GeoJournal 35.3 267–274

Protecting the Heritage of Rice Biodiversity

Jackson, Michael T., Dr., Genetic Resources Center, International Rice Research Institute, PO Box 933, 1099 Manila, Philippines

ABSTRACT: The development of improved rice varieties depends upon access to the genetic resources of rice. These are represented by the thousands of locally adapted varieties that farmers have grown for generations, and over 20 wild rice species native to Asia, Africa, and Latin America. Rice genetic resources are threatened with extinction in farming systems when farmers adopt improved varieties, and the wild species may be lost through destruction of their habitats.

IRRI has been at the forefront of international efforts for three decades to collect and conserve the biodiversity of rice. More than 80,000 samples of cultivated and wild rices are conserved *ex situ* in the genebank at IRRI. *In situ* conservation of rice genetic resources is likely to become an important complementary strategy in the future.

Through utilization of rice germplasm, resistances to pests and diseases have been incorporated into improved varieties. These are shared worldwide through the International Network for Genetic Evaluation of Rice (INGER). The impact of biotechnology and intellectual property rights on germplasm conservation is discussed.

The Rice Genepool

Two species of rice are important in human nutrition and the socioeconomic welfare of half the world's population. *Oryza sativa*, or Asian rice, is grown worldwide. *O. glaberrima* originated in West Africa, and still retains local importance there in some farming systems. Besides these two cultivated rices, there are more than 20 wild species in the genus *Oryza*, distributed throughout the tropics of Asia, Africa, and Latin America and the Caribbean (Tab 1). The origins and domestication of rice are lost in the mists of time. After millennia of selection by farmers since rice was domesticated in Asia, and in Africa, the rice crop today shows a broad range of genetic diversity. In Asia, rice cultivation spread from the foothills of the Himalayas, southwest into the Indian subcontinent, into Southeast Asia, and eastwards into China and Japan, even at an early stage in the development of agriculture in those regions, more than 5,000 years ago (Chang 1976a; Teng 1994). This has led to the differentiation of rice varieties adapted to local climatic and agroecological conditions. Selection by farmers produced an enormous array of rice varieties which differ in their response to the many biotic and abiotic stresses that affect the crop.

The landrace varieties of *O. sativa* and *O. glaberrima*, the wild species in the same genus, and the related genera in the Tribe *Oryzeae* (Tab 2), comprise the biodiversity of the rice genepool. These species and varieties are the genetic base for food security of the crop. The protection and use of this genetic diversity is the concern of the Genetic Resources Center at IRRI, in collaboration with scientists around the world, particularly those from the national agricultural research systems (NARS) in whose countries this germplasm originated.

Diversity and Use of Rice Varieties

The number of varieties of *O. sativa* is impossible to estimate, although claims of more than 140,000 have been made. Asian rice varieties show an impressive range of variation in many characters, such as plant height, tillering ability, maturity, and size of panicles, amongst others. Variation in grain characters such as size, shape and color is most useful for distinguishing different varieties (Fig 1). Farmers in Asia continue to grow thousands of different varieties. They may be cultivated for specific traits, such as aroma, or cooking quality, or because of a particular cultural aspect. In Cambodia, for example, farmers consider many characters to identify rainfed lowland rice varieties. They classify the maturity of varieties as early, medium, and late according to flowering and harvest dates, according to eating quality (including elusive characters such as aroma and softness, and volume expansion, and grain shape), yield potential, and cultural practices (Lando and Solieng Mak 1994).

Tab 1
Taxa in the genus *Oryza*: the species complexes and genome groups (adapted from Chang and Vaughan 1991)

Species complex	Taxa	Genome group	Distribution
O. sativa complex			
	O. glaberrima	A^gA^g	Africa (mainly West
	O. barthii	A^gA^g	Africa
	O. longistaminata	A^lA^l	Africa
	O. sativa	AA	Worldwide
	O. nivara	AA	Tropical and subtropical Asia
	O. rufipogon	AA	Tropical and subtropical Asia
	O. meridionalis	A^mA^m	Tropical Australia
	O. glumaepatula	$A^{gl}A^{gl}$	South America
O. ridleyi complex			
	O. longiglumis	Tetraploid	Irian Jaya, Indonesia
	O. ridleyi	Tetraploid	SE Asia
O. meyeriana complex			
	O. granulata	Diploid	S and SE Asia
	O. meyeriana	Diploid	SE Asia
O. officinalis complex			
	O. officinalis	CC	Tropical and subtropical Asia
	O. minuta	BBCC	Philippines
	O. eichingeri	CC	Sri Lanka, Africa
	O. rhizomatis	CC	Sri Lanka
	O. punctata	BBCC, BB	Africa
	O. latifolia	CCDD	Latin America
	O. alta	CCDD	Latin America
	O. grandiglumis	CCDD	South America
	O. australiensis	EE	Australia
	O. schlechteri	Diploid	Papua New Guinea
	O. brachyantha	FF	Africa

Nevertheless, Cambodian farmers take into account a whole range of factors such as soil and water conditions in the field, differences in maturity, and culinary qualities, to select the most appropriate local variety for each plot of land. Lando and Solieng Mak (1994) further emphasize that Cambodian rainfed lowland rice farmers understand the complexity and risks of the rainfed lowland rice environment, and consider these when choosing which varieties to grow.

The differentiation of *O. sativa* into distinct ecogeographical races, or even subspecies – *indica, japonica* and *javanica*, is a convenient although simplified classification of the diversity of this species (Chang 1976b). The *indica* and *japonica* rices can be broadly separated on the basis of characters such as photoperiod requirement and morphology, and reproductive barriers have developed during differentiation and selection. Furthermore, there has been selection for cultivation under many agroecological conditions, such as the rainfed lowland environment which is characterized by heterogeneity and variability in water supply, to flood-prone conditions, where rices have evolved the ability to elongate rapidly to several meters to keep pace with rising flood waters, and to upland conditions, where rices are subject to water deficit and their cultivation depends solely upon rainfall.

O. glaberrima in West Africa has two principal ecotypes – a deepwater form and an upland form. However, with the rapid spread of improved varieties of *O. sativa* in Africa, the production of *O. glaberrima* has declined in recent years.

The application of isozyme and molecular techniques now permits the analysis of genetic diversity in different ways. Glaszmann (1985) developed a classification of *O. sativa* based on the allelic pattern of 21 isozyme loci. The so-called *indica* and *japonica* rices are placed in Groups I and VI respectively, and the application of the isozyme classification has proved extremely useful for the effective utilization of different germplasm in rice breeding, because of the potential reproductive barriers mentioned earlier. The *javanica* rices also fall within the Group VI, and are often now referred to as tropical japonicas for this reason. They have become the basis of the new plant types being developed at IRRI, and described by Khush (1994). The other isozyme groups II, III, IV and V include rice varieties with rather restricted distributions, such as the rayada varieties of Bangladesh (Group IV), and the basmati rices, renowned for their aroma, from Pakistan (Group V). Analysis of nuclear and mitochondrial DNA has also added a new dimension to our understanding of the pattern of differentiation and diversity in rice (Second 1985; Second and Wang 1992).

The wild species of rice are found in many different habitats, from full sunlight to shade in forested areas. Some are species in climax vegetation, while others, such as *O. nivara* in Asia, and *O. barthii* in Africa for example, are weedy species, adapted to open, disturbed habitats. Under such conditions, they may come into contact with cultivated rices, and spontaneous hybridization between them can occur.

The wild species represent a rich pool of diversity, and variation exists between species populations in their ability to withstand the pressures of pests and diseases. Rice breeders are beginning to exploit the wild species for traits that have not been found in the cultivated forms. Wide hybridization is playing an increasingly important role in rice breeding, and there is an active program in this respect at IRRI. It is now possible to cross many of the wild species with *O. sativa*, although with varying degrees of difficulty (Khush et al. 1993). According to the genepool concept of Harlan and De Wet (1971) most of the wild species can be classified in the secondary or even tertiary genepool of *O. sativa*. Biotechnology tools, particularly embryo rescue, are becoming increasingly important to overcome barriers to crosses between related genepools and to transfer genes from the wild species (Vaughan and Sitch 1991).

Threats to Rice Biodiversity

Even though farmers continue to grow many different rice varieties, the number of local varieties has declined in recent years. The expansion of irrigated rice in particular, and the rice breeding efforts of the past three decades, have led to the development of improved, high-yielding varieties that are needed to keep pace with rapidly growing human populations, particularly in Asia. Breeding the improved rice varieties has also brought with it the danger of genetic vulnerability, as genetic uniformity of improved rices has replaced the diversity of locally adapted varieties developed by farmers over generations. The impact of rice breeding has been greatest in the irrigated rice ecosystem. The success of rice breeding is exemplified by the case of variety IR36, which was eventually grown over more than 11 million ha, and thus became the most widely grown variety ever (Swaminathan 1982). Its success was due to its resistance to several pests and diseases, particularly grassy stunt virus. Resistance to this disease was found in only one accession of the wild species *O. nivara*, from India. Fifteen other landrace rices are also included in the pedigree of IR36 (Plucknett et al. 1987). On the other hand, in the rainfed lowland and upland rice ecosystems, the loss of rice biodiversity has probably not been so dramatic. In Lao PDR, for example, more than 70% of rices are local, upland varieties. The farmers have developed farming approaches in these heterogeneous and variable systems based on the cultivation of a mix of rice varieties, as described by Lando and Solieng Mak (1994). Diversity reduces risk – yet the improvement of the rainfed lowland and upland systems, and the introduction of improved varieties will certainly have its impact on rice diversity.

Genetic erosion is a serious concern in countries that are undergoing rapid economic change such as Vietnam. Local rice varieties that farmers are growing today may be lost as new agricultural practices extend the cultivation of improved varieties, and if measures are not taken now to protect these valuable genetic resources. Wild species are less threatened with genetic erosion, provided that environmental degradation is not a problem.

Conservation Strategies

Ex situ conservation in genebanks has, to date, been the principal strategy for the preservation of crop genetic resources, and this applies especially to rice. *Ex situ* conservation is static, and as Guldager (1975) has indicated, it aims to retain as far as possible the structure of the original population. Static conservation of rice involves the storage of seeds in a genebank, through which the longevity of the seeds, and the original gene frequencies, are assured through provision of conditions that reduce to a low level the decline in viability of seeds, and the decay of variability of the stored sample. Conservation *ex situ* is a safe and efficient way of conserving rice genetic resources, and has the advantage of making the germplasm readily available for use by breeders and study by other researchers (Ford-Lloyd and Jackson 1986). Rice has so-called orthodox seeds, which can be dried to a relatively low moisture content (6%), and can be stored at sub-zero temperatures. Under these conditions, which also apply to a wide range of crop species, the viability of seeds can be maintained for long periods, certainly decades if not considerably longer. Therefore, the storage of seeds in genebanks has become the favored strategy for the conservation of cultivated rices.

Genera	No. of species	Distribution	Tropical (T)/temperate (t)
Oryza	22	Pan-tropical	T
Leersia	17	Worldwide	t + T
Chikusiochloa	3	China, Japan	t
Hygroryza	1	Asia	t + T
Porteresia	1	South Asia	T
Zizania	3	Europe, Asia, N. America	t + T
Luziola	11	N. and S. America	t + T
Zizaniopsis	5	N. and S. America	t + T
Rhynchoryza	1	S. America	t
Maltebrunia	5	Tropical and S. Africa	T
Prosphytochloa	1	S. Africa	t
Potamophila	1	Australia	t + T

Tab 2 Genera, number of species and distribution in the Tribe *Oryzeae* (adapted from Chang and Vaughan 1991)

Despite past losses of genetic diversity and current threats, considerable progress has been achieved in conserving rice biodiversity. Since the early 1960s, IRRI has played an important role, in collaboration with national scientists, in the collection and conservation of rice varieties and wild species, especially in Asia, and has been a catalyst for conservation activities in national programs. Three international workshops, in 1977, 1983, and 1990, developed the collaborative basis for rice germplasm collection and conservation (IRRI 1978, 1983, 1991). In 1993, the Swiss Development Cooperation provided funding for a 5-year Action Plan to accelerate and complete germplasm conservation efforts for rice, and to ensure that the broad base of rice biodiversity is secured before the end of the decade.

The rice germplasm collection conserved in the International Rice Germplasm Center, the IRRI genebank, has global importance. It comprises more than 80,000 samples or accessions of cultivated and wild rices. More than 75,000 of these accessions belong to Asian rice (*O. sativa*) and two-thirds of these are landraces that have been acquired over many years through joint collecting missions with national scientists in South and Southeast Asia, or as donations for safety duplication. Global efforts for rice germplasm conservation have depended on the mutual collaboration between IRRI and national programs throughout the rice-growing world.

The IRGC has provided an important safety net for several national conservation efforts, when for one reason or another national collections were lost, or no genebank was available within the country. In this respect, therefore, the germplasm conserved at IRRI has proven to have immeasurable significance, and whole collections have been repatriated to the country of origin. A notable example is Cambodia, where the cultivation of deepwater rices was actively discouraged during the period of civil strife. As a consequence, these rices were abandoned and lost in several provinces. Fortunately, earlier germplasm had been collected and conserved at IRRI. When the political climate changed, it was possible to return samples of these deepwater rices to Cambodia, so rice farmers could once again cultivate varieties which they thought were lost.

The first accessions were brought together at IRRI not long after the foundation of the Institute. In 1977, the present genebank facilities were constructed, and during 1993 and 1994, these were extensively remodeled and renovated. A dedicated seed drying room at 15 °C and 15% RH, where seeds equilibrate to ± 6% moisture content, and extended screenhouse facilities for growing the wild species under drip irrigation, are among the important additions to the genebank. Furthermore, modifications to germplasm multiplication and rejuvenation operations, and management of the Active and Base Collections ensure that the genebank is operated under internationally accepted standards adopted in April 1993 by the FAO Commission on Plant Genetic Resources[1)]

The Base Collection has a capacity of more than 120,000 accessions of rice, stored in vacuum-sealed aluminum cans, two cans (±120g = 6,000–12,000 seeds) per accession. This germplasm is stored at –20 °C. In the Active Collection, from which germplasm is exchanged with researchers worldwide, rice seeds are stored in hermetically-sealed aluminum foil packets, containing approximately 400–500 g of seeds. Separate 10 g packets are ready for immediate exchange. All germplasm is tested in IRRI's Seed Health Unit prior to conservation, in accordance with international quarantine standards, and in collaboration with the Philippine Plant Quarantine Service. All germplasm passes through the Seed Health Unit before being sent to collaborators outside the Institute.

In Africa, the International Institute for Tropical Agriculture (IITA) in Nigeria, has taken the lead for the collection and conservation of cultivated and wild rices. This germplasm is duplicated at IRRI. Safety duplicate storage of the IRRI collection is undertaken at the National Seed Storage Laboratory (NSSL) at Fort Collins, Colorado, in the United States. The germplasm stored at NSSL does not become part of the USDA collection, but is stored in sealed boxes in the –20 °C vaults.

As germplasm collections have grown in size, concern has been expressed as to whether the full range of genetic diversity they contain can be effectively utilized (Hodgkin 1991). Recent attention has therefore focused on the development of the concept of a core collection, which was first proposed by Frankel (1984) to rationalize the conservation effort required for a particular crop, and to provide a strategy for the study and evaluation of germplasm collections. Such a core collection should contain the range of diversity of the crop in question, including wild species, and with minimal repetition. It was intended that the core would become the focus of the search for desirable new characters, detailed evaluation, and work on the application of new techniques. However, the development of a core collection does not imply the downsizing of existing genebank collections (Hodgkin 1991). The core collection concept will have particular application for germplasm collections where there has been little study or evaluation, although this is not the case at IRRI. The close association between germplasm curators and users (plant breeders, plant pathologists, etc.) has encouraged the evaluation and use of the germplasm accessions. However, the development of a rice core collection would have relevance for safety duplicate storage. It is convenient to envisage the storage of subsamples representing the diversity of rice ("cores") at several genebanks around the world, instead of the whole collection in one location, as is the case of IRRI's agreement with the National Seed Storage Laboratory.

The identification of accessions to include in a core collection presents a number of difficult problems for the germplasm curator. Although morphological traits may exhibit considerable variation, there are no simple ways of correlating this with overall patterns of genetic diversity. It is believed that the application of molecular markers will overcome many of these problems and at the same time permit the identification of duplicate samples in the collection. IRRI is collaborating with The University of Birmingham, and the John Innes Centre, Norwich, UK, in the evaluation of several molecular techniques to characterize genetic diversity of rice germplasm accessions. In particular, the polymerase chain reaction (PCR)-based technique, random amplified polymorphic DNA (RAPD), and several allied approaches have already provided a useful insight into the nature of rice germplasm accessions selected for the study (Virk et al. 1994).

Seeds placed under *ex situ* conservation in a genebank become isolated from the environments where they originated, and the evolutionary processes which determined their patterns of genetic diversity. Concerns have been raised that static conservation may decrease the adaptive potential of crops and wild species populations in the future. In contrast *in situ* conservation aims to preserve the evolutionary or adaptive potential of species populations, and is particularly appropriate for wild species in their native habitats. However, it is important to point out that where wild species are threatened with extinction in nature, *ex situ* conservation is important for their long-term survival, and at the same time permits scientific study relevant for their conservation and use. *In situ* conservation of wild species is similar to nature conservation, but there are some important differences. Whereas nature conservation may emphasize interspecific diversity, *in situ* conservation for genetic purposes is more concerned with intraspecific variation and the distribution of genetic differences within and between species populations. In this context, therefore, a study of the ecological amplitude of species, of genetic diversity, and the changes in diversity over time are important aspects of *in situ* conservation. With the development of molecular marker techniques it is now possible to study genetic variation at the DNA level and more accurately determine the genetic structure of populations. Despite these developments, there has been surprisingly limited scientific input into *in situ* conservation and the design and management of genetic reserves. As far as wild rices are concerned, there are just a few populations of 10 species that have been reported from 18 reserves in Africa, and South and Southeast Asia (Vaughan and Chang 1992). The widespread distribution of some species as well as the disjunct distribution of others in small populations create special problems for *in situ* conservation. Given the taxonomic uncertainties of the wild rices, the need for biosystematic research is essential (Vaughan 1989), to provide the basic information on the nature of the species to be conserved.

On-Farm Conservation

For more than 20 years *in situ* or on-farm conservation of crop landraces has been dismissed as impractical and inappropriate. However, concern in developing countries about the concentration of genetic resources in genebanks in the industrialized countries, and the fact that static conservation halts evolutionary processes, has opened a debate concerning the value and objectives of on-farm conservation methods. Rural societies maintain agricultural biodiversity because it is essential to their survival. They select and breed new varieties for the same reason. There is no useful distinction for them between conservation and development. Indeed, conservation as such may not be a concept known to farmers. On-farm maintenance of local varieties is an existing strategy for food security. It is a potential strategy for genetic conservation. By its very nature on-farm conservation is dynamic, because the varieties that farmers manage continue to evolve in response to natural and human selection. It is believed that in this way crop populations retain adaptive potential for the future.

Fig While the diversity of rice is most easily observed in the shape, and color of individual grains illustrated in this figure, traditional rices also show diversity for many other traits, such as resistance to pests and tolerance of adverse environmental conditions

Brush (1993) has suggested that besides directly providing genes for crop improvement, on-farm conservation should be seen as satisfying four other needs:

1) It preserves evolutionary processes that generate new germplasm under conditions of natural selection;
2) *In situ* conservation will maintain important field laboratories for crop biology and biogeography;
3) It provides a continuing source of germplasm for *ex situ* collections; and
4) It provides a means for wider participation in conservation, allowing for a more equitable role for nations with abundant crop germplasm resources.

A number of non-governmental organizations (NGOs) are working in community conservation projects in the Philippines, Thailand and elsewhere in Southeast Asia[2)] to conserve the traditional varieties of rice that farmers cultivate (Salazar 1992). However, there has been only limited study of on-farm conservation systems worldwide and many questions remain to be answered about how on- farm conservation can become a viable method for genetic conservation. There is little understanding of the socio- economic and genetic aspects of on-farm conservation. In what way do varieties change over time? Do farmers conserve varieties or conserve traits, such as aroma, plant architecture, or disease resistance, for example? What is the importance of seed exchange among farmers for enriching their germplasm? Why, for example, do some farmers continue to grow their local varieties while others abandon them in favor of improved varieties? What is the degree of outcrossing between varieties in farmers' fields? Many factors affect the spread of varieties in the different rice ecosystems, and research is needed to answer the many biological and socioeconomic questions posed by on-farm conservation.

Biotic stress	*O. sativa* accessions screened	
	No.	% resistant*
Brown planthopper biotype 1	44,335	15.4
Brown planthopper biotype 2	10,053	1.9
Brown planthopper biotype 3	13,021	1.8
Green leafhopper	50,137	2.8
Rice whorl maggot	22,949	3.0
White-backed planthopper	52,042	1.7
Zigzag leafhopper	2,756	10.1
Rice leaf folder	8,115	0.6
Yellow stemborer	15,656	3.8
Striped stemborer	6,881	<0.02
Blast	36,634	26.2
Sheath blight	23,088	9.3
Bacterial blight	49,752	11.1
Rice rugged stunt virus	13,759	2.4
Rice tungro disease severity score	4,473	7.4
Rice tungro disease	15,795	3.5
Total	369,446	

* Based on the differentiation Resistant/Susceptible on the scoring scale

Tab 3 Accessions of *Oryza sativa* evaluated for resistance to 16 biotic stresses by 1993

Broadening the Genetic Diversity

Rice genetic resources stored in genebanks are not museum collections, or at least they should not be. Their value is enhanced through study and identification of important traits (IRRI 1991). Access to germplasm is facilitated by ready access to information about the conserved germplasm and its status, and data management is an extremely important aspect of any genebank's activities. At IRRI, we have recently developed the International Rice Germplasm Center Information System, which is a menu-driven system operating under the ORACLE software. It is accessed through IRRI's local area network, and it is anticipated that eventually access to the data base will be available from remote locations. Such technological developments will enhance significantly the exchange of germplasm and information.

Characterization and evaluation are important, and enhance the inherent value of the conserved germplasm. At IRRI, all conserved germplasm is studied for a range of morphological and agronomic characters, such as plant height, maturity, tillering capacity and grain characters, which facilitate the selection of appropriate germplasm accessions in response to requests from researchers. Evaluation of the materials is carried out by entomologists, plant pathologists, soil scientists, and physiologists to identify genes of use in rice improvement. This link with scientists from other disciplines has been one of the strengths of the germplasm activities at IRRI over more than 30 years.

Scientists at IRRI have effectively studied these materials in the search for resistances to pests and diseases (Tab 3). For some diseases such as rice blast, genetic resistance appears to be relatively common in rice. For others, however, such as grassy stunt virus, it has proved impossible to identify resistant *O. sativa* samples. Recent work at the Institute to identify resistance to grassy stunt virus strain 2 in cultivated rices has been abandoned (IRRI 1994), and the search for resistance genes is now targeted on the wild species. A study of abiotic stresses has also been done. Over 12,300 accessions from the germplasm collections have been screened for submergence tolerance over a 15-year period. Outstanding entries have been used by breeders at IRRI and the national programs (Vergara 1991). Cold tolerance is more complicated since the trait may need to be expressed during different growth stages.

Global Exchange of Germplasm

Another important way in which the diversity of rice is being broadened is through the exchange and selection of different breeding lines and varieties. Since 1975, the International Network for Genetic Evaluation of Rice (INGER), formerly the International Rice Testing Program (IRTP), has facilitated the global exchange of rice germplasm and has distributed more than 19,000 nursery sets to more than 60 countries.

Germplasm nurseries are composed of breeding lines or varieties from different countries, and are tested at many sites worldwide for adaptation, productivity and disease resistance. Through the network, germplasm bred in one country is evaluated and released in another as a new variety, or used as a parental line in a rice breeding program. In addition, through differential varietal reactions in multilocation screening tests, various biotypes and races of major insects and pathogens that attack the rice crop have been identified (Seshu 1991).

INGER nurseries include predominantly improved germplasm, but each year some landrace rice varieties are included in specific nurseries for evaluation against different stresses. Over 500 accessions from the IRGC collection have been included in the multilocation testing program (Seshu 1991).

Over the years, INGER has facilitated the flow and evaluation of rice germplasm between Asia, Africa and Latin America. Since INGER's inception, more than 400 rice varieties have been released through the network. This represents not only an increase in the genetic benefits to the rice crop, but also economic benefits to rice growers and consumers. The economic analysis of INGER made by Yale economists Robert Evenson and Doug Gollin[3)] clearly demonstrates the linkage between genetic conservation of rice landrace varieties and rice improvements (Jackson and Huggan 1993).

The pedigree complexity of improved varieties has increased over the years, with more landrace varieties being used, as well as wild rice species. IR36 illustrates this point particularly well. Compared to IR8, the first of the so-called "miracle rices", which was a hybrid between the Indonesian variety Peta and the Chinese local variety Dee-geo-woo-gen, IR36 contains genes from 15 local varieties and one wild species (Plucknett et al. 1987). The gene diversity within this single variety is high compared to many of its progenitors. Although the adoption of improved varieties has led to genetic erosion of the local varieties, the level of gene diversity has been increased through plant breeding. The development of new varieties, which combine genes for resistance and adaptation from many sources in a single genotype, continues today. Their deployment in farming systems permits breeders and farmers to keep ahead of the numerous stresses that constantly emerge in rice agriculture.

The economic benefits of utilizing conserved rice germplasm to produce improved varieties could easily finance the global network of rice germplasm conservation efforts. Although the trend has been towards genetic uniformity through crop improvement programs, the evaluation, selection and release of germplasm through INGER has tended to counteract this trend, and has increased the diversity of improved rice varieties available to farmers.

Impact of New Technologies on Rice Biodiversity

Today there are other issues that affect the survival of the diversity of rices, and access to these genetic materials. The increasing application of biotechnology, of plant breeders' rights, and even the patenting of genes are all factors that will affect access to germplasm. With respect to the genetic resources of rice, all nations have benefited from free access to and exchange of germplasm. IRRI does not claim ownership of the rice germplasm conserved in the genebank. On the contrary, the germplasm is held in trust for all nations, and particularly the poor farmers in those countries where the material originated. As trustee of the germplasm, a status accepted by the other international centers of the Consultative Group on International Agricultural Research (CGIAR), IRRI has a policy, approved by the Institute's Board of Trustees in September 1994 (see Box), which clearly states that no intellectual property protection on the designated germplasm will be sought.

The Convention on Biological Diversity[4)] came into force at the end of December 1993. *Ex situ* germplasm collections acquired before that date are not covered under the terms of the Convention. This has clearly been a cause for concern in some quarters, as is the legal status of international collections such as that at IRRI. Along with the other CGIAR centers with germplasm collections, IRRI has concluded an agreement with the Food and Agriculture Organization of the United Nations (FAO) to place its collection under the auspices of FAO in an international network of germplasm collections, and under which the trusteeship concept will be recognized by this intergovernmental body.

Nations have sovereign rights over their germplasm. There is concern that the implementation of intellectual property rights (IPR) may limit access to germplasm by its originators, the farmers who have selected and guarded germplasm for generations. The involvement of the private sector in plant breeding and biotechnology will undoubtedly lead to an expansion of IPR on germplasm derivatives - improved varieties and breeding lines. As yet, the involvement of the private sector in rice improvement is somewhat limited compared to wheat and maize for example. However, the rapid development of biotechnology in rice, coupled with the genome mapping initiatives in the USA and Japan, make rice a likely target for greater private sector involvement in the future. What will be the impact on rice genetic resources, their use and exchange? Clearly, the coming-into-force of the Convention on Biological Diversity has changed the ground rules for access to germplasm. Even though the Convention had been ratified by more than 50 nations by mid 1994, IRRI must follow the spirit of the Convention when making germplasm available to both public and private sector collaborators, and ensure that there are no opportunities for anyone to obtain monopoly rights over genes or genotypes from the germplasm collection.

There has been considerable controversy concerning the patent on transgenic cotton awarded to the US-based company Agracetus (Mestel 1994). Such broad "species" patents threaten not only access to technology, but have profound implications for the exchange and use of germplasm. In Europe the same company has filed a patent application on transgenic rice (Pat Roy Mooney, pers. comm.). If such a broad "species" patent is approved, then the opportunities for the developing nations where rice originated to have access to this technology through IRRI could be seriously hampered. Further development of policies that restrict the flow of germplasm between nations may have a serious impact on rice agriculture. The benefits of sharing germplasm and technology can be seen in its impact on rice production, particularly in Asia. Collaborative efforts to conserve and use rice germplasm have played an important role in feeding the growing populations in Asia, and elsewhere.

Complementarity between national and international germplasm conservation efforts must continue, not only to ensure the long-term preservation of rice genetic resources, but also to permit the study and use of this valuable biodiversity for the benefit of all peoples.

The Policy of the International Rice Research Institute on Intellectual Property Rights and Rice Genetic Resources

1. The rice genetic resources maintained in the genebank at IRRI are held in trust for the world community.
2. IRRI adheres to the principle of unrestricted availability to the rice genetic resources it holds in trust (except germplasm held under "black box storage" on which the donor of the germplasm has placed distribution restrictions) including related information.
3. IRRI will not protect the rice genetic resources it holds in trust by any form of intellectual property protection.
4. IRRI is opposed to the application of patent legislation to plant genetic resources (genotypes and/or genes) held in trust.
5. The rice genetic resources held in trust by IRRI will be made available on the understanding that the recipients will take no steps that restrict their further availability to other interested parties.

Endnotes

[1] The Commission endorsed Genebank Standards (CPGR/93/5 Annex) that had been prepared by an FAO/International Plant Genetic Resources Institute (IPGRI) expert group so that they might "acquire universal value and be more easily adopted by countries." See Diversity 9(1&2), 4-6 (1993)

[2] The Farmer-Scientist Participation for Development (MASIPAG) and the Sustainable Agriculture Coalition are working in the Philippines, while Technology for Rural and Ecological Enrichment (TREE) is based in Thailand. The South East Asia Regional Institute for Community Education (SEARICE) is involved in a project in the Mekong Delta in Vietnam.

[3] This 1992 study of germplasm dispersal examined data on the rice varieties released in 18 countries (1965-90). Almost 400 varieties were borrowed - developed in one country and released in another. These varieties were made available through INGER. The diversity of varietal pedigrees has increased over the years, indicating a greater awareness and use of the genetic resources of rice. From 1988 to 1992, 58 entries in INGER nurseries originating from 13 national breeding programs, IRRI, the International Institute of Tropical Agriculture (IITA) in Nigeria, and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia, were released as varieties in 18 countries in Asia, Africa, and Latin America.

[4] The Convention on Biological Diversity was signed by more than 160 countries at the UNCED Conference (Earth Summit) held in Rio de Janeiro in July 1992. Mauritius was the first nation to ratify the Convention on 4 September 1992, and Mongolia became the 30th nation on 30 September 1993. Ninety days after, on 29 December 1993, the Convention became a legal instrument. Although its articles are legally binding only on those nations that have ratified the Convention, the spirit of the Convention will undoubtedly influence the nature of conservation efforts globally, and the access to genetic resources and improved technologies. The Convention recognizes the sovereign rights of nations over their own biodiversity, including plant genetic resources.

References

Brush, S. B.: *In situ* conservation of landraces in centers of crop diversity. Paper presented at the Symposium on Global Implications of Germplasm Conservation and Utilization at the 85th Annual Meetings of the American Society of Agronomy, November 8, 1993, Cincinnati, Ohio 1993.

Chang, T.T.: The rice cultures. Philosophical Transactions of the Royal Society of London B. 275, 143-157 (1976a)

Chang, T.T.: The origin, evolution, cultivation, dissemination, and diversification of Asian and African rices. Euphytica 25, 425-441 (1976b)

Chang, T.T.; Vaughan, D.A.: Conservation and potentials of rice genetic resources. Biotechnology in Agriculture and Forestry 14, 531-552 (1991)

Ford-Lloyd, B.; Jackson, M.: Plant genetic resources: an introduction to their conservation and use. Edward Arnold, London 1986.

Frankel, O. H.: Genetic perspectives of germplasm conservation. In: Arber, W.; Llimensee, K.; Peacock, W.J.; Stalinger, P. (eds.), Genetic manipulation: impact on man and society, 161-170. Cambridge University Press, Cambridge 1984.

Glaszmann, J. C.: A varietal classification of Asian cultivated rice (*Oryza sativa* L.) based on isozyme polymorphism. In: Rice Genetics: Proceedings of the International Rice Genetic Symposium, 83-90. International Rice Research Institute, Los Baños, Philippines 1985.

Guldager, P.: *Ex situ* conservation stands in the tropics. In: Roche, L. (ed.), Methodology of Conservation of Forest Genetic Resources. Food and Agriculture Organization, Rome 1975.

Harlan, J.R.; De Wet, J.M.J.: Toward a rational classification of cultivated plants. Taxon 20, 509-517 (1971)

Hodgkin, T.: Improving utilization of plant genetic resources through core collections. In: Rice Germplasm; Collecting, Preservation, Use, 99-103. International Rice Research Institute, Los Baños, Philippines 1991.

International Rice Research Institute: Proceedings of the Workshop on the Genetic Conservation of Rice. IRRI, Los Baños, Philippines 1978.

International Rice Research Institute: 1983 Rice Germplasm Conservation Workshop. IRRI, Los Baños, Philippines 1983.

International Rice Research Institute: Rice Germplasm; Collecting, Preservation, Use. IRRI, Los Baños, Philippines 1991.

International Rice Research Institute: Annual Report for 1993. IRRI, Los Baños, Philippines 1994.

Jackson, M.; Huggan, R.: Sharing the diversity of rice to feed the world. Diversity 9(3), 22-25 (1993)

Khush, G. S.: Modern Varieties - their Real Contribution to Food Supply and Equity. GeoJournal 35.3, 275-284 (1995)

Khush, G. S.; Brar, D. S.; Zapata, F. J.; Nelson, R.; McCouch, S; Bottrell, D. G.: Biotechnology for rice improvement. In: Focused plant improvement - towards responsible and sustainable agriculture. Proceedings of the Tenth Australian Plant Breeding Conference, Gold Coast, 258-279 (1993)

Lando, R. P.; Solieng Mak: Cambodian farmers' decision making in the choice of traditional rainfed lowland rice varieties. IRRI Research Paper Series 154 (1994)

Mestel, R.: Rich pickings for cotton's pioneers. New Scientist 1913, 13-14 (1994)

Plucknett, D.L.; Smith, N.J.H.; Williams, J.T.; Anishetty, N. Murthi: Gene Banks and the World's Food. Princeton University Press, Princeton, New Jersey 1987.

Salazar, R.: Community plant genetic resources management: experiences in Southeast Asia. In: Cooper, D.; Vellvé, R.; Hobbelink, H. (eds.), Growing Diversity. Intermediate Technology Publications, London 1992.

Second, G.: Isozymes and phylogenetic relationship in *Oryza*. In: Rice genetics: Proceedings of the International Rice Genetics Symposium, 27-39. International Rice Research Institute, Los Baños, Philippines 1985.

Second, G.; Wang, Z.Y.: Mitochondrial DNA RFLP in genus *Oryza* and cultivated rice. Genetic Resources and Crop Evolution 39, 125-140 (1992)

Seshu, D.V.: Evaluating germplasm for resistances and tolerances - multilocation evaluation. In: Rice Germplasm; Collecting, Preservation, Use. IRRI, Los Baños, Philippines 1991.

Swaminathan, M. S.: Beyond IR36 - Rice Research Strategies for the 80s. Paper presented at the International Centers' Week, World Bank, November 10, 1982, Washington, DC 1982.

Teng, Shengxiang: Rice remains from Neolithic Age excavated in China. International Rice Research Notes 19, 4 (1994)

Vaughan, D. A.: The genus *Oryza* L. current status of taxonomy. IRRI Research Paper Series 138 (1989)

Vaughan, D. A.; Chang, T.T.: *In situ* conservation of rice genetic resources. Economic Botany 46, 368-383 (1992)

Vaughan, D. A.; Sitch, L. A.: Gene flow from the jungle to farmers. BioScience 41, 22-28 (1991)

Vergara, B. S.: Evaluating germplasm for resistances and tolerances - abiotic stresses. In: Rice Germplasm; Collecting, Preservation, Use. International Rice Research Institute, Los Baños, Philippines 1991.

Virk, P. S.; Ford-Lloyd, B.V.; Jackson, M.T.; Newbury, H. J.: The use of RAPD for the study of diversity within plant germplasm collections. Heredity (in press) (1994)