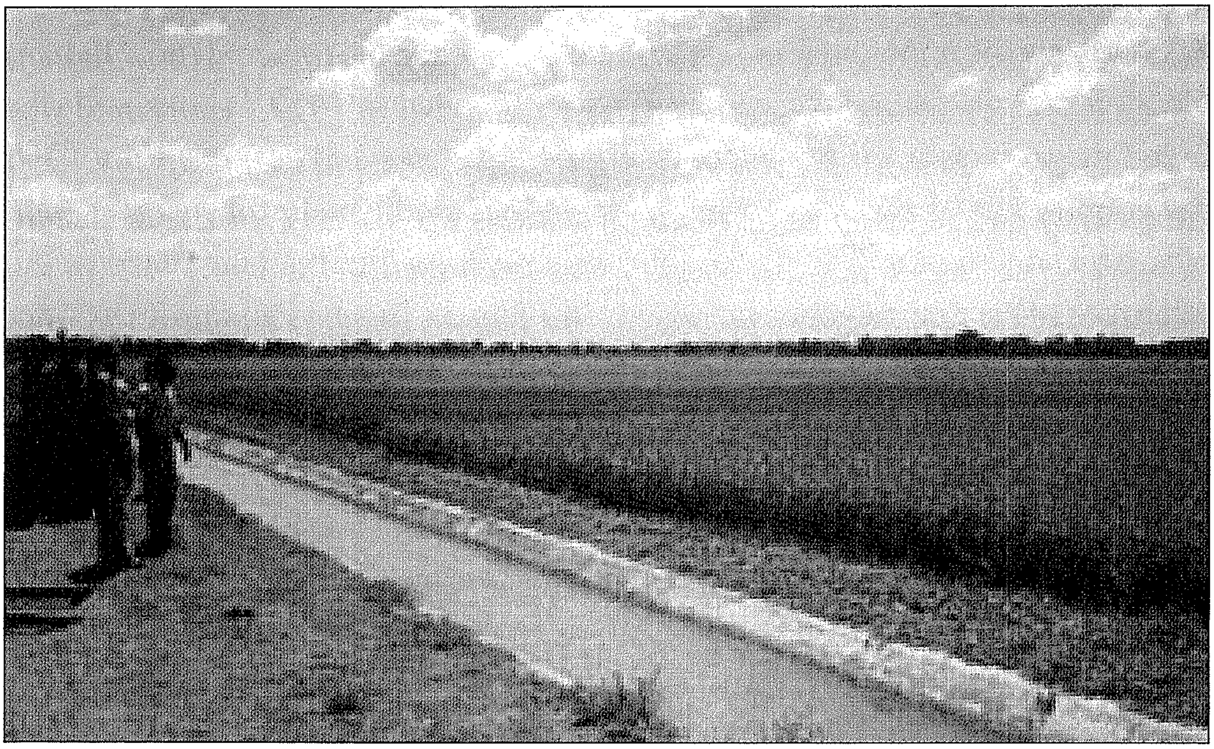


PLATE 4

A deepwater rice field in Bangladesh

Agriculture. The recommendations of the Commission culminated with the setting-up of the Central Rice Research Institute (CRRI) in Cuttack in 1946.

After the Second World War, when food grain supply fell far short of demand and threatened the world community, the Food and Agriculture Organization (FAO) founded the International Rice Commission (IRC) within the FAO framework to find ways of increasing rice production. IRC identified non-lodging habit, fertilizer responsiveness, early maturity and wide adaptability as the important varietal characteristics for achieving higher and more stable yields. Accordingly, FAO launched several regional network projects, including: "Cataloguing and Maintenance of Rice Genetic Stocks", "*Indica-Japonica* Hybridization, Cooperative Varietal Trials", "Wide Adaptability Test", "Variety-Fertilizer Interaction in *Indica* Varieties" and "Uniform Blast Nursery and International Training Program in Rice Breeding 1950-59".

Between 1950 and 1967, efforts towards achieving food self-sufficiency in India were not entirely successful. Efforts until 1967 mainly concentrated on expanding the farming area. In a classic case of Malthusian economics, the population was growing at a much faster rate than food production. This called for drastic action to increase yield. The action came in the form of the Green Revolution during the period from 1967 to 1978. Of the factors contributing to the Green Revolution, the credit for the scientific component, consisting of development, testing and release of modern genetically high-yielding varieties of rice and wheat, can be attributed solely to the effective utilization of genetic diversity. A simple comparison between rice production statistics in the country for 1951/52 (total area 30.81 million ha [Mha]; production 20.58 million tonnes [Mt]; productivity 668 kg/ha) and 1999/2000 (44.61 Mha; 88.55 Mt; 1 985 kg/ha) reveals the impact of rice research on food self-sufficiency.

Before the Green Revolution, varietal improvement had largely been confined to pure line selection, resulting in the identification of 445 varieties, such as Manoharsali and Latisail in the rainfed lowlands, Dular and N22 in the rainfed uplands and MTU 15 and GEB 24 in irrigated areas. As early as 1921, varietal improvement programmes were initiated in Uttar Pradesh. Beginning in 1932, research work in Nagina emphasized the development of better quality high-yielding rice varieties. Selection resulted in the production of several improved strains, such as N 105 (selection of Hansraj from Pilibhit), N 12 (selection of

Safeda from Punjab), T 3 (selection of Basmati from Dehradoon), T 9 (selection of Duniapat from Basti), T 1 (selection of Ramjiwain from Saharanpur) and T 23 (selection of Kalasukhdas from Banda). Basmati 370 was also selected at the same time in Kala Shah Kaku (now in Pakistan) in 1933. Varieties, such as Basmati 370, T 3, N 105 and T 9, are still popular and are grown on a sizeable area in the northwestern states.

The first serious research efforts to break the yield barrier of tropical rice were made through the intersubspecific (*indica* x *japonica*) hybridization programme, which combined the non-lodging habit and fertilizer responsiveness of *japonica* varieties with the adaptability and quality of *indica* rice. While the results were not as hoped, the programme did identify Mahsuri in Malaysia and ADT 27 in Tamil Nadu, resulting in significant production advancement in India. This breeding programme convinced breeders that the key to higher yield lay in breeding for non-lodging plants.

The introduction in 1965 of Taichung (Native) 1 was the first of several technological innovations leading to the realization of the potential of semi-dwarf, photo-insensitive, non-lodging, fertilizer-responsive varieties. A major breakthrough was witnessed in the history of rice breeding in the form of IR 8, which introduced the concept of the dwarf plant type. As information on different components of plant type became available, India recognized new horizons for increasing productivity through the identification of semi-dwarf varieties from introduced materials as well as selections from hybridization programmes. The coordinated research programme aimed to achieve the desired result as rapidly as possible, resulting in the release of IR 8 (from the material introduced from IRRI – International Rice Research Institute, Philippines) in 1966 and Jaya (from the hybridization programme of AICRIP – All India Co-ordinated Rice Improvement Project) in 1968. This was followed by the identification of several varieties combining improved plant type with high yield for different maturity groups. AICRIP's unique mechanism of multidiscipline-based multilocation testing facilitated the rapid development of varietal and production technologies appropriate for varied agro-ecologies. This model – now adopted by several countries and international institutions – helped to evolve more than 640 high-yielding varieties (Appendix 2) and enabled the country to boost rice production. While this article focuses on rice development in India during the period

1970-2000, earlier work has been reviewed elsewhere (Muralidharan *et al.*, 1996; Krishnaiah, 1998; Siddiq and Viraktamath, 2001).

BREEDING METHODS AND OBJECTIVES

The thrust in breeding research has varied with changing needs and socio-economic compulsions. It concentrated on high yield and general adaptability in the first decade. Following the introduction of dwarf varieties, stability of yield by breeding for resistance or tolerance to biotic and abiotic stresses was the priority in the following decade, while raising the genetic yield threshold and the development of varieties suited to rainfed ecologies received increased research attention from the third decade onwards. From the account below of the different breeding methods adopted, it is evident that that choice of method depended on: the breeding objective; the availability of suitable genetic diversity; knowledge of the genetics of the traits of interest; and the development of evaluation methodologies.

Introductions

Introduction is the oldest and simplest method of meeting the varietal needs of a given situation as well as an effective means of enlarging and enriching genetic variability. Varieties found popular for a given set of growing conditions in another country or a state within a country are introduced and evaluated in replicated trials under similar conditions to assess yield performance and adaptability. It is not necessary that all the introduced varieties become acclimatized to the new environment and be acceptable to farmers and consumers in order to justify more systematic investigations into their level of resistance to major pests and diseases and quality features. In the process of evaluation there is often scope for selection under the new environment and such selection may lead to some successful varietal introductions. Table 1 lists 21 rice varieties released as introductions from other countries. Of these, 16 were introduced for irrigated ecology (mostly from IRRI) and two for rainfed ecosystems. Several of the breeding lines developed at IRRI were extensively tested in the country and subsequently released as varieties suited for different purposes. One variety each was introduced for: Basmati quality; salt tolerance; deepwater rice with submergence tolerance; and rainfed lowlands. There are also examples of

TABLE 1
Rice varieties released in India as introductions from other countries

S. no.	Variety name	Year of release	Introduction from
	For irrigated ecology		
1	IR 20	1970	IRRI
2	IR 22	1975	IRRI
3	IR 24 (IR 661-1-1-143-3)	1972	IRRI
4	IR 28 (IR 2061-214-3--8-2)	1975	IRRI
5	IR 34 (IR 2061-213-217)	1979	IRRI
6	IR 36	1981	IRRI
7	IR 50	1982	IRRI
8	IR 64	1989	IRRI
9	IR 64	1992	IRRI
10	Palman 579	1972	IRRI[a]
11	PR 4141	1982	IRRI[a]
12	PR 109	1986	IRRI[a]
13	HKR 126	1992	IRRI[a]
14	PR 103	1976	IRRI[a]
15	PR 106	1978	IRRI[a]
16	Rajendradhan 1	1978	IRRI[a]
	For Basmati quality		
17	Hassan Sarai	2000	Iranian Basmati
18	Munal (C 15310)	1982	USA
	For salt tolerance		
19	Narendra Usar 2	1998	IRRI
	For rainfed ecology		
20	Hemavathi	2000	Bangladesh
21	Intan	1975	Indonesia

[a] Breeding line tested locally and released as variety.

successful state-to-state introductions. For example, Swarna (developed in Andhra Pradesh) has become popular in Orissa, Madhya Pradesh and West Bengal. Besides their usefulness as varieties, many of these introductions are being used as parental lines in cross-breeding programmes. Introduced varieties have thus played an important role, not only in enhancing genetic diversity, but in supporting the rice breeding programme.

Pure line breeding

Highly heterogeneous farmer-grown local varieties are purified for uniform height, maturity and other agronomic traits. This simple breeding/selection approach has both strengths and weaknesses. The process of purification begins either in farmers' fields or with farmers' strains raised on experimental farms. Seeds harvested from promising plants are raised in successive generations as panicle or plant progenies until they become uniform and stable. Following the seed increase, the chosen best line are intensively evaluated in replicated yield trials (where the local variety is the check) for at least 3 to 5 years, in order to ascertain stability of yield performance in the target environment. The best-performing entry, in terms of the breeding objective, is identified for general cultivation after evaluating for consumer quality. Pure line breeding is still relevant, when recombination breeding and other approaches are found to be slow and less effective in special situations, such as breeding for higher yield without compromising the prized quality features of Basmati. The main strength of this approach is that it does not disrupt the combination of characters preserved through generations of selection, while the main limitation is that variability and improvement of the desired character are both limited.

During the last three decades, 35 varieties for rainfed systems and 19 varieties for irrigated ecosystems have been developed through pure line selection (Table 2). Of these, 24 and 6 varieties, respectively, were pure line selections from landraces, while others were selections from elite breeding lines. Even the improved released variety, IR 50, was further selected for specific traits and formed the progenitor of three rice varieties: Sravani for irrigated ecologies in the early duration group; Swathi for rainfed shallow water; and Somasila for upland regions. Nine of the varieties developed for deepwater and nine for semi-deepwater were from selections from local landraces. Seven of the eight upland varieties developed through pure line breeding originated from local landraces. Likewise, nine varieties for rainfed shallow water lowland were also from pure line selections from both landraces and elite cultures. Six of the selections were from Basmati type locals with aroma and quality traits. Two varieties, namely Shindewahi 1 (selected from a local landrace) and Vyttila 2 (from the local variety Cheruviruppu), were released for saline/alkaline soils. Some of the earlier varieties developed as pure line selections (and to this day very popular in the country) are: GEB 24, Basmati 370 and Manoharsali, which have quality features; Ptb 18 and Ptb 33 for pest resistance; SR 26B and Vyttila 1 for salt tolerance; and FR 13A for deepwater situations. However, pure line selection also leads to genetic uniformity and erodes the prevailing diversity.

TABLE 2
Rice varieties developed in India as pure line selections

S. no.	Variety	Year of release	Ecology[a]	Selection from
1	ADT 41	1994	IRSCR	Basmati 370
2	J.J.92	1993	IRSCR	Dwarf Basmati
3	Basmati 386	1994	IRSCR	Pakistan Basmati
4	Ranabhir Basmati	1994	IRSCR	Basmati 370-90-95
5	Sugandha (T)	1983	IRSCR	Cuttack Basmati
6	Taraori Basmati	1996	IRSCR	Local Basmati
7	T 3 (T)	1973	IRSCR	Local Type 3
8	Jalgoan 5	1978	IRE	Local landrace
9	Sravani	1997	IRE	IR 50
10	Mata Triveni (PTB 45)	1990	IRE	Triveni
11	Terna	1989	IRE	MAU Sel. 9
12	Patel 85	1981	IRM	IR 8
13	Kolhapur	1971	IRM	Local landrace
14	Ambica	1991	IRM	SKL 47-8
15	HMT Sona	2000	IRM	Local landrace
16	T 141 (T)	1988	IRM	Local landrace
17	Kamini (SBR 80-643-14-1-1)	1991	IRM	Katarni Rice
18	Vytilla 2 (Cul. 174)	1980	IRM	Cheruvippu
19	Sindewahi 1	1988	IRSA	Local landrace
20	ADT 32	1972	RSL	Vaigai Samba
21	Swathi	1997	RSL	IR 50
22	Safri 17 (T)	1984	RSL	Safri
23	Seema	1991	RSL	Jagannath
24	BAM 6 (T)	1986	RSL	Ratna Chudi
25	Rajasree (T) (TCA 80-4)	1987	RSL	Local landrace
26	T 90 (T)	1988	RSL	Local landrace
27	T1242 (T)	1988	RSL	Local landrace
28	SR 26 B (T)	1988	RSL	Kalambanka
29	Janaki (T)	1983	SDW	Chenab Rice
30	Amulya	1988	SDW	Local Nagani
31	Nalini	1988	SDW	Sindu Raukhi
32	Vaidehi (T)	1995	SDW	Beldar (TCA 48)
33	Amulya	1988	SDW	Najani
34	Sabita (T)	1986	SDW	Boyan
35	FR 13A (T)	1988	SDW	Kalambanka
36	Nalini	1989	SDW	Sindhur Mukhi
37	Matangini	1989	SDW	Kajallata

[a] IRSCR = irrigated scented rice; IRE = irrigated early duration; IRM = irrigated medium duration; IRSA = irrigated saline/alkaline soils; RSL = rainfed shallow water depth; SDW = rainfed semi-deepwater.

TABLE 2
(contd.)

S. no.	Variety	Year of release	Ecology[a]	Selection from
38	Jalanidhi	1993	DW	Goanath
39	Jalpriya	1993	DW	IET 4060/Jalmagna
40	Jaladhi 1 (T)	1981	DW	Kalakher Sail
41	Jaladhi 2 (T)	1981	DW	Local Baku
42	Jalaprabha (T)	1996	DW	Local landrace
43	Jitendra	1994	DW	Local landrace
44	Jitendra (T)	1994	DW	Local landrace
45	Neeraja	1998	DW	Local landrace
46	Sudha (T) (TCA 72)	1987	DW	Local landrace
47	Suvarnamodan (ARC 11775)	1976	RUP	ARC 11775
48	Somasila	2000	RUP	IR 50
49	Tuljapur-1 (T)	1972	RUP	Lalsal 140-31
50	Imp. Ambemohar	1978	RUP	Local landrace
51	GR 5	1991	RUP	CR 319-344
52	Panke	1989	RUP	Local landrace
53	Birsagora 102 (T)	1992	RUP	Local landrace
54	Maruteru Sannalu	2000	RUP	Oodasannalu

[a] DW = rainfed deepwater; RUP = rainfed upland.

Mutation breeding

Mutation breeding is adopted to overcome the limitation of variability in the pure line selection. The original parent line or local landrace is subjected to mutagenesis, either through use of chemical mutagens or by subjecting it to ionizing radiations. Mutation breeding has been successfully exploited to improve many crop plants – including rice – for selective improvement of one or two simply inherited traits. Use of induced mutagenesis for improvement of rice began in India in the 1930s, but it received importance as a potential breeding tool in the late 1960s and 1970s with the active support of the International Atomic Energy Agency (IAEA). A wide range of mutagens were evaluated to induce mutations in rice. The physical mutagens: X-rays, gamma rays and fast neutrons, and the chemical mutagens: ethyl methane sulphonate (EMS), nitroso methyl urea (NMU) and sodium azide, were found to be potent for inducing point mutations. Rice genotypes differ in their response to mutagen since *japonica* varieties are, in general, more sensitive than *indica* and *javanica* types (Sharma, 1985). The sensitivity of genotypes to mutagens is greatly influenced by several factors, most critically: optimizing conditions to induce point mutations without adverse effects on the plant biology (Mehetre *et al.*, 1993); and post-treatment handling of the early generations to select mutants with desirable features. The mutagen-treated seed is grown as Ml generation to raise M2 generation. M2 and M3 are screened against the trait for which the breeding objective was initially set. Variants which do not show segregation for the desired trait in M3 and M4 are considered mutants.

Mutation breeding in rice was initially targeted at yield improvement, high protein content of seed and resistance to blast and bacterial leaf blight (Mikaelsen, 1979). Some mutants have been either released directly as mutant varieties or used as excellent donor sources for improving specific characters. Two of the mutant lines, namely Orumundakan and Calrose 76, possessed a wide range of gall midge resistance against different biotypes. Jagannath was the first rice variety developed in India through mutation breeding involving the parent line T 141. This variety has been used in the development of six improved varieties for the rainfed ecosystem. Table 3 lists 11 recent rice varieties developed through mutation breeding. One of these, Prabhavati, was developed from the local variety, Ambemohar, through somaclonal variation induced by the tissue culture technique. Two of the varieties were developed from IR 8 through

TABLE 3
Rice varieties of India developed through mutation breeding

S. no.	Variety	Year of release	Ecology[a]	Parental line
1	Biraj	1982	SDW	Co 1393 mutant
2	Padmini	1988	RSL	Mutant of CR 1014
3	Rasmi	1986	RSL	Oorapandy mutant
4	Bipasa	1993	RSL	X-ray mutant of Pankaj
5	Early Samba	2000	IRM	Mutant of BPT 5204
6	AU1	1976	IRE	Sel. from mutant of IR 8
7	Lakshmi (CNM 6)	1982	IRE	Mutant of IR 8
8	Prabhavati	1984	IRE	Mutant of local Ambemohar
9	Remanica	1998	IRM	Mutant of MO1
10	Radhi	1998	IRE	Swarnaprabha mutant
11	Indira (CR MUT 587-4)	1980	IRM	Tainan 3 mutant
12	Gautam	1995	IRME	Rasi, EMS induced mutant

[a] IRME = irrigated mid-early duration (others as in Table 2).

mutagenesis. However, no significant progress was made in the improvement of Basmati rice through mutation breeding (Singh *et al.*, 1989). One of the mutant rice lines, HPU8020, had strong blast resistance and was suited for cultivation in low altitude areas of Himachal Pradesh (Sharma *et al.*, 1985). An EMS-induced mutant of Rasi, PSRM1-16-4B-11, was superior in yield and cold tolerance and was released as Gautam for cultivation in high altitude areas of Bihar (Thakur *et al.*, 1994). Two of the varieties developed through mutation breeding in Kerala, namely Rasmi (mutant of Oorapundy) and Radhi (mutant of Swarnaprabha), have resistance to blast and BPH (brown planthopper), respectively. It is evident that mutation breeding has played an important role in enhancing genetic diversity in rice, which in turn has been gainfully exploited for rice improvement.

Recombination breeding

Recombination breeding consists of controlled crossing between parents of choice, followed by pedigree or mass pedigree selection in the segregating generations for targeted trait(s). It is the widely employed approach in rice improvement. Unlike the pureline selection, which is limited to identification of the best in the naturally available variability, recombination breeding is a device for generating variability and recombining desired characters for any given situation. There are different ways of making crosses and procedures for selection of the progeny depending on the breeding goal and the genetics of the trait(s) to be recombined. In breeding for quantitatively inherited traits, such as yield and tolerance to complex abiotic stresses, a straight single cross followed by selection through pedigree or modified pedigree methods is the usual practice. On the other hand, for simply inherited mendelian characters, depending on the agronomic potential of the parents, either single cross or backcross followed by pedigree selection is preferred. If the breeding objective is to combine a set of traits from diverse sources, a "convergent breeding" approach is followed. This involves the stepwise addition of constituent traits. For varieties with multiple pest resistance or diverse quality traits, convergent breeding is adopted.

Backcross breeding is used when a simply inherited trait is to be selectively transferred from a recalcitrant wild donor, e.g. a wild species or poor landrace, to an otherwise good agronomic base. It is necessary to go for several cycles of backcrossing of the recurrent parent with the recipient variety. This breeding method is effective for breaking tight linkages between desirable and undesirable traits and it is routinely used in hybrid breeding for the development of cytoplasmic male sterile lines. The method is quicker if the donor parent also has good agronomic traits. The successful introduction of bacterial leaf blight resistance genes (*Xa 21* and *Xa 4*) into Pusa 44 is a good example of the potential of backcross breeding.

The selection methodology employed also varies depending on numerous factors: the genetic control of the target trait; field/laboratory facilities; labour requirements and conduciveness of the environment for effective selection. The pedigree method is followed for the improvement of both qualitative and quantitative traits in situations where land/laboratory facilities and manpower are adequate, while the modified pedigree or mass pedigree method of selection becomes inevitable when the selection environment is not appropriate for discriminating desirable genotypes from undesirable ones. In such situations the segregating populations are bulked up to 4 to 5 generations right from F_2 followed by pedigree selection. When the breeding objective is the incorporation of resistance to a particular insect pest of variable incidence under field conditions and no method or facility is available for screening under artificial conditions, bulking of segregating populations is continued until the right screening environment occurs. This practice also holds good for breeding for drought resistance. The whole strategy of early generation bulking is practised when the F_2 population itself is too small or the likelihood of loss of valuable segregants is high under harsh target environments, such as salinity and drought. In the latter case, F_2 is raised under optimal conditions, and F_3 raised from bulked F_2 is screened under the stress.

About 500 of the 633 rice varieties developed for cultivation are through recombination breeding. More than 90 percent of these were developed from single straight crosses involving two parents, while 5 percent are from double cross involving three parents and only 2 percent involved four parents. Table 4 lists the most often used parent lines together with their attributes. IR 8 has been the most extensively used parent in the development of over 80 varieties for both irrigated and rainfed ecologies, followed by TN 1 (40 varieties developed), IR 36 (15), Jaya (14), Basmati 370 (10) and TKM 6 (10).

TABLE 4

Parents most often used in India's recombination rice breeding programme

S. no.	Parent	No. of derived varieties	Genes involved	Attributes involved[a]
Irrigated ecology				
1	IR 8	58	sd1	Photoperiod insensitive, semi-dwarf plant stature, high yield potential, medium maturity duration and MR to BL, GLH,
2	TN (1)	24	sd1	First semi-dwarf and photoperiod insensitive variety
3	Jaya	14	sd1	Photoperiod insensitive, semi-dwarf plant stature, high yield potential, medium maturity duration
4	IR 36	15		Early-mid early, suitable for intercropping, R to GM
5	Basmati 370	10		Aromatic, export quality rice
6	TKM 6	10		R to SB
7	Mahsuri	8		Indica/japonica derivative, stable, high yielding, suitable for shallow lowlands and irrigated areas, late duration
8	Sona	8		Fine grain, quality rice, MR to RTV, SB, leafhopper
9	Zinnia 31	7		Quality grain
10	T 90	6		Quality grain
11	IR 50	5		Early duration, high yield potential suitable for multiple cropping system
12	PTB 10	5	*Gm4*	Good for soil problems, R to GM
13	PTB 33	5		R to BPH, WBPH
14	Vikram	5	*Gm2*	R to GM, medium duration variety
15	ADT 27	4		Suitable for Kuravai, early monsoon, indica/japonica cross
16	IR 24	4		High yield, early, R to GM, good for saline soils
17	IR 28	4		Earliness, multiple resistance
18	MO 6	4		BPH resistance
19	PR 106	4		Medium maturity, high yield potential, export type non Basmati rice
20	Rasi	4		Indica/japonica derivative, stable, high yielding, suitable for shallow lowlands and irrigated areas, late duration
21	Triveni	4		MR to BL, suitable for direct seeding
22	W 1263	4	*Gm1*	R to GM, SB
23	W 12708	4	*Gm2*	R to GM, SB

TABLE 4
(contd.)

S. no.	Parent	No. of derived varieties	Genes involved	Attributes involved
Rainfed ecology				
1	Pankaj	24		Late duration, suited for rainfed lowlands, MR to BL, RTV
2	IR 8	21		Photoperiod insensitive, semi-dwarf plant stature, high yield potential; MR to BL, GLH
3	Mahasuri	19		Indica/japonica derivative, stable, high-yielding, suitable for shallow lowlands and irrigated areas, late duration
4	TN (1)	16		First semi-dwarf and photoperiod insensitive variety
5	IR 20	8		High seasonal stability, grain quality, R to RTV
6	Sona	8		Fine grain, quality rice
7	IR 36	7		Early-mid early, suitable to intercropping, R to GM
8	N 22	7		Drought tolerant
9	CR 1014	6		Late maturing, stable widely adaptable, quality rice
10	Jaganath	6		Mutant of T 141, photosensitive, lowland variety good for delayed rain
11	Jaya	6		Photoperiod insensitive, semi-dwarf plant stature, high yield potential
12	Fine Gora	5		Drought tolerant
13	Patnai 23	5		High yield potential, lowland variety
1	Bulk H 9	4		Late, photosensitivity
2	M 63 - 83	4		Drought tolerant
3	Rasi	4		Good for irrigated, rainfed uplands; cropping systems because of early maturity
4	RP 5-32	4		Late maturing, high yield potential
5	Vijaya	4		High seasonal stability, R to leaf hopper, Tol. SB

[a] T141 = selection from "Saruchinamali"; N22 = selection from "Rajbhog"; R = resistant; MR = moderately resistant; Tol. = tolerant; BL = blast; BPH = brown planthopper; GLH = green leafhopper; GM = gall midge; RTV = rice tungro virus; SB = stem borer; WBPH = white-backed planthopper.

Approaches for accelerated generation advance and selection

One of the major limitations of recombination breeding is the long period required for fixing genotype with desired character combinations. More genetically complex traits need longer to be fixed. It is all the more difficult and time consuming if such traits are to be incorporated in long-duration photosensitive varieties. Various techniques have been developed to reduce the breeding selection cycle.

Rapid generation advance (RGA): Well suited to breeding long-duration photosensitive varieties. Instead of one crop per year (as with long-duration photosensitive varieties under field conditions), three crops can be taken using the RGA strategy. This strategy is invaluable in breeding for lowland and deepwater ecologies.

***Shuttle breeding*:** This involves raising breeding populations alternatively in two agroclimatically diverse environments for two different purposes, namely: practising selection at one centre and advancing generation at another to take advantage of favourable weather; and selection and generation advance at both centres.

Selective diallele mating and recurrent selection

A number of characters cannot be easily bred through single cross/backcross breeding and pedigree/modified pedigree selection approaches, because their expression is governed exclusively by either minor genes or weak major genes in association with strong minor gene complexes. Such characters include resistance to stem borer, leaf folder, sheath blight etc. No strong source of resistance has to date been found against these pests, though sources of moderate resistance (believed to be governed by non-mendelian genes with small effect) are known to exist. Recurrent selection, involving repeated intercrossing among selected source parents and their progenies and practising selection successively, is a proven approach in cross-pollinated crops for selectively pooling desirable genes with little effect. The successive cycles of intermating among the selected recombinants followed by selection facilitate directed accumulation of desirable genes in the segregants, while enhancing the probability of breaking undesirable linkages. This method has many advantages but the main limitation has been the lack of an easy mechanism for ensuring random intermating. However, genetic male sterility could be effectively used for this purpose.

Heterosis breeding

It was the persistent effort of Chinese scientists that ultimately led to the successful development of hybrid rice technology during the 1970s. The first commercially usable cytoplasmic male sterile (CMS) line was developed in China in 1973 from a spontaneous male sterile plant isolated in a population of the wild rice, *O. sativa spontanea*, on Hainan Island (Virmani and Edward, 1983). A yield advantage of 15 to 20 percent over the best inbred varieties was the key factor in the wide adoption of the technology. The procedure for developing hybrids is quite different from that employed for conventional breeding. While conventional recombination breeding involves selective accumulation of yield related genes that perform well under homozygous conditions, in hybrid breeding yield genes are assembled and exploited under heterozygous conditions in the first filial F_1 generation. Heterosis is the phenomenon whereby the F_1 generation expresses quantitative traits better than the best parents. Although the genetic basis of heterosis in rice is not clearly understood, it can result from complete dominance, over dominance, epistasis or a combination of these factors (Virmani, 1996). More recent genetic and molecular studies revealed that differentially expressed DNA fragments occurring in only one parent of the cross were positively correlated with heterosis, while RNA hybridization detected an overall elevated level of gene expression in the hybrid compared with the parents (Zhang *et al.*, 2001). Generally, rice hybrids are developed by using either cytoplasmic male sterility or environment sensitive genic male sterility (EGMS) systems. Of these, the former is widely utilized, while efforts are still underway to utilize photoperiod sensitive and temperature sensitive genic male sterility to develop two-line hybrids.

CMS-based three-line approach: The development of a stable male sterility system is the prerequisite for commercial hybrid seed production. Of the different kinds of male sterility systems known in rice, the cytoplasmic-genic male sterility based three-line approach has proven most stable and commercially viable, as is the case in traditional hybrid crops. In this system, male sterility results from interaction between the sterility factor present in the cytoplasm and the nucleus. Absence of the sterility-inducing factor (gene) in either the cytoplasm or the nucleus makes a line become male fertile. This system involves a CMS (A line), maintainer (B line) and restorer (R line). A CMS line is maintained by crossing it with its B line. The A and B lines are similar in all respects except that the former is male sterile and the latter male fertile. The restorer line possesses dominant fertility restoring gene(s) and hence when crossed with a CMS line, produces a fertile F_1 hybrid. Since the system involves the use of three lines (A, B and R), hybrids developed using this method are called three-line hybrids.

Three factors are crucial for the commercial success of hybrid rice technology: high standard heterosis, stable male sterile source and efficient package for obtaining high seed yields. Yield heterosis has been reported to be as high as 370 percent, but realizable standard heterosis (yield advantage in comparison to the best standard variety) estimated across countries on the basis of population is only in the range of 18 to 36 percent. In the high-yielding varietal background, even an average standard heterosis of 10 to 15 percent would amount to an additional yield advantage of 1.0 to 1.5 t/ha.

EGMS-based two-line approach: The discovery of environment sensitive genic male sterility (EGMS), wherein alteration of male sterility/fertility is conditioned by environmental factors (e.g. photoperiod or temperature), has led to the development of a two-line breeding system (Virmani and Ahmed, 2001). The lines which respond to day-length changes are called photosensitive genic male sterile (PGMS). The first PGMS source was reported by Shi in 1981 in the *japonica* cultivar Nong-Ken 58 (Virmani and Edward, 1983). This variant remains male sterile under long day (> 14 hr) conditions and turns male fertile under short day (< 13.75 hr) conditions. PGMS lines are effectively utilized in those regions where day-length differences are quite distinct. The genetic source wherein alteration of male fertility/sterility is controlled by change in temperature, is called thermosensitive genic male sterility system (TGMS). In the tropics, where consistent temperature differences are found at different altitudes or during different seasons in the same location, the TGMS system is ideal for developing two-line hybrids. Unlike the CMS system, the TGMS system does not require a maintainer line for multiplication of the male sterile line. While a TGMS line in a sterile phase and a male fertile parent are required to produce hybrid seed, the TGMS line is maintained by growing under low temperature conditions and this facilitates its reversion to the fertile phase.

The PGMS/TGMS-based two-line system has the following advantages over the conventional CMS-based three-line system:

- There is no need for a maintainer line for seed multiplication of the male sterile line; hence seed multiplication is less cumbersome
- Any fertile genotype can be used as a male parent and there is no need to have a restorer gene; hence the choice of male parents is wide for developing two-line hybrids.
- The negative effects of sterility-inducing cytoplasm are not encountered.
- The TGMS/PGMS trait can be transferred to any desired genetic background without any restrictions, thus providing wider genetic and cytoplasmic diversity among the male sterile lines.
- The system is ideal for developing intersubspecific hybrids, as there is no need for restorer genes in the male parent.

The recent progress made in the development and adoption of hybrid rice technology in India is described in a separate section.

Cellular and molecular breeding

Advances in cell and molecular biology have opened up new opportunities for rice breeding. The new possibilities in rice breeding through application of biotechnology tools are: anther culture, wide hybridization, genetic engineering and DNA marker technology. Both genetic engineering and wide hybridization are expected to help in enlarging the gene pool by accessing variations beyond cultivated rice genome, while DNA markers and anther culture help, respectively, to increase selection efficiency and compress the breeding cycle.

Tissue culture in rice improvement: Tissue culture is an all-embracing term denoting *in vitro* culture of gametic cells, tissues, organs and isolated protoplasts.

The promising tissue culture techniques relevant to rice breeding are: anther culture for speed and efficiency in breeding a variety; somatic cell culture for efficient screening of large cell populations for variants resistant to biotic and abiotic stresses; and embryo culture to rescue hybrid embryos in interspecific and intergeneric crosses for transfer of useful traits from alien taxa. Another important area of application of tissue culture is the recovery of novel genetic variants – somaclonal variation – in regenerated plants in tissue culture and gametoclonal variation in anther/pollen-derived plants. As mentioned above, one variety, Prabhavati, was developed from the local variety Ambemohar through somaclonal variation induced by tissue culture technique.

Anther culture: Production of doubled haploids (DH) through anther culture is a rapid approach for attaining homozygosity and can shorten the time required to develop a cultivar. It has a potential use in self-pollinated crops, such as rice, because it recovers homozygous lines in the very next generation and has enhanced selection response due to the presence of additive genetic variance alone in dihaploid population. Anther culture as a tool in rice breeding has several other advantages besides providing the quickest method of fixation of homozygous lines: it increases selection efficiency and facilitates early expression of recessive genes; it discriminates genotypes better due to the absence of dominance effects. Compared to the F_2 population, fewer DH plants are sufficient for the selection of desired recombinants. Over the years, the technique of anther culture has been considerably improved, particularly for *japonica* rice. This approach has also been refined to suit *indica* rice (Sandhu *et al*., 1993; Raina *et al*., 1996; Vijaya Laxmi and Reddy, 1997) and is being employed in breeding for tolerance to cold (Gupta *et al*., 1996), submergence (Mandal and Gupta, 1997), salinity (Miah *et al*., 1996) etc. In spite of such unique advantages, the strategy is not widely used, due mainly to the very low frequency of regenerants, especially in *indica* rices (due to strong genotype influence and media interaction).

Tissue culture and somaclonal variation: Variation induced in *in vitro* culture provides another option for rice improvement. The basic advantage of somatic cell culture is the ability to screen myriads of cells to increase the probability of identifying rare variants. The effectiveness of cell selection and exploitation of genetic modifications induced in cell cultures (somaclonal variation) largely depend on the ability to regenerate variants from selected cell variants and the stability of expression of the trait at cellular as well as plant level. A large number of somaclones of the local Basmati rice cultivar, Karnal, were generated and evaluated for semi-dwarf stature, earliness, grain and cooking quality (Raina *et al.*, 1996).

Wide hybridization: Anther culture has potential application in wide crosses to develop substitution and addition lines. In addition to the two cultivated species of rice, *O. sativa* and *O. glaberrima*, there are 21 wild species in the genus *Oryza.* While wild species belonging to the AA genome can be easily crossed with cultivated species, embryo rescue needs to be used for obtaining hybrids between cultivated and distantly related species of other genomes. A number of useful genes have been introgressed into cultivated rice from wild germplasm (Brar and Khush, 1997). Diversification of sources of cytoplasmic male sterility is another important objective in wide hybridization. A gene conferring resistance to the Indian biotype of BPH has been introgressed from *O. officinalis* and is being used in resistance breeding (Jena *et al.*, 2000). New cytosterile stocks alternative to the widely used WA (Wild Abortive) have been developed using male sterile inducing cytoplasm from *O. rufipogon* and *O. nivara* through substitution backcrossing (DRR, 2001).

Genetic transformation: Advances in recombinant DNA technology have provided new means for mobilizing genes within and across the plant and animal kingdom. It is now possible to identify, isolate and transfer genes into rice plants, no matter what the source is. Transformation of rice is done via various techniques, including protoplasm-mediated DNA uptake, microprojectile electroporation and *Agrobacterium*-mediated transfer. The process of genetic transformation accomplishes the same objectives as plant breeding, i.e. transfer of one or a few genes from one organism to another. Genetic engineering techniques are more precise and not limited by sexual compatibility between the donor and recipient variety.

DNA marker technology: Differences in the genomic DNA between potential parents in a genetic cross can be detected by studying variations in the nucleotide sequence polymorphisms. There are several molecular tools, such as restriction fragment length polymorphism (RFLP), simple sequence repeats (SSR) and amplified length polymorphism (AFLP) markers, for detecting such variations. Polymorphism can be used in genetic analysis because at a given allelic locus the markers show mendelian inheritance. This characteristic makes it possible to estimate the genetic distance between each polymorphism and construct genetic maps based on DNA markers.

Progress has been made in tagging and mapping many agriculturally important genes with molecular markers (Mackill and Ni, 2001) which form the basis for marker assisted selection (MAS). DNA markers have enhanced the scope for improving the efficiency of conventional plant breeding through indirect selection for the trait of interest linked to the marker. Of the various molecular markers developed, RFLPs are the most reliable as they are numerous and codominant and distributed all over the genome complement. With the aid of RFLPs, each gene (trait) can be linked to one or more markers, and by following the segregating pattern of the trait and markers in crosses, it is possible to tag the gene(s). Tagging facilitates indirect but precise selection for the gene of interest. Using RFLP markers, genetic maps have been constructed and rice is the most extensively analysed crop species. The availability of comprehensive molecular genetic maps in rice has facilitated tagging of many genes of economic importance with DNA markers. DNA markers have several potential applications in rice improvement. These include germplasm characterization, assessment of genetic diversity, tracking the gene through segregating generation and marker assisted selection (MAS). Pyramiding of genes conferring the same phenotype is important, as gene transfer by MAS is precise and fast, especially when the trait is difficult to select on the basis of phenotype. Similarly, when a number of genes governing the expression of same phenotype-like resistance to a disease or an insect pest are to be pooled, pyramiding is facilitated by the use of markers.

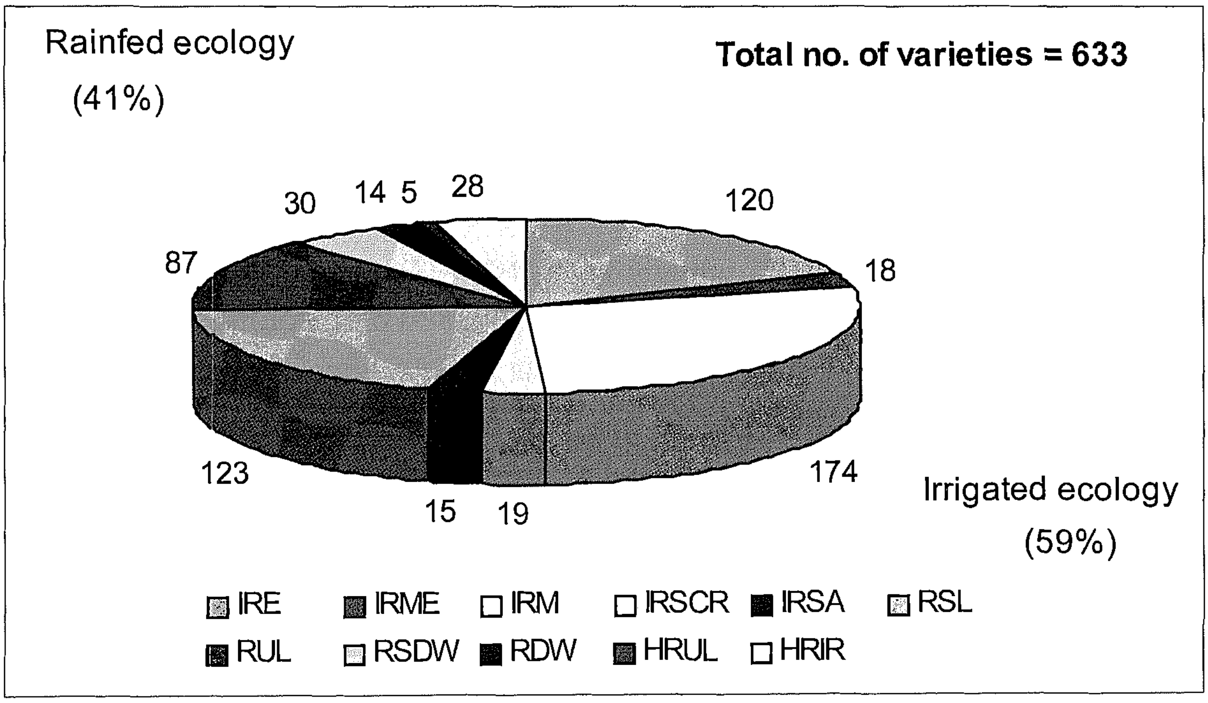
RICE VARIETIES DEVELOPED

The "post-Jaya" period of varietal development in India may broadly be grouped into four phases:

- breeding for yield improvement with different maturity periods and varied grain quality;
- aggressive breeding for resistance to pests and diseases;
- breeding for high-yielding varieties adapted to diverse rainfed ecologies; and
- the development and use of hybrid rice technology.

During the last three decades, 633 rice varieties have been developed and released for commercial cultivation by the central and state variety release committees for diverse ecologies (Fig. 3). These varieties have been developed as follows: 374 (59%) for the irrigated ecosystem under early (120, 19%), medium (174, 27.5%) and mid-early (18, 2.8%) duration groups; 15 (2.4%) for irrigated saline/alkaline soils; and 19 (3%) for the Basmati region with aromatic and quality grains. Besides these inbred varieties, 16 rice hybrids have been released mainly for the irrigated system. For rainfed shallowlands 123 (19.4%) varieties have been developed, 87 (13.7%) for rainfed uplands, 30 (4.7%) for rainfed semi-deepwater and 14 (2.2%) for rainfed deepwater. Under

FIGURE 3
Rice varieties released during 1970-2000 in India for different ecosystems



hill ecology, 28 (4.4%) varieties for irrigated areas and 5 (0.8%) for rainfed uplands have been released. Collectively, these high-yielding varieties now occupy over 77 percent of the rice area in the country.

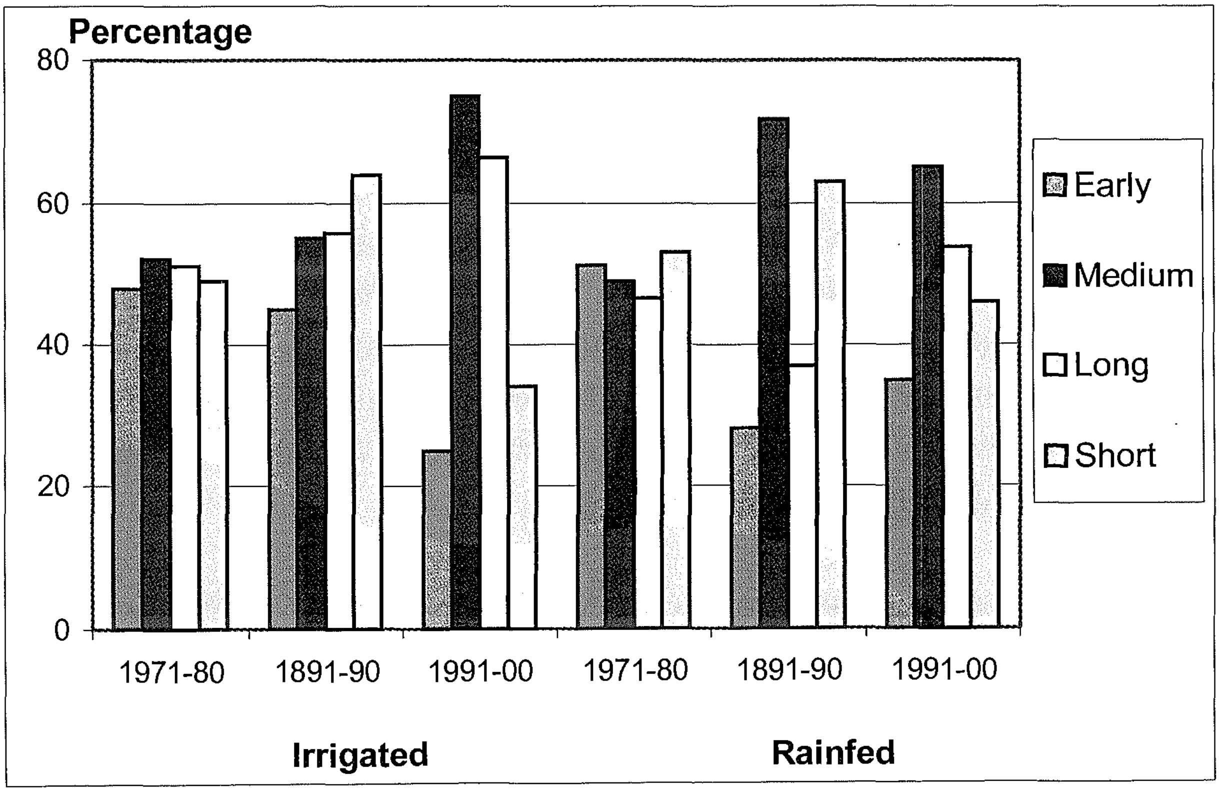
Breeding for yield enhancement

Intersubspecific hybridization: As mentioned earlier, ADT 27 (developed in India) and Mahsuri (Malaysia) became popular in India, thus limiting the adoption of *indica-japonica* hybridization as a breeding strategy to increase the genetic yield level of tropical rices which began in the early 1950s as part of the massive FAO-sponsored programme. The relatively non-lodging habit of *japonica* varieties under higher fertilizer management led to high yields. It seemed that varieties adapted to mild temperate conditions would be more compatible than those adapted to the extremely cold temperate zone. This was proved so when tropical *japonica* varieties from Taiwan - Taichung 65 (introduced in Karnatake), Tainan 3 (Kerala), and Kaohesing 18 and Herunchu (Uttar Pradesh) - were a great success in terms of productivity, although their adoption could not be sustained on account of their poor consumer quality.

Semi-dwarf varieties: The development of short-statured varieties from the spontaneous dwarf mutant Dee-Geo-Woo-Gen (DGWG) with *sd1* gene is a landmark in the history of rice breeding. Rutger and Mackill (2001) are of the opinion that *sd1* gene of rice and *Rht* gene of wheat are the cornerstone of the Green Revolution. The semi-dwarf varieties are characterized by: non-lodging ability, which results in good response to higher rates of fertilizer in the form of productive growth; photo-insensitivity, which helps breeders select for different growth periods; upright foliage and high leaf area index with delayed senescence enabling good utilization of solar energy; and desired partitioning ability of dry matter resulting in higher harvest index. From the breeder's point of view, the use of DGWG as a source for yield improvement has unique advantages, for example: inheritance of dwarf stature as a simple monogenic recessive trait and facilitated fixation of the plant types. Taichung Native 1 (TN 1), a product from the cross between DGWG and Sai-Yuan-Chung, was released in 1949-1950 and was the first dwarf variety. However, it was IR 8 (developed at IRRI) that heralded the Green Revolution in tropical Asia.

Using largely IR 8, TN 1 and Jaya as the donors for dwarf stature and high yield potential, and several local selected varieties with adaptability and quality traits (Table 4), 633 rice varieties (including 17 released prior to 1970) were developed and released for commercial cultivation by the central and state variety release committees (Appendix 2, Fig. 3). While yield gain was the primary objective in this phase, other goals included the development of short-duration varieties for irrigated areas (enabling farmers to take 2-3 rice crops a year) and rainfed uplands, as well as grain quality. This is evident from the fact that 66 percent of varieties released for irrigated ecology during the period 1991-2000 have long grains compared to 51 percent of the varieties released during 1971-1980 (Fig. 4). Rainfed ecology revealed a similar trend. However, 75 percent of varieties for irrigated area released in the last decade had medium maturity duration, compared to 52 percent for the period 1971-1980. At the outset, genetic uniformity rather than diversity is seen among these semi-dwarf

FIGURE 4
Trend in growth period and grain type among the rice varieties developed in India during the last three decades



rice varieties. Extensive use of *sd1* gene from DGWG source has been a universal phenomenon in rice breeding (Rutger and Mackill, 2001). However, extensive use of varied landraces and improved local varieties has been the strength of rice improvement in India.

New Plant Type: By the early 1990s, it was evident that yield gains through semi-dwarf varieties were plateauing. However, a marginal advantage was posted through the reduction in maturity duration, thereby increasing per day productivity. Breeders are again on the look out for new grounds to break the genetic yield barrier. Plant architecture is being redesigned with a more efficient morphophysiological frame to achieve the next quantum jump in yield. Early attempts to find exploitable variability for physiological components that directly or indirectly contribute to yield were not successful. On the basis of experience and experimental findings, breeders and geneticists believe that the genetic yield level of rice could be further raised by 20 to 25 percent through enhancement of biomass from the present level of 20 t/ha without altering the harvest index. Similar efforts in India at the Indian Agricultural Research Institute (IARI) led to a new plant type capable of breaching yield levels of IR 8 or Jaya. However, no variety has so far been released for commercial cultivation.

Breeding for cooking and nutritive quality

The cooking quality of rice is determined by the physicochemical properties of starch, while the nutritive quality depends on the content and quality of proteins, vitamins and minerals. Nutritive quality is as important as cooking quality for tropical countries, where it is the primary source of dietary protein, vitamins (B10) and minerals. Rice accounts for 40 percent of the average protein consumption in Asia. Except for a few characters, such as aroma, nearly all the indices of quality follow complex polygenic inheritance, making breeding and selection very difficult for evolving varieties.

Varieties of Basmati quality: Ever since the introduction of high-yielding varieties, there has been research to combine Basmati quality into the high-yielding background. Although these efforts led to the release of 23 high-yielding and improved tall traditional Basmati varieties, none gained the acceptance of either farmer or consumer. Since the 1990s, there has been a concerted effort to breed for quality rice using a network system involving different institutions. This has led to the development of 11 Basmati rice varieties (Pusa Basmati 1, Kasturi, Haryana Basmati 1, Ranbir Basmati, Taroari Basmati, Basmati 385, Basmati 386, Yamini, Vasumati, Pusa Sugandh 2 and Pusa Sugandh 3) after extensive quality testing for the entire range of physicochemical characteristics.

Of the different quality characters of Basmati rice, it is the amylose content of the grain that determines the relative stickiness or dryness of cooked rice. The highly prized Basmati rices have amylose content of around 22 percent. Varieties with high amylose content (> 25%) cook dry and flaky, while those with low amylose content (< 15%) are sticky. The majority of the popular varieties the world over have intermediate amylose content (≈ 23%). Gelatinization temperature (alkali digestion score) determines the resistance to cooking. The soft cooking *japonica* rices have a low gelatinization temperature (GT), while relatively hard cooking *indica* varieties have high GT. Gel consistency is another important cooking quality index which determines how long cooked rice remains soft. Varieties of medium and low gel consistency (largely associated with medium and low amylose) and medium to low GT are generally preferred, as they remain soft long after cooking. High volume increase and optimum water uptake are other desirable features. Aroma (determined by 2 Acetyl 1-pyrolline) and extra kernel elongation (approximately twice uncooked length) with minimal swelling are the key characteristics qualifying Basmati quality. From the trader's point of view, the percentage of milling out-turn (rice obtainable per unit quantity of paddy milled), head rice recovery (percentage of unbrokens) and colour are important factors. Table 5 lists the quality characteristics of some of the traditional and recently released Basmati varieties.

Development of Basmati hybrids: Pusa RH 10, the world's first hybrid rice with superfine grain and the cooking qualities of aromatic rice, was developed and released recently for cultivation under an ICAR (Indian Council for Agricultural Research)/UNDP/FAO-sponsored project on the development and use of hybrid rice technology. It has a 40 percent yield advantage over Pusa Basmati 1. Being 15 to 20 days early, it escapes infestation by major pests and diseases. It is recommended for areas in the states of Haryana, New Delhi and Uttaranchal.

TABLE 5

Yield, agronomic and grain quality characteristics of traditional and improved Basmati rice varieties developed in India

S. no.	Character	Variety							
		Karnal Local	Pakistani Basmati	Basmati 370	Vasumati (IET 15391)	Yamini (IET 14720)	Pusa Sugandh 2	Pusa Sugandh 3	Taroari Basmati
1	Grain yield (*t/ha*)	2.13	2.12	2.23	3.73	3.27	3.74	375	2.12
2	Plant height (*cm*)	178	180	165	103	118	102	100	48
3	Duration (*days*)	155	155	145	135	150	125	131	120
4	Tillers/m^2	285	286	277	327	364	340	350	237
5	Grains/panicle	138	139	140	108	125	124	106	61
6	Lodging score	9	9	9	9	3	3	3	9
7	Milling (%)	66	65	67.9	69.7	64.8	64.63	69	61.1
8	Head rice (%)	38	40	46.2	55.3	58.7	45.9	49.63	49.6
9	Kernel length								
	· Raw	7.07	7.3	6.93	7.23	7.12	7.66	7.66	7.05
	· Cooked	14.25	14	12.8	13.5	13.1	13.4	13.6	13
10	Elongation ratio	2.01	1.92	1.85	1.86	1.84	1.74	1.77	1.84
11	Alkali spreading value	5.4	4.7	6.2	4.2	4.7	7.7	7	6.2
12	Amylose content	23.21	23.4	22.1	25.1	23.8	22.43	24.39	28.8
13	Aroma	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong

Non-Basmati rices: Non-Basmati quality rice has also become a major thrust item for export promotion and foreign exchange earning. Non-Basmati rice of *indica* type constitutes over 80 percent of the world rice trade. Varieties, such as Prakash, PR 106, Kavya, Kamini, White Ponni, Krishna Hamsa, Sona Mahsuri, Ranjit, Krishna Veni, White Ponni, IR 64 and Samba Mashuri, were identified as exportable non-Basmati rices.

Breeding for pest resistance

The second phase of breeding followed the observation that the yield potential of the new high-yielding varieties (HYV) could often not be realized due to severe biotic constraints (diseases and insect pests). In fact, the pest scenario changed rapidly following the widespread adoption of HYVs. The application of high doses of nitrogenous fertilizers leading to luxuriant vegetative growth with closed leaf canopy changed the micro-environment in favour of pest build-up. The introduction of short-duration varieties and the consequent rice-rice production throughout the year facilitated the survival and carry-over of pest populations from one season to the next. During the period 1965 to 1995, the number of insects classified as "major pests" rose from three to thirteen and the number of serious diseases rose from two to eight (Reddy and Bentur, 2000). The Green Revolution pest, brown planthopper (BPH), even threatened rice production in several Southeast Asian countries during the late 1970s and 1980s. As for diseases, besides the age-old problem of blast and brown spot, several viral (rice tungro virus, grassy stunt virus, ragged stunt virus etc.) and bacterial (bacterial leaf blight and bacterial leaf streak), as well as a few fungal (sheath blight and sheath rot) diseases came to prominence. Strain variation established in bacterial leaf blight (BLB) and grassy stunt virus (GSV), in addition to the known races of blast pathogen, made disease management increasingly difficult. Biotypic variation in gall midge and BPH also increased the insect pest problems. The second phase of rice development focused on breeding for disease and insect resistance.

Resistance to diseases

In the case of blast, resistance is required: during the seedling and vegetative phases against leaf blast; and in the reproductive phase against neck blast. High correlation between resistance to leaf and neck blasts, however, suggests that they may be governed by the same gene(s). Breeding for blast resistance in India dates back to the 1920s when resistance donor sources, such as CO4, TKM9 and GEB24, were used (Manibhushanrao, 1994) leading to the development of improved varieties, such as CO25, CO26 and Ratna. However, by the late 1930s these donors were reported to be susceptible. Subsequently, other cultivars, such as Tetep, Tadukan, Zenith, BJ1, CR905 and CR906, showed promise against the disease. Several popular rice varieties cultivated have blast resistance (Table 6). However, the population of the causative pathogen, *Pyricularia grisea*, adapts to resistant varieties and resistance breaks down

TABLE 6
Popular rice varieties resistant to blast

S. no.	Variety	Parentage	Source of resistance	Year of release	50% flowering duration	Ecology	Grain type
1	IR 20	IR 262-24-3 /TKM 6		1970	105	IRM	
2	IR 36	IR 1561-228-1-2/IR 1737//CR 94-13		1981	84	IRE	LS
3	IR 64	IR 5657-33-2-1/IR 2061-465-1-5-5		1992	84	IRE	LS
4	IR 8	Peta/Dee-Geo-Woo-Gen		1966	105	IRM	LB
5	Pantdhan 10	IR 32/Mahsuri//IR 28		1992	90	IRM	LS
6	Pinakini	Bulk H 9/Millek Kuening		1987	130	RSL	MS
7	Rasi	TN1/Co.29		1977	84	IRE	MS
8	Swarnadhan	RPW 6-13/Sona		1979	125	RSL	SB
9	Tikkana	RP 31-49-2/BCP 2		1988	120	RSL	SB
10	VL Dhan 221	IR 2053-521-1-1-1/CH 1039		1991	85	HRUR	MS
11	VLK Dhan 39 (K39-96-31-1-1-9)	China 1039/IR 580-19-2-3-1		1980	85	HRIR	MS
12	Rasmi	Oorapandy mutant		1986	120	RSL	SB
13	Himadhan	R 575/TN 1		1978	105	HRIR	SB
14	Himalaya 1	IR 8/Tadukan	Tadukan	1982	95	HRIR	LB
15	Himalaya 2 (Pusa 33-C-30)	Imp. Sabarmati/Ratna		1982	95	HRIR	LS

rapidly. For example, rice varieties NLR 9672, Intan and Tellahamsa are no longer effective against the local races of the pathogen.

Earlier studies on the genetics of blast resistance in India by Padmanabhan and associates pointed to the presence of dominant genes in Zenith, Tetep and Tadukan (Manibhushanrao, 1994). They also suggested combining a high degree of resistance to hyphal penetration (polygenic trait) with resistance to the spread of the disease inside the tissue (conferred by major genes) for effective resistance against blast. Studies carried out elsewhere identified over 16 resistance genes. The racial spectrum of the pathogen varied from region to region, as revealed in studies using the molecular approach and covering several blast isolates from south India (Sivaraj *et al.*, 1996) and from the Himalayan region (Kumar *et al.*, 1996). While 29 distinct clonal lineages were identified from the former collection, 46 lineages were found in the latter. As many as 14 pathotypes were recognized in the south Indian collection based on the reaction against a set of national and international differentials. These pathotypes were grouped into four race groups: IA, IB, IC and ID. This study revealed a partial relationship between virulence and phylogeny. Recent field monitoring of virulence has shown a broad range of resistance in varieties, such as Tadukan, Tetep and IR 64 (DRR, 2001). Six varieties (Archana, Deepa, Bhagya, Himalaya 1, Rajendradhan 201 and IR 22) derived from Tadukan, one from Tetep (Swarnamukhi) and one from IR 64 (Cottondora sannalu) have been released for cultivation.

In the case of bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae*, as many as 77 of the released rice varieties have been claimed to possess some degree of resistance. As for blast, variability in the pathogen population has been the main obstacle to the development of resistant varieties. HKR 120 possessing *Xa4* gene was the first variety released in 1987 in Haryana for the pest endemic area (Panwar *et al.*, 1989). Ajaya, developed from the cross IET 4141 and CR 98-7216, was released during 1992. On the basis of the genetics study in Punjab using the local isolate of the pathogen, it is suggested that Ajaya (IET 8585) has two dominant genes conferring resistance (Saini *et al.*, 1996). Thus, Ajaya appears to be a naturally bred gene pyramid with a wide range of resistance across test locations (DRR, 2001). Following BLB epidemics in Punjab during 1980, concerted efforts were made to incorporate resistance into local popular rice varieties (e.g. PR 106) by incorporating disease resistance from different sources, such as Patong 32 (in PR 110, PR 114, PR 116), IR 54 (PR 111) and RP 2151-sister selections of Ajaya (PR 113, PR115), in addition to the direct introduction (PR 4141). Of these, PR 116 now occupies a quarter of the rice area in the state.

While more than 20 genes conferring BLB resistance have been characterized mainly on the basis of genetic studies carried out in countries such as Japan and the Philippines, the availability of Near Isogenic Lines carrying each of these genes has helped to establish the allelic relationship of the resistance genes identified in Indian cultivars (Goel and Singh, 1999). Field monitoring of virulence among pathogen populations on test locations suggested a prevalence of pathotype Ia at Titabar, Ib at Ludhiana and of pathotype II at Faizabad (DRR, 2001). A subpopulation of the pathogen in Kerala is reported to have overcome the resistance conferred by *Xa21* gene – introgressed from wild rice, *O. longistaminata*, and known to confer a wide range of resistance across races of India and the Philippines.

In view of the frequent breakdown of blast and BLB resistance, various gene deployment strategies are proposed to effectively manage/contain the disease. Sequential release of R genes is the widely employed strategy. Varietal mosaic – i.e. planting varieties carrying diversely different resistance genes – is another approach. With the development of markers for 16 blast and 8 BLB resistance genes (Mackill and Ni, 2001), the development of gene pyramids appears to be a more feasible and effective strategy. For example, two-gene pyramids with *Pi1* + *Pi4, Pi1* + *Pi2* and *Pi2* + *Pi4* gene combinations were susceptible to the disease at Titabar and Hazaribagh, while a three-gene pyramid with *Pi1* + *Pi2* + *Pi4* was resistant on all 19 test sites (Kumar *et al.*, 1999). On the contrary, a two-gene pyramid with *Pi1* + *Pi2* genes has shown consistent resistance on test sites in Kerala (Gnanamanickam *et al.*, 1999). A molecular breeding approach for combined resistance to both blast and BLB is being followed (Babujee *et al.*, 2000).

The first rice tungro-resistant variety, Vikramarya, was developed from the cross between Vikram and Ptb 2 and released for cultivation during 1986. It possesses resistance to both the vector and the virus. Another variety, Nidhi, developed from the cross Sona/IET 14529, also has resistance to tungro disease.

Resistance to insect pests

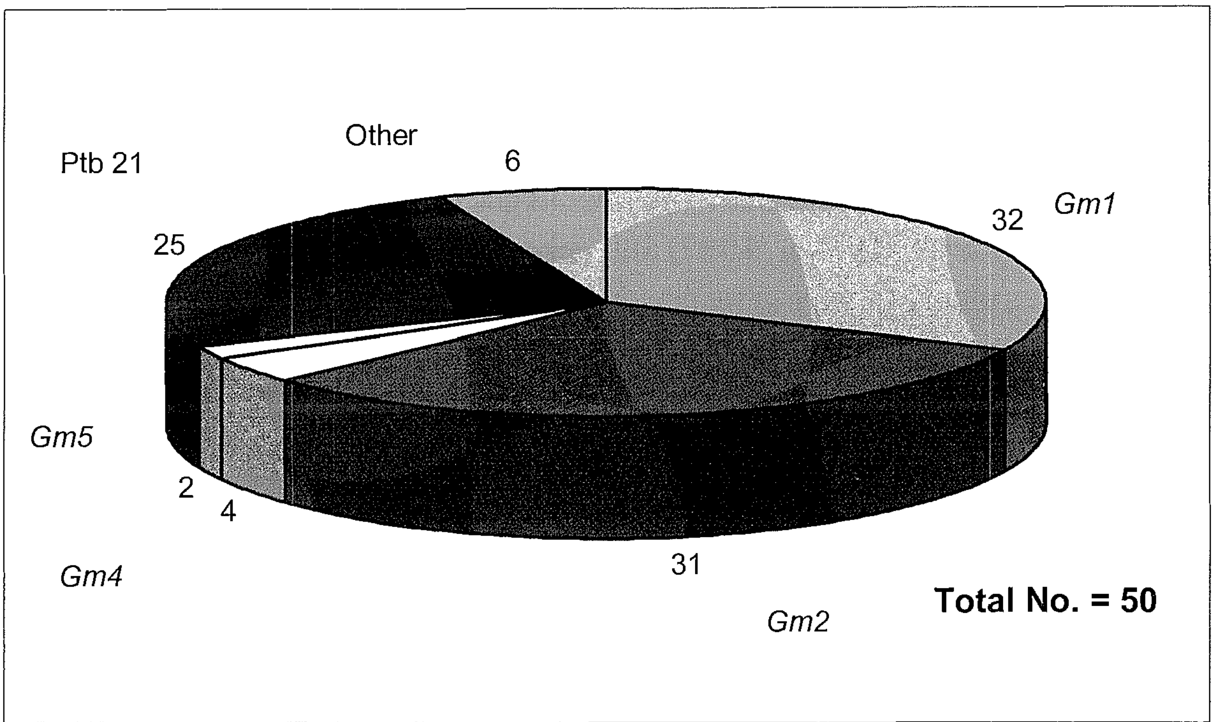
Significant impact has been made in the development and adoption of insect-resistant rice varieties. Though breeding for resistance to rice gall midge (GM), *Orseolia oryzae,* was initiated in the 1950s, the first high-yielding resistant variety Kakatiya was not released until 1974, since when over 50 GM-resistant rice varieties have been released. The prevalence of three distinct biotypes prior to 1988 (Kalode and Bentur, 1989) and subsequent reports of the evolution of three more virulent biotypes in response to the widespread cultivation of resistant varieties hindered the task of resistance breeding. The virulence pattern and distribution of gall midge biotypes in India is provided in Table 7. While over 250 primary sources of GM resistance have been identified through greenhouse and field evaluation of germplasm, genetic studies covering some of these donors have characterized at least 11 distinct genes. As a result, 88 percent of released resistant varieties are derivatives of three-gene sources only (Fig. 5). Breeding for GM resistance at Warangal in Andhra Pradesh and Raipur in Madhya Pradesh has mainly used resistance sources containing *Gm1* gene, while at DRR *Gm2* gene sources (e.g. Siam 29) have been extensively used. Varieties released for cultivation by the latter programme include Phalguna, Vikram and Surekha.

TABLE 7
Virulence pattern and distribution of rice gall midge biotypes in India

Biotype	Reaction against differential group[a]				Distribution
	1	2	3	4	
1	R	R	R	S	Andhra Pradesh (Hyderabad), Madhya Pradesh (Raipur), Orissa (Sambalpur)
2	S	R	R	S	Orissa (Cuttack)
3	R	S	R	S	Andhra Pradesh (Jagtiyal), Bihar (Ranchi)
4	S	S	R	S	Andhra Pradesh (Srikakulam), Maharastra (Sakoli)
5	R	R	S	S	Kerala (Moncompu)
6	R	S	S	S	Manipur (Wangbal)

[a] Group 1 with differentials W1263 (having gene *Gm1*) and ARC 6605 (to be confirmed).
Group 2 with Phalguna (*Gm2*) and ARC 5984 (*Gm5*).
Group 3 with Abhaya (*Gm4*), RP 2068-18-5 (*Gm3*) and others.
Group 4 with susceptible check TN 1.

FIGURE 5
Proportion of GM resistant varieties derived from different resistance sources



Phalguna proved very popular, covering over 80 percent of the rice area in the pest endemic regions of Andhra Pradesh and Maharastra. This extensive cultivation was probably responsible for: the 1986 epidemics of the new virulent GM biotype 4 in the northeastern coastal region of Andhra Pradesh; the 1989 epidemics in the Vidarbha region of Maharastra; and the evolution of biotype 3 in the Karimnagar region of Andhra Pradesh in 1993. Subsequently, new sources of resistance, such as Ptb 21 (leading to the development of Suraksha), Velluthacheera and CR309, have been used in the local breeding programme. A similar epidemic in the Kattanad area of Kerala State in 1993 (the population was later identified as biotype 5) rendered all the earlier varieties susceptible. A re-oriented breeding programme using *Gm1* and *Gm2* gene sources led to the development of Panchami and Pavithra, respectively. The development of specific gene markers (Mackill and Ni, 2001) is now paving the way for the adoption of the gene pyramiding strategy through marker aided selection.

Extensive damage by BPH during the late 1970s triggered an active breeding programme aimed at planthopper resistance. Efforts at DRR led to the release of Mansarovar in 1983, with resistance derived from the donor source Leb Mue Nahng. Of the various breeding lines field-evaluated in Kerala, M11-57-5-1 (from IR 8 and Ptb 20) withstood the severe BPH outbreak during 1975-77. This culture was later released as the BPH-resistant variety Bhadra (Joseph *et al.*, 1990). To date, about 23 resistant varieties have been released with diverse genetic sources of resistance, including Manoharsali, ARC 6650 and ARC 5984, and some of these varieties are also resistant to white-backed planthopper (WBPH) (Table 8). While four varieties each have been developed from Manoharsali and ARC 6650, it is not certain whether or not these two donors carry the same gene. Although the presence of a more virulent biotype of BPH in northern India was suspected during the 1980s, subsequent monitoring of virulence did not confirm these observations. However, the introduction of

TABLE 8
Rice varieties with resistance against BPH

S. no.	Name	Donor	Gene/nature
1	Chaitanya[a]	ARC 5984	bph4/wbph4
2	Cottondora Sannalu[a]	ARC 5984	bph4/wbph5
3	Deepti	ARC 6650	bph3
4	Vajram	ARC 6650	bph3
5	Pratibha	ARC 6650	bph3
6	Triguna[a]	ARC 6650	bph3
7	Suraksha[a]	CR 57 (Ptb 18, Ptb 21)	2 recessive
8	Neela	CR 94 (Ptb 21)	2 recessive
9	Manasarovar	Leb Muey Nahng	Single recessive
10	Nagarjuna	Manoharsali	Single dominant
11	IET 7575	Manoharsali	Single dominant
12	Sonatali	Manoharsali	Single dominant
13	Ch'andana	Manoharsali	Single dominant
14	Aruna	PTB 33	3 complimentary/bph3
15	Kanakam	PTB 33	3 complimentary/bph3
16	8116[a]	Andrewsali	3 complimentary
17	Bhadra (MO 4)	Ptb 20	?
18	Asha (MO 5)	Kochuvithu	?
19	Pavizham (MO 6)	Karivennel	?
20	Kartika (MO 7)	Triveni	?
21	Radhi	Swarnaprabha Mutant	?
22	Vijetha[a]	MTU 5249/MTU 7014	?
23	ADT 42[a]	AD 9246/ADT 29	?

[a] Also resistant to WBPH.

varieties with resistance to BPH alone resulted in an outbreak of WBPH in some parts of the country, which meant that varieties had to be developed with resistance against both BPH and WBPH. Rice varieties now available have this combination. While genetic studies reveal a wide genetic diversity in sources of resistance, fewer than a dozen sources of resistance have been used in breeding planthopper-resistant varieties. Furthermore, wild rice accessions have been an additional source of BPH resistance (Jena *et al.*, 2000).

Given that single pest-specific resistance does little to reduce crop losses in multi-pest-prone rice-growing areas, the emphasis of breeding strategies has shifted from specific to multiple resistance over the last two decades and many of the varieties under cultivation today are resistant to more than one pest or biotype (Table 9).

Breeding for tolerance to abiotic stresses

Rainfed rice – accounting for about 50 percent of rice area with varied moisture regimes (uplands, lowlands and deepwater), injurious soils (due to acidity/alkalinity and salinity across ecologies) and subject to extreme temperatures – is generally grown in the less favourable environments. Each of these environments is complex in nature and is characterized by more than one constraint. Upland problems are: moisture stress, impoverished soil, weed infestation and P deficiency, while lowland problems are: continuous anoxic conditions due to stagnant flood water, submergence, intermittent drought and low light. In the coastal areas and irrigation commands, on the other hand,

TABLE 9
Rice varieties possessing multiple pest resistance

Variety	Resistance
IR 36, Rasi	Blast, brown spot
Vikramarya	Blast, RTV
Swarnadhan, Pankaj, Radha	Blast, sheath blight
CNM 539	Blast, brown spot and RTV
Suraksha, Shaktiman	GM, BPH, WBPH, blast
Lalat	GM, BPH, GLH
Rasmi	GM, BPH
Daya, Smalei	GM, BPH, GLH
Kshira	GM, BPH, WBPH, GLH, RTV

salinity and sodicity are the constraints, while low temperature is the problem in high altitude areas.

Finding a varietal solution to such harsh environments is quite challenging. Rice improvement in the third phase concentrated on breeding for abiotic stresses. As a short-term approach, the pure line selection method was adopted, involving native varieties well adapted to a given stress environment. Thanks to the availability of diverse genetic sources and an understanding of the genetic basis of tolerance to specific stresses, together with national and international collaborative efforts, more targeted breeding was initiated as a long-term strategy. The breeding efforts for tolerance to salinity, drought and submergence are briefly presented below.

Salinity tolerance

Salt stress is a major yield-destabilizing factor in coastal areas and irrigation commands. Unlike coastal salinity, which remains almost static in terms of area, inland salinity is on the increase due to poor water management in canal-irrigated areas. Salt stress in coastal areas is not the same as in irrigation commands and waterlogged lowlands. The former is saline, due largely to chloride and sodium sulphate, while the latter is alkaline (sodic). The composition and level of severity vary, depending on the salts involved and their proportions. Tolerance in plants to salinity is growth-stage specific. Recent breeding efforts for salt tolerance have been very encouraging; indeed, over 30 rice varieties with varying levels of tolerance to salinity and alkalinity have been developed (Table 10) (Mishra, 1999). The screening methodology has been improved to detect salt tolerance at the reproductive stage, while the selection criteria and breeding methodology have been standardized. A wide spectrum of rice germplasm (both indigenous and exotic) have been evaluated for salt tolerance and suitable donors have been identified. Basic studies indicate no significant correlation between the score of salinity tolerance during vegetative stage and reproductive stage and/or grain yield. $K+$ content exhibited strong positive correlation with grain yield while the ratio of $Na+/K+$ revealed significant negative correlation with grain yield. Genetic studies suggested both additive and non-additive gene effects for salt tolerance. Studies under controlled conditions in lysimeters further confirmed the involvement of a few major genes

TABLE 10
Rice varieties with salt tolerance

S. no.	Variety	Parentage	Stress adaptation	
			pH	ECe (dSm^{-1})
1	CSR1 (Damodar)	Local selection of Sunderban area	9.8-10.4	6.11
2	CSR2 (Dasal)	Local selection of Sunderban area	9.8-10.4	6.11
3	CSR3 (Getu)	Local selection of Sunderban area	9.8-10.4	6.11
4	CSR5	TKM6/IR 8	9.0-9.5	<6.0
5	CSR8	CSR1 mutant	9.0-9.6	<7.0
6	CSR9	CSR1/Basmati 370//CSR5	>9.7	<9.0
7	CSR10	M40-431-24-114/Jaya	9.8-10.2	6-11.0
8	CSR11	M40-431-24-114/Basmati 370	9.8-10.2	6-11.0
9	CSR12	CSR1/Basmati 370//CSR5	9.2-9.8	<9.0
10	CSR13	CSR1/Basmati 370//CSR5	9.2-10	<9.0
11	CSR14	Milyang 23/Milang 30	9.2-9.8	<8
12	CSR15	Sipi 661044/Sipi 651202	9.2-9.8	<8
13	CSR16	CSR1 mutant	9.2-9.8	<8
14	CSR17	IR19661-131-1-2/IR9129-209-2-2-2-1	9.2-9.8	<8
15	CSR18	RPA 5829/CSR5	9.2-9.8	<8
16	CSR19	CSR1/Basmati 370//CSR5	9.2-9.8	<8
17	CSR20	CSR5/Palaman 579	9.2-9.8	<8
18	CSR21	IR 5657-33-2/IR 4630-22-2-5-1-3	9.8-10	<9
19	CSR22	IR 64//IR4630-22-2-5-1-3/IR 9764-45-2-2	9.6-9.9	<10
20	CSR23	IR 64//IR 4630-22-2-5-1-3/IR 9764-45-2-2	9.8-10	<10
21	CSR24	IR 8/Chettivirippu	9.6-9.9	<10
22	CSR25	IR 17494-32-3-1-1-3/IR 4432-52-6-4	9.8-10	<10
23	CSR26	Nona Bokra/IR5657-33-2	9.8-10	<9
24	CSR27	Nona Bokra/IR5657-33-2	9.8-9.9	<10
25	CSR28	IR 42/IR 4630-22-2-5-1-3	9.8-9.9	<9
26	CSR29	IR 14632-22-3/IR 19799-17-3-1-1	>10	6-10.0
27	CSR30	BR4-10/Pakistan Basmati	>9.7	6.7
28	Panvel 1	IR 8/ BR4-10	NA	NA
29	Panvel 2	BR4-10/IR 8	NA	NA
30	Panvel 3	Damodar/Pankaj	NA	NA
31	Vyttila 1	Selection from Pokkali	NA	NA
32	Vyttila 2	Selection from Chettivirippu	NA	NA
33	Vyttila 3	Vytilla 1/TN1	NA	NA
34	Vyttila 4		NA	NA
35	Karishma	MO1/MO6	NA	NA
36	Uma	MO6/Pokkali	NA	NA

along with numerous minor genes for salinity tolerance, but there was a lack of maternal influence (Mishra *et al.*, 1998).

Tolerance to NaCl salinity in the majority of donor sources is due to the relatively high retention of Na and Cl in roots compared to shoots. In salt-tolerant SR26B and PVRI, the regulation of accumulation of Na and K during tillering appeared to be the physiological basis of tolerance (Balasubramanian and Rao, 1977). In the salt-tolerant variety, Pokkali, tolerance is partly due to the compartmentation of Na in leafsheath sparing the leaf blades, while the mitigation of high Na content in shoots is due to the faster growth rate. In tolerant sources (e.g. Taipei 309), tolerance appears to be through higher tissue tolerance of Na content in the shoot due to either osmotic adjustment or compartmentation. By and large, a plant's ability to regulate either Na uptake or selective accumulation of K, the translocation of salts from root to shoot and the ionic balance (ratio of Na to macro-/micronutrients) – rather than just absorbed Na content – determine the level of tolerance (Siddiq *et al.*, 1999).

Initial breeding attempts at the Central Soil Salinity Research Institute, Karnal, involved pure line selections from the local traditional cultivars collected in the Sunderban region of West Bengal leading to the development of Damodar (CSR1), Dasal (CSR2) and Getu (CSR3). Varieties adapted to salinity stress were later identified as also possessing sodic tolerance. A later stage of the hybridization programme involved CSR1 as a promising source of tolerance. This led to the release of as many as 24 varieties that not only are tolerant to salt and sodic stress but also possess quality features. Through the shuttle breeding programme under the ICAR-IRRI collaborative project, more than a dozen promising breeding lines have been identified and they are undergoing advanced field testing. Furthermore, anther culture derivative lines generated at IRRI led to the identification of additional salt-tolerant rice varieties, such as CSR 21 and CSR 28 (Singh and Mishra, 1995). Nona Bokra, Damodar (West Bengal), BR 4-10 (Bangladesh), Chettiviruppu (MO1) and Pokkali (Kerala) have also been extensively used in breeding for salt stress in other parts of the country, leading to the release of varieties, such as Panvel 1, Panvel 2 and Panvel 3 in Maharastra, and Vittyla 1, Vyttila 2, Vyttila 3, Vyttila 4, Uma and Karishma in Kerala. For the acid-saline soils (pH 3.5, ECe 4.5 dS/m) of coastal West Bengal, Thailand rice varieties, such as Khao Dawk Mali and RD 19, were found promising (Bandyopadhyay, 1986).

Drought tolerance

Moisture stress at any stage of crop growth causes significant yield reduction.

Escape, avoidance and tolerance are the three mechanisms by which rice copes with a drought environment. Upland varieties generally survive through either the escape mechanism (facilitated by early maturity) or the avoidance mechanism (by stress-induced root elongation to reach moisture zones). The tolerance mechanism operates by curtailing transpiration losses via leaf-rolling, early stomatal closure and cuticular resistance. Another important mechanism is rapid recovering ability, when moisture is replenished after a prolonged drought. Since most of the indices of stress resistance are independently inherited, there is good scope for recombining them through convergent breeding. The absence of leaf-rolling under drought has been used as an index of reduced drought sensitivity. A major dominant gene controlled leaf-rolling under drought stress in some of the varieties studied. While genetic variability for drought resistance at the reproductive stage is meagre, concerted efforts are needed to screen germplasm for reproductive-stage drought resistance, as it is directly related to productivity under drought.

The breeding programme for developing early-duration rice varieties with drought tolerance for the rainfed upland areas initiated at DRR in 1975 led to the identification of several superior cultivars (Prasada Rao, 1984). Of the 85 varieties released for this specific ecosystem, 42 (49.6%) have growth duration of 100 days or less. Of the varieties so far developed, Sattari has the shortest growth period of 70 days and has been dubbed "super fast rice". While the grain yields of these varieties are understandably low, they are nevertheless important for sustenance farming by poor farmers with small landholdings. Further yield improvement under this harsh ecology has been achieved with the utilization of local landraces, such as N22 (7 varieties developed), Fine gora (5), M63-83 (4), Black gora (1) and Brown gora (1), which are moderately drought tolerant. Of these donors, local "gora" landraces from Bihar are known for drought avoidance thanks to their good root system, while M63-83 has a rapid recovery mechanism and N22 escapes drought through early maturity. Some of the developed varieties and breeding lines, such as Rasi, Ratna, UPLR 5, IR 4575 and IR 6023-10-1-1, also have good recovering ability and have been used for yield improvement. Salt tolerance donors, such as Tadukan (2) and SR26 B (1), have also been used as sources of drought tolerance.

Submergence tolerance

Submergence is as serious and important a physical constraint as drought in rainfed lowland ecologies. Submergence tolerance is defined as the ability of rice crop to survive under complete submergence for as long as 10 days. Submergence due to flash floods or excessive rain causes inundation without effective drainage in low-lying areas and may occur at any stage of crop growth. The underlying mechanisms of tolerance to submergence are: i) an ability to survive without any growth under water until after drainage; and ii) escape from submergence by growing along with the rising water level and remaining above the flood waters by stem or leaf elongation. A set of morphophysiological traits confer submergence tolerance, for example, by building up or conserving carbohydrate reserves before or during flooding and or by maintaining physical structure during submergence and/or avoiding submergence by emerging above the water.

There is a lack of initiative for targeted breeding for submergence tolerance. Breeding efforts in Bihar prior to 1970 were pure line selections leading to the identification of improved varieties, such as BR 14, BR 15 and BR 46 (Saran, 1977). Of the 14 varieties subsequently identified for deep water and the 28 for semi-deep water, 9 and 8 varieties, respectively, are pure line selections. In the limited hybridization programme, Patnai 23 has been the most extensively used donor for submergence tolerance through stem elongation. Pankaj is another common donor well suited to poorly drained shallow-water lands.

Besides the above-listed abiotic stresses, varietal improvement has been attempted for several other constraints, such as P-, Zn- and iron-deficient soils, iron and aluminium toxic soils and low light intensity (Singh, 2000).

Development of hybrid rice technology

Though research efforts into hybrid rice in India were initiated during the 1970s, they were mostly of an academic nature. There was no coordinated, applied and result-oriented programme aimed at the development, evaluation and release of the hybrids, or at the development of seed production technology and technology transfer activities for the popularization of hybrids. Hence, in the project initiated in 1989, a national network approach was adopted, bringing together research institutions, public and private seed agencies and departments of agriculture of the target states. International organizations were also involved for consultancy and training purposes. Effective linkages were established among the agencies and the project was implemented involving all the partners in a coordinated and mission mode approach.

The hybrid rice research network comprises 12 centres across the country in the target states, with the Directorate of Rice Research (DRR), Hyderabad the coordinating centre. Each centre in the network has a specific responsibility, for example, development of: the Basmati hybrid (New Delhi centre); hybrids for shallow lowland (Cuttack); long-duration hybrids for the coastal region (Maruteru); two-line hybrids (DRR, Hyderabad, Coimbatore, Pantnagar); or intersubspecific *indica* x tropical *japonica* hybrids (DRR, Hyderabad, Maruteru, Delhi, Kapurthala, Coimbatore and Pantnagar). Other centres are developing region-specific hybrids well adapted to their state/region. Hybrids developed by various centres and those nominated by the private seed sector and IRRI are pooled together and shared by all the centres and private seed companies for critical evaluation.

Development, evaluation and release of hybrids

The development of high-yielding hybrids is one of the project's main objectives. During the last 10 years, over 1 000 experimental hybrids developed by different network centres, IRRI and private sector seed companies have been evaluated in multilocation trials. To date, 16 hybrids showing consistent yield superiority over local inbred check varieties have been released for commercial cultivation in different regions by the respective state variety release committees (Table 11). Of these, three privately bred hybrids, namely PHB-71 (Pioneer Overseas Corporation) and 6201 and HRI 120 (Hybrid Rice International), have been released by the Central Variety Release Committee (CVRC), and another six to eight hybrids are being marketed by private seed companies. Pusa RH 10 is the first Basmati rice hybrid in the world which has been developed and released through the national network on hybrid rice. All these hybrids possess a mean grain yield of 6 to 8 t/ha with 15 to 20 percent yield superiority over corresponding high-yielding inbred check varieties.

Out of the 16 hybrids released so far, large-scale seed production of five hybrids, namely DRRH-1, KRH-2, Sahyadri, PHB-71 and PA 6201, has been

TABLE 11
Rice hybrids released in India

S. no.	Hybrid	Year of release	Duration (*days*)	Yield of hybrid (*t/ha*)	Yield of check (*t/ha*)	Yield adv. over check (*%*)	Released for the state of
1	APHR-1	1994	130-135	7.14	5.27 (Chaitanya)	35.4	Andhra Pradesh
2	APHR-2	1994	120-125	7.52	5.21 (Chaitanya)	44.2	Andhra Pradesh
3	MGR-1	1994	110-115	6.08	5.23 (IR 50)	16.2	Tamil Nadu
4	KRH-1	1994	120-125	6.02	4.58 (Mangala)	31.4	Karnataka
5	CNRH-3	1995	125-130	7.49	5.45 (Khitish)	37.4	West Bengal
6	DRRH-1	1996	125-130	7.3	5.50 (Tellahamsa)	32.7	Andhra Pradesh
7	KRH-2	1996	130-135	7.4	6.10 (Jaya)	21.3	Karnataka
8	Pant Sankar Dhan -1	1997	115-120	6.8	6.20 (Pant Dhan-4)	9.7	Uttar Pradesh
9	CORH-2	1998	120-125	6.25	5.20 (ADT 39)	20.2	Tamil Nadu
10	ADTRH-1	1998	115-120	7.1	4.90 (ASD-18)	44.9	Tamil Nadu
11	Sahyadri	1998	125-130	6.64	4.89 (Jaya)	35.8	Maharashtra
12	Narendra Sankar Dhan-2	1998	125-130	6.15	4.94 (Sarjoo-52)	24.5	Uttar Pradesh
13	PHB 71 [a]	1997	130-135	7.86	6.14 (PR 106)	28	Haryana, UP, TN
14	PA 6201 [a]	2000	125-130	6.18	5.03 (Jaya)	22.9	Eastern and some parts of southern India
15	HRI 120 [a]	2001	105				Southern, eastern, western regions
16	Pusa RH 10	2001	95				Haryana, Delhi, Uttranchal

[a] Developed by the private sector.

PLATE 5

Hybrid rice variety 6021

PLATE 6
An upland rice variety in East Timor

taken up by public and private sector seed agencies. Hence, seed of the above-mentioned hybrids is available to the rice farmers for undertaking large-scale cultivation. At present, hybrid rice is reported to be grown on approximately 200 000 ha. The area under hybrid rice will further increase once heterotic hybrids suitable for the high productivity areas of Punjab, Haryana, the coastal region of Andhra Pradesh and shallow lowland areas have been identified and an effective transfer of technology programme has been initiated in the target states.

Genetic diversity in hybrid rice breeding

Use of genetically diverse material is the prerequisite for the success of heterosis breeding. At present, the Wild Abortive (WA) source of cytoplasmic male sterility is the widely used source for developing hybrids in many countries, including India. Such over-dependence on a single source may prove disastrous if it becomes vulnerable to any serious pest or disease (as with maize). Concerted efforts are therefore made to diversify the CMS source at DRR and CRRI. Six CMS lines have been developed in the background of *O. nivara* and *O. rufipogan* at DRR. Efforts are underway to identify restorers to these new CMS sources (DRR, 2001). Similarly, at CRRI, CMS lines in the background of Kalinga have been developed.

In order to widen the genetic basis of parental lines, specific breeding programmes involving cross breeding and male sterility-facilitated recurrent selection approaches were followed to improve the restorers and maintainers. Crosses between *indica* and tropical *japonica* were made and more than 2 500 diverse derivatives isolated. These diverse materials are now being utilized in hybrid rice breeding.

Quality considerations

Rice quality means different things to different people and it is region-specific. The best quality type in one region may not be liked at all in another region. Therefore, breeding for better quality hybrids depending upon the local requirement assumes added significance. The acceptance of hybrids by consumers is primarily determined by the cooking and eating quality characteristics. The price which the farmers get for their produce is also determined by quality traits. The Chinese hybrids which were introduced earlier, besides being poorly adaptable to Indian conditions, had very poor grain quality. At present, hybrids are developed using the locally developed parental lines and those introduced from IRRI. All the released hybrids in India and the promising pre-released hybrids have moderate acceptable quality, but they cannot be compared with high quality varieties, such as Samba Mahsuri in Andhra Pradesh, White Ponni in Tamil Nadu and the Basmati varieties of northern India. Separate breeding programmes must be initiated to develop hybrids of very high quality.

Hybrids have been evaluated for quality characteristics. Some of the hybrids, namely ADTRH-1 and DRRH-1, possess good quality characters. With the availability of a large number of CMS lines and the pollen parents, it would be possible to develop hybrids with desired quality characters.

Resistance to major pests and diseases

For large-scale adoption of hybrid rice technology, the released hybrids should possess a fair degree of resistance to some of the major diseases/pests in the target areas, in addition to the distinct yield advantage over the existing varieties. Promising hybrids are, therefore, being regularly evaluated for resistance to major pests and diseases, both in glass houses and under field conditions. Promising hybrids and some parental lines with resistance to major pests and diseases have been identified

INTERNATIONAL COLLABORATION

Genetic diversity in rice germplasm is nature's gift to mankind. Were it not for the extensive international collaboration in identifying this diversity, preserving and sharing it, the benefits of the Green Revolution would not have spread globally. The role of International Rice Research Institute, and specifically its International Rice Testing Program (IRTP) initiated in 1975, is most commendable. India has been a major partner in this endeavour. So far, over 30 000 germplasm accessions and breeding lines have been tested in India under diverse environments. Of these lines, 3 500 have been contributed by India. More than 250 varieties (40% of the total) developed in India have derived benefit from the genetic potential of this shared material. Reciprocally, several germplasm and breeding lines from India have been utilized in breeding programmes in many rice-growing countries across the continents. Table 12 lists 46 rice varieties of Indian origin adopted and released in over 27 countries.

POTENTIAL AND CONSTRAINTS

The large collection of rice germplasm maintained within the country is a rich source of genetic diversity yet to be fully characterized and utilized. A recent network project undertook the evaluation of about 16 000 accessions of germplasm against biotic stresses and identified several new sources of resistance (DRR, 2000). Detailed genetic studies must follow to characterize these sources and utilize them in the breeding programme for biotic stresses. A better understanding of pest-host interactions has helped to develop strategies for the development of durable resistance. Marker aided selection has been a reality in tracking and pyramiding genes in any desired combination. Recent advances in DNA markers and mapping of several quantitative trait loci (QTLs) has provided breeders with new tools while dealing with quantitative traits, such as tolerance for abiotic stresses. The genetic engineering approach has pulled down the taxonomic barrier for transferring genes of desirable traits. Thus there is great potential for enhanced utilization of genetic diversity for rice improvement in the years to come. However, with WTO conventions and Trade Related Intellectual Property Rights (TRIPS), genetic resources and tools to harness these are becoming ever less available for the public cause. Even the free exchange of germplasm among researchers is becoming a difficult proposition. While some of the toughest technical hurdles in harnessing genetic diversity have been overcome, we are entering a new era of socio-legal and environmental issues. A new order must evolve to ensure the equitable distribution of what mother nature has provided for the benefit of present and future generations.

A critical analysis of the parentage of released varieties in India indicates that the genetic base is narrowing and this is a matter of concern. Recent studies have shown that landraces and even wild species could contribute genes for yield enhancement. Rice breeders should make a concerted effort to utilize the genetic diversity in the development of varieties so as to achieve the expected outputs and maintain the natural balance.

TABLE 12
Rice varieties developed in India and released in other countries

Country where released	Designation	Year released	Ecosystem
Afghanistan	CR 44-11	1975	Irrigated
Afghanistan	Cauvery	1975	Upland
Afghanistan	Padma	1975	Irrigated
Benin	CO 38	-	Irrigated
Benin	RAU 4072-13	1991	Upland
Bhutan	Barkat (K 78-13)	1992	Irrigated
Brazil	Seshu	1984	Upland
Burkina Faso	Rp 4-2	1979	Irrigated
Burkina Faso	Vijaya	1997	Rainfed
Burkina Faso	RP 6-13 (Vikram)	1979	Irrigated
Burundi	CR 1009	-	Irrigated
Cambodia	OR 142-99	1992	Rainfed
Cameroon	Jaya	1977	Irrigated
Côte d' Ivoire	Jaya	-	Irrigated
Dominican Republic	IR 2153-276-1-10-PR 509	1986	Irrigated
Ghana	RP 6-13 (Vikram)	1982	Irrigated
Iran	Sona	1982	Irrigated
Iraq	RP 2095-5-8-31	-	Rainfed
Kenya	Basmati 217	-	Irrigated
Kenya	AD 9246	-	Irrigated
Malawai	CR 156-5021-207 (Kitish)	1993	Irrigated
Mali	RPCB-28-849 (Rasi)	1984	Rainfed
Mali	Vijaya	1978	Irrigated
Mali	Jaya	-	Irrigated
Mauritiana	Jaya	-	Irrigated
Mynmar	Mahsuri mutant 3628	1977	Irrigated
Nepal	CR 123-23	1978	Upland
Nepal	RPCB-28-849 (Rasi)	1981	Upland
Nepal	IR 2298-PLPB-3-2-1-1B	1982	Irrigated
Nepal	IR 3941-4-PLP2B	1982	Irrigated
Nepal	K 39-96-1-1-1-2	-	Irrigated
P.R. China	M 114	1981	Irrigated
Pakistan	CR 156-5021-207 (Kitish)	1984	Irrigated
Paraguay	CR 156-5021-207 (Kitish)	1989	Irrigated
Paraguay	R 22-2-10-1	1989	Irrigated
Senegal	RPCB-28-849 (Rasi)	1981	Upland
Senegal	Jaya	-	Irrigated
Tanzania	BIET 360	1986	Irrigated
Tanzania	RPCB-28-849 (Rasi)	1984	Upland
Tanzania	RP 143-4	1984	Rainfed
Tanzania	L 5P23	-	Irrigated
Tanzania	Sabarmati BC 5/55	-	Rainfed
Togo	RPCB-28-849 (Rasi)	1978	Upland
Venezula	PR 106	1984	Irrigated
Viet Nam	Jaya	-	Irrigated
Zambia	RTN 500-5-1	-	Irrigated

REFERENCES

Babujee, L., Venkateshan, B., Kavitha, S., Gnanamanickam, S.S., Leenakumari, S., McCouch, S.R. & Leong, S.A. 2000. *Molecular breeding of rice for resistance to Magnaporthe grisea and Xanthomonas oryzae pv. oryzae in southern India.* Abstracts, p. 85. Fourth International Rice Genetics Symposium, 22-27 Oct. 2000, IRRI, Manila, Philippines.

Balasubramanian, V. & Rao, S. 1977. Physiological basis of salt tolerance in rice. *Il Riso*, 26: 291-294.

Bandyopadhyay, A.K. 1986. Varieties screened for acid saline soils. *Intl Rice Res. Newsl.*, 11(6): 14.

Brar, D.S. & Khsuh, G.S. 1997. Alien introgression in rice. *Plant Molecular Biology*, 35: 35-47.

DRR (Directorate of Rice Research). 2000. *Evaluation of rice germplasm for biotic stresses: Final report.* Hyderabad, India, DRR. 341 pp.

DRR. 2001. *Annual report 2000-2001.* Hyderabad, India, DDR. 107 pp.

Gnanamanickam, S.S., Dayakar, B.V., Babujee, L., Leenakumari, S., Levy, M., Leong, S. & McCouch, S.R. 1999. *Lineage exclusion resistance breeding and marker assisted selection for management of rice blast in India.* Abstracts, General meeting of the International Program on Rice Biotechnology, 20-24 Sept., Phuket, Thailand. 80 pp.

Goel, R.K. & Singh, O. 1999. Genetic basis of resistance against bacterial blight caused by *Xanthomonas oryzae* Ishiyama pv. *oryzae* (Swings *et al.*) in three breeding lines of rice (*Oryza sativa*). *J. of Genetics and Breeding*, 53: 87-91.

Gupta, H.S., Bhuyan, R.N., Pattanayak, A. & Pandey, D.K. 1996. Development of cold-tolerant rice through anther culture. *Intl Rice Res. Notes*, 21(1): 20.

Jena, K.K., Pasalu, I.C., Varalaxmi, Y., Kondal Rao, Y., Krishnaiah, K., Kochert, G. & Khush, G.S. 2000. *Molecular mapping and marker aided selection (MAS) of a gene conferring resistance to Indian biotype of brown planthopper in rice.* Abstracts. Fourth International Rice Genetics Symposium, 22-27 Oct. 2000, IRRI, Manila, Philippines. 77 pp.

Joseph, C.J., Remabai, N., Devika, R., Regina, A. & Radha Devi, D.S. 1990. Rice Breeding. In *Five decades of rice research in Kuttanad*, p. 9-26.

Kerala Agricultural University, Thrissue, Kerala.

Kalode, M.B. & Bentur, J.S. 1989. Characterization of Indian biotypes of the rice gall midge, Orseolia oryzae (Wood-Mason) (Diptera: Cecidomyiidae). *Insect Sci. and its Application*, 10: 219-224.

Krishnaiah, K. 1998. Rice (*Oryza sativa*) research in India. *Indian J. Agric. Sci.*, 68: 385-395.

Kawai, T. 1980. Current rice mutation breeding in Japan. *Intl Rice Commission Newsl.*, 29: 19-21.

Kumar, J., Nelson, R.J. & Zeigler, R.S. 1996. Population structure of Magnaporthe grisea in the traditional Himalayan rice system. *In* Khush, G.S. (ed.) *Rice genetics III*, p. 963-969. Manila, Philippines, IRRI. 1011 pp.

Kumar, J., Ramos, M.S., Leuing, H. & Zeigler, R.S. 1999. *Analyzing Himalayan rice blast populations: I. Genetic diversity, virulence and migration.* Abstracts, General Meeting of the International Program on Rice Biotechnology, 20-24 Sept., Phuket, Thailand. 247 pp.

Mackill, D.J. & Ni, J. 2001. Molecular mapping and marker assisted selection for major-gene traits in rice. *In* Khush, G.S., Brar, D.S. & Hardy, B. (eds) *Rice genetics IV*, p. 137-151. New Delhi, Science Publishers, Inc. and Philippines, IRRI. 488 pp.

Mandal, N. & Gupta, S. 1997. Anther culture of an interspecific rice hybrid and selection of fine grain type with submergence tolerance. *Plant Cell, Tissue and Organ Culture*, 51: 79-82.

Manibhushanrao, K. 1994. *Rice blast disease*. Delhi, India, Daya Publishing House. 180 pp.

Mehetre, S.S., Patil, P.A., Machajan, C.R. & Dhumal, P.M. 1993. Effect of different doses of gamma rays on germination and survival of upland rice varieties. *Intl Rice Res. Notes*, 18(4): 23.

Miah, M.A.A., Pathan, M.S. & Quayum, H.A. 1996. Production of salt tolerant rice breeding line via doubled haploid. *Euphytica*, 91: 285-288.

Mikaelsen, K. 1979. Mutation breeding in rice. *IRC Newsl.*, 28: 1-6.

Mishra, B. 1999. Recent advances and breeding strategies for salt tolerance in rice. *J. of Indian Soc. for Coastal Agric. Res.*, 171: 109-116.

Mishra, B., Singh, R.K. & Jetly, V. 1998. *Inheritance pattern of salinity tolerance in rice.*

Muralidharan, K., Prasad, G.S.V. & Rao, C.S. 1996. Breeding for rice improvement: where do we stand? *Current Sci.*, 71: 438-448.

Panwar, D.V.S., Gupta, K.R. & Battan, K.R. 1989. Resistance breeding against bacterial blight of rice in Haryana, India. In *Bacterial blight of rice*, Manila, IRRI. 235 pp.

Prasada Rao, U. 1984. Breeding of rice varieties for rainfed upland areas. *Indian J. of Genetics and Plant Breeding*, 44: 42-48.

Raina, S.K., Khanna, H., Bisht, M.S., Kumar, K., Kumar, U., Irfan, S.T. & Singh, V.P. 1996. Haploid, somaclone, and transformation studies in basmati rice. *In* Khush, G.S. (ed.) *Rice genetics III*, p. 487-491. Philippines, IRRI.

Reddy, A.P.K. & Bentur, J.S. 2000. Insect and Disease Resistance in Rice. *In* Nanda, J.S. (ed.) *Rice breeding and genetics*, p. 143-167. New Delhi, Oxford & IBH Publishing. 382 pp.

Rutger, J.N. & Mackill, D.J. 2001. Application of mandelian genetics in rice breeding. *In* Khush, G.S., Brar, D.S. & Hardy, B. (eds) *Rice genetics IV*, p. 27-38. New Delhi, Science Publishers, Inc and Philippines, IRRI. 488 pp.

Saini, R.S., Goel, K.K. & Sharma, S.C. 1996. Genetic analysis of resistance to bacterial blight (Xanthomonas oryzae pv. oryzae Ishiyama) in some rice (Oryza sativa L.) lines. *Indian J. of Genetics*, 56: 178-181.

Sandhu, J.S., Gill, M.S. & Gosal, S.S. 1993. Callus induction and plant regeneration from cultured anthers of indica rice varieties. *Plant and tissue culture*, 3: 17-21.

Saran, S. 1977. Progress of deep-water rice research in Bihar, India. In *Deep-water rice*, p. 145-150. Manila, Philippines, IRRI. 239 pp.

Sharma, K.D. 1985. *Induced mutagenesis in rice.* Rice Genetics Symposium II: Abstracts, p. 27-31. IRRI, Philippines.

Sharma, K.D., Kaushik, R.P. & Sharma, S.L. 1985. HPU8020, a promising mutant rice. *Intl Rice Res. Newsl.*, 10(5): 5.

Siddiq, E.A., Garg, A.K. & Ali, J. 1999. Breeding for salt tolerance in rice. Paper presented at the Indo-UK Soil Salinity Project: End of Project Workshop, 12-14 Oct. 1999. 12 pp.

Siddiq, E.A. & Viraktamath, B.C. 2001. Rice. *In* Chopra, V.L. (ed.) *Breeding field crops*, p. 2-85. New Delhi, India, Oxford and IBH Publishers.

Singh, B.N. 2000. Breeding for adverse soil problems in rice. *In* Nanda, J.S. (ed.) *Rice breeding and genetics*, p. 219-240. New Delhi, Oxford & IBH Publishing. 382 pp.

Singh, R.K. & Mishra, B. 1995. Screening anther culture derivatives of rice for salt tolerance. *In* Sharma *et al.* (eds) *Genetic research and education: Current trends and the next fifty years*, p. 501-513. New Delhi, India, Indian Society of Genetics and Plant Breeding.

Singh, V.P., Siddiq, E.A., Zaman, F.U. & Sadananda, A.R. 1989. Induced variation in aromatic rice cultivars. *Intl Rice Res. Newsl.*, 14: 14.

Sivaraj, R., Gnanamanickam & Levy, M. 1996. Studies on genetic diversity of Pyricularia grisea: a molecular approach for management of rice blast. *In* Khush, G.S. (ed.) *Rice genetics III*, p. 958-962. Manila, Philippines, IRRI. 1011 pp.

Thakur, R., Sahu, S.P., Mishra, S.B., Singh, U.K., Mishra, M. & Rai, J.N. 1994. Gautam, an improved rice variety for winter (boro) season in Bihar, India. *Intl Rice Res. Notes*, 19(2): 19.

Vijaya Laxmi, G. & Reddy, G.M. 1997. Anther culture of indica rice. Technical improvements in callus induction and green plant regeneration (*Oryza sativa* L.). *J. of Genetics and Breeding*, 51: 295-301.

Virmani, S.S. & Ahmed, M.I. 2001. Environment sensitive genic male sterility (EGMS) in crops. *Advances in Agronomy*, 72: 139-195.

Virmani, S.S. & Edward, I.B. 1983. Current status and future prospects for breeding hybrid rice and wheat. *Advances in Agronomy*, 36: 145-214.

Virmani, S.S. 1996. Hybrid rice. *Advances in Agronomy*, 57: 377-462.

Zhang, Q., Hua, J., Yu, S., Xiong, L. & Xu, C. 2001. Genetic and molecular basis of heterosis in rice. *In* Khush, G.S., Brar, D.S. & Hardy, B. (eds) *Rice genetics IV*, p. 173-185. New Delhi, Science Publishers, Inc. and Philippines, IRRI. 488 pp.

Utilization of genetic resources for rice production in Nigeria

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INTRODUCTION

Rice production trends and genetic improvement in Nigeria are closely interwoven. Genetic resources utilization for rice improvement in Nigeria can be broadly divided into phases which coincide with the history of rice research and production in the country. Thus, genetic diversity amounts to a discussion of trends in genetic resource utilization and the history of rice production in the country.

TRENDS IN GENETIC RESOURCE UTILIZATION FOR RICE IMPROVEMENT

In the beginning

Rice cultivation in Nigeria dates back about three-and-a-half-centuries to a period when the indigenous red rices – *Oryza glaberrima* varieties – were the only cultivated rice species, as was the case for other parts of West Africa (Carpenter, 1978). Worldwide, only two of the over 20 known species of the genus *Oryza* are domesticated. Of these cultivated species, one is indigenous to Asia (*O. sativa* L.), while the other is indigenous and endemic to West Africa, (*O. glaberrima* Steud). The latter is distributed mainly in the savannah along the southern fringes of the Sahara desert (Oka, 1988).

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O. glaberrima was first grown as a crop in the central Niger Delta and Sokoto Basin, among other places, but it later spread into the bush fallow upland farming systems of the western forest zones of Nigeria. *O. glaberrima* probably developed independently and was domesticated from a wild progenitor, *O. barthii* (Jacquot, 1977). *O. glaberrima* is believed to have originated or to have first been domesticated in the flood plains of the Niger River (Hardcastle, 1959). Just half a century ago, *O. glaberimma* accounted for up to 60 percent of total rice production in Nigeria (Hardcastle, 1959). The genetic diversity of the species is clear from the wide range of growing conditions that exist from north to south and in which these varieties have thrived for centuries. These conditions range from the floating/very deep to deep waters of the Sokoto-Rima Basin in the northwest along the basins of the River Rima (an important tributary of the Niger River) and the Jere Bowl in the northeast to the lowlands and uplands of central and southern Nigeria. The floating/deepwater conditions in the flood plains were significantly reduced following the construction of the Bakolori Dam in the upper section of the River Rima. Thus, while a number of varieties adapted to the floating/deepwater conditions, others grew well under drought-prone upland conditions. *O. glaberrima* is still cultivated today 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, and almost replaces the *sativa* cultivars in some farmers' fields, both in the shallow swamps of the flood plains of the Hadejia, Kano, Niger, Benue and other rivers, and in dryland rice crops in southern parts of the country. However, as a cultivated rice crop, *O. glaberrima* is fast being replaced by its Asian counterpart, *O. sativa*. That *O. glaberrima* still exists as both a crop and a volunteer, is probably due to its high level of adaptability to African rice ecological conditions. Until the 1960s, the yield of *O. glaberrima* in Sokoto fadama was superior to that of available *O. sativa* floating cultivars (Carpenter, 1978). Two *glaberrima* varieties, Badande and Jatau, outyielded some of the most successful *sativa* cultivars, such as FARO 6 and FARO 7, in Sokoto fadama in 1960 (Oka and Chang, 1964). Similarly, a number of these varieties thrived well in the rainfed lowlands of the country (Hardcastle, 1959). On the basis of studies on genetic diversity in *O. glaberrima,* Jacqout (1977) indicated that there were two major groups: floating and upland.

A number of these varieties can still be found in farmers' fields, particularly in the northern parts of the various rainfed rice ecologies. They are named in many ways, for example: after the cultivation location (Dan Zaria, Godongaji, Katsina Ala Shendam etc. – all of which are towns in Nigeria); or after the farm where or farmer from whom they are collected (Dogo, Baba Hawa etc.). Some of these *glaberrima* varieties were collected and preserved in the short term by the National Cereals Research Institute (NCRI), Badeggi, and in the medium term at the West Africa Rice Development Association (WARDA), Bouake. WARDA's working collection includes about 300 accessions of *O. glaberrima* collected between 1985 and 1990 in Nigeria (Jones *et al.*, 1997). The gene bank of the International Institute of Tropical Agriculture (IITA), Ibadan, has a collection of over 2 000 entries of *O. glaberrima* from 22 African countries, and the International Rice Research Institute (IRRI), Philippines, keeps duplicates of all materials under long-term storage (Singh *et al.*, 1997). At the same time, many of these varieties may have disappeared through the evolutionary processes (Singh *et al.*, 1997; Guei, 2000).

These varieties are characterized mostly by short to medium, red grain types and they shatter very badly on ripening. Under farmers' conditions, grain yields are often very low but stable – probably as a result of the varieties' high adaptability to the ecology (Chang and Vegara, 1975; Fagade and Ayotade, 1978; WARDA, 1992; Jones *et al.*, 1997). *O. glaberrima* varieties have very good early vegetative growth and ground cover and thus compete favourably with weeds, which are major constraints in rainfed rice production in Nigeria and West Africa generally. They also possess acceptable tolerance or resistance levels to many of the prevalent adverse soil and environmental conditions (diseases, pests and weather) in the country. They are considered more resistant to flooding due to their good elongation ability under flooded conditions.

Two recent studies characterized the diversity of *O. glaberrima*. Jones *et al.* (1993, 1997) concluded that there is very wide variability in the important morphological and agronomic traits within both *O. glaberrima* and traditional improved *sativa* accessions.

Breeding methods, varieties and their impact on rice production

There were initially no attempts to improve varieties, despite their possession of the above-mentioned desirable agronomic traits (Abifarin *et al.*, 1972). At best, there may have been some selection process by farmers who tend to look for and plant materials most suited to their environment and tastes. As in other parts of the world, farmers began crop varietal selection and were regarded as pioneer plant breeders. In Nigeria, as in other parts of Africa where *O. glaberrima* was the first rice crop, development of a wide range of *O. glaberrima* cultivars was practised through farmer selection. The selection practice led to the vast diversity of cultivated African rice known today: floating varieties, photoperiod sensitive, photoperiod insensitive, swamp and upland cultivars, short and long duration cultivars, materials with varying levels of pest and disease tolerance, and varieties with all kinds of grain characteristics (Virmani *et al.*, 1978). Unfortunately, these selection practices did not appreciably improve the yield potential of *O. glaberrima.* As a result, the introduced *O. sativa* varieties with superior grain yield were widely adopted and threatened the genetic base of the African rice. However, African rice survived the onslaught thanks to its wide adaptability.

There were attempts to improve *O. glaberrima* and produce hybrids or select cultivars for higher grain yield, adaptability to soil and other abiotic and biotic production constraints. *Sativa/glaberrima* crosses were mostly unsuccessful due to high sterility and continued segregation of progenies up to eighth or more generations (FAO, 1971).

As a result, total national rice production remained low for many years, averaging only a few thousand tonnes and a low productivity rate of about 0.5 t/ha. Rice consumption before 1960 was restricted to the areas of production, and for many years rice in most households in Nigeria was used only for festivals or other special occasions (Ayotade, 1991). Rice was not the national staple it is today. Prices were higher than those of the main staple root, tuber, or of other cereal foods. Rice consumption was regarded as elitist – a special food only for well-to-do and urban consumers. On important occasions, it was a status symbol to serve a rice meal instead of the normal daily staple, such as yam/cassava fufu or a cereal dish. Rice was generally preferred by children, but it was rarely sufficient to satisfy their needs. At Independence in 1960 for example, Nigeria produced only 0.134 million tonnes (Mt) of paddy from 0.156 million hectares (Mha) with an average yield of 0.8 t/ha. *Glaberrima* rices accounted for 60 percent of total national rice production at this time, despite the introduction several years earlier of white-grained *O. sativa*.

The arrival of *Oryza sativa*

O. sativa is believed to have been introduced into Africa some 2 200 years ago (Jacquot, 1977; Gupta and O'Toole, 1986). The route of *O. sativa* into Nigeria is not quite certain; however, Asian rice is known to have reached Africa through Madagascar from Java. It is likely that many African countries, including Nigeria, received their rice via this route. Another possibility is that Asian rice was introduced into Senegal, Guinea Bissau and Sierra Leone by the Portuguese around 150 AD (Porteres, 1950), and Nigeria may also have received the Asian rice by the same route. It should however be noted that Nigeria (like many other West African countries) established contact with the Arab traders and later Arab Islamic Missionaries through North Africa long before the arrival of the Europeans. The same Arabs were already in contact with Asia and could just as well have introduced Asian rice into the country. However, the most significant recorded introduction to Nigeria was in the 1920s when some form of research work started on rice at Moor Plantation, Ibadan (Hardcastle, 1959; Obasola *et al.*, 1981). This period marked the beginning of rapid genetic erosion in the indigenous *O. glaberrima.* Over three-quarters of a century, the white-grained *sativa* varieties almost completely replaced the red rices. These rices of Asian origin had in turn adapted so well to rice-growing conditions that the country and the entire West Africa region became a new centre of genetic diversity (Sharma and Steele, 1978). However, the introduction of these varieties was largely uncoordinated with no significant progress made in rice production.

Breeding methods, varieties and their impact on rice production

Organized rice research activities in Nigeria began in 1953 with the establishment of a rice research unit at Badeggi as a station of the then Federal Department of Agricultural Research (FDAR), Moor Plantation, Ibadan (Hardcastle, 1959). Rice improvement efforts in this period concentrated on improving farmers' yields through the replacement of farmers' traditional varieties with exotic materials. The main breeding strategies of the new station were:

- collection, testing and selection from local varieties; and
- introduction, selection and adoption from exotic varieties.

From 1954, efforts were geared towards the collection of both *glaberrima* and *sativa* rice varieties available or grown in the country. In the first year, nearly 200 accessions were collected and maintained in the gene bank of the station at Badeggi. This collection increased to over 2 000 accessions in the first two decades of the station's existence (FDAR, 1974). Each new collection was entered into a varietal collection nursery and assessed with standard varieties for given agronomic traits, such as duration, height, reaction to diseases (blast, brown spot, onion shoot) and pests (stem borers), grain type and yield. Different nurseries were planted for different ecologies: upland, swamp (rainfed lowlands of varying water depths) and floating rice. Outstanding entries from the varietal collection nursery were moved to station yield trials lasting 2 to 3 years. Materials with superior performance to the standard varieties were then evaluated further in different locations in the country (zonal trials). Materials with higher yield and other desirable traits from zonal trials were then recommended to replace the existing farmers' varieties. It is therefore a lengthy process before a new variety reaches the farmers.

FARO 1 (or BG 79) was introduced from Sri Lanka. It has the FDAR/NCRI (National Cereal Research Institute) genebank accession no. 131 and was later named as FAROE 131-54. FARO 1, recommended for lowlands, was one of the first white-grained varieties to be successfully introduced into the country. Another is FARO 3 (Agbede) recommended for the upland areas. Agbede is a pure line selection from local Agbede 16/56 (Obasola *et al.,* 1981). These two varieties (and others that followed them until about 1966) are late-maturing, poor nitrogen responsive, disease and pest susceptible, and with moderately high-yielding capacity even under the farmers' poor management practices. These earlier recommended, introduced varieties have the good grain qualities sought by consumers and were so widely grown by farmers that they were considered 'local varieties' and given local names by farmers (Fagade and Ayotade, 1978). They were cultivated all over the country in the recommended ecology. Other varieties were: FARO 2, 5, 6, 7 and 8 for rainfed lowland; FARO 11 for upland; and FARO 4 and 9 for deepwater ecologies (Ayotade, 1991) (Table 1).

TABLE 1

Origin and characteristics of varieties released in Nigeria before 1965

FARO no.	Origin	Pedigree/ parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
1	Guyana	BG 79	Shallow swamp	1954	135-174	105-120	3.0-5.0
2	Guyana	D 144	Shallow swamp	1957	135-115	100-115	3.0-4.5
3	Nigeria	Agbede	Upland	1958	95-120	95-100	1.5-2.5
4	India	Kavunginpoothala 12	Deepwater	1959	189-220	145-150	2.0-4.0
5	Madagascar	Makalioka 825	Shallow swamp	1960	135-154	111-115	2.0-4.5
6	F/Guinea	Indochinablank (ICB)	Deepwater	1961	176-198	156-160	2.0-3.0
7	Thailand	Maliong	Deep flooded water	1962	160-217	160-165	2.5-3.5
8	Indonesia	Mas 2401	Shallow swamp	1963	155-160	120-125	3.5-4.5
9	Malaya	Siam 29	Shallow swamp	1963	189-220	120-125	2.5-3.0
10	Kenya	Sindano	Shallow swamp (high altitude)	1963	115-162	125-130	2.5-4.5

There was a national need in the period 1966-1970 for early-maturing and high-yielding varieties which could be used for double-cropping in the irrigation schemes that were being established in the country. At this time IRRI was disseminating the 'ideal plant type' for tropical rice varieties. As a result, stiff-strawed, non-lodging, nitrogen-responsive, high-yielding varieties were both introduced and adapted or bred in the country. Prominent among the introduced and adapted varieties were SML 140/10 and IR 8 (recommended as FARO 12 and 13, respectively). High-yielding or modern varieties (not recommended, but found in farmers' fields) include: IR 1416, BG 400-1 and IR 30.

The release and adoption of modern varieties greatly influenced national rice production. Production increased from 135 000 tonnes in 1960 to 308 780 tonnes in 1970. At present, some farmers still grow mixed portions of *O. glaberrima* and *O. sativa* in both upland and floating rice conditions; however, the proportion of *O. glaberrima* has reduced remarkably to around 10 to 15 percent of the total area.

The period from 1970

Restructuring rice research and streamlining germplasm exchange

In 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 in the national research and extension systems in Nigeria. In 1975, FDAR became the National Cereals Research Institute (NCRI) with its headquarters at Badeggi. Rice improvement was accorded higher priority in the NCRI programmes. This period also coincided with the establishment in 1975 of a global network for the systematic collection, evaluation and distribution by IRRI of genetic materials through the International Rice Testing Programme (IRTP). In 1989, IRTP was renamed the International Network for Genetic Evaluation of Rice (INGER). Nigeria has participated in this network since its inception (Seshu, 1986). WARDA (the coordinator of INGER-Africa activities) and IITA (which had a rice mandate for Africa until 1991) also collaborate with Nigeria in the exchange and development of germplasm. The mid 1970s therefore marked the watershed for the systematic exchange, utilization and spread of improved genetic materials in Nigeria. It also greatly increased the range of genetic diversity available for breeding purposes.

Development and spread of high-yielding cultivars

The breeding effort in Nigeria continued to focus on the selection of tall vigorous and photoperiod sensitive varieties for swamp rice ecologies with their varying water depths and growing seasons. These efforts led to the development and release of a number of varieties, such as FARO 12, 15, 16 and 17 (Table 2). FARO 12 was introduced from Suriname. It is a tall long duration variety with narrow long leaves and it was recommended to suit the long growing seasons found in the rainfed swamps of the south, e.g. those in Bende, southeast Nigeria. It has very long and slender grains. FARO 15 has a strong culm, medium-size grain, broad leaves and is more adapted to a medium- to deepwater ecology because of its elongation ability, but lodges heavily when subjected to heavy doses of nitrogen fertilizer. FARO 15 is still very much cultivated in the country in rainfed shallow and deepwater fadamas. There is hardly any trace today of FARO 16 and 17 in farmers' fields, either because they no longer exist or because other names are used by farmers and extension workers.

At this time, the Asian revolutionary development of the semi-dwarf rice plant type (which drastically raised rice yield potential to about 5 to 6 t/ha) was being pursued. This led to the development of high-yielding semi-dwarf IRRI varieties and others from other Asian national research institutes.

Varieties introduced into Nigeria included IR 8 (FARO 13) and Taichung Native 1 (FARO 21). Other IRRI lines were released as FARO 19-23 (Table 2). Seven of the new high-yielding varieties: IR 8, IR 20, BPI-76, TN 1, IR 627-1-31-3-37 and IR 5, were released for cultivation between 1970 and 1974.

At the same time, the breeding programme screened introductions for donors of useful traits, such as high yield potential, adaptability to target environment, and tolerance or resistance to major stresses. Part of the strategy was to incorporate these traits into either local varieties or improved materials. The pedigree method is used to evaluate the lines simultaneously for agronomic traits and resistance/tolerance to different stresses.

From 1976 onwards, greater attention was devoted to developing varieties for the target environment, e.g. early-maturing stress resistant varieties for irrigated ecologies. This culminated in the development and release of a number of varieties, such as FARO 31, 32, 33 and 34 (Fagade *et al.*, 1988; Nkwungu *et al.*, 1990) (see Table 2).

TABLE 2

Released rice varieties in Nigeria, 1965-1986

FARO no.	Origin	Pedigree/parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
11	Congo/Zaire	OS 6	Upland	1966	115-120	115-120	1.5-2.5
12	Surname	SML-140/10	Shallow	1969	145	135-140	3.0-4.0
13	Philippines	IR 8	Shallow	1970	135-140	90-100	2.0-4.0
14	NCRI, Nigeria	Chanyza 123 x ICB	Deepwater	1971	170-198	150-160	2.5-4.0
15	NCRI, Nigeria	BG 79 x IR 8	Shallow	1974	145-160	115-120	3.5-4.5
16	NCRI, Nigeria	Mas 2401 x SML 14/10	Shallow	1974	140-160	90-100	2.5-3.5
17	NCRI, Nigeria	Mas 2401 x Tjina	Shallow	1974	145-160	110-120	2.0-3.0
18	Indonesia	Tjina	Shallow	1974	179	145-150	2.0-3.0
19	Philippines	IR 20	Shallow	1974	135-140	90-100	
20	Philippines	BPI-76	Shallow	1974	125-130	90-100	2.5-4.0
21	Philippines	Taichung Native 1	Shallow	1974	90-110	80-90	2.5-4.0
22	Philippines	IR 627-1-31-3-27	Shallow	1974	145-150	90-110	2.0-3.0
23	Philippines	IR 5-47-2	Irrigated/shallow swamp	1974	145-150	90-100	2.0-3.0
24	Viet Nam	Degaule	Irrigated/shallow swamp	1974	135-145	135-145	2.5-3.5
25	NCRI, Nigeria	Jete x Tjina (FAROX 56/30)	Upland	1976	115-120	105-100	2.5-3.5
26	NCRI, Nigeria	TOS 78	Shallow	1982	130-135	105-100	2.5-3.5
27	NCRI, Nigeria	(TOS 103) IR 400-15-12-10-2 x IR 662	Shallow	1982	110-115	90-100	3.0-4.0
28	NCRI, Nigeria	Tjina x IR 8 (FAROX 118°)	Shallow	1982	135-140	125-130	3.0-4.0
29	NCRI, Nigeria	Pesa/TN 1 Remadja (BG 90-2)	Shallow	1984	125-135	100-115	2.5-3.5
30	NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-2-1-1)	Shallow	1986	110-115		5.0

FARO no.	Origin	Pedigree/parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
31	NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-2-1-2)	Shallow	1986	110-115	120-125	5.0
32	NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-1-1-1)	Shallow	1986	110-115	110-120	4.5
33	NCRI, Nigeria	IR 28/FARO 12 (FAROX 233-1-1-1)	Shallow	1986	110-115	115-125	4.0-5.0
34	NCRI, Nigeria	FARO12/IR28 (FAROX 239-1-1-1)	Shallow	1986	105-115	115-120	4.0-5.0
35	IITA, Nigeria	ITA 212 (BG 90-2*4/Tetep)	Shallow	1986	120-135	100-115	4.5-5.0
36	IITA, Nigeria	ITA 222 Maushuri/IET 1444	Irrigated swamp	1986	120-135	100-115	4.5-5.0
37	IITA, Nigeria	ITA 306 (TOX 494-3696/TOX 711/BG 6812)	Irrigated swamp	1986	125-140	100-115	4.5-5.0
38	Côte d'Ivoire	IRAT 133 (IRAT 13/IRAT 10)	Irrigated swamp	1986	100-105	100-110	1.0-3.0
39	Côte d'Ivoire	IRAT 144 (IRAT 13/IRAT 10)	Irrigated swamp	1986	100-105	95-105	1.0-3.0
40	NCRI, Nigeria	FAROX 299 (Multiline)	Irrigated swamp	1986	115-120	115-120	1.0-3.0
41	Côte d'Ivoire	IRAT 170 (IRAT 13/Palawan)	Upland	1986	115-120	80-90	1.0-3.0
42	IAR & T, Nigeria	ART 12 (ITA116)	Upland	1986	115-120	110-115	1.0-3.0
43	IITA, Nigeria	ITA 128 (63-83/Iguape Cateto, IET 144, IR 1416-131, Lite 506)	Upland	1986	115-120	110-115	1.0-3.0

Table 2 also includes varieties officially released in the country in the last two decades. These include two each of early- and medium-maturing upland varieties (Fagade *et al.*, 1987a, 1987b). Nineteen percent of the upland varieties released from 1976 to 1995 – i.e. FARO 25, FARO 39 (IRAT 144), FARO 40 (FAROX 299) and FARO 42 – were not grown in any of the country's geopolitical zones. This might be because of the high preference for FARO 11 and FARO 46 (ITA 150). FARO 38 is listed as being grown only in the northeast zone. Similarly, FARO 26 (TOS 78) among the lowland varieties is listed as growing in only one zone, i.e. the southwest. Field surveys, however, are required to confirm that these varieties are no longer planted in farmers' fields, as many released varieties have been renamed using local dialects. The other varieties are widely spread in the country and have made an important contribution to the nation's increased production.

Prior to 1976, only one early-maturing variety, FARO 21 (TN 1), had been released (see Table 2). However, the number of early-maturing varieties released increased from one in 1976 to over ten in 1995 (Table 2). In the 1970s, the Government started to address the constraints to rice production, and large-scale development projects (in the river basins) were among the first attempts to stem imports. Thus, this may have been a reflection of the demand for early-maturing varieties in the irrigated schemes being developed in the upland and lowland areas of the drier north characterized by only 3 to 4 months of rainfall.

A great upland rice discovery (mostly early-maturing varieties) was reported by the River Basin Development Authorities of the northwest zone. It was reported as occupying a significant proportion of the total rice production area in the states, even posing a problem for the early planting of dry season crops (e.g. wheat) (NARP, 1995). The area occupied was, however, not quantified. These areas, known as 'upland rice areas', could also be rainfed lowland rice areas since they were in the river basin schemes.

Farmers adopted some of the improved varieties even without their formal release through the national varietal release mechanism. These varieties included: IR 1416 and Cisadane in the southeast; BG 400-1, IR 30, IR 72 and others in the northern zones. Breeders' seeds of released rice varieties are provided by the research institute to the National Seed Service (NSS) set up in 1975 for further multiplication to foundation seed (Nyanteng, 1986). These are distributed to the ADP (Agricultural Development Project) at state level or to ministries of agriculture for the production of certified seeds which are sold to farmers. The National Seed Service uses the services of the research institutes, NAFPP (National Accelerated Food Production Program) and private seed growers to obtain both foundation and certified seeds (Nyanteng, 1986).

In 1986, the seed multiplication efforts were intensified in Kaduna State with the multiplication and distribution of over 50 tonnes of seeds of ITA 257, FARO 15 and FARO 27 (FACU, 1988); but this was a far cry from farmers' needs. As 1 tonne of seed could plant about 20 ha, some 10 000 ha would have been planted to these improved varieties.

In Kano State, Kano Agricultural and Rural Development Authority (KNARDA) multiplied and sold seeds of ITA 116, ITA 118 and ITA 235 to farmers (FACU, 1988). The area under the authority's rice programme was 40 000 ha. There is thus confirmation of the wide diversity in the use of improved varieties.

Modification of the variety release mechanism

The improved varieties found in farmers' fields could be traced to a number of sources, but research sources were the most predominant. Prior to 1984, the varietal release system in Nigeria was such that rice varieties could reach farmers through many research institutes or channels with a rice component in their programme. At national research level, following two or more advanced yield trials, the most outstanding entries were tested for a further two years in zonal trials. The national research institute then released outstanding varieties to replace existing ones. Other research centres go directly to the farmer. For example, FARO 26 (TOS 78 = IR 269-26-3) and FARO 27 (TOS 103 = IR 790-35-5) were originally introduced into Nigeria by IITA from IRRI. They were used in zonal trials and fertilizer trials between 1976 and 1978, before being released as varieties in 1982 (NCRI, 1978). FARO 28 (FAROX 188A) was developed at NCRI as a cross between Tjna and IR 8 (introduced from Indonesia and IRRI in 1960 and 1967, respectively); it passed through the zonal trials between 1976 and 1978 (NCRI, 1978). Similarly, FARO 29 (BG 90-2), released in 1984, was identified in the IRTP nursery in 1979 and tested in the zonal trial (medium duration) from 1980 to 1982 (Table 2) (NCRI, 1983).

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 Rice Varieties Evaluation Trials (CRET) coordinated by NCRI. These institutions included: national institutes, such as NCRI and IAR&T (Institute of Agricultural Research and Training); and international centres, such as IITA, IRRI/IRTP, INGER and WARDA. After two years the best entries from CRET in each ecology were recommended for release to the national varietal release committee. Thus in 1985, IRAT 133, IRAT 144 (from upland short duration CRET), IRAT 170, ART 12 (ITA 116), FAROX 299, ITA 128 (from upland short medium CRET), FAROX 228-2-1-1, FAROX 228-3-1-1 and FAROX 228-4-1-1 (from lowland short CRET) and ITA 212, ITA 222 and ITA 306 (from lowland medium CRET) were recommended by the Third National Coordinating Research Project on Rice for release to farmers and were consequently released by NCRI in 1986 (Fagade *et al.*, 1987a, 1988).

The method of release was modified slightly in 1986, so that between two and five of the most promising materials from any CRET nursery are nominated into NAFPP farmers' field trials and the farmers' choices are released after one or two years of trials. The varieties released in 1986 and 1993 are listed in Table 2. Ninety percent of the varieties released between 1985 and 1995 appeared in the CRET trials. Sixty-seven percent of the varieties released in Nigeria originated directly from IRRI. Eighty-six percent passed through INGER-Africa trials for at least 1 year before release, while all had one or more of their parents originating from IRRI/IRTP or INGER-Africa sources. This showed greater diversity of materials and facilitated the monitoring of varietal types compared to the method previously adopted for varieties released in Nigeria.

Genetic composition of released varieties

Tables 1 and 2 show that the rice varieties released in Nigeria had varying genetic contributions from across the globe. The parentage of the early introductions was not recorded, which places limitations on the discussion of diversity in the genetic make-up of released varieties. However, the spread in the country of origin, diverse morphological and physiological characteristics, adaptation to different ecologies and differences in reactions to environmental stresses are evidence that the varieties have diverse genetic make-up. The high level of resistance to blast in Tjina, for example, was used for developing high-yielding blast-resistant varieties, such as FARO 16 and FARO 25, as well as semi-dwarf FARO 28. The genetic make-up of varieties that were introduced or developed later were traceable. As seen in Table 2 and discussed earlier, most of the varieties bred in the country since 1986 have parents originating from IRRI. IR 28 was used in crosses to incorporate its gene for earliness, traceable from early IRRI lines into:

- FARO 15, a highly adaptable and high-yielding variety, in order to obtain stiff-strawed early-maturing high-yielding varieties. FARO 15 had the high-yielding stiff straw from its IR 8 parent. The other parent of FARO 15 is BG 79, used because of its wide adaptability to the Nigerian ecosystem. This combination resulted in the development and release of FARO 30, 31 and 32 as early-maturing high-yielding varieties for irrigated schemes in the country.
- FARO 12, also a long duration (140-160 days), photoperiod-sensitive variety with long grains. The selected and released lines from this cross (FARO 33 and 34) were weak-strawed (like the FARO 12 parent), but they inherited the long grains of FARO 12 and the earliness of IR 28. They perform well under moderate levels of fertilizer and are grown in most of the irrigated schemes of the north.

Genetic uniformity in rice production in Nigeria is most common in the upland rice-growing zones of the forest zone where farmers stuck to growing only one variety, FARO 11, prior to the introduction of earlier-maturing FARO 46 only a few years ago. There was no serious disease or pest outbreak in this variety, partly because of its tolerance to the most common disease: blast. Farming systems where rice is intercropped with maize, cassava, melon and so on, as well as the fallow system, may have assisted in stemming the incidence of major disease or pest attacks. Genetic uniformity is also found in the Bende irrigation scheme where FARO 12 and 23 are the only common varieties. Again, blast is the major rice disease in this area and the two varieties, particularly FARO 12, are tolerant. The long fallow period due to the insufficient water supplies for a dry season crop may also have helped to reduce serious pest and disease outbreaks. However, in neighbouring Ebonyi State, where gall midge is highly prevalent, there were reports of complete crop failure of all varieties grown in endemic years in the rainfed lowland crops, as no tolerant variety was identified until the official release of tolerant Cisadane just 4 years ago.

New areas of collaborative rice improvement and genetic diversity

Significant to rice development in recent years is the increasingly high level of collaborative research activities from which rice varietal improvement in Nigeria has benefited greatly. The impact is already being felt, but the greater part is to be witnessed in the near future. These activities included the new concept of collaborative research between WARDA and the national programmes within the subregion through task forces. Some production constraints were identified and a task force was allocated to develop technologies aimed at solving such constraints. Rice breeding had three such task forces in which Nigeria actively participated: upland, rainfed lowland and irrigated lowland. Through the task forces, lines bred for different ecological problems were composed into nurseries of nominations from both WARDA and national programmes. The National Agricultural Research Systems (NARS) that share similar production constraints in a given ecology evaluated these nurseries. Part of the funding was undertaken by WARDA and results were discussed at WARDA headquarters at the end of each cropping season. Varieties from these nurseries were identified for national use. WARDA at full incorporation in the CGIAR (Consultative Group on International Agricultural Research) system established a lowland breeding station at IITA when the latter ceased its rice research work. The national programme benefited because scientists could enjoy closer collaboration with their WARDA counterparts at the station.

A recent development is farmer participatory varietal selection (PVS) – a collaboration between WARDA and NARs with the participation of Nigeria. This approach places the farmer first in the varietal selection process, which in turn makes it possible to identify farmer-acceptable rice cultivars, shortens the time lag between varietal development and release (adoption) and utilizes farmers' knowledge to breed acceptable rice varieties.

Another collaborative activity was a national initiative through the now suspended National Agricultural Research Project (NARP), a World Bank assisted project. The project that took off in 1990 brought together all rice scientists within the country to participate in collaborative rice research. The programme contributed by expanding the scope of CRET and bringing the state Agricultural Development Projects (ADPs) and the universities into the mainstream of rice varietal evaluation nationwide.

Most recent sources of diversity through varietal releases

The most recent batch of varieties released in Nigeria were mainly upland with only two lowland varieties (Table 3). The upland varieties were mostly those developed earlier by IITA. Though some of these varieties were developed in the early 1980s, the long process of varietal evaluation meant that they were not released until 1992. They are short-statured varieties, selected to reduce the height of FARO 11 and increase tillering ability. The result was the

TABLE 3
Released rice varieties in Nigeria, 1987 to present

FARO no.	Origin	Pedigree/ parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
44	Taiwan	SIPI 692033(SIPI 661044/SIPI651021	Irrigated/ shallow	1992	110-120	95-110	4.0-6.0
45	ITA, Nigeria	ITA 257(IRAT 13/Dourado Precose 689/TOX 490-1	Upland	1992	90-100	90-100	2.0-3.0
46	ITA, Nigeria	ITA 150 (63-83/Multiline	Upland	1992	100-105	80-90	2.0-3.0
47	ITA, Nigeria	ITA 117 (13A-18-3-1/TOX 7)	Upland	1992	115-120	90-110	2.0-3.0
48	ITA, Nigeria	ITA 301 (IRAT 13/Dourado Precose 689/Padipapayak)	Upland	1992	115-120	90-110	2.0-3.5
49	ITA, Nigeria	ITA 315 (IR 43/Iguape Cateto)	Upland	1992	115-120	90-110	2.0-3.5
50	ITA, Nigeria	ITA 230 (BG 90-2*/Tetep)	Irrigated/ shallow swamp	1992	130-135	90-115	3.0-4.0
51	Indonesia	Cisadane (Pelita-1/IR/ 789-98-2-3/IR 2157-3	Irrigated	1997	130-135	100-120	3.0-4.0
52	IITA/WARDA	WITA 4 (TOX 3100-44-1-2 -3-3)	Irrigated/ shallow	2000	120-135	115-120	3.0-4.5

ITA 300 series, of which ITA 301 and ITA 315 were released as FARO 48 and 49, respectively. These two cultivars are of medium maturity and high yielding, particularly under high nitrogen fertilization. They also have good grain type (B type grain), but are susceptible to drought and under the heavy humidity of the moist forest zone of western Nigeria are highly susceptible to leaf scald (*Gerlachia oryzae*) and bacteria blight (*Xanthomonas campestris*).

ITA 117 (FARO 47) is a much taller variety, of medium maturity and with lower yield potential. FARO 48 and 49 are widely adopted in the middle belt zone, especially in Benue and Plateau states. FARO 46 is the most widely adopted improved upland rice variety in Nigeria today. With a moderate yield potential of about 2 t/ha, it is intermediate to tall plant type, depending on the water and fertility conditions of the soil. The paddy grain is golden, easy to thresh and long grained. The variety is even grown in the northern parts of the country: Kano, Adamawa and beyond, where it is intercropped with sorghum, maize and millet. It is also widely grown in the southwest, where two crops a year are cultivated.

The NCRI effort to produce similar upland varieties led to the development of the FAROX 400 series, of which three were nominated into coordinated trials: FAROX 406-1-1, 408-1-1 and 408-1-2. Only FAROX 408-1-1 was finally approved for on-farm trial, but it was not released due to lack of an on-farm performance record.

The two varieties released for swamp ecology in this period were ITA 230 (FARO 50) and Cisadane (FARO 51). ITA 230 has superior grain yield and blast resistance over earlier released ITA lines and it was generally adopted by farmers. Cisadane was introduced through INGER Africa. In 1988, there was a serious outbreak of African Rice Gall Midge (AfRGM) in eastern Nigeria in the Abakaliki area. As a means of finding a solution to the problem through the varietal resistance approach, several cultivars were screened for resistance in the area. All tested lines were susceptible, but Cisadane – although attacked – produced higher grain yields due to its ability to compensate for lost tillers. Subsequent evaluation of the cultivar clearly showed its yield advantage over all local varieties under pest pressure (Williams *et al.,* 1999). The variety was well adopted by the farmers in eastern Nigeria before its release in 1998. WITA 4 (FARO 52), in particular, is widely adapted for both rainfed and irrigated lowland. It combines drought resistance with iron toxicity tolerance, two main constraints limiting rice production in rainfed lowland ecology in Nigeria. It also combines high yield with yield stability even under low input conditions. Its deficiency is its susceptibility to AfRGM.

Promising varieties of the future

There are a few promising varieties expected to make a major impact on rice production in the near future in all rice ecologies in Nigeria. There are a number of IITA-developed but WARDA/NCRI-selected and evaluated lines that are still highly promising in the lowlands, including some WITA lines. WITA 1 and 3 are most promising. Other promising lines currently in coordinated trials include TOX 4004-8-1-2-2-3, TOX 4004-43-1-2-1, TOX 4008-34-1-1-1-2 and TOX 3440-164-3-3-2. In the uplands there are a series of materials, such as WAB 56-50, WAB 35-2-FX, WAB 99-1-1 and WAB 96-1-1, which are developed by WARDA and introduced through the task force programme. These materials are already in CRET. WAB 35-2-FX has already been advanced to on-farm.

Another important development in rice improvement in Africa generally is the successful crosses between *glaberrima* and *sativa* species. This breakthrough by WARDA was made possible through the backcross method and anther culture technique. Progenies of these interspecific crosses are already being evaluated in Nigeria. The varieties have good weed competitiveness, drought tolerance and high yield under the low-input conditions of Nigeria's resource-poor farmers.

Production trends

Several reports – FAO, 1999, 2000; WARDA, 1999a; Yap, 1994; NCRI, 1996 – reveal marked increases in rice production in Nigeria from the 1970s to the present. Production rose from about 0.5 million tonnes (Mt) to over 3.5 Mt. This figure (which accounts for approximately 25% of the region's total rice output) is the single biggest increase in output in Africa (Yap, 1994). The increase in production is sometimes attributed to government policies, such as the introduction of import restriction measures in 1985 (Nyanteng, 1986; Yap, 1994) and the expansion of rice area with rice lands tripling over the 10-year aggregate periods of 1975-1985 and 1986–1995. The release of improved high-yielding varieties, however, is one of the major contributing factors to increased rice production.

The annual growth rate of area (over 10%) is the highest in the world (IRRI, 1995) and the growth rate in output of between 8 and 10 percent is also amongst the world's greatest. These figures surpass the projections in the national agricultural development plans of the Federal Ministry of Agriculture for the period from 1974 to 1985.

POTENTIALS, SUSTAINABILITY, CONSTRAINTS AND UTILIZATION OF RICE GENETIC DIVERSITY

The main sources of rice genetic diversity in Nigeria can be classified into three basic categories: *O. sativa, O. glaberrima* and wild species, such as *O. bathii.*

O. sativa sources

O. sativa germplasm consists of landraces and improved germplasm. Landraces are characterized by tall plant type and strong culm, and usually contain both photoperiod-sensitive and non-sensitive cultivars; they have low tillering potential but heavy panicles. Generally, they are yet to be fully exploited to improve varieties for upland ecology and rainfed deepwater ecologies. The low tillering ability, deep root nature and heavy panicles that combine big and strong culm can be utilized to develop materials for drought tolerance and lodging resistance that characterize upland ecologies, particularly in the high rainfall areas of the rain forest zone. The tall nature of these materials and their photoperiod sensitivity can also make them ideal for the development of rainfed deepwater ecology materials for the flood plains of the Niger, Benue and Kaduna rivers. The rice production potential in these areas is seriously under-utilized. When these materials are crossed with modern semi-dwarf materials, they may result in progenies where intermediate plant types, better tillering and stronger culms are selected. These heavier tillering intermediate plant types are ideal for shallow rainfed ecologies where weed management is a major production constraint.

The improved modern, semi-dwarf germplasm currently used in most irrigated and rainfed inland valleys do not offer much opportunity for improved yield.

Their high dependence on high nutrient input and management levels makes them less attractive to the country's resource-poor farmers. Most of the improved modern varieties are also prone to one stress or another, hence crosses between any two of them do not solve the multiple stress problems typical of the rice production ecologies. For example, the most recently released improved lowland variety in Nigeria (FARO 52 – WITA 4) was developed by IITA/WARDA. It has good stable grain yield potential due to high tillering ability, drought and iron-toxicity tolerance, but is very susceptible to AfRGM. In the 2001 season almost all the nurseries of this cultivar were destroyed by rice blast at Edozhigi, both in research and farmers' nursery beds. Long-term evaluation of new improved varieties by NCRI revealed that new elite lines do not show remarkable yield advantages over materials released in the 1980s, such as FARO 29 and FARO 36 – an indication of yield plateau in the breeding programme.

Use of *O. glaberrima* sources

The second group of germplasm resources is *O. glaberrima*, which did not only originate in but is endemic to the West Africa subregion. Research activities showed that these materials are well adapted to the adverse African rice-growing soils, harsh climatic conditions and biotic stresses, such as drought, RYMV (rice yellow mottle virus), weed competitiveness, acidity and many others (Maji and Singh, 1993; Paul *et al.*, 1995). More attention must therefore be paid to *glaberrima* materials for genetic rice improvement in Nigeria.

O. glaberrima lines are however characterized by very low yield potential, grain shattering before full maturity, grain characters appealing to neither agronomists nor consumers and weak culm that predisposes them to high lodging susceptibility. Other undesirable traits include long awn, black husk at maturity and red seed coat. These limitations are however variable and materials that possess the positive side of these characters are abundant (Maji *et al.*, 1998). They offer great potential for genetic improvement because of their wide adaptation to various rice-growing ecologies, ranging from upland to deepwater. WARDA has pioneered the use of intraspecific crosses between *O. glaberrima* and *O. sativa* and has generated a large number of interspecifics, now code-named "NERICA" (New Rice for Africa). Many of these are currently being evaluated, mainly in upland rice ecologies, although a number of them are now

PLATE 7
A rainfed lowland/swamp rice field in Sierra Leone

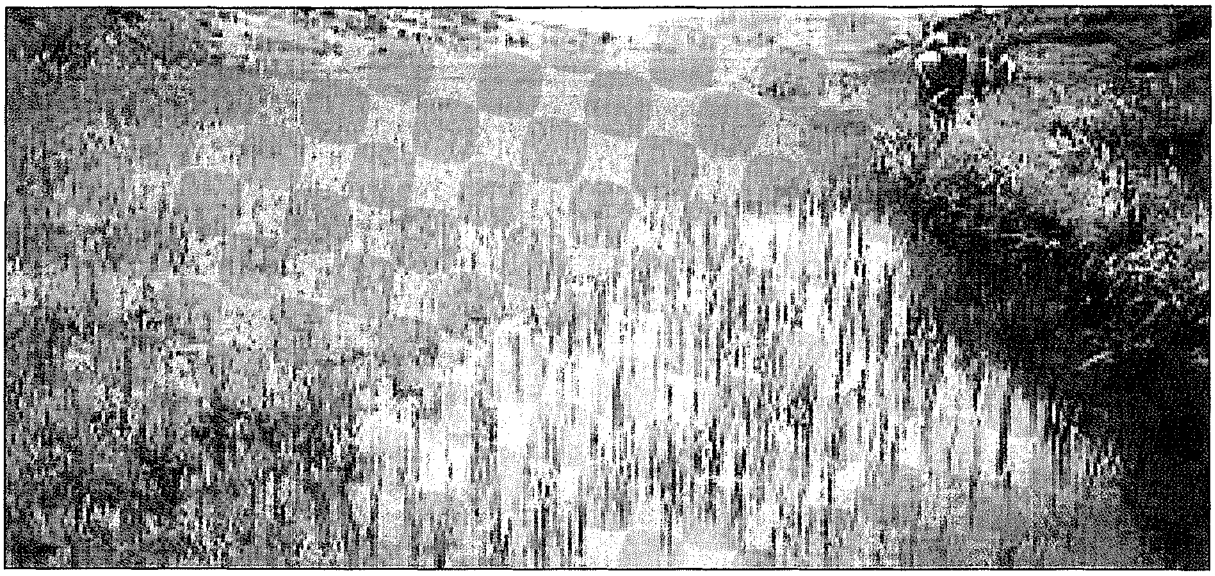

PLATE 8
A field of NERICA rice at a research field of WARDA

Source: WARDA, 1999b.

known to be equally adapted to the lowlands. They are highly weed competitive and suitable for the farmers' low management practices because of their high seedling vigour and intermediate plant height.

However, the use of *glaberrima* germplasm has a major constraint. The F_1 plant in 90 percent of cases is sterile and two or three backcrosses may not have a major impact on the high sterility situation. This is what makes anther culture attractive for the production of double haploids that may be fertile and fixed. The National Cereals Research Institute made a series of backcrosses in its *sativa-glaberimma* interspecific hybridization and discovered that there are only a small number of compatible lines that can give a high percentage of fertile individuals after two or three backcrosses.

Use of wild rice cultivars

Though wild rice cultivars, such as *O. bathii*, abound in Nigeria to the extent that they constitute a menace in some rice fields, especially in flood plains and some inland valleys, their use as genetic resources are constrained by a number of factors.

- Given the wide genetic distance between these wild germplasm materials and cultivated species, particularly *O. sativa*, the success of cross hybridization is quite low and highly technical and therefore requires advanced breeding techniques. Such techniques include embryo rescue, transformation through identification of genes of interest in these wild species, tagging such genes, isolating them and transferring them directly into current varieties.
- There is very little information available concerning these materials and their response to biotic or abiotic rice production constraints in Nigeria, although some information is available at IRRI. It is necessary to identify suitable germplasm materials within these wild species, followed by basic screening activities for various biotic and abiotic rice production constraints.
- The main research institute with the mandate for rice varietal improvement in Nigeria, the National Cereals Research Institute (NCRI), has limited resources in terms of modern research tools to effectively conduct the basic research required for identification of these germplasm. It must

therefore maintain collaborative research with centres that have such facilities in order to optimize the country's abundant sources of genetic diversity.

GENERAL CONSTRAINTS FOR UTILIZATION OF GENETIC RESOURCES AND SUSTAINABLE RICE PRODUCTION

The majority of rice producers in Nigeria are low resource base farmers producing at a subsistence level either as a food crop or as a cash crop. The majority of these farmers have no formal education or a very limited education. The implications of these two factors are the poor resource base and the slow adoption process of rice research improved technology packages. It must be asked whether farmers have access to improved farming techniques, such as rice varieties, farm implements and chemical inputs (fertilizer, insecticides and herbicides), and whether Nigerian rice farmers have access to financial assistance in the form of loans. The answers to these questions are more often than not negative. Although there have been impressive figures showing an increase in production, rice productivity in Nigeria, while not stagnant, has had a very low growth rate. This may be attributed to a number of factors, some of which are explained below.

Available germplasm

A high number of Nigerian rice farmers still depend largely on either *O. glaberrima* germplasm (especially in some northern upland ecologies and deep flood plains) or traditional landraces (as in most of the country). Farmers hold onto these materials tenaciously as they can give substantial grain yields with low management. They have a poor response to fertilizer input but perform relatively better than improved varieties where inputs, such as fertilizer and protection against pests and diseases, are minimal or absent. *O. glaberrima* varieties are generally vigorous in tillering and early seedling growth and better in the exploitation of inherent soil nutrients, and are hence better in weed competition and low input conditions. The traditional tall and strong culm varieties are adapted variously to upland and rainfed lowland ecologies. They are low tillering, but produce heavy panicles. These characteristics also make them attractive to farmers as a result of reduced weeding efforts and there is no need to use fertilizers. The improved rice varieties in Nigeria today are semi-dwarf materials generally bred for irrigated ecologies that constitute less than 10 percent of the rice production ecology (Maji *et al.*, 1999). They are less adapted to rainfed lowland ecologies (which give most of Nigeria's rice output) and they require high levels of nutrients in order to maximize their yield potential. Hence no sooner does a farmer adopt these materials than he forgoes them for traditional types, particularly in rainfed ecologies. However, improved yields require an improved production management package to be developed and propagated.

Adoption rate

The adoption rate is reported to be very low, probably for the reasons given above. There were also complaints that research packages do not take into account farmers' varietal preferences. This has led to the recent research strategy known as farmer participatory varietal selection (PVS), culminating in particular in the development of NERICA rice varieties.

Marginal lands

Some Nigerian rice farmers operate in marginal rice production ecologies where soil problems also aggravate biotic problems. Such soil problems include iron toxicity under rainfed lowland ecologies, acidity in high rainfall upland rice ecologies and salinity in the far north irrigated areas. In some cases, soils are sandy, which worsens the fertility problem. These problems combine to aggravate biotic constraints, such as blast, brown spot, gall midge attack and, in rare cases, rice yellow mottle virus. Traditional varieties give marginal yields under these conditions but improved varieties perform poorly.

Lack of farming tools

Most small-scale Nigerian farmers operate with cutlass and hoes, even in some irrigated ecologies, resulting in high labour demand and exorbitant costs in peak periods with farm holdings reduced to the barest minimum. Irrigation facilities in some of these areas need to be improved to provide for efficient water usage and control. In some irrigated fields water inflow cannot be properly managed, hence some fields have excess water while others within the same scheme have inadequate water supply. These problems of poor crop and water management make the traditional low-yielding varieties more attractive to farmers than the high-yielding, but high management-demanding semi-dwarf improved cultivars.

RECOMMENDATIONS FOR THE MAXIMUM UTILIZATION OF RICE GENETIC RESOURCES

National level

Research and extension

To derive maximum potential from the genetic material available in Nigeria for the benefit of rice production in the country, research must be refocused, more committed and closely monitored. Rice yields – even in research fields – have reached a plateau. What is more, even the plateau cannot be realized by the farmers. To fight this dual problem, genetic improvement effort must look beyond the current semi-dwarf improved materials towards traditional and *O. glaberimma* germplasm for sources of new genes to combat production constraints. Hence, wide hybridization is a key factor in breaking the plateau, if not in the research field at least in farmers' fields. These however will require modern breeding techniques, such as anther culture and biotechnology (molecular genetics), of which national programmes are incapacitated, not necessarily in terms of manpower, but in terms of the equipment and infrastructure needed for such an undertaking.

The current effort and the methodologies required for getting the new cultivars of varieties to farmers need to be doubled and re-examined. The extension efforts are limited, and extension approaches are mostly top-down, which do not work well. Participatory varietal selection has been found to be a better approach. But WARDA's efforts are currently limited because of the wide area in which the farmers that need to be contacted are located. The rate of adoption of research packages is low, due to factors such as low level of farmer education, limited economic capacity, lack of infrastructures and tools. Research packages are usually tailored towards modern farming techniques, such as appropriate spacing, fertilizer usage and other chemical inputs (e.g. herbicides and insecticides). Lack of these facilities hinders the optimum benefits which can be obtained by farmers using new techniques and varieties and so farmers revert to old technologies.

Government role

National governments must invest more in research and implement measures that ensure that such investment is used appropriately. Research is currently seriously underfunded and much of the money provided is not correctly used. In rice-producing countries, governments must invest in the development of irrigation facilities in fadama areas. Irrigation facilities in these states are far below their potential. This effort will extend rice production activities into the dry season when maximum yields are attainable. In addition, the provision of land-preparation equipment, such as rotavators, is important. Use of water and good land preparation will minimize the weed and pest problem. An added advantage will be larger farm holdings – at present limited given that fewer family members are involved in farm work as a result of the urbanization process.

Organizing farmers into cooperative societies facilitates bank loans (for small-scale irrigation facilities, for example) and is an easy way of securing government attention and obtaining other farm inputs from relevant organizations and governments.

The role of international organizations

International organizations can help in exploiting the potential of rice genetic resources in Nigeria in two main areas:

- basic research; and
- research extension services.

Research funding comes in two forms: direct involvement in research activities through the use of experts both outside Nigeria and inside the countries with specific objectives through proposed project funding; and provision of research facilities, such as laboratories and equipment. These laboratories should be equipped with modern research equipment for breeding and other research activities, such as tissue culture facilities, molecular biology equipment for gene mapping, screen houses and greenhouses. The provision of energy sources, such as portable generators in laboratories, is essential for the success of research.

In extension, as highlighted earlier. Nigeria is a vast country with numerous widespread rice-growing ecologies. Extension activities therefore suffer due to lack of funds and transport facilities. Carrying research packages to farmers requires extensive travelling and monitoring; provision of funds or vehicles for research institutions or organization with sponsored projects will greatly improve contact with farmers. Participatory variety selection has been found to greatly facilitate the adoption and dissemination of selected varieties, hence it is a model that can be of great benefit to Nigerian rice farmers.

Training and retraining of officers is of great importance for the exploitation of rice genetic materials in Nigeria. Such training areas will include both formal training (e.g. masters and Ph.Ds) and informal training of technicians in areas of tissue culture and molecular techniques. These are essential for effective management of laboratories and other research facilities provided. Retraining of farmers who have already received training but have little or no experience is required to bring them up to date with new methods and technologies. This may be achieved through attachment to overseas laboratories carrying out similar research activities.

REFERENCES

Abifarin, A.O., Chabrolin, R., Jacquot, M., Marie, R. & Moomaw, J.C. 1972. Upland rice improvement in West Africa. In *Rice breeding*, p. 625-635. Los Baños, Philippines.

Ayotade, K.A. 1991. Improvement of rice production in Nigeria, 1969-1989 and beyond. Paper presented at the Faculty of Agriculture, University of Ilorin, Ilorin. Seminar 29 May 1991. 37 pp.

Carpenter, A.J. 1978. The history of rice in Africa. *In* Buddenhagen, I.W. & Persley, G.J. (eds) *Rice in Africa*, p. 3-10. London, Academic Press.

Chang, T.T. & Vegara, B.S. 1975. Varietal diversity and morpho-agronomic characteristics of upland rice. In *Major research in upland rice*, p. 72-78. IRRI.

FACU. 1988. *Problems and prospects for rice production in Northern Nigeria.* Second study report. Federal Agricultural Coordinating Unit Sept. 1988. 33 pp.

Fagade, S.O., Pillai, P.G. & Kehinde, J.K. 1987a. Two upland rice varieties recommended for release in Nigeria. *IRC Newsl.*, 12(2): 8.

Fagade, S.O., Pillai, P.G. & Kehinde, J.K. 1987b. A high yielding medium duration upland rice for Nigeria. *IRC Newsl.*, 12(2): 5.

Fagade, S.O. & Ayotade, K.A. 1978. The race towards the Green Revolution for rice in Nigeria: Is the technology available? Paper presented at 2nd WARDA Rice Workshop, 25 Sept. 1978, Ibadan.

Fagade, S.O., Pillai, P.G. & Kehinde, J.K. 1988. Improved rice varieties released in Nigeria. *Intl Rice Res. Newsl.*, 13(1): 17-18.

FAO. 1971. *Rice research development in West Africa.* Rome, Italy.

FAO. 1999. *Africa rice paddy production*, FAOSTAT Database Records.

FAO. 2000. *Africa rice paddy production*, FAOSTAT Database Records.

FDAR. 1974. Federal Department of Agricultural Research Annual Report 1975.

Guei, R.G. 2000. Rice Biodiversity and PVS at the Community Level. *In* Proc. PRIGA Workshop, WARDA, Bouake, April 2000.

Gupta, P.C. & O'Toole, J. C. 1986. *Upland rice: A global perspective.* IRRI. 368 pp.

Hardcastle, J.E.Y. 1959. The development of rice production and research in the Federation of Nigeria. *Trop. Agr. (Trinidad)*, 36: 79-95.

IRRI. 1995. *International Rice Research Institute Rice Facts, 1995.*

Jacquot, M. 1977. IRAT and rice genetic resources. Paper presented at Rice Genetic Conservation Workshop, IRRI/IBPGR, Dec. 1977.

Jones, M.P., Heinrichs, E.A., Johnson, D.E. & Riches, C. 1993. Characterization and utilization of Oryza glaberrima in upland rice improvement. In *WARDA Annual Report 1993*, p. 3-12.

Jones, M.P., Aluko, G.K. & Semon, N. 1997. Characterization and utilization of *Oryza glaberrima* in upland rice improvement. *In* Jones, M.P., Dingkuhn, M., Johnson, D.E. & Fagade, S.O. (eds) *Interspecific hybridization: Progress and prospects*, p. 43-60, Bouake, WARDA.

Maji, A.T. & Singh, B.N. 1993. *Drought tolerance in African rice, Oryza glaberrima Steud.* Proc. 17th International Congress of Genetics, International Convention Centre, Birmingham, UK, 15-21 Aug. 1993. 73 pp.

Maji, A.T., Akenova, M.E. & Singh, B.N. 1998. Variability studies in African rice *Oryza glaberrima* using principal component analysis. *Nig. J. Genetics*, 13: 34-42.

Maji, A.T., Gana, A.S., Ukwungwu, M.N., Imolehin, E.D. & Misari, S.M. 1999. Utilization of rice genetic resources in Nigeria. In *Genetics and food* *security in Nigeria. A commemorative book of the genetic society of Nigeria*, p. 63-70.

NARP. 1995. *Report on acivities in the North-West Zone.* Ibadan, NARP.

NCRI. 1978. *National Cereals Research Institute, Annual Report 1978.* Ibadan, NCRI.

NCRI. 1983. *Coordinated Rice Evaluation Report, 1983 Report.* Ibadan, NCRI.

NCRI. 1996. *Coordinated Rice Evaluation Report, 1995 Report.* Bida, NCRI.

Nkwungu, M.N., Joshi, R.C. & Winslow, M.D. 1990. Collaborative research on resistance to African rice gall midge. *Discovery and Innovation*, 2(3): 17.

Nyanteng, V.K. 1986. *An overview of rice related policies and developments in Nigeria.* Occasional Paper No. 10. Monrovia, Liberia, WARDA.

Obasola, C.O., Olufowote, J.O. & Fagade, S.O. 1981. *Upland rice and its improvement in Nigeria.* Proc. WARDA workshop on upland rice research policy, May 1981. 27 pp.

Oka, H.I. & Chang, W.T. 1964. *Observation of weed and cultivated rice species in Africa.* A report of the trip from Sierra Leone to Chad, 1963. Submitted to IRRI, Institute of Biology, Academia Sinica, Research of China and the National Institute of Gen., Japan.

Oka, H.I. 1998. *Origin of cultivated rice.* Tokyo, Japan Scientific Society Press.

Paul, C.P., Ng, N.Q. & Ladeinde, T.A.O. 1995. Diallel analysis of resistance to virus in African rice *Oryza glaberrima. J. Gen. and Breeding*, 217-272.

Porteres, R. 1950. Vieillia Agric. Africaines arant le Xvic siecle, Berceaux d'agric et centres de variation. *L'Agron. Trop.*, 5: 489-507.

Seshu, D.V. 1986. *An overview of International Rice Testing Program in Africa. 1975-85.* Manila, Philippines, IRRI. 44 pp.

Sharma, S.D. & Steele, W.M. 1978. Collection and conservation of existing rice species and varieties of Africa. *In* Buddenhagen, I.W. & Persley, G.J. (eds) *Rice in Africa*, p. 61-68. London, Academy Press.

Singh, B.N., Maji, A.T., Ng, N.Q., Paul, C., Williams, C. & Ukwungwu, M.N. 1997. *Utilization of Oryza glaberrima genetic resources for lowland rice improvement.* Ibadan, Nigeria, WARDA c/o IITA.

Virmani, S.S., Olufowote, J.O. & Abifarin, A.O. 1978. Rice improvement in Tropical Anglophone Africa. *In* Buddenhagen, I.W. & Persley, G.J. (eds)

Rice in Africa, p. 101-116. New York, Academic Press Inc.

WARDA. 1992. *West Africa Rice Development Association Annual Report 1991*. Bouake, Côte d'Ivoire.

WARDA. 1999a. *PVS: The spark that lit a flame.* Bouake, WARDA. 32 pp.

WARDA. 1999b. *Annual Report 1998.* Côte d'Ivoire, WARDA. 71 pp.

Williams, C.T., Ukwungwu, M.N., Singh, B.N., Odhidievbie, O. & Nnaho, J. 1999. Farmer-managed trials in south-east Nigeria to evaluate the rice variety Cisadane and estimate yield losses caused by the African rice gall midge, *Orseolia Orvzivora* Harris and Gagne. *Pest Management*, 45(2): 117-124.

Yap, C.L. 1994. Supply and demand for rice in the medium and longer term. *Intl Rice Comm. Newsl.*, 43: 47-61.

Appendixes

APPENDIX 1

List of varieties released in Latin America

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
IAC 1246	-	Pratao/Perola	UL	-	Brazil
IAC 47	1971	IAC 1246/IAC 1391	UL	90	Brazil
IAC 25	1974	Dourado Precoce/IAC 1246	UL	65	Brazil
IAC 164	1980	Dourado Precoce/IAC 1246	UL	-	Brazil
IAC 165	1980	Dourado Precoce/IAC 1246	UL	-	Brazil
IRAT 112	1982	IRAT 13/Dourado Precoce	UL	117	Brazil
IREM 16-B	1982	PJ110/IAC 25	UL	116	Brazil
BR 4	1983	IAC 5544/Dourado Precoce	UL	70	Brazil
IAPAR 9	1983	Batatais/IAC F3-7	UL	-	Brazil
Emcapa 01	1984	IAC 5544/Dourado Precoe	UL	80	Brazil
Cuiabana	1986	IAC 47/SR2041-50-1	UL	90	Brazil
Araguaia	1986	IAC 47/TOS 2578-7-4-2-3-B2	UL	98	Brazil
Rio Paranaíba	1986	IAC 47/63-83	UL	100	Brazil
Cabaçu	1987	Mutant of 63-83	UL	102	Brazil
Guarani	1987	IAC 25/63-83	UL	80	Brazil
Centro América	1987	IAC 25/63-83	UL	70	Brazil
Tangará	1988	IAC 25/IRAT 13	UL	70	Brazil
Guaporé	1988	IAC 47/IRAT 13	UL	85	Brazil
Mearim	1989	Mutant of OS6	UL	75	Brazil
Douradão	1989	IAC 25/63-83	UL	80	Brazil
Xingu	1989	IAC 47/IRAT 13	UL	85	Brazil
Rio Doce	1991	Batatais/IAC F3-7	UL	-	Brazil
Triunfo	1991	IAC 47/IRAT 13	UL	-	Brazil
Rio Verde	1992	M 312A/Colombia 1	UL	90	Brazil
Rio Paraguai	1992	IAC 47/63-83	UL	87	Brazil
IAC 201	1992	IAC 165/Labelle	UL	85	Brazil
IAPAR 62	1993	Native	UL	65	Brazil
IAPAR 63	1993	IAC 1246/IR665-4-1-1	UL	105	Brazil
IAPAR 64	1993	IAC 47/L71-5-3-2	UL	105	Brazil
Progresso	1993	(Colômbia 1xM312A)/IRAT 124//RHS 107-2-1-2TB-1JM	UL	105	Brazil
Acrefino	1993	Rustic/Tapuripa	UL	95	Brazil
Maravilha	1993	TOx1010-49-1/IRAT 121//IRAT 216	UL	132	Brazil
Caiapó	1994	IRAT 13/Beira Campo//CNAx104/Perola	UL	93	Brazil
Carajás	1994	IREM 293/IAC 81-176	UL	84	Brazil
Progresso	1994	P 5607/RHS 107-2-1-2TB-1JM	UL	-	Brazil
Uruçui	1994	IAC 165//IAC 165/PI-9	UL	70	Brazil
Canastra	1996	Tox 939-107-2-101-1B/(Colômbia 1xM312A)//Tox 17806-5-1-2-B	UL	100	Brazil
Confiança	1996	IAC 164/Rio Verde	UL	105	Brazil
Primavera	1997	IRAT10/LS 85-158	UL	75	Brazil

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
IAC 202	1997	-	UL	-	Brazil
Carisma	1999	CT7244-9-1-5-3/CT6196-33-11-1-3//CT6946-2-5-3-3-2-M	UL	94	Brazil
BRS Bonança	2001	CT7244-9-2-1-52-1/CT7232-5-3-7-2-1P//CT6196-33-11-1-3-AP	UL	-	Brazil
Aimoré	2001	IAC 164/Rio Verde	UL	75	Brazil
EEA-404	-	Zenith/Maravilha	IR	-	Brazil
EEA-406	-	Zenith/Maravilha	IR	-	Brazil
IAC 435	-	IAC 1/IAC 3	IR	-	Brazil
IAC 120	1965	Iguape Agulha/Nira	IR	-	Brazil
IR 22	1970	IR 8/Tadukan	IR	-	Brazil
Cica 7	1971	IR22//IR930/Colombia 1	IR	102	Brazil
IRGA 407	1971	-	IR	-	Brazil
Cica 8	1972	Cica 4//IR665-23-3-1/Tetep	IR	111	Brazil
IR841	1974	IR262-43-8-11/Khao Dawk Mali 10	IR	-	Brazil
BR-IRGA 408	1975	IR8/IR12-178-2-3	IR	-	Brazil
IR665	1976	IR 8//Peta*5/Belle Patna	IR	95	Brazil
BR-IRGA 409	1978	IR930-2/IR665-31-2-4	IR	-	Brazil
BR-IRGA 410	1978	IR930-53/IR665-31-2-4	IR	-	Brazil
BR 1	1978	Belle Patna/Dawn	IR	-	Brazil
BR 2	1978	ÌR9595-31-4/Leb Mue Nang	IR	-	Brazil
Empasc 100	1980	IAC 435/Taichung 24	IR	-	Brazil
Empasc 101	1980	IR930-80/IR532-E-208	IR	-	Brazil
Empasc 102	1980	IR930-53/IR579-160	IR	-	Brazil
IAC 1278	1982	P 1217/P 1236	IR	-	Brazil
IAC 4440	1982	Cica 4//IR665-23-3-1/Tetep	IR	-	Brazil
Pesagro 101	1983	IR3265-193-3/IR2061-213-2-1-6	IR	135	Brazil
Pesagro 102	1983	IR2058-78-1-3-2-3	IR	110	Brazil
Pesagro 103	1983	NSW/IR648	IR	130	Brazil
Empasc 103	1983	IR930-53/IR579-160	IR	-	Brazil
BR-Caeté	1984	Selection of Pisari	IR	100	Brazil
Empasc 104	1985	IR262-43-8-11/Khao Dawk Mali 10	IR	-	Brazil
MG1	1985	P1217/P1232	IR	105	Brazil
MG2	1985	BG66/IR26	IR	105	Brazil
BR-IRGA 411	1985	Dawn/IRGA 407	IR	135	Brazil
BR 3 Caeté	1985	Pisari Selection	IR	-	Brazil
Metica 1	1986	P738/P881//P738/P 868	IR	100	Brazil
Pesagro 104	1986	IR 22//IR930-147-13/Colombia 1	IR	-	Brazil
Pesagro 105	1986	IR 22/Pazudofuzu	IR	-	Brazil
EPEAL -101	1986	IR665-33-5-B/Tetep	IR	105	Brazil
EPEAL -102	1986	P1219/P1249	IR	105	Brazil
Ajuricaba	1986	BG90-2//4440/Colombia 1	IR	120	Brazil

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
BR-IRGA 412	1986	Selection in BR-IRGA 409	IR	105	Brazil
BR-IRGA 413	1986	IR930-2/IR665-31-2-4	IR	125	Brazil
Empasc 105	1986	Bin-Tang-Chieh/IR661-1-140-3-54	IR	-	Brazil
BR-IRGA 414	1987	IR930/IR665-31-7-4	IR	115	Brazil
Curumin	1987	BN 1/CR 115	IR	-	Brazil
IAC 238	1988	5685//3250/IRAT 8	IR	135	Brazil
IAC 242	1988	5685//3250/IRAT 8	IR	135	Brazil
Franciscano	1988	Cica 7//4440/Pelita 1/1	IR	140	Brazil
Pericumã	1989	Cica 4//4440/Cica 7	IR	-	Brazil
BR-IRGA 415	1989	Cica 9/BR-IRGA 409	IR	120	Brazil
BR/MS –1	1989	BR-IRGA 409/Cica 9	IR	65	Brazil
BR/MS-2	1989	Kaghsung sem 12/IR22	IR	90	Brazil
Aliança	1990	4440//BG90-2/Tetep	IR	115	Brazil
IRGA 416	1990	IR841-67-1/BR-IRGA 409	IR	-	Brazil
BR-IPA	1990	-	IR	-	Brazil
IAC 100	1991	5738/3224//Costa Rica	IR	115	Brazil
IAC 101	1991	5738/3224//Costa Rica	IR	115	Brazil
Embrapa 6-Chui	1991	Selection in BR-IRGA 410	IR	110	Brazil
Embrapa 7-Taim	1991	Unknown	IR	130	Brazil
Epagri 106	1992	P3085/IR5853-118-5//IR1943-25-2-2-3-1	IR	75	Brazil
Javaé	1993	P3085//IR5853-118-5/IR19743-25-2-2-3-1	IR	80	Brazil
El Paso 144	1993	IR930-2/IR665-31-2-4	IR	-	Brazil
IAPAR 58	1993	IR579-160-2/P849	IR	110	Brazil
Diamante	1993	Sigadis 2/Taichung Native 1//IR24	IR	90	Brazil
BR-IPA 101	1994	Naylamp//IR840/Tetep	IR	-	Brazil
Capivari	1994	5006//H5/Ceysvoni	IR	132	Brazil
Epagri 107	1994	Cica 4//BG90-2/Cica 7	IR	95	Brazil
Pesagro 106	1994	P1221/P1224	IR	110	Brazil
Pesagro 107	1994	5738//3224/Costa Rica	IR	110	Brazil
Sapucaí	1994	P 901-22-7-2-3-2-1B/P 918-19-9-3-1-3-1B//P 918-25-1-4-2-3-1B/P 882-12-6-1-5-3-1-1-1B	IR	130	Brazil
Urucuia	1994	Nanicão/Cica 8//MG1	IR	123	Brazil
IRGA 417	1995	New Rex/IR19743-25-2-2//BR-IRGA 409	IR	-	Brazil
Epagri 108	1995	17719/5738//IR21015-72-3-3-3-1	IR	105	Brazil
Embrapa 38	1995	Selection in BR-IRGA 410	IR	70	Brazil
Embrapa 39	1995	CL Seleção 62a/CL Seleção 49-2	IR	125	Brazil
Samburá	1995	Nanicão/BG90-2//MG1	IR	135	Brazil
Mucuri	1995	Nanicão/Cica 8//MG1	IR	130	Brazil
Emcapa 104	1996	LI84215/LI82227	IR	105	Brazil
São Francisco	1996	5732//3234/Costa Rica	IR	100	Brazil

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Diamante	1996	Sigadis 2/Taichung Native 1//IR24	IR	100	Brazil
Rio Formoso	1997	17719/5738//IR21015-72-3-3-3-1	IR	95	Brazil
Jequitibá	1997	Cica 9/BR-IRGA 409	IR	90	Brazil
Embrapa 130	1997	-	IR	-	Brazil
Rio Grande	1999	18467//2940/5730	IR	110	Brazil
Formoso	2000	-	IR	95	Brazil
Epagri 109	-	CT7347/IR21015-72-3-3-3-1	IR	105	Brazil
SCS-111	2000	P2867F4-31-5/P4383F3-75	IR	90	Brazil
SCS-112	2000	Empasc 101/Cica 8	IR	105	Brazil
BRS Pelota	2001	BR-IRGA 410	IR	95	Brazil
BRS Biguá	2001	Bluebelle/Pisari	IR	95	Brazil
BRS Jaburu	2001	PDR/P 3790//P 5746	IR	95	Brazil
Palmar INTA	-	Itape F.A./Bluebonnet 50	IR	-	Argentina
San Miguel INTA	-	Selection within Bluebelle	IR	-	Argentina
Jojutla	1956	-	IR	-	Mexico
Apikalo	1959	SML 80-5/SML 81A	IR	-	Suriname
Tapuripa	1959	SML 80-5/SML 81A	IR	-	Suriname
Alupi	1960	SML 77A/Dima	IR	-	Suriname
Nilo 1	1962	77-5-3-4//Bluebonnet 50/Mars	IR	-	El Salvador
Nilo 2	1962	SML 80-5/SML 81A	IR	-	El Salvador
Nilo 10	1962	SML 77A/Dima	IR	-	El Salvador
Napal	1963	Bluebonnet 50/Palmira 105	IR	-	Colombia
Matapi	1963	Lacrosse/Nickerie//Magali	IR	-	Suriname
Apura	1964	Apikalo/Venezuela 503	IR	-	Suriname
Oro	1964	-	IR	58	Chile
Fuerte A64	1964	Bluebonnet 50/Gulfrose//Bluebonnet 50	IR	-	Mexico
Guasave A64	1964	Bluebonnet 50/Gulfrose//Bluebonnet 50	IR	-	Mexico
Mochis A64	1964	Rexoro/Purple Leaf Sel "G"	IR	-	Mexico
Sinaloa A64	1964	Edith/Fortuna	IR	-	Mexico
Colombia 1	1965	Napal/Takao Iku 18	IR	98	Colombia
Peru 65	1965	-	IR	-	Peru
Temerin	1965	Lacrosse/Magali//Magali	IR	-	Suriname
Corerepe	1966	Rexoro/Purple Leaf //Bluebonnet 50	IR	-	Mexico
ICA 10	1967	BG79/B 572[A]1-6-5-3P//B 572A1-6-5-3P	IR	90	Colombia
Bachoco A67	1967	Bluebonnet 50*2/Jojutla Mejorada	IR	-	Mexico
Kapuri	1967	Lacrosse/Nickerie//Magali	IR	-	Suriname
Rios A67	1967	Zacatepec/Bluebonnet 50	IR	-	Mexico
Milagro Filipino	1968	Peta/Dee-Geo-Woo-Gen	IR	-	Mexico
Sinaloa A68	1968	Nahng Mon S4/Taichung Native 1	IR	-	Mexico

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Venus A68	1968	Delrex C.I. 83-20/CP231//Bluebonnet 50	IR	110	Mexico
Morelos A70	1970	-	IR	-	Mexico
Zapata A70	1970	-	IR	-	Mexico
Acorni	1971	Bluebelle/Magali//Magali	IR	-	Suriname
Apani	1971	Bluebelle/Magali*3	IR	-	Suriname
Awini	1971	Taichung Native/Apura*3	IR	-	Suriname
Cica 4	1971	IR 8/IR12-178-2-3	IR	-	Colombia
INIAP 2	1971	IR 8/Tadukan	IR	-	Ecuador
Grijalva A71	1971	Bluebonnet 50/Gulfrose//Bluebonnet 50*3	IR	-	Mexico
Nayar C71	1971	Nahng Mon S4/Taichung Native 1	IR	-	Mexico
Navolato A71	1971	IR 8/Tadukan	IR	98	Mexico
Naylamp	1971	IR 8/IR12-178-2-3	IR	-	Peru
Boewani	1972	Bluebelle/Alupi//77-5-3-4	IR	-	Suriname
Chancay	1972	IR 8/IR12-178-2-3	IR	92	Peru
Huallaga	1972	IR95-31-4/Leb Mue Nang 111	IR	-	Peru
INIAP 6	1972	IR 8/IR12-178-2-3	IR	100	Ecuador
Juma 57	1972	Nilo 1/IR 8	IR	110	D. Republic
Juma 58	1972	Toño Brea 91/IR 8	IR	115	D. Republic
Pisari	1972	-	IR	-	Suriname
San Lorenzo A72	1972	IR 8*2//CP-SLO*2/Nahng Mon S4	IR	-	Mexico
Sinaloa A72	1972	IR262-43-8-11*2/Khao Dawk Mali 105	IR	-	Mexico
Camponi	1974	SML 1010/Apura//IR 8	IR	100	Mexico
Ceysvoni	1974	SML 997/Awini	IR	88	Suriname
Cica 6	1974	IR930-2/IR822-432	IR	90	Colombia
Ciwini	1974	Boewani/Washabo	IR	95	Suriname
CR1113	1974	IR 8//Pankari 203/IR 8	IR	110	Costa Rica
Inti	1974	IR 8//Fortuna/Minagra	IR	102	Peru
Joachin A74	1974	Corerepe A66*3/TN1//IR160-27-4	IR	-	Mexico
Juchitan A74	1974	B 572-A3-47-15/B 589-A4-18-1	IR	100	Mexico
Piedras Negras	1974	IR262-43-8-11/Niiaw San Pahtawang	IR	-	Mexico
Bamoa A75	1975	IR262-43-8-11/Niiaw San Pahtawang	IR	98	Mexico
Diamante	1975	Agostano/P6///Blue Rose/RB2//Balila	IR	60	Chile
Macuspana A75	1975	Venus A68//Peta/Tangkai Rotan	IR	-	Mexico
Ñiquen	1975	Rexoro Red/Bozu//Oro	IR	-	Chile
Quella	1975	Rexoro Red 119-1-1/Bozu//Oro	IR	60	Chile
Cica 7	1976	IR 22//IR930-147-8/Colombia 1	IR	95	Colombia
Cica 9	1976	IR665-23-3-1/P 894	IR	92	Colombia
CR5272	1976	IR930-80/IR822-432	IR	100	Costa Rica

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Diwani	1976	Washabo/IR454-1-17-1-1	IR	90	Suriname
INIAP 7	1976	Cica 4//IR665-23-3/Tetep	IR	100	Ecuador
Anayansi	1977	IR 8/Nilo 1	IR	-	Panama
Rustic	1977	(Precoz de Machiques-37)/(ZenithxD85-42)//Century Patna 231/SLO-17	IR	100	Guyana
Tikal 2	1977	IR930-2/IR822-43	IR	90	Guatemala
Araure 1	1978	IR930-147-13/Colombia 1	IR	102	Venezuela
Cica 8	1978	Cica 4//IR665/Tetep	IR	105	Colombia
Damaris	1978	IR 8/Nilo 1	IR	-	Panama
IR1529	1978	IR305-3-17-1-3/IR 24	IR	-	Cuba
Eloni	1979	Acorni//kapuri/IR454	IR	100	Suriname
INIAP 415	1979	P 738-137-4-1/P 723-6-3-1	IR	105	Ecuador
Campeche A80	1980	Grijalva A71*3/Tetep	UL	115	Mexico
Champoton A80	1980	Grijalva A71*3/Carreño	UL	-	Mexico
CR-201	1980	IR 22//IR930-147-8/Colombia 1	IR	102	Costa Rica
Huastecas A80	1980	Sinaloa A68/Sinaloa A64	IR	-	Mexico
ICTA-Virginia	1980	Cica 4//IR665-23-3/Tetep	IR	105	Guatemala
Juma 51	1980	Toño Brea 91/IR 8	IR	110	D. Republic
Metica 1	1980	P 996/P 1000	IR	95	Colombia
Metica 2	1980	P 738-137-3-1/P 997	IR	-	Colombia
Sinaloa A80	1980	Sinaloa A68/Bluebonet 50	IR	105	Mexico
Tanioka	1980	Toño Brea 91/IR 8	IR	100	D. Republic
Cardenas A80	1981	C 4-63//Gow Ruang 88/Sigadis	IR	105	Mexico
ICTA-Tempisque	1981	P 761-40-2-1/P 881-19-14-10	IR	105	Guatemala
J-104	1981	IR430-5-9-2/IR930-16-1	IR	110	Cuba
Araure 2	1982	P 1221/P 1230	IR	112	Venezuela
Centa A-2	1982	P 761-40-2-1/P 881-19-14-10	IR	106	El Salvador
Culiacan A82	1982	Rexoro/Colusa	IR	-	Mexico
Hurangopampa	1982	-	IR	-	Peru
Oryzica 1	1982	P 1223/P 1225	IR	100	Colombia
Tallan	1982	Naylamp/Tetep//Naylamp	IR	-	Peru
Tucumen 5430	1982	-	IR	100	Panama
Viflor	1982	Naylamp/Tetep//Naylamp	IR	-	Peru
Morelos A83	1983	Jojutla mejorada/Naylamp	IR	117	Mexico
Araure 3	1984	IR 8//Peta*5/Belle Patna	IR	90	Venezuela
Araure 4	1984	Cica 7//Cica 8/Remadja	IR	102	Venezuela
Chiapas A84	1984	Y 3/R 2-111-1//M.L.E.	IR	97	Mexico
Yojoa 44	1984	Cica 4//IR665-23-3-1/Tetep	IR	-	Honduras
Oryzica 2	1984	BG90-2//Cica 8/Cica 7	IR	103	Colombia
PA 2	1984	Cica 4//Cica 8/Cica 7	IR	110	Peru
PA 3	1984	IR1702-74/IR1721-11//IR2055-481	IR	115	Peru
Amistad 82	1985	IR1529 ECIA/VNI IR3223	IR	88	Cuba
CR1821	1985	IR 22//IR930-147-8/Colombia 1	IR	110	Costa Rica
ICTA-Poloquic	1985	P 1223/P 1225	IR	98	Guatemala
Altamira 7	1986	Cica 4//Cica 8/Cica 7	IR	110	Nicaragua
Iniap 10	1986	Cica 4//Cica 9/Cica 7	IR	100	Ecuador

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Porvenir 86	1986	Cica 7//S 12-30/Cica 8	IR	-	Peru
San Martin 86	1986	Inti/P 792-2-2	IR	110	Peru
Juma 62	1986	IR1541-102-6-3//IR 20*4/*Oryza nivara*	IR	100	D. Republic
Amazonas	1987	IR1721-14-6-4-3/Inti	IR	115	Peru
Apatzigan A87	1987	Cica 7//Cica 8/Pelita I-1	IR	-	Mexico
Centa A-4	1987	P 1223/P 1225	IR	105	El Salvador
Chetumal A86	1987	Navolato A71/Carreon//Grijalva A71/Tetep	IR	105	Mexico
Cuyamel 3820	1987	Cica 7//IR5533-13-1-1/Costa Rica	IR	-	Honduras
Guayquiraro P.A.	1987	IR224-54/H 99-20	IR	-	Argentina
Juma 61	1987	J 212/Cica 9	IR	100	D. Republic
Oryzica 3	1987	Cica 7//Cica 8/Pelita I-1	IR	105	Colombia
Palizada A86	1987	Navolato A71*3/Tetep	IR	110	Mexico
Panama 1048	1987	P 1221/P 1229	IR	105	Panama
Panama 1537	1987	Cica 7//S 12-30/P 901-22-11-5-3-2-1B	IR	105	Panama
Saavedra	1987	Nam Sagui 19/IR2071-88//IR2061-214-3-6-20	IR	105	Bolivia
San Pedro	1987	P 1220/P 1254	IR	-	Bolivia
Villaguay P.A.	1987	H 122F2/H 136F2	IR	80	Argentina
Alto Mayo 88	1988	P 2030-F4-2-17-4//P 3980	IR	117	Peru
Anabel	1988	BG90-2/Anayansi	IR	-	Panama
Cimarron	1988	Hebi G11330//Chianung Sen Yu 7/IR1561	IR	105	Venezuela
El Paso L-48	1988	Starbonnet/Bluebelle	IR	-	Uruguay
El Paso L-94	1988	Lebonnet/Bluebelle	IR	80	Uruguay
El Paso L-227	1988	C.I. 9902/Labelle	IR	-	Uruguay
Huimanguillo A-88	1988	P738-137-3-1/P 881-19-14-10//P 738-137-3-1/P 868B-24-5	IR	95	Mexico
ICTA-Montagua	1988	Oryzica 1//63-83/Camponi	IR	95	Guatemala
ICTA-Quirigua	1988	Cica 7//Cica 8/Pelita I-1	IR	105	Guatemala
Morelos A-88	1988	Iguala A-70/Tetep//Jojutla Mejorada/Iguala A-70	IR	-	Mexico
CEA 1	1989	BU1/CR115	IR	102	Paraguay
CEA 2	1989	P 1221/P 1260	IR	102	Paraguay
CEA 3	1989	IR 8/Sigadis	IR	102	Paraguay
Centa A-5	1989	P 1274-6-8M-1-3M-1/P 3118	IR	100	El Salvador
Iniap 11	1989	IR5657-33-2-1/IR2061-465-1-5-5	IR	94	Ecuador
Oryzica Llanos 4	1989	P 4568/P 5003	IR	95	Colombia
Oryzica Llanos 5	1989	P 5269/P 2060-F4-2-5-2	IR	100	Colombia
Palmar	1989	Cica 7//Cica 8/Pelita I-1	IR	100	Venezuela
Cardi 70	1990	P 3990/Metica 1	IR	100	Belize
Cotaxtla A90	1990	CR126-42-5/IR2061-213	IR	105	Mexico
Ferrini	1990	SML 77041-1/SML 77036-31//SML 7802-5	IR	-	Suriname

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Guaymas 90	1990	P 2053-F4-26-4-6/P 3990	IR	-	Guyana
ICTA-Crispo 38	1990	IR 24*2/IR747B2-6-3	IR	90	Guatemala
IIAC 14	1990	CP1C8/ECIA 22-8-163	IR	-	Cuba
IIAC 15	1990	CP3C2/ECIA 13-31-1//CP1C8/CE 4-10-1	IR	105	Cuba
Juma 63	1990	J 212/Mingolo	IR	110	D. Republic
Juma 64	1990	Oryzica 1/P 3567	IR	110	D. Republic
Perla	1990	-	IR	90	Cuba
Sureste A90	1990	IR9538/IR9575	IR	100	Mexico
Altamira 9	1991	Oryzica 1/P 3567	IR	115	Nicaragua
Altamira 10	1991	P 2053-F4-26-4-6//P 3990	IR	-	Nicaragua
Buli-INIA	1991	Lemont/Quilla 66304//Diamante	IR	65	Chile
Comedero A91	1991	Sinaloa A80/ITA 231//Navolato A71	IR	-	Mexico
Guyana 91	1991	IR21841-81-3-3-2/Ceysvoni//IR21848-65-3-2	IR	-	Guyana
Jalapa 1	1991	Cica 7//Cica 8/Pelita I-1	IR	-	Nicaragua
Loma Bonita A91	1991	Cica 8//BG90-2/Cica 4	IR	108	Mexico
Oryzica Sabana 6	1991	CT6491/IAC 47	UL	-	Colombia
Costa Norte	1992	Inti/IR8460-120-2-2	IR	100	Peru
CR8341	1992	Cica 7/P 1908	IR	-	Costa Rica
Humaya A-92	1992	Sinaloa A80/ITA 231//IR 8	IR	95	Mexico
Oryzica Turipana 7	1992	P 4971/P 5004	UL	103	Colombia
Perla Indus	1992	-	IR	65	Chile
Sican	1992	Inti/PNA 386-F4-341-1	IR	100	Peru
Capi 93	1993	P 5560/P 2057-F4-88-3-1	IR	-	Honduras
Fonaiap 1	1993	P 1386-6-8M-1-3M-1/P 3767	IR	105	Venezuela
Fonaiap 2	1993	P 5269/P 2060-F4-2-52	IR	110	Venezuela
INIA Tacuari	1993	Nwbt/Nrx L9	IR	83	Uruguay
INIA Yerbal	1993	L 58/Bluebelle	IR	83	Uruguay
Oryzica Caribe 8	1993	P 1274-6-8M-1-3M-1/P 4205	IR	105	Colombia
Panama 3621	1993	Metica 1//Suakoko 8/Ceysvoni	IR	110	Panama
Panama 4721	1993	BG90-2/Anayansi//Cica 7	IR	110	Panama
Sacia-1 (Tacu)	1993	TOx 1010-45-1/Col 1 x M312A-74-2-8-8	IR	92	Bolivia
Sacia-2 (Tari)	1993	IR1529-430/VNI IR3223	IR	95	Bolivia
CEA 4 – Punta	1994	Jayant/IET 3144	IR	-	Paraguay
CR-751	1994	P 5555/P 4179	IR	-	Costa Rica
INIAP 12	1994	CT7347/IR21015-72-3-3-3-1	IR	96	Ecuador
Oryza Yacu 9	1994	CT8774/CT5746-18-11-2-2-2X	IR	110	Colombia
Sacia-3 (Tutuma)	1994	P 5607/RHS 107-2-1-2TB-1JM	IR	95	Bolivia
Sacia-4 (Jisunu)	1994	Ngovie/IRAT 124//Col 1 x M312A	IR	100	Bolivia
Selecta 3-20	1994	Sinaloa A80/ITA 231//IR8/ECIA 50 GF4-S3///Linea 2/ECIA 323F3-12-S1	IR	110	Colombia
Tolima	1994	P 5269/P 2060-F4-2-5-2	IR	-	Guyana

Variety	Year of release	Parents	CS[a]	Flowering (*days*)	Country
Altamira 11	1995	J 104//J 104/Cica 8	IR	-	Nicaragua
Altamira 12	1995	CE4-10-1/Colombia 1	IR	-	Nicaragua
Capirona	1995	Tox 1766-4-B-201-1B/P 1274-6-8M-1-3M-1//P 3084-F4-56-2-2	IR	-	Peru
Centa A-6	1995	CT7347/IR21015-72-3-3-3-1	IR	-	El Salvador
Huallaga-INIA	1995	CT7347/IR21015-72-3-3-3-1	IR	130	Peru
IA Cuba 20	1995	ICA 10/ECIA 31-104-2-1-4	IR	-	Cuba
IA Cuba 21	1995	-	IR	-	Cuba
IA Cuba 23	1995	Mutant of J-104	IR	-	Cuba
IA Cuba 25	1995	Somaclones of Amistad 82	IR	-	Cuba
ICTA-Pazos	1995	CT7347/IR21015-72-3-3-3-1	IR	-	Guatemala
INIA Caraguata	1995	L38//L75 Beamount/Texas 23	IR	-	Uruguay
Oryzica Sabana 10	1995	P 5607/RHS 107-2-1-2TB-1JM	UL	-	Colombia
Porvenir-95 INIA	1995	P 5269/P 2060-F4-2-5-2	IR	110	Peru
Selva Alta	1995	CT7347/IR21015-72-3-3-3-1	IR	110	Peru
Uqui Hua	1995	P 5268/Campeche A80	IR	-	Peru
ICTA-Colomgua	1996	P 4278-F2-80-4-1X/TOx 1768-1-2-1//P 3059-F4-79-1-1B	IR	-	Guatemala
ICTA-Izabal	1996	CT10730/CT6947	IR	-	Guatemala
IDIAP T4-70	1996	BG90-2/Anayansi//Cica 7	IR	-	Panama
Sacia-5 (Urupe)	1996	IR46/IRAT 120//P 1274-6-8M-1-3M-1	IR	-	Bolivia
Anar 97	1997	PDR 34-2-1-2/P 3790-F4-6-1-1X//CT5746-18-11-2-2-2X	IR	-	Nicaragua
Coprosem-1	1997	P3059-F4-11M-2P-1B/IR21015-72-3-3-3-1//P 5413-8-3-5-11-2X	IR	-	Colombia
BR 444	1998	IR43//P 2887-F4-9-4/IR21015-72-3-3-3-1	IR	-	Guyana
Fedearroz 50	1998	Oryzica Llanos 4/P 1274-6-8M-1-3M-1	IR	-	Colombia
Jasaye	1998	IRAT 13/Palawan 37-1	UL	95	Bolivia
Universidad 3189	1998	P 3050-F4-52/Oryzica 1//IR21015-72-3-3-3-1	IR	-	Panama
D-Primera	2001	-	IR	115	Venezuela
Fedearroz 2000	2000	P 3084-F4-56-2-2/P 3844-F3-19-1-1B-1X//CT8154-1-9-2	IR	-	Colombia
Fonaiap 2000	2000	P 5446-6-3-2/CT5690-3-19-2//P 3059-F4-79-1-1B	IR	75	Venezuela
Fundarroz PN 1	2000	P 3084-F4-56-2-2/ITA 306//CT8154-1-9-2	IR	-	Venezuela
Fundarroz PN 1	2000	P 3084-F4-56-2-2/ITA 306//CT8154-1-9-2	IR	-	Venezuela
INIAP 14	2000	-	IR	-	Ecuador
Zeta 15	2000	CT7347/IR21015-72-3-3-3-1	IR	-	Venezuela

[a] CS = cropping system (UL = upland; IR = irrigated).

APPENDIX 2

Statewise list of varieties released in India, 1970-2000

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
CVRC					
Aditya	M 63-83/Cauvery	1989	70	RUP	LB
Ajaya	IET 4141/CR 98-7216	1992	105	IRM	LB
Akashi	IR 8/N 22	1975	80	IRE	SB
Amulya	Pure line selection Najani	1988	140	SDW	LS
Anamica	MNP 36/CR 12	1980	115	RSL	LB
Cauvery	TN(I)/TKM 6	1970	84	IRE	SB
CR 1002	CR 70-80-2/PANKAJ	1992	115	RSL	SB
CSR 10	M40-431-24-114/Jaya	1989	95	IRSA	SB
CSR 13	CSRI/Basmati 370//CSR 5	1999	95	IRSA	LS
CSR 27	Nona Bokra/IR 5657-33-2	1999	110	IRSA	LB
CST 7-1	Damodar/IR 24	1991	115	IRSA	LB
Dharitri	Pankaj/Jagannath	1988	120	RSL	SB
Govind	IR 20/IR 24	1989	75	RUP	LS
Haryana Basmati	Sona/Basmati 370	1991	110	IRM	LS
Heera	CR 404-48/CR 289-1208	1991	45	RUP	LB
IR 20	IR 262-24-3/TKM 6	1970	105	IRM	MS
IR 36	IR1561-228-1-2/IR1737//CR 94-13	1981	84	IRE	LS
IR 64	IR 5657-33-2-1/IR 2061-465-1-5-5	1992	84	IRE	LS
IR 8	Peta/Dee-Geo-Woo-Gen	1966	105	IRM	LB
Jawahar Rice 3-45	IR 36/Lohandi	1997	70	RUP	LB
Jaya	TN1/T141	1968	100	IRM	LB
Jitendra	Selection from landraces	1994	135	DW	LS
Kasturi	Basmati 370/CRR 88-17-1-5	1989	100	SCR	LS
Lunishree	NONASAL MUTANT	1992	115	IRSA	LS
Mahamaya	Asha/Kranti	1995	100	IRM	LB
Manasarovar	RP 31-49-2/Leb Muey Nahng	1983	120	RSL	SB
Nalini	Pure line selection Sindhur Mukhi	1989	140	SDW	MB
Narendra 97	N 22/Ratna	1992	70	RUP	LS
Narendradhan 359	BG 90-2-4/OBS 677	1993	100	IRM	SB
Nidhi	Sona/IET 14529	1996	84	IRE	LS
PA 103 (6201)	6CO2/6MO1	2000	100	IRM	SB
Pankaj (IR 5-114-3-1)	Peta/Tongkai Rotan	1969	115	RSL	LB
PNR 381	T 33 Mutant/Basmati 370	1992	65	RUP	LS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Pooja	Vijaya/T 141	1999	115	RSL	MS
Pranava	Vikram/Benong 111	1988	120	RSL	LB
Purnendu	Patnai 23/Jaladhi 2	1994	160	SDW	LS
Pusa 169	IR 28/Pusa 140-56	1986	84	IRE	LS
Pusa 2-21	IR 8262/TKM 6	1970	95	IRM	MS
Pusa 44-33	IARI 5901-2/IR 8	1993	87	IRME	LS
Pusa 677-5-103-2-9	TKM -9/P.312	1997	84	IRE	LB
Pusa 834	IR 50/PP 33 BP	1995	84	IRE	LB
Pusa Basmati	Pusa 150/Karnal Local	1989	105	SCR	LS
Pusa205	IR 28/Pusa 33-18	1986	84	IRE	LS
Rasi	TN1/Co.29	1977	84	IRE	MS
Ratna	TKM 6/IR 8	1970	84	IRE	LS
Salivanana	RP 5-32/PANKAJ	1988	128	RSL	SB
Sasyasree	TKM 6/IR 8	1979	95	IRM	LS
Sattari	NSJ 200/Padma mutant	1983	40	RUP	SB
Savithri	Pankaj/Jagannath	1983	120	RSL	SB
Shaktiman	CR 94-1512-6/Pusa 2-21	1990	84	IRE	SB
Suraksha	Sasyasree/CR 57-MR 1523	1988	103	IRM	LB
Swarnadhan	RPW 6-13Sona	1979	125	RSL	SB
Triguna	Swarnadhan/RP 1579-37	1997	98	IRM	LS
Tulasi	Rasi/Fine Gora	1988	70	RUP	LS
Vikas	TKM 6/IR 8	1983	84	IRE	MS
Vivekdhan 62	China 4/BG367-4	2000	90	HRIR	SB
VL Dhan 221	IR 2053-521-1-1-1/CH 1039	1991	85	HRUR	MS
VL Dhan 61	Jaya/Tapoo-cho-Z	1998	100	HRIR	LB
VL Dhan 81	CH 988/HPU 741	1999	100	HRIR	LB
Andhra Pradesh					
Abhaya	CR 157-392/OR 57-21	1989	84	IRE	MS
APHR 2	IR 62829 A/MTU 9992 (R)	1994	95	IRM	LS
APHR-1	IR 58025 A/Vatram (R)	1994	95	IRM	LS
Badava Mahsuri	Mahsuri/Vijaya	1982	135	SDW	MS
Bhadrakali	Phalguna/IR 36	1994	105	IRM	LS
Bharani	IR 36/IET 2508	1997	125	IRM	MS
Chaitanya	Soubhagya/ARC 5984	1988	120	RSL	MS
Chandana	Sona/Manoharsali	1989	120	RSL	LS
Cottondora Sannalu	Krishnaveni/IR 64	2000	120	IRM	LS
Deepti	Sowbhagya/ARC 6650	2000	120	IRM	MS
Dhanya Lakshmi	Sabarmati/W 12708	1982	84	IRE	LS
Divya	WGL 23022/Surekha	1989	105	IRM	MS
DRR H1	IR 58025/IR 40750 R	1997	100	IRM	LS
Early Samba	Mutant of BPT 5204	2000	105	IRM	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Erramallelu	BC 5-55/W 12708	1991	84	IRE	LS
Gautami	IR 8/SL013	1976	120	RSL	LS
Gutti Akkullu (C3282)	T 945/MTU-1	1969	110	RSL	LB
Hari	IR 8/TR 5	1988	100	IRM	MS
Indursamba	BPT 5204/Surekha	1997	125	RSL	MS
Kakatiya	IR 8/W1263	1974	95	IRME	LS
Kavya	WGL 27120/WGL 7672//Mahsuri/Surekha	1991	100	IRM	LS
Kesava	WGL 28712/IR 36-1996	1997	125	RSL	LS
Kotha Bayyahunda (AKP7073)	BAM 3/IR 20	1982	130	RSL	MS
Kothamolago-lukulu	Bulk HG 9/Millek Kuening	1982	130	RSL	SB
Kothamolago-lukulu	Bulk H 9/Millek Kuening	1979	130	RSL	SB
Krishna Hamsa	Rasi/Fine Gora	1997	90	IRME	LS
Krishnaveni	Sowbhagya/ARC 5984	1989	120	RSL	MS
Lakshmi	Sabarmati/W 12708	1982	84	IRE	LS
Mahendra	BAM 3/TN (1)	1986	120	RSL	LS
Mahsuri	Mayang Ebos 80/2/Taichung 65	1972	120	RSL	MS
Maruteru Sannalu	Pureline sel. Oodasannalu	2000	75	RUP	LS
MTU 9993	Rasi/Fine Gora	1993	75	RUP	LS
Nagarjuna	Sona/Manoharsali	1988	120	RSL	LS
Nagavali (RGL 52)	RGL 1/IR 8	1982	130	RSL	MS
Nandi	Sowbhagya/ARC 6650	1991	120	RSL	MS
Narsing	TN1/CO29	1972	95	IRME	SB
Oragallu	OBS 677/IR 2070-423-2-5	1993	125	RSL	LS
Penna (NLR 33365)	NLR 9672/IR 36	1997	130	RSL	SB
Phalguna	IR 8/Siam 29	1977	115	RSL	LS
Pinakini	Bulk H 9/Millek Kuening	1987	130	RSL	MS
Pothana	IR 579/WGL 12708	1988	84	IRE	LS
Prabhat	IR 8/MTU 3	1976	102	IRM	LB
Prasanna	IRAT 8/N 22	1986	75	RUP	LS
Pratibha	Saubhagya/ARC 6650	1986	120	RSL	LS
Pushkala	IR 28/TellaHamsa	1986	75	IRE	LS
Rajavadlu	Rajendra/IR 30	1993	105	IRM	LS
Rajendra	IJ 52/TN 1	1976	75	RUP	MS
Ravi	M 63-83//RP 79-5/Rikotu Norin 21	1989	75	RUP	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Rudramma	HR 19/TN1	1991	75	RUP	LB
Sagarsamba	IR 8/Siam 29//IR 8/PTB 21	1993	120	RSL	MS
Saleem	GEB 24/Sigadis/IR 8/RNR 8102	1987	105	IRM	LS
Samba Mahsuri	GEB 24/TN1/Mahsuri	1986	120	RSL	MS
Satya	Tella Hamsa/Rasi	1987	80	IRE	LS
Seshu	T 141/IR 24	1985	84	IRE	LS
Simhapuri	RP 5-32/Bulk H9	1991	130	RSL	SB
Siva	Phalguna/IR 50	1997	130	RSL	LS
Somasila	Reselection from IR 50	2000	75	RUP	LS
Sona Mahsuri	Sona/Mahsuri	1982	115	RSL	MS
Sonasali	Sona/Manoharsali	1986	105	IRM	LS
Sowbhagya	Mahsuri/Vijaya	1982	130	RSL	MS
Sravani	Reselection from IR 50	1997	120	IRE	LS
Srikakulam Sannalu	CRT -145-CR 1014	1997	13	RSL	MS
Srinivas	IR 8/Latisail	1985	130	IRE	LS
Sriranga	RP 5-32/Mahsuri	1991	130	RSL	MS
Surekha	IR 8/Siam 29	1976	104	IRM	LS
Surya	Sona Mahsuri/ARC 6650	2000	130	RSL	LS
Swarna	Vasishtha/Mahsuri	1982	125	RSL	MS
Swarnamukhi	Cica/IR 625-23-3-1//Tetep	1991	100	IRM	LS
Swathi	Reselection from IR 50	1997	125	RSL	LS
Tellahamsa	HR 12/TN1	1971	84	IRE	MS
Tikkana	RP 31-49-2/BCP 2	1988	120	RSL	SB
Vajram	MTU 4569/ARC 6650	1986	120	RSL	LS
Vamshi	BAM 3/TN(1)	1986	105	IRM	LS
Varsha	IR 50/Mahsuri	1993	84	IRE	MS
Vasista	IR 8/SL013	1976	120	RSL	LS
Vasundhara	Phalguna/IET 6858	1997	130	RSL	LS
Vedagiri	NLR 9672-96/Iet7230	2000	120	RSL	MS
Vibhava	CR 4435/W 2708	1989	105	IRM	MS
Vijaya Mahsuri	Mahsuri/Vijaya	1982	115	RSL	MS
Vijetha	MTU 5249/MTU 7014	1995	110	IRM	MS
Vikramarya	RPW 6-13/PTB 2	1986	105	IRM	LB
Assam					
Bahadur	Pankaj/Mahsuri	1991	125	RSL	MS
Basundhara	IET 9711/IET 11161	1998	120	RSL	MS
Bhogali	Ghewbora/KMJ 1-52-2	1990	125	RSL	LS
Chilarai	IR 24/CR 44-118-1	1987	95	IRME	LS
Jayamati	Jaya/Mahsuri	1998	120	RSL	LB
Kapilee	Heera/Annada	1993	70	RUP	LB
Ketekijoha	Savithri/Bhashabhog	1998	120	RSL	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
KMJ 1-17-2	IR 8/Manoharsali	1978	110	RSL	MS
KMJ 1-19-1	IR 8/Manoharsali	1978	100	IRM	MS
Kushal	Pankaj/Mahsuri	1991	128	RSL	LB
Lachit	CRM 13-3241/Kalinga III	1987	95	IRME	LB
Lakshmi	RP 31/49-2/Patnai 23	1991	120	RSL	LS
Luit	Heera/Annada	1998	65	RUP	LB
Madhab	IR 8/CH 63	1977	100	IRM	SB
Maniram	Pankaj/Mahsuri	1991	125	RSL	MS
Latisail/Gauchari		1968	130	RSL	LS
Padmanth	Pankaj/Jaganath/Nagubha	1998	131	DW	LB
Pamindra	Pankaj/Naguba	1998	120	RSL	MB
Piolee	Pankaj/Mahsuri	1991	130	RSL	MS
Rangilee	Ghew Bora/KMJ 1-52-2	1990	130	RSL	LB
Ranjit	Pankaj/Mahsuri	1991	130	RSL	MS
Rongdoi	Prasadbhog/IR 8	1981	100	IRM	MS
Satyaranjan	IET 9711/IET 11162	1998	120	RSL	MS
Bihar					
Archana (no. 9156)	IR 8/Tadukan	1972	75	RUP	LS
Barahavarodhi	Madhukar/Sona	1995	145	SDW	LS
Birsadhan 103	Fine Gora/IET 2832	1992	75	RUP	LB
Birsadhan 104	Fine Gora/IET 2832	1992	60	RUP	LB
Birsadhan 105	Fine Gora/IET 2832	1995	60	RUP	SB
Birsadhan 106	Bala/Black Gora//OS 36/CH.1039	1995	75	RUP	SB
Birsadhan 107	Gora mutant/IAC 125	1995	90	IRME	SB
Birsadhan 201	TN 1/Brown Gora	1985	65	RUP	LB
Birsadhan 202	Jaya/BR 34	1985	75	RUP	LB
Birsadhan 202	Jaya/BR 39	1995	98	IRM	LB
Birsagora 102 (T)	Pure line sel. from Gora	1992	75	RUP	LB
Deepa (No. 9157)	IR 8/Tadukan	1972	75	RUP	LS
Gautam	Rasi mutant	1995	95	IRME	MS
Janaki (T)	Sel. from Chenab Rice	1983	135	SDW	LB
Jayashri	Jaya/Mahsuri	1981	120	RSL	MS
Kamini (SBR 80-643-14-1-1)	Pureline Katarni Rice	1991	105	IRM	MS
Kanak	Jaya/BR 34	1987	110	RSL	LS
Kanchan	IR 8/N 22	1976	70	RUP	SB
Kiran	TN1/N22//T90/IR 8	1976	90	IRME	SB
Mahsuri	Taichung 65/2 Mayang Ebos 80/2	1971	115	RSL	MS
Panidhan 2 (CR 260-30)	(Peta/TN1)/Lebmuey Nahng	1972	115	RSL	MS
Panidhan-1	(Peta/TN1)/Lebmuey Nahng	1972	110	RSL	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Prabhat (MTU 3626)	IR 2033-531-1/IR261-264-2//IR 36	1994	55	RUP	MS
Prahlad (CR44-35)	TKM 6/IR 8	1972	84	IRE	LS
Radha (BR 51-91-6)	IR 20/IR 5-114-3	1984	115	RSL	MS
Rajasree (T) (TCA 80-4)	Pure line selection	1987	115	RSL	MS
Rajendradhan 201 (IR 579-97-2-2)	IR 8/Tadukan	1978	105	IRM	MS
Rajendradhan 202	IR 8/W 1251	1978	95	IRM	LS
Shakuntala	Pankaj/BR 8	1995	120	RSL	LS
Sita (IR 930-67-2-2)	IR 12-178-2-3 IR 8	1972	105	IRM	LS
Sudha (T) (TCA 72)	Pure line selection	1987	140	DW	LS
Sugandha (T)	Pure line sel. from Cuttack Basmati	1983	110	SCR	MS
Sujatha (BG 90-2)	Peta/TN1//Remadha	1984	105	IRM	LS
Turant Dan	Sattari/Rasi	1995	75	RUP	MB
Vaidehi (T)	Pure line sel. from Beldar (TCA 48)	1995	135	SDW	LB
Vandana	C 22//Kalakari	1992	65	RUP	LB
Vishnu (C8481)	TN 1/CO 29	1972	75	RUP	MS
GOA					
Goa 1	MTU 15/Waikoku	1997	75	RUP	SB
Gujarat					
Ambica	SKL 47-8 reselection	1991	100	IRM	LS
GAUR 1	Zinnia 31/IR 9-60	1973	90	IRME	SB
GAUR 10	Zinnia 31/IR 9-60	1973	95	IRME	LS
GAUR 100	Zinnia 31/IR 8-246	1973	96	IRM	MS
GR 101	IR 8/Pankhari 203	1984	100	IRM	LS
GR 102	IR 8/Pankhari 203	1986	105	IRM	LS
GR 103	GR 11/Mahsuri	1991	95	IRM	MS
GR 11	Zinnia 31/IR 8-246	1977	95	IRM	MS
GR 2	IR 8/Kada 176-12	1976	80	IRE	LB
GR 3	N 19/IR 60	1977	70	RUP	LS
GR 4 (Sel. 118-1-5)	Zinnia 31/IR 8-246	1981	90	IRME	LS
GR 5	Local selection from CR 319-344	1991	60	RUP	LS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
GR 6	GR 3/Pusa 33	1991	90	IRME	MS
Gurjari	Asha/Kranti	1998	120	IRM	LB
IR 22 (IR 579-60-2)	IR 8/Tadukan	1975	105	IRM	LS
IR 28 (IR 2061-214-3--8-2)	IR 833-6-1-1-1/IR 1561-49-1//IR 1737	1975	95	IRME	MS
IR 579 (IR 579-48-1-2)	IR 8/Tadukan	1975	95	HRIR	LS
Kasturi	Bas. 370/CR 88-17-1-5	1995	100	SCR	LS
Kolhapur	Local sel.	1971	100	IRM	MS
Narmada	TN 1/Basmati 370	1991	105	IRM	LS
SLR 51214	Vijaya/PTB 21	1984	90	IRME	LB
T 3 (T)	Selection Local Type 3	1973	115	SCR	LS
VL Dhan 121	IR 2053-521-1-1-70-75-1/CH 1039	1995	75	HRIR	MB
Haryana					
CSR 10	M40-431-24-114/Jaya	1989	95	IRSA	SB
Damodar (CSR 5)	TKM 6/IR 8	1979	95	IRSA	MS
Haryana Basmati	Sona/Basmati 370	1991	100	SCR	LS
HKR 46	RP 6-516-316/Pusa 33	1999	135	IRM	LS
HKR 120	PTB 33/IR 3403-267-1	1987	105	IRM	LS
HKR 126	Namsagui19/IR 4215-301-2-2-6//IR 5853-162-1-2-3	1992	100	IRM	LS
Sabarmati/ Ratna		1982	90	SCR	LS
Taraori Basmati	Pure line sel. from Local Basmati	1996	105	SCR	LS
Himachal Pradesh					
Himadhan	R 575/TN 1	1978	105	HRIR	SB
Himalaya 1	IR 8/Tadukan	1982	95	HRIR	LB
Himalaya 2 (Pusa 33-C-30)	Imp. Sabarmati/ Ratna	1982	95	HRIR	LS
Himalaya 2216	IR 8/IR 2053-521-1-1//R 36	1994	95	HRIR	LS
Himalaya 741	CR 126-42-5/IR 2061-213	1986	80	HRIR	LS
Himalaya 799	IR 28/Shensi var.//IR 28	1992	95	HRIR	LB
Nagardhan	CHING.SAI.25	1992	110	HRIR	LB
PNR 519	Tainan 3 Mutant/Basmati 370//PNR 417-3	2000	75	RUP	LS
RP 2421	Rasi/Kathawar	1994	95	HRIR	MS
RP 732	RP 107-13/Sona	1992	95	HRIR	LB

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Jamuu & Kashmir					
Chenab	K 21-9-10-1/SR 2053-521-1-2	1994	85	HRIR	LB
Giza 14	Sel. from Giza 14	1965	85	HRIR	SB
Jhelum	Jinoku/IET 4444	1994	88	HRIR	SB
K 84	Indica mutant of T 65	1967	75	HRIR	SB
K78-13	Shinei/CH. 971	1978	90	HRIR	SB
PC 19-13 (TAWI)	Sec. sel. from IR 8/ IR 127-2-2	1978	80	HRIR	SB
Ranabhir Basmati	Selection from Basmati 370-90-95	1994	95	SCR	LS
Karnataka					
Abilash	CR 63-6218/ Pankaj	1985	125	RSL	MB
Akash	Jaya/Mahsuri	1994	105	IRM	LB
Amrut (IET 7991)	M 63/83/RP 79-5/R.N 21	1993	75	RUP	LB
Avinash (Gama 318)	Bangwan/Hatsuisiki	1985	110	RSL	MB
Hemavathi	Int. from Bangladesh	2000	132	DW	MS
Hemavati	DWR 4107	1993	135	SDW	MS
IET 7191	RP 5-32/Pankaj	1987	117	RSL	MB
IET 7564	IRAT/N 22	1994	65	RUP	LS
IET 7575	Sona/Manoharsali	1988	135	IRM	LS
IET 8116	Vikram/Andersali	1998	100	IRM	LB
Intan	Introduction for Indonesia	1975	135	RSL	LS
IR 30864	IR 17-18/IR 7801-1-2-1// IR 46/Khaola	1991	75	RUP	LS
Karna	Jaya/W 1263	1986	105	IRM	LB
KHP 5	INTAN/IET 7191	2000	125	IRM	MB
KPH 2 (IR 1078)	BG 90/2 IR 2863-38-1	1990	100	IRM	MS
KPRH 2	IR 58025A/KMR 3A	1996	103	IRM	LB
KRH 1	IR 58025A/IR 9761	1994	95	IRM	LS
Kusuma	Bas./TN(1)	1969	90	IRME	MS
Madhu (MR 136)	TN (1)/TKM 6	1972	90	IRE	MS
Mahaveera	IET 2885/Red Annapurna	1985	80	IRE	MS
Mandya Vani	CR 1014/IR 8 (Sec. sel.)	1982	100	IRM	MS
Mandya Vijaya	Sona/Mahsuri	1986	115	RSL	MS
Mangala	Jaya/S 317	1975	80	IRE	MS
Manila Paddy	Peta/BPI 76	1970	90	IRE	MS
Mukti	S.I Renah Mehrah/IR 2153	1990	95	IRM	MS
Netravathi	IR 2886/Annapurna	1990	110	RSL	MS
Pragathi	Jaya/S 317	1975	100	IRM	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Prakash	T 90/IR 8	1977	105	IRM	LS
Pushpa (MR 301)	Jaya/Bangaru Thegalu	1976	95	IRM	LS
Red Annapurna	IR 8/PTB 10	1977	85	IRE	SB
Suma	TN(1)/TKM 6	1969	85	IRE	MS
Vikram	IR 8/SIAM 29	1974	100	IRM	LB
Kerala					
Aiswarya	Jyothi/BR 51-46-1	1992	84	IRE	LB
Annapurna (Cul. 28)	PTB 10/TN1	1966	70	IRE	SB
Aruna	Jaya/PTB 33	1989	80	IRE	SB
Aswathy	PTB 10/Dee-Geo-Woo-Gen	1971	80	IRE	LB
Athira (PTB 51)	BR 51-46-1/C. 2332-2-2	1992	95	IRM	SB
Bhadra (M 11-57-51)	IR 8/PTB 20	1979	105	IRM	MB
Bhagya (Kayamkulam 2)	Tadukan/Jaya	1986	80	IRE	SB
Bharathi (PTB 41)	PTB 10/IR 8	1972	90	IRE	LB
Jayathi (PTB 46)	Triveni/IR 2061	1990	100	IRM	MB
Jyothi (PTB 39)	PTB 10/IR 8	1972	85	IRE	LB
Kairali (PTB 49)	IR 36/Jyothi	1992	84	IRE	LB
Kanakam	IR 1561/PTB 33	1989	100	IRM	LS
Kanchana (PTB 50)	IR 36/Pavizham	1992	80	IRE	LB
Karishma	MO 1/MO6	1998	105	IRM	MB
Kartika	Triveni/IR 1539	1989	80	IRE	LB
Kayamkulam. 1 (Cul.31-1)	Kottarakara-1/Poduvi	1980	135	RSL	LB
Krishna anjana	MO 1/MO6	1998	105	IRM	MB
Makom	ARC 6650/Jaya	1989	80	IRE	SB
Mata Triveni (PTB 45)	Reselection from Triveni	1990	80	IRE	SB
MO 5	IR 11-1-66/Kochuvithu	1980	95	IRM	SB
Neeraja	IR 20/IR 5	1990	115	RSL	MS
Nila (PTB 48)	Triveni/Vellathi Kalappala// CO 25	1992	100	RSL	SB
Onam	Kechuvithu/TN 1//Tricveni	1986	85	IRM	SB

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Panchami	Pothana/MO 5	1998	100	IRM	MB
Pavithra	Surekha/MO 5	1998	100	IRM	MB
Pavizham	IR 8/Karivennel	1982	95	IRM	SB
Ranjani	MO 5/Imp. Sona	1996	84	IRE	LB
Rasmi	Oorapandy mutant	1986	120	RSL	SB
Remanica	Mutant of MO 1	1998	100	IRM	SB
Remya	Jaya/PTB 33	1989	84	IRE	SB
Revathy	Culture 12814/MO 6	1998	105	IRM	MB
Rohini (PTB 36)	PTB 10/IR 8	1971	70	IRE	LB
Sabari (PTB 40)	IR 8/Annapurna	1972	100	IRM	LB
Suvarnamodan (ARC 11775)	ARC 11775 Pure line sel.	1976	75	RUP	MS
Swarnaprabha	Bhavani/Triveni	1986	80	IRE	MB
Triveni	Annapurna/PTB 15	1970	70	IRE	LB
Uma	MO 6/Pokkali	1998	100	IRM	MB
Vytilla 2 (Cul. 174)	Pure line sel. from Cheruvippu	1980	95	IRM	LB
Vytilla 3	Vytilla 1/TN 1	1987	84	IRE	MB
Madhya Pradesh					
Annapurna	IR 8/SLO 16	1972	75	RUP	MS
Garima	Cross 4/TN1	1977	75	RUP	LB
Jagruthi	Rikku 132/R 4	1976	75	RUP	SB
JR 75	IR 20/L-14// BSJ 205	1984	60	RUP	MS
Kranthi	Cross 116/IR 8	1976	84	IRE	SB
Madhuri	Jaya/R 11	1980	84	IRE	LS
Mahamaya	Asha/Kranthi	1994	100	IRM	LB
Patel 85	Selection from IR 8	1981	105	IRM	LB
Poorva	CR 44-35/JR 2-331	1981	60	RUP	LS
Praghathi	TN1/Laugi 70	1976	75	RUP	LS
R 281-PP-31-1	-	1996	100	IRM	LB
Radhe	IR 36/IR 2053-541	1990	84	IRE	LS
Ruchi	R 1924/RP 9-4	1988	100	IRM	LB
Safri 17 (T)	Selection from Safri	1984	115	RSL	LS
Shyamala	R 60-2712/R 2389	1995	110	RSL	LB
Maharashtra					
ACK 5	Dodga 6-2-2/IR 8	1986	95	IRM	SB
Ambika	MAU Sel. 1	1984	88	IRE	LS
HMT Sona	Local selection	2000	106	IRM	MS
IGP 1-37 (Darana)	Late Kolpi 248/ IR 8	1980	110	RSL	LB
Imp. Ambemohar	Local selection	1978	75	RUP	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Indrayani	Ambemohar 157/IR 8	1987	102	IRM	LS
Jalgoan 5	Local selection	1978	85	IRE	LS
Karjat 1 (KJT 24)	Holamaldiga/IR 36	1985	75	IRE	SB
Karjat 184	TN1/Kolamba 540	1971	80	IRE	LS
Karjat 2	Phalguna/Prakash	1994	105	IRM	LS
Karjat 3	IR 36/Karjat 35-3	1994	85	SCR	SB
Karjat4	IR 22/Zinia 63	2000	85	IRE	SS
Kundalika	Ratnagiri 24/IET 3228	1989	95	IRM	LS
Palghar 1	IR 22/PLG 141-1	1988	100	IRM	MS
Palghar 60	Zinnia 31/IR 8	1971	90	IRE	MS
Panvel 1	IR 8/BR 4-10	1984	95	IRSA	SB
Panvel 2	BR 4-10/IR 8	1987	90	IRM	LS
Panvel 3	Damodar/Pankaj	2000	100	IRSA	LB
Pawana	IR 8/ Pusa 33	1988	90	IRE	LS
Phule Mawal	Pavana/Indrayani	2000	95	IRM	LB
Pondaghat 1	RP 4-14/R 711	2000	90	IRM	LS
Prabhavati	Mutant of local Ambemohar	1984	85	IRE	MS
Radhangiri 185-2	Halwasal 17/TN(1)	1975	85	IRE	LS
Ratnagiri 73-1	RTN 23/KTJ 87-2	1979	70	IRE	LB
Ratnagiri 1	IR 8/RTN 24	1985	80	IRE	LB
Ratnagiri 2	RTN68-1/ WARANGAL 487	1985	125	RSL	SB
Ratnagiri –24	Zinnia 63/TN(1)	1971	80	IRE	MS
Ratnagiri 3	CR 57-MR 1523/IR 36// RTN 68	1994	110	IRM	LB
Ratnagiri 71-1-41	IR 8/ Ratnagiri 24	1978	85	IRE	LS
Sahayadri		1998	100	IRM	LS
Sakoli –6	Nagpur 27/IR 8	1989	90	IRE	LS
Satya	BG 79/IR 400-28-4-5	1973	100	IRM	LB
Sindewahi 1	Local selection	1988	95	IRSA	LS
SKL 47-8 (Sakoli. 7)	TN(1)/Basmati 370	1988	100	SCR	LS
Sugandha	Prabhavati/IET 8573	1994	85	IRE	LS
Suhasini	BG 79/IR 8	1973	84	IRE	LS
Surya	BG 79/IR 400-28-4-5	1973	82	IRE	LB
SYE 75	TN(1)/WL 112	1979	110	RSL	LB
SYE -ER 1	Sona/SYE44*-3	1990	85	IRE	SS
Terna	MAU sel. 9 (Pure line sel.)	1989	80	IRE	LS
Tuljapur-1 (T)	Sel. from Lalsal 140-31	1972	75	RUP	LB
Manipur					
Akutiphou	Langphou/IR 1364-37-3-1	1999	95	HRIR	LB
Eriemaphou	Taothabi/IR 1125-21-2-1	2000	140	DW	SB
Lemaphou	Tall Indiaca/Lawagin	1999	100	HRIR	LB

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Pheu-Oibi	Pheuran/IR 661-1-140-3-2	1991	100	IRM	LS
Punshi	Pheuran/IR 661-1-140-3-2	1981	105	IRM	LS
Re Maniphou 1	Kalinga 2/Palman	1992	85	IRE	MS
Re Maniphou 2	Kalinga 2/Palman	1992	90	IRE	LB
Sanaphou	Marangphou/Lawagin	2000	100	IRM	SB
Meghalaya					
Khonorulu (T)	Landrace	1965	120	RSL	SB
NEH Megha Rice 1	Pusa 33/Khonorullu	1992	130	HRIR	MB
NEH Megha Rice 2	Khonorullu/Pusa 33	1992	130	HRIR	MB
Ngoba (T)	Landrace	1965	125	RSL	SB
Orissa					
Ananga	Kumar/CR 57-49	1988	85	IRM	MS
Annada	MTU 15/Waikoku	1987	75	RUP	SB
Badami	Suphala/Annapurna	1992	65	RUP	MB
BAM 6 (T)	Pure line selection Ratna Chudi	1986	130	RSL	MS
Bhanja	IR 36//Hema/Vikram	1992	105	IRM	MB
BHOI	Gauri/RP 825-45	1998	90	IRM	LB
Bhuban	CR 158-5/Rasi	1988	105	IRM	MS
Birupa	ADT 27/IR 8//Annapurna	1992	105	IRM	LB
CR 1014	T 90/Urang Urangan	1988	120	RSL	MS
Dala Heera	CR 404-48/CR 289-1208	1998	70	RUP	LB
Daya	Kumar/ CR 57-49	1984	105	IRM	MS
Dharithri	Pankaj/Jagannath	1988	120	RSL	SB
FR 13A (T)	Pure line sel. Kalambanka	1988	131	SDW	LB
Gajapathi	OR 136-3/IR 13429-196-1-120	1998	125	IRM	LS
Gauri	T 90/IR 8//Vikram	1984	105	IRM	MS
Gayatri	Pankaj/Jagannath	1988	125	RSL	SB
Ghanteswari	IR 2061-628/N 22	1992	70	RUP	LB
Heera	CR 404-48/CR 289-1208	1988	65	RUP	LB
Hema	T 141/IR 8 - 246	1974	105	IRM	LB
Indira (CR MUT 587-4)	Tainan 3 Mutant	1980	95	IRM	MS
Indravati	IR 56/OR 142 - 99	1999	120	RSL	MB
Jajati	Rajeswari/T 141	1980	105	IRM	MS
Kalashree	CR 151-70/CR 1014	1988	130	RSL	MS
Kalinga 1	Dhunghansali/IR 8	1973	75	RUP	LB
Kalinga 2	Dhunghansali/IR 8	1973	70	RUP	LB
Kalinga III	AC 540/Ratna	1983	55	RUP	LS
Kalyani II	Sattari/Rasi//Kalinga III	1988	65	RUP	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Kanchan	Jajati/Mahasuri	1992	125	RSL	MS
Keshari	Kumar/Jagannath	1980	70	RUP	MS
Khandagari	Parijat/IR 13429-94-3-2-2	1992	70	RUP	MS
Kharveli	Daya/IR 13240-108-2-2-6	1998	101	IRM	MS
Konark	Lalat/OR 135-3-4	1998	100	IRM	MS
Kshira	CR 94-1521-6/ Vijaya	1988	105	IRM	MB
Kumar	T 90/IR 8	1974	95	IRE	MS
Lalat	OBS 677/IR 2071//Vikram/ W 1263	1988	95	IRM	LS
Lalithagiri	Badami/IR 1966-364	1998	95	RUP	MB
Mahalaxmi	Pankaj/Mahsuri	1992	125	RSL	MB
Mahanandi	OR 1301/IR 19661-131-3-1//Savitri	1999	120	RSL	MB
Manika	CR 210-1010/OBS 677	1992	130	RSL	LB
Mehar	OBS 677/IR 2071//Vikram/ W 1263	1992	105	IRM	LB
Moti	CR 151-79/CR 1014	1988	115	RSL	LS
Neela	CR 94-1512-6/Pusa 2-21	1985	60	RUP	MB
Nilgiri	Suphala/DZ-12	1992	70	RUP	MB
Padmini	Mutant of CR 1014	1988	115	RSL	MS
Pallavi	Jikkoku/Seraup Kechil	1980	70	RUP	MS
Panidhan	CR 151-79/CR 1014	1988	140	SDW	MS
Parijat	TKM 6/TN1	1976	70	RUP	MS
Pathara	Hema/CO 18	1985	75	RUP	MS
Prachi	IR 9764 – 45 – 2-2/OR 149-3-2	1999	120	RSL	MB
Pratap	Kumar/CR 57-49	1983	100	IRM	MS
Radhi	Swarnaprabha mutant	1998	83	IRE	LB
Rajeswari	T 90/W 1251	1974	100	IRM	MS
Ramakrishna	TKM 6/IR 8	1980	100	IRM	MS
Rambha	Pankaj/ W-1263	1985	120	SDW	MB
Ramchandi	IR 17494-32-2-2-1/Jaganath	1998	125	RSL	MB
Rudra	Parijat/IET 3225	1983	60	RUP	MS
Samalei	Leaung 152/IR 8	1980	120	RSL	LS
Samanta	T 90/IR 8//Vikram///SIAM 29/Mahasuri	1992	105	IRM	LB
Sarasa	CR 94-512-6/ Ratna	1985	90	IRE	LS
Sarathi	T 90/IR 8//W 1263	1983	85	IRE	MB
Sattari	NSJ 200/Padma Mutant	1980	45	RUP	SB
Sebati	Daya/IR 36	1998	125	IRM	MS
Seema	Jagannath natural cross	1991	120	RSL	MS
Shakti	PTB 18/PTB 21	1973	100	IRM	SB
Shankar	Parijat / IET 3225	1983	55	RUP	MS
Shravani	Mahsuri/IR 30	1988	85	IRE	MS
Sneha	Annada/CR 143-2-2	1991	50	RUP	LS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Sonamani	Velki/Mahsuri	1998	120	RSL	SB
SR 26 B (T)	Pure line sel. Kalambanka	1988	115	RSL	LB
Subhadra	TN (1)/SR 26 B	1980	60	RUP	LB
Suphala (OR 35-61-23)	TN 1/T141	1976	75	RUP	MS
Supriya	IR 8/ GEB 24//TN (1)	1973	75	IRE	MS
Surendra	OR 158-5/Rasi	1998	101	IRM	MB
T 141 (T)	Pure line selection	1988	110	IRM	MS
T 90 (T)	Pure line selection	1988	120	RSL	LS
T1242 (T)	Pure line selection	1988	125	RSL	LB
Tapaswini	Jagannath/Mahsuri	1998	105	IRM	MS
Tara	CR 94-1512-6/Pusa 2-21	1988	70	IRE	MB
Tulashi	CR 151-79/CR 1014	1988	125	RSL	MS
Udaya (CR 190-103)	CR 129-118/ CR 57-9-2	1985	100	IRM	LB
Udayagiri	IRAT 138/IR 13543 - 66	1999	92	IRM	MB
Urbashi	Rajeswari/Jajati	1992	85	RSL	LB
Utkal Prabha	Waikokku/CR 1014	1983	130	SDW	MS
Vanaprrabha	ARC 12422/ARC 12751	1988	65	RUP	MS
Pondicherry					
Aravinder	Swarnadhan/NLR 9674	1994	105	IRM	LS
Bharathidasan (BPHR 5-IR13427-45-2)	IR 3403-267/PTB 33//IR 36	1984	85	IRE	LS
Jawahar	IR 8/H 4	1988	120	RSL	LS
Puduvaiponni-1	Ponni/IR 8	1980	130	RSL	LS
Punithabathy (P 1275)	Kannagi/Cul. 2032	1980	100	IRM	LS
Subramanya Bharathi	IR 19661/CR 1009	2000	110	IRM	MS
Punjab					
Basmati 385	TN1/Basmati 370	1992	105	SCR	LS
Basmati 386	Sel. from Pak. Bas.	1994	105	SCR	LS
Hybrid Mutant 95	Jhona 349/TN1	1972	95	IRME	LS
Palman 579	Introduction form IRRI	1972	95	IRME	LS
PR 103	IR 8/IR 127-2-2	1976	95	IRM	LS
PR 106	IR 8/Peta 5/Bella Patna	1978	100	IRM	LS
PR 108	Vijaya/PTB 21	1986	100	IRM	LS
PR 109	IR 19660-73-4/IR 2415-90-4-3-2//IR 5853-162-1-2-3	1986	100	IRM	LS
PR 110	TN1/Petang 32//PR 106	1992	95	IRE	LS
PR 111	IR 54/PR 106	1994	108	IRM	LS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
PR 113	IR 8/RP 2151-173-1-8//IR 8	2000	95	IRM	LS
PR 114	TN1/Patong32//PR 106/// IR 8	2000	110	IRE	LS
PR 115	RP 2151-173-1-8/PR133	2000	95	IRM	LS
PR 116	PR 18/PAU 1628//PR 106	2000	110	IRE	LS
PR 4141	IR 8/BJ 1//IR 22	1982	95	IRM	LS
Punjab Basmati 1 (PAU 269-2-31-1-4)	Sona/Basmati 370	1982	95	SCR	LS
Rajasthan					
BK 190	R 14/IR 8	1980	105	IRM	SB
BK 79	TN1/NP 130//Basmati 370	1981	100	IRE	LS
Chambal (Cul. 8050)	IR 8/NP 130	1975	100	IRM	LB
Khushboo	Baran Basmati/Pusa 150	1994	90	SCR	LS
Mahisugandha	BK 79/Basmati 370	1994	100	SCR	LS
Vagaddhan	M 63 - 83/Cauvery	1998	70	RUP	LB
Tamil Nadu					
ADT 28	ADT 3/CH. 42	1965	85	IRE	MS
ADT 32	Sel. from Vaigai Samba	1972	115	RSL	SB
ADT 36	Triveni/IR 20	1981	77	IRE	MS
ADT 37	BG 280-12/PTB 33	1987	75	IRE	SB
ADT 38	IR 1529-680-3-2/IR 4432-52-6-4//IR 7963-30-2	1987	105	IRM	LS
ADT 39	IR 8/IR 20	1988	95	IRM	MS
ADT 40(IET 5656)	Sona/RPW 6-13	1989	120	RSL	SB
ADT 41	Sel. from Basmati 370	1994	85	SCR	LS
ADT 42	AD 9246/ADT 29	1996	105	IRM	LS
ADT 43	IR 50/Imp. White Ponni	1998	80	IRE	MS
ADT 44	IR 56/OR 142-99	2000	115	RSL	SB
ADTRH – 1	IR 58025 A/IR 66 R	1999	90	IRM	LS
ASD 16	ADT 31/Co 39	1986	85	IRE	MS
ASD 17 (AS 688)	ADT 31/Ratna//ASD 8/IR 8	1988	70	IRE	SB
ASD 18	ADT 31/IR 50	1991	80	IRE	MS
ASD 19	Lalnakanda/IR 30	1996	95	IRM	MS
ASD-20	IR 18348/IR 25863//IR 36	1996	105	IRM	LS
AU1	Sel. from mutant of IR 8	1976	75	IRE	SB
Bhavani	Peta/BP 176	1976	105	IRM	LB
C 7306	HR 19/TN 1	1977	87	IRE	LB
CO 36	IR 8/CO 32	1973	100	RSL	MS
CO 41	Cul.240/IR 22	1979	75	IRE	MS
CO 43	Dasal/IR 20	1982	110	RSL	LS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
CO 44	ASD 5/IR 20	1982	105	IRM	MS
CO 45	Rathuheenati/IR 3403/267-1	1991	110	RSL	LS
CO 47	IR 50/CO 43	2000	115	IRM	MS
CO.46	T 7/IR 20	1996	125	RSL	LS
CORH-2	IR 58025 A / C 20 R	1999	99	IRM	LS
CORH-1	IR 62829A/IR 10198-66-2R	1996	105	IRM	MS
CR 146-7027-224	CR 10-114/CR 115	1977	85	IRE	LS
CR 149-3244-198	IR 8/CR 1014//Pankaj/ MNP 36	1977	125	RSL	LB
IR 34 (IR 2061-213-217)	Peta/TN1/Gampai	1979	77	IRE	LS
IR 50	IR 2153-14-6-6-2/IR 28/IR 2070-625-1-252	1982	85	IRE	LS
IR 64	IR 5657-33-2/IR 2061-465-1-5-5	1989	90	IRE	LS
J.J.92	Sel. from Dwarf Basmati	1993	50	SCR	LB
Karikalan (C5652)	TN(1)/ADT 27	1972	83	IRE	SB
Karuna (C11321)	IR 8/ADT 27	1971	85	IRE	SB
MDU 1	IR 8/Chitrakar	1981	90	RUP	LS
MDU 2	CO 25/IR 8	1983	105	IRM	LS
MDU 3	IR 8/W 1263	1989	90	IRM	LB
MDU 4	AC 2386/Jagannath	1991	105	IRM	LS
MGR 1	IR 62829A/IR 10198	1994	95	IRM	LS
Paiyur 1	IR 1721-14/841330-3-3-2	1981	115	RSL	MS
Paramakudi 1 (PMK 1)	Co.25/ADT 31	1984	85	RUP	MS
PKU 2	IR 13564-149/ASD 4	1996	80	IRE	LB
PMK 2	IR 13564-149-3/ASD 4	1996	85	IRE	MB
Ponni (ASD 14)	TN 1/ADT 27	1970	80	IRE	LB
Ponni (Mahsuri)	T 65-2/Mayang EBOS 80/2	1971	110	RSL	MS
PVR-1	SR 26B/MTU 1	1968	115	IRSA	SB
T.P 4121	CO.251/CO.40	1988	105	IRM	MS
Thirupathisaram1	IR 8/Kaltisamba	1983	105	IRM	MS
TKM 10	CO 31/C 22	1993	105	IRM	MS
TKM 11	C22/BJ 1	1998	90	IRE	LS
TKM 9	TKM 7/IR 8	1978	80	IRE	SB
TPS 2	IR 26/CO.40	1986	100	IRM	SB
TPS 3	RP 31-492/LMN	1993	105	IRM	SB
TRY 1	BR 153-2B-10-1-3	2000	110	IRSA	SB

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
Vaigai (CO 37)	TN(1)/CO 29	1974	75	RUP	MS
White Ponni	T 65/ME.80	1986	105	IRM	MS
Tripura					
TRC Borodhan-1	Thimpu/IR 9219-102-1//KN 1B-361-1-8-6-8	1991	110	IRE	SB
Uttar Pradesh					
Aswani (KR 5-142)	N 22/Cauvery	1986	75	IRE	SB
Barah Avarodhi	Madhukar/Sona	1995	145	SDW	LB
Govind	IR 20/IR 24	1982	75	RUP	LS
Hassan Sarai	Intoduction from Iranian Basmati	2000	95	SCR	LS
IR 24 (IR 661-1-1-143-3)	IR 8/IR 127-2-2	1972	95	IRE	LS
Jal Lahari	Pankaj//Mahsuri/TKM 6	1993	140	SDW	MS
Jalanidhi	Sel. from Goanath	1993	150	DW	MB
Jalmagna(T)	Sel. from Bhadon	1969	130	SDW	SB
Jalpriya	Sel. from IET 4060/Jalmagna	1993	130	DW	LB
Madhukar (T)	Sel. from Gonda	1969	120	SDW	LB
Majhera 3 (T)	Selection from Jaulia	1968	90	HRIR	LS
Manhar (UPR 103-44-2)	IR 24/Cauvery	1985	90	IRE	LS
Narendra 118	IR 36/Hansraj	1987	65	RUP	MS
Narendra 80	N 22/IR 36	1986	75	RUP	MS
Narendra Sankar Dan	IR 58025 A/ NDR 3026-3-1-R	1999	98	IRM	LS
Narendra Usar 2	IRRI Line F2	1998	95	IRSA	LB
Narendra Usar 3	Leaung ya 1148/IR 9125-209-2-2-2-1//IR18272-27-3-1	2000	100	IRSA	LS
Narendradhan 1	Bella Patna/IR 8	1981	75	RUP	MB
Narendradhan 2	IR 8/Tadukhan//TKM 6/ TN(1)	1982	85	RUP	LS
Narendradhan 359	BG 90-2-4/OBS 7-677	1992	79	IRE	LS
Pantdhan 6	IR 8608-298-3-1/IR 10179-2-3	1986	90	IRE	MS
Pant Sankar Dhan 1	Upr 195-178A/Upr 192-133R	1997	105	IRM	LS
Pantdhan 10	IR 32/Mahsuri//IR 28	1992	90	IRM	LS
Pantdhan 11	VL 206/Dagi	1992	100	HRIR	LB
Pantdhan 12	Govind/UPR 201-1-1	1994	95	IRE	LS
Pantdhan 4 (BG 90-2)	IR 262/Remadja	1983	100	IRM	LS
Pantdhan 957	IR 32429-122-3-1-2/IR 31851-63-2-3-1	1999	105	HRIR	SB

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
PHB 71		1997	95	IRM	LS
Prasad (IR 1516-2-216-6)	IR 747B-26-3/IR 57948	1978	90	IRE	MS
Renu (PNR 162)	Jaya/Basmati 370	1993	70	RUP	LS
Saket 4	TKM 6/ IR 8	1971	85	IRE	LS
Sarjoo 52 (FH 132)	TN1/Kashi	1980	100	IRM	LB
Ushar 1	Jaya/Getu	1984	100	IRSA	MS
VL Dhan 16	JP 5/Y.R.L.I.	1984	95	HRUR	LS
VL Dhan 163 (VRS 163-2-2-3)	IR747/KN16-36-1/IR2053-521-1-1-1	1987	80	HRUR	MS
VL Dhan 206	Sel. from Bamni	1983	105	HRUR	MS
VL Dhan 221	IR 2053-521 K 116//KN18-361	1991	100	HRUR	MS
VL Dhan 97	N 22/Ratna	1991	85	RUP	LS
VLK Dhan 39 (K39-96-31-1-1-9)	China 1039/IR 580-19-2-3-1	1980	85	HRIR	MS
West Bengal					
Amulya	Sel. from Local Nagani	1988	140	SDW	LS
Bagheerathi	JHINGASAIL/Patnai 23	2000	160	SDW	SB
Bhupen	C 22/IR 26//C.22/OS 4	1993	75	RUP	LS
Bipasa	X-ray mutant of Pankaj	1993	125	RSL	LB
Biraj	Co 1393 mutant	1982	140	SDW	MS
CNRH 3	IR 62869 A/Ajaya R	1995	95	IRM	LS
Dinesh	Jaladhi 2/Pankaj	1988	140	DW	SB
GOLAK	JHINGASAIL/CN644	1998	135	SDW	SB
Jaladhi 1 (T)	Sel. from Kalakher Sail	1981	140	DW	SB
Jaladhi 2 (T)	Sel. from Local Baku	1981	145	DW	LB
Jalaprabha (T)	Selection from Composite	1996	140	DW	SB
Jamini	BG 280-112/PTB 33	1996	100	RUP	LB
Jitendra (T)	Selection from landraces	1994	155	DW	LS
Jogen (T)	IR 20/SML 40-10-4	1986	140	SDW	MB
Khanika	Jaya/CR 237-1	1996	100	RUP	LS
Khitish	Bulk /CR 115	1982	90	IRE	LS
Kiron	N22/TN// T90/IR8	1986	75	RUP	MS
Kunti	RPW 6-13/Sona	1982	100	IRM	LS
Lakshmi (CNM 6)	Mutant of IR 8	1982	90	IRE	LB
Mahananda	IR 36/Patnai 23	2000	135	SDW	SB
Mandira	IR 34/KLS 6980-143-2-P//IR 2070-2-5-6/HB.DW.8	1986	140	SDW	MS
Matangini	Pure line sel. from Kajallata	1989	140	SDW	SB
Munal (C 15310)	An exotic introduction from USA	1982	100	IRE	LB
Nalini	Sel. from local Sindu Raukhi	1988	140	SDW	MS

Name	Cross	Year	50% flowering	Ecosystem[a]	Genotype[b]
NEERAJA	Selection from landraces	1998	160	DW	LB
Panke	Pure line selection	1989	75	RUP	LB
Purnendu	Patnai 23/Jaladhi 2	1994	160	SDW	SB
Sabita (T)	Pure line sel. from Boyan	1986	135	SDW	LS
Saraswathi	Pankaj/Patnai 23	1996	135	SDW	LB
Sashi	IR 50/Patnail 23	2000	140	RSL	LS
Satabdi	Cr 10-114/CR 10115	2000	130	IRM	LS
SUDHIR	FR13A/CNM539	1998	150	SDW	LS
SUNIL	OC1393/B1047-BPN-18-1-4	1998	135	DW	LS
Suresh	IR 262/Khao Nahng Muey 11	1982	135	SDW	LS

[a] IRE = irrigated early; IRM = irrigated medium; RUP = rainfed upland; RSL = rainfed shallow lowland; SDW = semi-deepwater; DW = deepwater; HRIR = irrigated hills; HRUR = upland hills; IRAK = alkaline soils; SCR = scented; IRSA = saline alkaline.
[b] SB = short bold; MB = medium bold; LB = long bold; MS = medium slender; LS = long slender.

APPENDIX 3

List of varieties released in Nigeria

Origin	Pedigree/ parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
Guyana	BG 79	Shallow swamp	1954	135-174	105-120	3.0-5.0
Guyana	D 144	Shallow swamp	1957	135-115	100-115	3.0-4.5
Nigeria	Agbede	Upland	1958	95-120	95-100	1.5-2.5
India	Kavunginpoothala 12	Deepwater	1959	189-220	145-150	2.0-4.0
Madagascar	Makalioka 825	Shallow swamp	1960	135-154	111-115	2.0-4.5
F/Guinea	Indochinablank (ICB)	Deepwater	1961	176-198	156-160	2.0-3.0
Thailand	Maliong	Deep flooded water	1962	160-217	160-165	2.5-3.5
Indonesia	Mas 2401	Shallow swamp	1963	155-160	120-125	3.5-4.5
Malaya	Siam 29	Shallow swamp	1963	189-220	120-125	2.5-3.0
Kenya	Sindano	Shallow swamp (high altitude)	1963	115-162	125-130	2.5-4.5
Congo/Zaire	OS 6	Upland	1966	115-120	115-120	1.5-2.5
Surname	SML-140/10	Shallow	1969	145	135-140	3.0-4.0
Philippines	IR 8	Shallow	1970	135-140	90-100	2.0-4.0
NCRI, Nigeria	Chanyza 123 x ICB	Deepwater	1971	170-198	150-160	2.5-4.0
NCRI, Nigeria	BG 79 x IR 8	Shallow	1974	145-160	115-120	3.5-4.5
NCRI, Nigeria	Mas 2401 x SML 14/10	Shallow	1974	140-160	90-100	2.5-3.5
NCRI, Nigeria	Mas 2401 x Tjina	Shallow	1974	145-160	110-120	2.0-3.0
Indonesia	Tjina	Shallow	1974	179	145-150	2.0-3.0
Philippines	IR 20	Shallow	1974	135-140	90-100	
Philippines	BPI-76	Shallow	1974	125-130	90-100	2.5-4.0
Philippines	Taichung Native 1	Shallow	1974	90-110	80-90	2.5-4.0
Philippines	IR 627-1-31-3-27	Shallow	1974	145-150	90-110	2.0-3.0
Philippines	IR 5-47-2	Irrigated/ Shallow swamp	1974	145-150	90-100	2.0-3.0
Viet Nam	Degaule	Irrigated/ shallow swamp	1974	135-145	135-145	2.5-3.5
NCRI, Nigeria	Jete x Tjina (FAROX 56/30)	Upland	1976	115-120	105-100	2.5-3.5
NCRI, Nigeria	Tos 78	Shallow	1982	130-135	105-100	2.5-3.5
NCRI, Nigeria	(Tos 103) IR 400-15-12-10-2 x IR 662	Shallow	1982	110-115	90-100	3.0-4.0
NCRI, Nigeria	Tjina x IR 8 (FAROX 118A)	Shallow	1982	135-140	125-130	3.0-4.0

Origin	Pedigree/ parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
NCRI, Nigeria	Pesa/TN 1 Remadja (BG 90-2)	Shallow	1984	125-135	100-115	2.5-3.5
NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-2-1-1)	Shallow	1986	110-115		5.0
NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-2-1-2)	Shallow	1986	110-115	120-125	5.0
NCRI, Nigeria	FARO 15/IR 28 (FAROX 228-1-1-1)	Shallow	1986	110-115	110-120	4.5
NCRI, Nigeria	IR 28/FARO 12 (FAROX 233-1-1-1)	Shallow	1986	110-115	115-125	4.0-5.0
NCRI, Nigeria	FARO12/IR 28 (FAROX 239-1-1-1)	Shallow	1986	105-115	115-120	4.0-5.0
IITA, Nigeria	ITA 212 (BG 90-2*4/Tetep)	Shallow	1986	120-135	100-115	4.5-5.0
IITA, Nigeria	ITA 222 Maushuri/IET 1444	Irrigated swamp	1986	120-135	100-115	4.5-5.0
IITA, Nigeria	ITA 306 (Tox 494-3696/Tox 711/BG 6812)	Irrigated swamp	1986	125-140	100-115	4.5-5.0
Côte d'Ivoire	IRAT 133 (IRAT 13/IRAT 10)	Irrigated swamp	1986	100-105	100-110	1.0-3.0
Côte d'Ivoire	IRAT 144 (IRAT 13/IRAT 10)	Irrigated swamp	1986	100-105	95-105	1.0-3.0
NCRI, Nigeria	FAROX 299 (Multiline)	Irrigated swamp	1986	115-120	115-120	1.0-3.0
Côte d'Ivoire	IRAT 170 (IRAT 13/Palawan)	Upland	1986	115-120	80-90	1.0-3.0
IAR & T, Nigeria	ART 12 (ITA116)	Upland	1986	115-120	110-115	1.0-3.0
IITA, Nigeria	ITA 128 (63-83/Iguape Cateto, IET 144, IR 1416-131, Lite 506)	Upland	1986	115-120	110-115	1.0-3.0
Taiwan	SIPI 692033(SIPI 661044/SIPI 651021	Irrigated/ shallow	1992	110-120	95-110	4.0-6.0
ITA, Nigeria	ITA 257(IRAT 13/Dourado Precose 689/Tox 490-1	Upland	1992	90-100	90-100	2.0-3.0
ITA, Nigeria	ITA 150 (63-83/Multiline	Upland	1992	100-105	80-90	2.0-3.0
ITA, Nigeria	ITA 117 (13A-18-3-1/Tox 7)	Upland	1992	115-120	90-110	2.0-3.0
ITA, Nigeria	ITA 301 (IRAT 13/Dourado Precose 689/Padipapayak)	Upland	1992	115-120	90-110	2.0-3.5

Origin	Pedigree/ parentage	Ecology	Year of release	Growth duration (*days*)	Plant height (*cm*)	Yield potential (*t/ha*)
ITA, Nigeria	ITA 315 (IR 43/Iguape Cateto)	Upland	1992	115-120	90-110	2.0-3.5
ITA, Nigeria	ITA 230 (BG 90-2*/Tetep)	Irrigated/ shallow swamp	1992	130-135	90-115	3.0-4.0
Indonesia	Cisadane (Pelita-1/IR/ 789-98-2-3/IR 2157-3	Irrigated	1997	130-135	100-120	3.0-4.0
IITA/ WARDA	WITA 4 (Tox 3100-44-1-2 -3-3)	Irrigated/ shallow	2000	120-135	115-120	3.0-4.5

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