PN-AAQ-743

ISN 36074

THE CONSERVATION AND USE OF RICE GENETIC RESOURCES

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I. INTRODUCTION

A. Increasing Importance of Rice

Rice and wheat share equal importance as the world's staple cereals. Rice is the primary source of energy and protein for 4.5 billion people in the most populous nations of Asia. Rice is a secondary staple for another 450 million people. The demand for rice is rapidly rising in Africa and Latin America. The order of preference is rice, corn, yam, and cassava. However, the average annual income of rice consumers in the developing nations is less than $200.

Rice produces more calories and carbohydrates per hectare than any other cereal under normal production practices. Its protein yield per unit of land and amino acid balance among the cereals are only below those of oats (Lu and Chang, 1980).

Despite significant increase in the rice yields of Bangladesh, China, Colombia, India, Indonesia, Korea, Pakistan, Philippines, and Sri Lanka since the advent of the high-yielding semidwarfs and the associated production technology beginning in the late 1960s, the world's supply of rice continues to lag behind the demand. First, the production of rice in the developing nations from 1967 to 1975 rose only at a rate of 2.4% a year while the population increased at 2.5%. Recent trends in crop production suggest that the developing countries may find it difficult to maintain the same rate of growth in production (IFPRI, 1977). Second, the developing countries have been suffering from a deficiency of 4–5% per capita in the daily energy supply (Zwartz and Hautvast, 1979). It would be a tremendous task to make up this deficit even if the world's population were to stay at the present level.

The projected increase in food consumption of the food-deficient developing countries between 1975 and 1990 will amount to 241 million metric tons at low rates of increase in per capita income. The increase would represent about two-thirds of the 1975 consumption level. About 182 million tons are needed to meet

the increased need due to population growth. For all developing countries, increased consumption above the 399 million tons of 1975 would range between 262 and 286 million tons, of which 200 million tons would be due to population growth. Asia would bear the largest share of the projected increase in consumption between 1975 and 1990: about 48% (IFPRI, 1977).

Because of limited arable land area in Asia, future increase in food production will depend largely on increases in crop yield or cropping intensity as experienced during the last two decades. Considerable areas of uncropped or marginal production may be brought into rice cultivation, but serious climatic, hydrologic, or edaphic constraints generally exist in such areas. For Asian countries, the production increase of cereals would have to surpass the 1960–1970 rate of 2.5% in order to meet the projected increase in consumption.

For Africa and Latin America, a brighter prospect looms as a potential expansion in production area is feasible, although the per capita consumption of rice will also continue to rise (IFPRI, 1977).

Rice will continue to make up nearly one-half of the major staples in Asia: about 30% for all developing countries (IFPRI, 1977). Therefore, it is imperative that the increase in rice production be sustained through improved yield or stabilized production or both. At places where the growing season permits, increasing the number of rice crops planted in a year offers another means of augmenting rice production.

B. Comparative Late Start in Rice Breeding and Conservation

Recorded history may not mention man's earliest efforts to improve the rice plant. However, long before the advent of science, man undoubtedly had made good use of natural variability in the crop and its wild relatives, spontaneous mutations, natural hybrids, and introductions from foreign lands. Susrutha (ca. 1000 B.C.), in his Ayurvedic "Materia Medica," recognized the differences among rices existing then in India and separated them into groups based upon their growth duration, water requirements, and nutritional values (Ramiah and Rao, 1953). Chinese classics show that Emperor Wen Ti of the Wei Dynasty (A.D. 186–226) discussed with his cabinet staff about a quality rice having strong and fragrant aroma. Another emperor, K'ang Hsi (1662–1723) of the Ching Dynasty, selected an early maturing and aromatic mutant for a crop of rice grown in the imperial garden which later became the main staple of his household. The new strain was named "Imperial Rice." The large scale introduction, testing, and extension of the early maturing Champa rices in central and east China during the eleventh century marked the first massive government-sponsored efforts to utilize efficient and productive genotypes (Chang and Li, 1980).

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On the other hand, rice has a relatively short history of scientific improvement when compared to wheat. The first rice variety bred by hybridization, "Omini-shiki," was developed in Japan around 1906. In tropical Asia, breeding began in the 1950s. Genetic conservation of the crop began even later. Conservation efforts gained momentum in the mid-1960s.

A combination of the late start in both plant breeding and genetic conservation led to the situation in the early 1960s that tens of thousands of rice cultivars were grown by Asian farmers over vast rice lands.

Rice breeding in the United States was started in a minor way early in the twentieth century. The program at the start consisted of introducing a few rice cultivars from foreign countries and growing them in small plots in farmer fields in Louisiana and later in California. Selections were made from these plantings by federal and state agriculturists and by local farmers. Some selections from these introductions were increased and quite widely grown for several years. Cultivars selected by farmers included "Blue Rose," "Early Prolific," "Edith," and "Lady Wright." Some of those selected by government personnel included "Fortuna," "Nira," "Rexoro," "Colusa," and "Caloro." These cultivars were widely grown until they were gradually replaced by improved cultivars that were developed after about 1935. However, Colusa and Caloro were still of major importance in California through the late 1960s.

The rice-breeding program initiated in the United States was a cooperative endeavor of the U.S. Department of Agriculture (USDA) and State Agricultural Experiment Stations. These projects were expanded by the addition of personnel in Louisiana and California about 1915. The work was further expanded by the hiring of federal rice breeders in Arkansas, Louisiana, and Texas in 1931.

Rice was a minor crop in the United States in the earlier years, thus more funds and personnel were assigned to breeding the major cereals than were allotted for rice breeding. As a result, more comprehensive programs were established for wheat, corn, barley, and oats than for rice breeding, so rice improvement was much delayed. The conservation of rice germ plasm also was much neglected in the earlier years. This was due to the meager number of cultivars available and the lack of personnel and storage facilities.

C. Importance of Genetic Resources to Rice Improvement

Crop researchers generally recognize that a wealth of genetic resources provides the building blocks for effective crop improvement. In the case of rice, the germ plasm of the two cultigens (Asian and African rices) is unusually rich in genetic diversity, much of which remains to be tapped. Until a decade or two ago, the full spectrum of germ plasm in the genus *Oryza* (see Chang, 1979) could

be readily found in their indigenous habitats and was available to rice researchers.

The rich diversity in rice stemmed largely from its wide geographic dispersal and ecogenetic diversification. Among major food crops rice is one of the few staples which are continually expanding into new production areas. Rice can be grown in vast uncropped areas in Africa and Brazil. Rice is also being grown experimentally at numerous locales where irrigation water is available, but cool temperatures and blast disease at high elevations are major constraints. Numerous requests for seed recently received at the International Rice Research Institute (IRRI) for deepwater rices indicate another trend in area expansion. Moreover, in South and Southeast Asia large tracts of land can be brought into profitable rice production if the adverse soil factors such as salinity and acidity are overcome by adequate levels of cultivar tolerance and soil management.

The rich diversity in rice presents great promises for rice researchers to alleviate the various production constraints, most of which are known while a few more remain to be identified. As rice expands into new areas, new environments will present challenges to the research community. Among cereals that can be grown in a new area of cultivation, rice has the unique advantage over other staples in that it can thrive in flooded or waterlogged soils. Thus, rice will continue to be the main staple of numerous subsistence farmers in the humid tropics and subtropics.

The rapid spread of the high-yielding semidwarfs since 1966–1967 has greatly narrowed the genetic base of the rice crop. The preservation and use of the diverse germ plasm in rice is not only vital to the further improvement of the crop but also serves as a means to safeguard the crop against its vulnerability to attack by diseases and insects which is imminent because of the genetic uniformity among rice cultivars.

It has been estimated by plant physiologists that the maximum yield potential of rice in the tropics may be as high as 15.9 tons/ha for a single crop in the dry season and 9.5 tons/ha in the wet season (Yoshida and Oka, 1981). Yield was 25.65 tons/ha total for a four-crop experiment (Yoshida *et al.*, 1972). The estimate is certainly much higher than the 11.7-tons/ha record obtained at IRRI (De Datta and Malabuyoc, 1976).

Moreover, the yield potential of the current improved rices far exceeds the yield levels being obtained on the farms of tropical Asia (cf. IRRI, 1977, 1979). The main biological constraints are lack of resistance to insects and diseases, resistance to drought, and competitiveness with weeds. The biological constraints attributable to insects and weeds are being tackled by rice researchers. On the other hand, the socioeconomic constraints related to land tenure, availability of capital, infrastructure, government pricing policy, technical know-how, and traditions require the concerted efforts of the farmers, private indus-

tries, and government sectors to remove a portion of the limiting factors. Coordinated efforts in such directions would undoubtedly raise farm yields.

II. DIVERSITY IN RICE GENETIC RESOURCES

The genetic diversity existing in rice germ plasm is amazingly enormous. The 2 cultigens and 18 wild species of the genus *Oryza* are not only widely distributed (Chang, 1976a) but also represent an extremely ancient grass in the plant kingdom (Stebbins, 1971). Evidence on the diversification process is presented as follows:

A. Gondwana Origin of the Genus and Evolutionary Pathway

The pan-tropical and widely scattered distribution of the 18 wild species in the genus covers Africa, Asia, Australia, and Central and South America (cf. Chang, 1976a, for their geographical distribution). The dispersal pattern has intrigued many botanists and geneticists since the nineteenth century and has given rise to divergent hypotheses about the progenitors of the two cultigens (*O. sativa* L. and *O. glaberrima* Steud.) and the centers of origin for the genus. Thus, various workers postulated that *O. sativa* was derived from *O. fatua* Koenig, *O. perennis* Moench, *O. officinalis* Watt, or *O. minuta* J. S. Presl: (see summary in Chang, 1964), which are distinct taxa involving different genomes and ploidy levels. Roscheviez (1931) postulated Africa as the center of origin for the section *Sativa* Rosch., to which both *O. sativa* and *O. glaberrima* belong. Oka (1977) has lumped the ancestral forms of the two cultigens into one species-complex, *O. perennis* Moench.

Chang (1976a,c,d) has pointed out that the geographical distribution of the wild species strongly suggests the Gondwana (Gondwanaland) supercontinent as the original habitat of the genus. The pantropical distribution of the *Oryza* species lies within the Paleozoic regions of the fossil fern Glossopteridae (Melville, 1966): the latter is believed by many botanists to be one of the principal progenitors of the angiosperms. Thus, the distant progenitors of the *Oryza* species had likely differentiated before the Cretaceous period. When the known genomic symbols of 15 *Oryza* species are placed by their present locations, they match well with their adjoining positions on the Gondwana components (Chang, 1976d).

Fracture and drift of the major Gondwana components led to separate entities which are now known as Africa, Antarctica, Australia, Malagasy, South Amer-

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ica, and South Asia along with its associated portion of Southeast Asia. The geological changes can readily explain the finding of the immediate wild relatives of the two cultigens (all of which have the A genome) present in Africa, Asia, Australia, and South America. Because human activities in cultivation and selection began early in Africa and Asia, the cultigens evolved at least 7000 years ago, while in Australia and South America only the wild forms are found (Chang, 1976c).

As in other cereals, the evolutionary pathway of the two rice cultigens may be conceptualized as: wild perennial → wild (prototype) annual → cultivated annual. The evolutionary trend was parallel and independent for the African and Asian rices, but the Asian cultigen was further differentiated into three ecogeographic races. Detailed discussions were provided by Chang (1976c).

B. Diversity in *O. sativa* and Its Wild Relatives

The rich diversity found in the Asian rices is probably unparalleled in other crop plants. Dispersal and selection by man have extended rice cultivation from the banks of the Amur River (53° north latitude) on the Sino-Russian border to central Argentina (40° south latitude). As the tropically based and semiaquatic plant was introduced into the cooler regions to the North or the high elevation areas of the tropics and subtropics, ecogenetic differentiation and human selection have greatly intensified the diversification process.

Cultivation in different soil-and-water regimes led to extreme types which are adapted to pluvial (rainfed-dryland), phreatic (wetland) or fluxial (deepwater) conditions. Varietal sensitivity to photoperiod and temperature regimes at different growth stages became markedly divergent along latitudinal and altitudinal inclines. In the Ganges River delta, crops for three seasons (winter, summer, and autumn) evolved to fit into varying water and temperature regimes. Such variety groups are known as "boro," "aus," and "aman," respectively. Rice cultivators' personal preferences and socioreligious traditions have further added morphologic diversity to the cultivars (Chang, 1976c; Chang and Oka, 1976; O'Toole and Chang, 1979).

Undoubtedly natural crossing between land races followed by differentiation and both natural and human selection have accelerated the diversification process. The rich diversity of the land races found in their native habitats of Bangladesh, Indonesia, and Sri Lanka has been described by Vaughan and Chang (1980).

The wild perennial (*O. rufipogon* Griff.) and the wild annual (*O. nivara* Sharma et Shastry) relatives of *O. sativa* are generally found in the humid tropics of Asia. The wild forms have retained a high rate of natural crossing (5–40%) which enabled the populations to maintain their diverse and heterozygous com-

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position (Oka and Morishima, 1967). However, the wild rices do not have the extreme range of adaptation to dryland or deepwater conditions found in the Asian cultivars (Chang *et al.*, 1977).

Intercrossing among the wild perennial, wild annual, and the cultigen has produced numerous intergrades which could be conveniently grouped as the *spontanea* forms of *O. sativa* or the weedy annuals (Chang, 1976a,b). Hybridization among the four types in areas where they coexist continues to add genetic diversity to the hybrid swarms. Their dispersal is assisted by flowing water and seed exchange of the contaminated cultivars.

Scientific plant breeding in many rice-growing countries has further enriched the diversity of the cultivars. In recent decades it has become increasingly difficult to classify rice varieties into their ecogeographic races (Indica, Sinica or Japonica, and Javanica) by their morphologic traits or grain characteristics. Many United States and Korean cultivars belong to this intermediate category.

C. Diversity in *O. glaberrima* and Its Wild Relatives

The African cultigen also contains great diversity. *O. glaberrima* is found in a full range of water regimes varying from dryland to deepwater conditions (Porteres, 1956; Oka, 1974). On hydromorphic soils the African rice is a self-perpetuating crop in admixture with other grasses and bushes. But its total range of diversity is less than that of *O. sativa*. The smaller magnitude of varietal diversity in *O. glaberrima* as compared to *O. sativa* may be traced back to a low population density, a narrow north-to-south distribution, a rather flat topography, and a dearth of iron farm implements, irrigation facilities, and draft animals in Africa since the dawn of civilization (Chang, 1976c). With the rapid expansion of the Asian rices in the favorable areas of Africa where progressive agriculture is practiced, *O. glaberrima* has been frequently reduced to the status of a weed race in fields planted to *O. sativa* (Moormann and Van Breemen, 1978). As a result of natural crossing between the two cultigens, an increasingly large proportion of *O. glaberrima* samples has lost their typical features (glabrous leaves and hulls) and meanwhile acquired a few other *O. sativa* characteristics (Chang *et al.*, 1977).

The wild perennial *O. longistaminata* A. Chev. et Roehr. is widely distributed in Africa, strongly rhizomatous, and incompatible upon self-fertilization. The wild annual (*O. barthii* A. Chev.) is quite diverse in morphologic and electrophoretic properties, probably exceeding that of the African cultigen but less than that of *O. sativa* (Bezancon *et al.*, 1977). Intercrossing among the three African taxa has given rise to a weedy race known as *O. stapfii* (Chang *et al.*, 1977).

III. RECENT EFFORTS IN GENETIC CONSERVATION

A survey made in 1970–1971 indicated that agricultural research centers of major rice-producing countries had made varying attempts to assemble and conserve the indigenous rice cultivars shortly after World War II. Commercial varieties in the readily accessible areas were the main target in field collection. Minor varieties in the remote areas and wild rices in their natural habitats were largely overlooked, however (Chang, 1972a).

Systematic collection efforts in tropical Asia were initiated when the high-yielding varieties spread quickly from 1967 to 1970 and threatened to replace numerous traditional (unimproved) varieties in the irrigated areas. Several national centers joined IRRI, USDA, USAID, and the Rockefeller Foundation country programs in developing plans for field collection. Systematic plans were formulated at the Rice Breeding Symposium held in 1971 and the IRRI–IBPGR (International Board of Plant Genetic Resources) Workshop on the Genetic Conservation of Rice convened in late 1977, both of which were hosted by IRRI (IRRI, 1972, 1978b). One hundred rice breeders present at the 1971 Symposium requested IRRI to initiate and coordinate field collection activities (IRRI, 1972).

Priority for implementation and for IRRI's participation in a country program is based on:

1. The rate at which improved cultivars replace local or traditional varieties
2. The richness of genetic diversity and the range of environments within countries or areas
3. The time and extent of past collection and preservation efforts
4. The accessibility of potentially rich germ plasm areas to field collectors
5. The extent of local (in-country) support for collection
6. Funding from an outside source

Thus, the high-priority areas have been Bangladesh, Burma, Southwest China, India, Indonesia, Kampuchea, Laos, Philippines, Sri Lanka, and Vietnam. Fortunately, flexibility and opportunities in timing have enabled IRRI to work cooperatively with most of the countries mentioned (Chang, 1980).

A. Status of Genetic Conservation in the United States

No species of *Oryza* including the Asian cultigen (*O. sativa* L.) are indigenous to continental United States. As a result, all the materials in the USDA collection are foreign introductions or lines derived from them. In the earlier years the only

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material received was seeds sent to the United States by embassy personnel or collected by plant explorers who were interested primarily in collecting other crops. It was not until about 1926 that J. W. Jones, then the USDA rice breeder in California, made a trip to Asia and collected seeds of leading commercial and experimental rice varieties in Japan, China, and Indonesia. Through contacts made by Mr. Jones, he continued to receive new varieties from rice breeders in the countries he visited. For a few years immediately following World War II many agricultural scientists were on temporary assignments in Asia and collected rice seeds and sent them to the USDA. From this source United States rice workers received seeds of many varieties from China, Japan, Korea, Taiwan, and some Middle East countries.

In the early years of this century United States agricultural personnel stationed in the Philippines sent seeds of many of the commercial rice varieties to the United States. In recent years the USDA has sponsored rice collection programs in Assam State in India and in Pakistan. Seeds of the varieties collected were sent to the United States and to IRRI, in addition to being added to the rice collections in the country of origin.

Until about 1957 no rice seed storage facility was available in the United States so the seed had to be regenerated frequently to retain viability. Because of this condition many entries were lost and the genetic structure probably was altered for some entries. In 1957 a medium-term storage facility was established at the Beltsville (Maryland) Research Center, and soon after that the National Seed Storage Laboratory (NSSL) was established at Fort Collins, Colorado. Space was made available in both of these facilities for rice storage. Since these facilities were established, it has been possible to retain viable seed on a somewhat more reliable basis than in earlier years. A recent check of the material in the USDA rice collection illustrated this fact. Of the varieties received before 1919, less than 7% are still in the collection; of those received from 1919 to 1933 about 9% are still available; of those received from 1934 to 1948 about 37% are still available; but of those received after 1948 practically all were in the collection. Most of the accessions introduced recently but not now in the collection are for the most part long-season, daylength-sensitive, tropical cultivars. The number of entries in the United States rice cultivar and genetic stocks collections is now in excess of 13,000. Included in this number are all cultivars that have been grown commercially in the United States. The accessions in the USDA collection were received from about 75 countries throughout the world. The USDA collection is probably deficient in land races and wild species of *Oryza* and some of the long-season tropical types. However, this collection does contain a fairly good representation of the rice germ plasm of most countries.

In 1962–1963, seed of all varieties in the USDA rice collection were sent to IRRI for testing and inclusion in the genetic stocks collection at that institution. Since then all new entries in the USDA collection have been sent to IRRI. In

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turn, USDA also has received all released varieties and many experimental lines from IRRI.

Since about 1963 small quantities of seed of all entries in the USDA rice collection have been stored in the NSSL. Small samples of seed of most varieties in the IRRI collection also are stored in the facility at NSSL.

The introduction of rice seed for growing in rice-producing areas of the United States is restricted by a federal law. Before about 1968, all rice introductions were grown in a greenhouse at Arlington Farm Virginia or at the Beltsville Research Center (Cooper, 1976). Starting in 1968 a cooperative arrangement was developed with the California Agricultural Experiment Station to grow new introductions at the Imperial Valley Field Station at El Centro (Lehman *et al.*, 1970). This location is far removed from commercial rice-production areas. Before planting at this location the introduced seeds were treated in hot water and with pesticides to reduce the risk of introducing diseases, nematodes, or insects. Recently another method for introducing seeds by cooperating research stations has been developed. Under this arrangement a qualified plant pathologist can obtain an official permit from USDA Plant Quarantine officials to import seed to his location. The introduced seeds are treated as above, then dehulled and the hulls burned, the naked seeds sterilized and then seeded in pots isolated in the greenhouse. The seed produced from these isolated plants then can be seeded in the field, provided the greenhouse plants remain healthy.

For the past two to three decades rice researchers have been requesting additional funding, facilities, and qualified personnel to properly maintain and classify the entries still available in the USDA Rice World Collection and to computerize the available data. Progress has been slow, but Oakes (1980) reported that some additional space in a rejuvenated USDA laboratory recently had been provided for improved storage of rice germ plasm at Beltsville. In addition, available data are being computerized for more ready access. More recently (A. J. Oakes, personal communication, May 1982) word was received that the rice germ plasm (USDA Rice World Collection) has been consolidated with and made a part of the USDA Small Grains World Collection at Beltsville.

The National Plant Genetic Resources Board (NPGRB) (1979) in a report to the Secretary, USDA, described a seven-phase program for conserving and using plant genetic resources and stated as follows: "The program includes plant introduction, classification, screening, basic genetics, developmental research, applied research, and finally production of seeds of improved cultivars for sale to farmers." In discussing this program they further stated:

> This seven-phase program represents an outstanding example of State, Federal, and private industry cooperation and planning. The program has been and continues to be extremely successful, but it tends to receive low priority ratings in the budget process in spite of the fact that it is fundamental to all agricultural missions. Plant germplasm resources and their use are central to a multitude of national goals, including increasing exports, boosting farm income and enhancing the

national economy; protecting the environment; conserving energy; helping with soil conservation; minimizing cost of food; providing safe, nutritious food; developing pest-resistant crops and crops better adapted to less favorable environments; and minimizing cost of building materials and other forest products.

This NPGRB report cites a "white paper" by several outstanding crop scientists who caution that well-proven plant-breeding methodologies that make use of the variability existing in domestic and exotic germ plasm must not be discarded for the more glamorous "genetic engineering." They state that genetic engineering is a potentially useful tool that must concurrently employ plant-breeding techniques if it is to be effectively applied. They contended that plant germ plasm conservation and use and conventional plant breeding do not now receive the high priority in research funding that they deserve.

Reports by P. R. Mooney (1980) and by the Comptroller General of the United States General Accounting Office (1981) review the United States germ plasm conservation programs and offer suggestions for improvement. Many of the suggestions are good but, for the most part, only reiterate what researchers have been proclaiming for many years.

B. Status of Conservation by Other National and Regional Centers

The following is a survey on the status of genetic conservation in major rice-producing countries or by regional centers based mainly on the proceedings of the 1977 IRRI–IBPGR Workshop on the Genetic Conservation of Rice (IRRI, 1978a).

1. Bangladesh

Varietal diversity was rich in Bangladesh because the boro, aus, and aman types were grown in three seasons over different hydrological regimes. Dryland rices are also found in the hilly tracts.

Assemblage of farmers' varieties began in 1911 when an economic botanist was appointed by the East Bengal Department of Agriculture at Dacca. Workers of the former Agricultural Research Institute collected thousands of cultivars from 1918 to 1960. Purification, selection, and removal of duplicate samples reduced the total number to 1442 entries. A substantial portion of the collection was of the aus type which is the summer crop. Since 1972 about 2450 samples were collected in collaboration with IRRI. Local efforts brought together 2780 more samples. The collection phase is being continued by the staff of the Bangladesh Rice Research Institute and extension workers.

Replacement of traditional varietjes was much greater in the aus and trans-

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planted-aman varieties than in the broadcast-aman (deepwater) and boro varieties because breeding efforts for the latter categories have been small.

2. *Burma*

Rice lands extend from 10 to 28° north latitude and include many distinct ecotypes. About 736 accessions were maintained by the rice experiment stations. During 1973–1974, 1100 samples were gathered from the less accessible areas with the cooperation of IRRI and local extension workers. This was followed by local efforts, and 960 more samples were collected from 1975 to 1980.

The rate of replacement by improved cultivars is rather slow, but many hilly areas along the border remain inaccessible to the field collectors.

3. *China*

Rich diversity existed in China as rice cultivation dated back to 7000 years ago or even earlier, and the production areas extend from tropical Hainan Island to the Amur River at 53° north latitude. The temperate race Keng (Sinica or Japonica) was differentiated inside China. Three wild species are found in China (Lu and Chang, 1980).

Thousands of farmers' varieties were assembled before World War II and many samples were purified. About 710 samples were sent by the National Agricultural Research Bureau staff to the USDA in the late 1940s.

In the early 1950s, China began a massive campaign to collect, conserve, and use its vast crop genetic resources. Between 1955 and 1958, about 40,000 rice samples were gathered from various provinces and maintained by each province concerned. During the Cultural Revolution (1967–1976) a number of seedstocks were lost due to lack of rejuvenation. About 33,000 samples remained mostly in small seed quantities. The national Crop Germ Plasm Resources Institute was established in 1978. It holds the regional rice collection of 2500 accessions for North China and aspires to be the national depository for crop germ plasm (Rockefeller Foundation, 1980).

Field collection efforts were renewed in 1979. A team canvassed extensively in the hills of Yunnan province in the southwest where Indica and Sinica races are distributed along altitudinal clines (Ting, 1961).

The Taiwan Agricultural Research Institute separately maintains a rice collection of about 2500 accessions, of which 1662 are Chinese varieties originating from the mainland or from Taiwan.

The replacement of traditional varieties on the mainland had been rapid since the semidwarfs were developed during 1959–1963 and the F_1 hybrids were extensively grown in 1978. On the island of Taiwan, traditional varieties of the Indica type practically vanished after Taichung Native 1 was released in 1961. The wild rices became extinct in the 1970s.

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4. *India*

Rice lands cover a vast array of ecological niches, and the diversity of germ plasm, both cultivated and wild, is enormous.

An assemblage of farmers' varieties began in 1911 when an economic botanist for rice and other crops was appointed at the Paddy Experiment Station of Madras State at Coimbatore. The Coimbatore station also served as the central depository for rice until the Central Rice Research Institute (CRRI) was established in 1946. Since 1929 the Indian Council of Agricultural Research (ICAR) has assisted the states of Bihar, Orissa, Madhya Pradesh, and Uttar Pradesh to add rice botanists to their agricultural departments. The rice botanists made the early collection of local varieties for breeding purposes (Parthasarathy, 1972). By 1946–1947, about 2000 varieties were assembled.

During the early 1950s CRRI was designated by FAO as the regional center for Indica varieties. Hundreds of foreign varieties were assembled by CRRI for use under the FAO Indica/Japonica hybridization project.

National awareness of genetic conservation was spurred by a conference held in 1951 (Ramiah and Ghose, 1951) which led to a systematic survey of the Jeypore Tract by the CRRI staff during 1955–1956 and 1958–1960. More than 1500 samples were collected. This was followed by collection in Manipur State during 1965–1970. An intensive collection project in northeast India was assisted by PL 480 funds. About 6630 samples were assembled under the ARC (Assam Rice Collection) code, from which many promising sources of useful traits were later identified. Collection in rainfed and dryland areas was implemented during 1976–1977. The Indian Council of Agricultural Research sponsored a massive collection project during 1978–1979 and about 5400 samples were collected from 14 states. The collection efforts are being continued by several state and regional centers.

The national collection held at CRRI is approximately 15,000 accessions. Holdings at various state levels amount to 35,000 or more. Considerable duplication exists in the state collections.

Field collectors need to canvass many small ecological pockets where traditional types are grown, especially in the northeast region. The rate of genetic erosion has been rapid in the irrigated areas.

5. *Indonesia*

Although climatic conditions of the Indonesian islands were generally similar, the hydroedaphic variation is marked. Indonesia is also the home of the Javanica ecogeographic race (locally called the bulu and gundil types) which coexists with the predominant Indica race (tjereh or cere).

Field collections were made in the 1930s, but no rigorous effort was made to

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preserve the collection. Since 1972, systematic efforts were executed with IRRI's participation, and a total of 10,000 samples has been assembled from the major islands. Recent collection efforts were directed toward the smaller islands in the east.

The rate of replacement of traditional varieties by semidwarfs has been rapid. About 60% of the rice area is planted to the high-yielding cultivars.

6. *Japan*

All of the Japanese varieties belong to the temperate-zone race, Japonica or Sinica. Twenty leading varieties are grown on about 60% of the rice land. In 1962, about 1300 local varieties were collected from farmers' fields. Japanese scientists have actively collected cultivars and wild taxa in South and Southeast Asia, Australia, Africa, and Latin America. The National Institute of Agricultural Sciences at Tsukuba maintains a collection of about 10,500 native rices, while six major experiment stations have 9000 stocks. Other collections maintained by Kyushu University, the National Institute of Genetics, and other universities amount to 16,000; collections of prefectural agricultural experiment stations totals about 8000 varieties.

7. *Kampuchea*

Local collections were maintained at different stations. During 1973, IRRI assisted the local workers in assembling 948 samples around Phnom Penh and Lake Battambang. Areas formerly controlled by the Khmer Rouge have not been covered by systematic canvassing; however, the adoption of high-yielding varieties is negligible.

8. *Korea (South)*

Prior to the release of "Tong-il" in 1971, all Korean varieties were of the Sinica race. Field collection of local varieties began in 1906 with the establishment of the national agricultural experiment station. By 1977 the collection had grown to 4227

High-yielding cultivars of Indica/Sinica parentage now occupy 60–75% of the total rice area.

9. *Laos*

In the early 1970s the government had a collection of about 250 varieties. The USAID Mission to Laos assisted extension workers during 1972–1973 in assembling 898 samples, a substantial portion of which was harvested from preceding

crops and was therefore nonviable. The canvassed areas were confined to those controlled by the former royalist government. The spread of semidwarfs in Laos was negligible.

10. Malaysia

Conservation of local rices grown in West Malaysia was largely completed in the late 1960s. About 3130 varieties were maintained by the Malaysian Agricultural Research and Development Institute (MARDI). Missionary workers in Sarawak State of East Malaysia collected 166 varieties from the hilly areas and sent the seed to MARDI and IRRI. Further collection in Sarawak and Sabah States is needed.

11. Nepal

Despite Nepal's small size, the hilly topography encompasses climatic conditions ranging from tropical to temperate. Thousands of varieties were grown. In 1971 the USAID financed collection in 57 of the 75 districts, and 780 rices were gathered. Collection efforts are being renewed for the less accessible mountainous areas.

Genetic erosion is serious in the Kathmandu and Chitawan valleys where improved varieties of foreign origin occupy more than 80% of the rice area. In the hills the traditional varieties are predominant.

12. Pakistan

Rice is largely grown in the hot and semiarid regions, but varieties grown in the northernmost and northwest corners represent different ecotypes. Collections made during the early 1930s, early 1940s, and in 1955 totalled 555 accessions. From 1972 to 1977 a United States-sponsored PL 480 project helped the staff of the Agricultural Research Council and rice experiment stations to assemble and evaluate about 900 rices. These latter accessions included current and obsolete cultivars and primitive varieties or land races. Insofar as possible the accessions were classified for botanical, morphological, and agronomic characteristics as well as for resistance or tolerance to diseases, insects, and adverse environmental conditions (Husain, 1978).

Modern varieties are rapidly replacing traditional types in the major production areas. Renewed collection efforts are needed to cover central Punjab, Swat Valley, and both banks of the Indus River.

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13. Philippines

Ecological variation is considerable among the hundreds of islands stretching from 5 to 19° north latitude. Foreign introductions were extensively obtained before and after World War II. Local varieties of the Indica type probably amounted to 1500 while the Javanica race predominates in the Mountain Province. Before the war 828 varieties were collected and maintained. The national collection of 607 accessions was turned over to IRRI in 1962. Another total of 805 samples was collected from 1962 to 1980. An anthropology team from Yale University collected intensively in the mountainous areas and donated 466 Javanica varieties to IRRI. Canvassing in a number of isolated areas is being continued by Philippine extension workers in cooperation with IRRI staff.

In tropical Asia, the Philippines has the largest proportion of rice area (about 90%) planted to the high-yielding cultivars. But a substantial proportion of the replaced varieties was foreign introductions.

14. Sri Lanka

Although Sri Lanka is a small island, it has marked variations in climatic, edaphic, and hydrological conditions. The island is a microcenter of varietal diversity. Its rices are also a principal source of resistance to several major insects and to adverse soil factors.

Collaborative collection efforts with IRRI from 1972 to 1980 led to the acquisition of 2200 samples. The canvassing is essentially complete for the island. The national collection holds 2516 land races.

Genetic erosion has rapidly taken place since the early 1970s. Locally improved cultivars are grown on over 90% of the rice area.

15. Thailand

Similar to neighboring Burma and Vietnam, Thailand is rich in the genetic diversity of shallow- and medium-depth lowland varieties, deepwater rices, and hill (dryland) rices. An extensive collection campaign from 1950 to 1967 yielded 6739 samples from wetland areas. Evaluation, purification and selection reduced the collection to 2434 stocks. Field collection in the 1960s and 1970s were largely for the dryland types (hill rices). The collection efforts are being sustained with IBPGR–IRRI assistance.

Genetic erosion has proceeded at a rather slow pace as the improved cultivars are grown largely in the dry season in irrigated areas. The wet-season crop is dominated by the traditional rices.

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16. Soviet Union

Rices found in the Soviet Union are either foreign introductions or locally improved cultivars. The national collection initiated by N. I. Vavilov now totals 3200 accessions, most of which are introductions.

17. Vietnam

Owing to the long north-to-south configuration, Vietnam is also rich in varietal diversity. The early-maturing Champa rices of central Vietnam in the eleventh century contributed much to China's increased rice production during the ensuing centuries (Ho, 1956).

No information is available on the national collection. About 387 accessions were maintained in Saigon during the 1960s. A collaborative venture with IRRI in early 1975 led to the assemblage of 760 samples from the sourthern provinces. Collection efforts have been implemented in recent years. The University of Cantho in the south has assembled a collection of 1350 samples.

Genetic erosion had already taken its toll in the late 1960s and early 1970s when the semidwarfs spread rapidly in the favored areas.

18. Central and South America

During the period from the fifteenth to the eighteenth centuries, numerous rices were introduced from Europe, Asia, and North America. Extensive exchanges among Latin American countries were known (Lu and Chang, 1980). Local selection and breeding efforts have enriched the limited diversity of the *O. sativa* introductions.

Among the Latin American countries, Brazil has maintained a collection of 4000 accessions since 1974. A survey and collection project was implemented in 1976–1977, and it led to the assemblage of 533 unimproved cultivars. Argentina has a collection of 3200 samples.

Genetic erosion has been nearly complete in the irrigated and mechanized upland areas. Unimproved varieties can be found only in the unmechanized upland areas.

19. East and North Africa

Malagasy probably has the longest history of growing *O. sativa* in East Africa because of its proximity to South and Southeast Asia. The Indica race dominates the plains while the Javanica race occupied the central plateau. Malagasy has a collection of about 2000 accessions (Toll *et al.*, 1980).

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Mozambique also has a long history of rice cultivation (Lu and Chang, 1980), but the germ plasm is composed of foreign introductions.

Rice cultivation in Egypt dates back to the seventh century. Egypt has about 2500 entries in a working collection for breeder's use (personal communication from Dr. M. I. Maximos).

20. West Africa

The introduction of Asian rices has been rather recent, no earlier than the fifteenth century (Lu and Chang, 1980), but the Asian cultivars underwent considerable genetic changes and diversification after local selection took place in the widely scattered production areas of diverse ecosystems. On the other hand, no breeding work has been carried out on the African cultigen.

Systematic collection in the Francophone countries was first implemented by staff from the Institut de Recherches Agronomiques et des Cultures Vivrières (IRAT) and the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM), both of France, since 1950. Parts of Liberia, Tanzania, and Madagasy were also included. The collections assembled up to 1979 totaled 996 *O. sativa* samples, 636 *O. glaberrima* populations, and 500 wild taxa.

The UNDP/FAO project staff in Liberia mounted an extensive collection operation from 1971 to 1974 and gathered 1734 *O. sativa* and 135 *O. glaberrima* samples.

The International Institute of Tropical Agriculture (IITA) in Nigeria began extensive collection efforts in 1976 with the support of IBPGR. More than 10 countries in West, Central, and North Africa were covered during a 4-year period. The collections amounted to 2363 samples of *O. sativa* land races, *O. glaberrima* samples, and wild taxa.

The West Africa Rice Development Association (WARDA) located in Liberia has also assembled 7650 samples from six African countries.

West African countries including Ghana, Liberia, Nigeria, and Sierra Leone also maintain rice collections at their national agricultural research centers.

C. Conservation of the Wild Species

The wild species are widely distributed in the humid tropics of Africa, Asia, Australia, and Central and South America. Initial collection was made by botanists primarily for taxonomic studies. With funds from The Rockefeller Foundation, scientists of the National Institute of Genetics in Japan extensively collected in South and Southeast Asia, West Africa, Latin America, and East Africa during the late 1950s and early 1960s. Several university professors of Japan also collected wild rices while they systematically surveyed the genetic diversity of

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rice cultivars in South and Southeast Asia (cf. Chang, 1975). Field collectors of IRRI have also gathered wild rices while collecting cultivars in remote areas of tropical Asia. Volunteer efforts of workers in Australia, Brazil, and Liberia have expanded the collection maintained at IRRI. The most extensive collection of the African taxa was made by the staff of IRAT and ORSTOM.

IRRI has practically all of the collected materials. The total size is around 1100 samples, many of which are heterozygous populations rather than pure strains. The size also indicates that only a small segment of the wild taxa has been conserved.

The wild rices of tropical Asia are rapidly dwindling or decreasing in population size in their traditional habitats: canals, ponds, and roadside ditches. Moreover, the wild rices are losing many of their characteristic features because of introgressive hybridization with the rice cultivars grown in their vicinity. A recent study by the IBPGR–IRRI Rice Advisory Committee urges that immediate steps be taken to conserve the rich gene pools in the wild relatives (IBPGR–IRRI, 1982).

D. Collaborative Conservation Efforts

From the beginning of its research operations in 1962, IRRI has served and continually expanded its role as a central depository for rice germ plasm. The growth of the IRRI germ plasm bank into a genetic resources center has been described (Chang, 1972b, 1980; Chang *et al.*, 1975b).

Since 1972 IRRI staff has directly participated in the collection programs of Bangladesh, Burma, Indonesia, Kampuchea, Philippines, Sri Lanka, and Vietnam, leading to the acquisition of 10,352 samples from many remote areas (Table I). During their field travel, the teams inquired about the existence of ecoedaphic constraints in the canvassed areas. Such efforts have enabled the collectors to acquire cultivars having tolerance to one or more of the adverse factors (IRRI, 1981).

Through IRRI's promotion and technical assistance, workers in 14 Asian countries have implemented field collection activities and assembled more than 22,000 samples (Table I), although a higher proportion of duplicate and nonviable samples exists in the collections than those canvassed by the team of national and IRRI staff members.

The collaborating workers include not only research scientists, college professors and their students, and extension workers in the national program concerned, but also foreign missionary workers, United States Peace Corps members, other service volunteers, and anthropologists. The national center concerned and IRRI share the collected seed samples.

IRRI's catalytic role in pooling financial and manpower resources for systematic field collection efforts has been discussed (Chang and Perez, 1975; Chang,

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Table I
Indigenous Rice Varieties Collected with IRRI's Direct or Indirect Participation in 14 Collaborating Asian Countries, 1971 to 1981

Country	Years	Indigenous varieties collected (number)	
		With direct participation of IRRI	With indirect participation of IRRI
Bangladesh	1973–1981	2451	2857
Bhutan	1975–1976	—	121
Burma	1973–1974, 1976, 1980	225	967
India	1976, 1978–1981	—	4828[a]
Indonesia	1972–1976, 1978–1981	5103	4681
Kampuchea	1973	280	—
Laos	1972–1973	—	898
Malaysia	1973–1979	—	972
Nepal	1971–1972, 1979–1981	—	1688
Pakistan	1972–1973, 1976, 1979	—	772
Philippines	1973–1976, 1977–1980	510	1971
Sri Lanka	1972, 1975–1976, 1978–1981	1675	550
Thailand	1973, 1975–1976, 1978–1981	—	2650
Vietnam	1972–1975, 1978–1980	108	1650
	Total	10,352	24,605

[a]Partial estimate based on seed samples received by IRRI

1980). The development of a manual for field collectors (Chang *et al.*, 1972) has proved to be most helpful to field collectors in national programs.

Since its establishment in 1973, the International Board for Plant Genetic Resources (IBPGR) has given high priority to the collection of rice in tropical Asia and in West Africa (IBPGR, 1976). Recently the Board has channeled funds through IRRI to assist a number of Asian centers in continuing the field collections, upgrading seed storage facilities, and training field collectors (IRRI, 1981). The Rice Advisory Committee cosponsored by IBPGR and IRRI has assisted in developing plans for field collection and in producing a set of uniform descriptors for rice cultivars (IBPGR–IRRI, 1980).

Field collection in 12 West African countries has been implemented by the Food and Agriculture Organization (FAO)–United Nations Development Programme (UNDP) Project in Liberia, and by IITA, IRAT, WARDA, and ORSTOM. The IBPGR has financed the collection activities of IITA.

The Centro Nacional de Recursos Geneticos (CENARGEN) of Brazil has surveyed and collected indigenous varieties. Each of the above institutions has provided IRRI with duplicate sets of collected samples for preservation. IRRI has received about 3000 duplicate seed samples from the above centers.

The overall and cooperative efforts on the genetic conservation of rice un

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doubtedly excel those of other major food crops. However, collaborative efforts have been seriously hampered in those areas where politicomilitary strife exists. The rate of collection has been rather low in other areas which are frequently inaccessible to collectors during the wet season, for instance, the deepwater areas and high elevations.

IV. DISSEMINATION AND EVALUATION OF GERM PLASM

A. Distribution and Evaluation by United States Workers

In the earlier years rice germ plasm evaluation and distribution were conducted by USDA in cooperation with State Agricultural Experiment Stations in Arkansas, California, Louisiana, and Texas. Also, some introduced cultivars were grown in farmers' fields and in some cases these growers selected, increased, and distributed selections from these materials (Jones, 1936).

Until about 1930, the evaluation program for rice consisted of general observation on the adaptability, yield, and milling quality. During that period many varieties were distributed which were superior to the ones currently being grown. The varieties developed and distributed during that period were described by Jones (1936).

In 1931, additional federal and state employees were added so there was a gradual increase in the germ plasm evaluation program. During the past half-century many of the entries in the USDA rice germ plasm collection have been evaluated for reaction to disease and nematodes and to field- and stored-grain insects (Rush *et al.*, 1977, 1978a,b; Marchetti, 1975; Atkins, 1974; Cogburn, 1977a; Anon., 1980).

Blast (*Pyricularia oryzae* Cav.) is one of the most serious diseases of rice. This disease has been the subject of much research in recent years in the United States. The reaction of cultivars and advanced lines to the causal fungus was observed at many locations in North America. There was a wide range in varietal reaction and a differential reaction among varieties at different locations. These observations led to studies of different strains of the fungus and to the setting up of a group of differential varieties to categorize these strains or physiologic races (Atkins *et al.*, 1967). The reaction of rice varieties to *P. oryzae* when artificially innoculated has been studied in Texas (Atkins, 1965).

For several years in the late 1960s and early 1970s, G. E. Templeton and T. H. Johnston (unpublished) had reasonably good success in annually screening about 2000 varieties and breeding lines for resistance to rice seedling blast in

Arkansas under conditions of late seeding, sprinkler irrigation, and natural infection. Two lines found resistant in these tests were later released as the cultivars "Nova 76" and "Mars" (Johnston, *et al.* 1979a,b).

More recent research by Marchetti (1978) dealt with screening for general resistance to rice blast. For the past several years Fleet N. Lee in Arkansas and M. A. Marchetti in Texas (both unpublished) have screened hundreds of varieties and breeding lines under artificial inoculation to find the best possible sources of blast resistance in adapted types. These are being used as parents in the cooperative breeding programs.

A large number of varieties were evaluated for reaction to the stem rot fungus *Magnaporthe salvanii* (Catt.) Krause and Webster by Cralley (1936) in Arkansas. Additional studies to evaluate the reaction of genetic stocks to *M. salvanii* were conducted in Louisiana by Amad *et al.* (1974). Hoff *et al.* (1976) reported on evaluation of varietal resistance to the stem rot fungus in Louisiana studies. Stem rot studies also were conducted in California by Ferreira and Webster (1975). Figoni *et al.* (1981) reported that *Oryza rufipogon* has greater resistance to stem rot than found to date in *O. sativa*. Inheritance of resistance in the interspecific cross (*O. sativa*/*O. rufipogon*) appears to be polygenic (Figoni, 1981).

Brown leaf spot (*Helminthosporium oryzae* B. de H.) is sometimes a serious disease in the sourthern United States. Varietal differences were noted and the heritability of reaction to *H. oryzae* was studied (Adair 1941). More recently the reaction of many varieties to *H. oryzae* has been studied by Harahap *et al.* (1974) in Louisiana and by Atkins (1974) in Texas and other southern states. According to Atkins (1974), Tullis in 1935 noted that United States varieties showed a wide range in reaction to the brown spot fungus. Adair and Cralley (1952) tabulated reactions of numerous varieties to *H. oryzae* in Arkansas.

Sheath blight of rice incited by *Rhizoctonia solani* Kuehn has become of increasing importance in the United States in recent years. Templeton and Johnston (1969) reported varietal differences in resistance among United States varieties. Eleven hundred and fifty rice cultivars and advanced lines were evaluated for response to this disease in Louisiana (Masajo *et al.*, 1974). Some medium-grain varieties were more resistant than long-grain varieties, but no United States variety was highly resistant. A moderately high level of resistance was found in less than 1% of the 1150 varieties tested.

In recent years hundreds of varieties and breeding lines have been evaluated under inoculated conditions for resistance to the sheath blight organism in separate extensive reaction tests by M. C. Rush and W. O. McIlrath and co-workers in Louisiana, by M. A. Marchetti in Texas, and F. N. Lee in Arkansas. Although the reaction data have not been formally published, they have been made available to rice breeders and other interested persons for use in current improvement programs.

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Kernel smut of rice [*Neovossia barclayana* Bref. = *Tilletia barclayana* (Bref.) Sacc. and Syd.] is usually a minor disease of rice in the United States. This disease has been studied intensely (Tullis and Johnson, 1952), and an inoculation technique has been developed (Whitney, 1974). Reaction of varieties to this fungus has been studied (Templeton and Johnston, 1970b). Varietal differences in reaction were found. Two Arkansas selections which carry the designations C.I. 9695 and C.I. 9808 have shown a high degree of resistance to kernel smut in several cooperative tests in Arkansas and elsewhere (Templeton and Johnston, 1970a).

Hoja blanca is a virus disease of rice that is transmitted by the planthopper *Sogatodes orizicola* Muir. This disease was a serious menance to rice production in many areas of Central and South America. It was first noted in the United States in 1957 (Atkins and Adair, 1957) and subsequently for a few years, but it did not become a serious disease in the United States because the vector did not become established. The United States collection of rice varieties was grown in Cuba and Venezuela. Several varieties were found to be resistant to hoja blanca (Atkins and Adair, 1957). Resistant short- and medium-grain varieties were distributed and a breeding program was conducted in the United States to develop resistant long-grain varieties (Adair et al., 1973). Lamey (1969) summarized information then available on varietal resistance to hoja blanca.

Straighthead, usually described as a "physiological disturbance" has occurred in the United States for the past 70–80 years. Damage to highly susceptible varieties may range from slight to almost total loss of grain yield, depending on several environmental conditions. Reports by Atkins *et al.* (1956a,b, 1957) list reaction to straighthead of numerous varieties and describe testing methods used. Johnston *et al.* (1959) discussed straighthead and rice varieties in Arkansas and pointed out the differential reactions. Johnston and Templeton (1970) reported on the comparative performance of rice varieties grown under severe straighthead and normal conditions. For the past several years Johnston (unpublished) has tested from 600 to 2000 varieties and breeding lines annually using a method partially based on research by Wells and Gilmour (1977). Application of arsenic as MSMA to the soil surface and working it into the upper few inches of soil is used along with continuous flooding to artifically induce "straighthead." Reactions of several of the older varieties tested under these conditions correlate very well with results obtained previously under "natural" field conditions conducive to straighthead.

White tip disease of rice is caused by the seed-borne nematode *Aphelenchoides besseyi* Christie (Cralley, 1949). This disease was observed and reaction of many varieties was recorded (Atkins, 1974) before the causal agent was determined. In recent years the disease has been of relatively little commercial importance in the United States because the old susceptible varieties are no longer grown and most new varieties are resistant. However, "Brazos" and several of the currently or

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recently grown California cultivars frequently show rather severe white tip symptoms when conditions are favorable and when the white tip nematodes are present. Atkins and Todd (1959) reported on the effect of white tip on yield of about 20 resistant and susceptible cultivars.

Reaction of rice cultivars and advanced lines to the principal field insects has been studied. Many of these studies have been conducted in Louisiana and Texas since most insects are more prevalent in that region although studies also have been conducted in other areas. In a recent general report, Bowling (1980a) discussed the field insect pests of rice and the progress made in finding resistance among the thousands of accessions in the USDA World Collection of rice. Reaction of varieties to the rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) was reported by Bowling (1963, 1973) in Texas; by Oliver *et al.* (1970, 1971), Gifford *et al.* (1974), Latson *et al.* (1976), Gifford and Trahan (1976), Robinson *et al.* (1978), and Smith *et al.* (1980) in Louisiana; and by Grigarick (1974) and Grigarick *et al.* (1976) in California.

The stink bug (*Oebalus pugnax* Fabriciis) is a major pest of rice in the southern rice-producing states. Varietal reaction to infestation by this insect was studied by Latson *et al.* (1976) in Louisiana. Bowling (1980b) reported on the differential reactions of a number of cultivars and advanced lines from the USDA World Collection and the Regional Uniform Rice Nursery.

The stem borer (*Chilo plejadellus* Zencken) causes serious damage to rice in some fields in the Gulf coast areas of Louisiana and Texas. Resistance in rice to this pest was studied by Oliver *et al.* (1970, 1971) in Louisiana.

Differential susceptibility of varieties of stored rice to losses caused by storage insects was reported by Cogburn (1974, 1977a, 1980). In other studies Cogburn (1977b) found resistance to the angoumois grain moth (*Sitotroga cerealella* Oliv.) in some varieties of rice from the USDA World Collecton. Cogburn *et al.* (1980) also studied the effect of field environment on the grain of some of these varieties and its ultimate resistance to this insect. Another study conducted in Texas dealt with varietal differences and the nature of the resistance to this insect (Cogburn and Bollich, 1980). Russell and Cogburn (1977) reported on differences in resistance to seed penetration by this insect (*S. cerealella*) among USDA World Collection varieties.

The reaction of rice varieties to low temperatures in the seedling and flowering stage is an important characteristic, especially in California. This characteristic has been studied (Adair, 1968; Li, 1975; Lin and Peterson, 1975; Peterson *et al.*, 1972, 1974) and varietal differences have been found. Seedling vigor over a range of temperatures also was found to differ among varieties (Jones *et al.*, 1974). Peterson *et al.* (1979) reported on cool-temperature screening of rice varieties and lines for seedling vigor. Rutger and Peterson (1979) discussed techniques for determining cold tolerance in rice varieties in California. Peterson *et al.* (1972) discussed differential panicle blanking under California conditions.

Li and Rutger (1980) reported on the inheritance of cool-temperature seedling vigor.

Research studies have been made to determine susceptibility of rice varieties to commonly used herbicides. In a 2-year field test by Johnston and Smith (1976) an experimental high-protein variety from the cross "Zenith"/"ADT3" showed 70% injury from molinate whereas 15 other advanced lines or cultivars showed little or no injury. Other breeding lines and many of the newer cultivars developed at IRRI and elsewhere also have shown high susceptibility to damage from molinate. Differential varietal responses to molinate and other commercial herbicides also have been noted by other researchers at other locations (unpublished observations).

The physicochemical properties and cooking characteristics of the milled rice have been determined. The cooking characteristics of rice are correlated with the physicochemical characters of the grain. The physicochemical characteristics commonly used to screen rice varieties for cooking quality are: amylose content, reactions in dilute iodine and dilute (2.0, 1.7, or 1.5%) potassium hydroxide solutions, gelatinization temperature, viscosity of the rice flour paste, and parboil–canning stability (Adair *et al.*, 1971, 1973). Many varieties in the United States collection have been evaluated for these characteristics (Webb *et al.*, 1968; Adair *et al.*, 1971) and the information is used in breeding programs. An example of the use of these tests in rice breeding is the development of "Newrex," a cultivar with higher amylose content than other United States long-grain types and thus more suitable for canning (Webb and Bollich, 1980).

The data obtained in the evaluation tests are entered in the USDA World Collection Rice Data Bank (Johnston *et al.*, 1978, 1980). This data bank is patterned after the Rice Data Bank System of Louisiana State University (Schilling and Parenton, 1976).

Seed samples of public rice cultivars in the United States are available to seedsmen and farmers. Each state in the United States has a program of seed certification and distribution. The methods used in seed production and certification are described by Adair *et al.* (1973). New cultivars developed by public institutions and private breeders are registered and a description of each is published in *Crop Science*. The procedure was instituted for rice in 1958. All major rice cultivars that had been distributed before that date were registered and a description published that year (Johnston, 1958). Varieties developed since that date have been registered and a description published at the time of release. Not only are commercial varieties (cultivars) registered, but breeding and genetic lines (elite germ plasm) are registered and a description published, and seed is made available to all rice breeders (Rutger *et al.*, 1979a).

The entries in the USDA rice collection are available for distribution to public and private breeders after they have cleared quarantine.

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B. The Genetic Evaluation and Utilization Program of IRRI

Since IRRI began research operations in 1962, its staff has actively screened large numbers of accessions for reactions to the blast fungus, bacterial blight pathogen, the stem borers, and for grain quality. The evaluation program was soon expanded to include bacterial streak, the virus diseases, sheath blight, green leafhopper, brown planthopper, other planthoppers, rice whorl maggot (Chang *et al.*, 1975a,b), adverse soil factors (Ponnamperuma and Castro, 1972), nutritive quality (Juliano, 1972), and drought resistance (Chang *et al.*, 1974). The multidisciplinary evaluation program was expanded and systematized during 1974 as the Genetic Evaluation and Utilization (GEU) Program (IRRI, 1974; Brady, 1975).

One of the major focuses under the GEU Program is to develop rices that can cope with the biological and physical constraints found in the unfavored rice production areas. Farmers in such areas were bypassed by the modern technology associated with the semidwarf rices and access to irrigation water. Their numbers represent nearly three-fourths of the rice growers of tropical Asia (IRRI, 1976a).

Interdisciplinary and problem-oriented rice breeding is the backbone of GEU, while the IRRI germ plasm bank provides the genetic inputs. Under the program, plant breeders are teamed up with "problem area" scientists, such as plant pathologists, entomologists, soil chemists, and cereal chemists, in planning and developing evaluation and breeding operations. Each team member contributes his specialized knowledge to the joint effort in identifying, screening, and hybridizing diverse rices to meet specified objectives. By so doing, a spectrum of the desired characteristics can be incorporated into a high-yielding or an adapted background which could meet a wider array of rice-growing environments, especially those of the rainfed areas. The major GEU problem areas include: resistance to diseases, resistance to insects, high levels of grain and nutritive quality, resistance to drought, tolerance to adverse soils, tolerance to submergence, ability to survive deep water, and tolerance to extreme temperatures. The team of each research area includes at least one plant breeder and one or more scientists in the problem area. As many as five disciplines may be involved in one problem area, such as nutritive quality.

The team approach covers the development of mass screening techniques, identifying the outstanding sources of resistance or tolerance, research on the mechanism of resistance or tolerance, investigations on the interpopulational variation in a pathogen or insect, and study on the inheritance of resistance and the allelism among donor genes. In-depth research on complex traits is being jointly undertaken by scientists in academic institutions of advanced nations and by IRRI staff on a collaborative basis.

Systematic evaluation under the GEU Program includes 5 tests on diseases, 11 tests on insects, 4 tests on grain quality, 10 scores on drought resistance, 4 tests on adverse soil factors, 2 tests on flood tolerance, and 1 test on low temperature tolerance. Tests of other traits on smaller scales are also made by GEU scientists, but the data have not been fully computerized.

In the breeding process, the rice breeders provide the expertise and leadership in choosing breeding approaches, selecting the cross combinations, planting the breeding nurseries, selecting the desirable progenies, processing the selected seeds for multidisciplinary testing for further selection, and collating the experimental findings for the next cycle of crossing and selection. Integration of collaborative testing efforts begins as soon as sufficient seed is obtained to test for a specific trait.

The massive research data are entered into computerized files, summarized, analyzed, and updated by the statisticians. Research findings are discussed among members of each team before planting the next generation. The GEU scientists meet once a month to discuss and review current findings and problems. Visits to experimental plots form a part of the monthly gathering. Annual and 5-year program reviews help to set or modify breeding strategies and related investigations. The annual International Rice Research Conferences sustain the dialogue and collaboration with workers in national centers.

Figure 1 exemplifies the operational flow of research in the drought-resistance component. Resistant or tolerant reactions are verified by repeated testing or expanded testing at additional sites and under diverse hydrologic–edaphic regimes (Chang *et al.*, 1982).

The evaluation techniques and findings of promising sources have been summarized by several IRRI scientists (Ou, 1972; Ling, 1974; Chang *et al.*, 1974, 1975a, 1977; Chang, 1976e; Vergara *et al.*, 1976; Juliano, 1977; Ponnamperuma, 1977; Pathak, 1977; Khush, 1977). Computerized data systems have been developed for the massive GEU program and for linking the GEU data with the morphoagronomic data of the germ plasm bank (Gomez *et al.*, 1978; IRRI, 1980c).

Certain GEU tests are accelerated when the germ plasm staff feeds newly harvested seeds of accessions reputed to have special characteristics to the concerned GEU scientist in order to speed up the evaluation process. Such special characteristics include tolerance to cool temperatures, floating ability, and tolerance to adverse soil factors. Among cultivars collected from high elevations, Japanese breeders on Hokkaido island have identified Silewah (Acc. 25718) of Sumatra, Indonesia, as the most cold tolerant (Satake and Toriyama, 1979). Several saline-resistant accessions were collected from salty areas.

The rapid growth of the GEU program may be indicated by the number of seed samples requested by the GEU scientists from IRRI's germ plasm bank for

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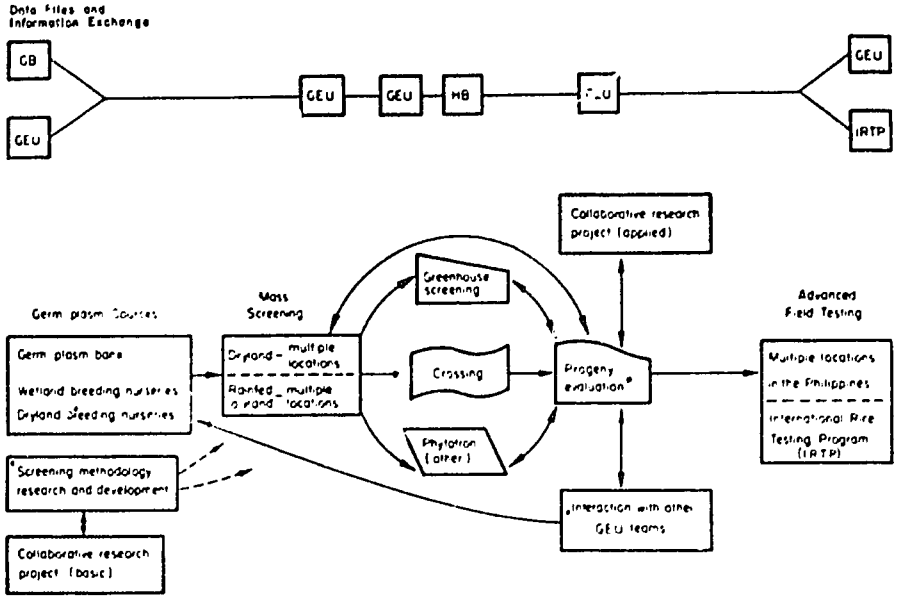

FIG. 1. Schematic representation of the activities collectively representing the drought resistance component of IRRI's Genetic Evaluation and Utilization Program. (*)Progeny evaluation includes mass screening under different hydrologic–edaphic–cultural regimes.

testing purposes: 2,300–10,600 packages per year during 1971–1973 to 20,500–50,350 packages during 1974–1977. The number of crosses made in a year likewise leaped from 287–485 crosses during 1971–1972 to 4,525–5,780 during 1976–1977 along with the development of a vacuum emasculation technique (Herrera and Coffman, 1974). More than 100,000 breeding lines are tested annually for various GEU traits.

Since 1975 a GEU training program has provided hundreds of young scientists in national programs with specialized knowledge on different facets of the GEU program. Moreover, the trainees are frequently recruited on a team basis so that they can implement multidisciplinary national programs after returning to their home country.

While the young scientists are residing at IRRI, each trainee completes a certain number of crosses which are planned to meet the breeding needs of his home country. The trainee takes the F_1 seeds with him when returning home.

The GEU Program together with the International Rice Testing Program (IRTP) now takes up 40% of IRRI's annual research funds.

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C. Evaluation by Workers in National Rice Research Centers of Asia

Historical records of China documented varietal differences and their descriptions as early as the first century A.D. (Ting, 1961). Empirical evaluation of economic traits undoubtedly was made when rice breeders of Asia began to select among farmers' varieties in the early part of this century.

Scientific breeding of rice began rather late. In Japan, the first variety developed by hybridization, "Ominishiki," came out in 1906 (Matsuo, 1957). One of the early examples of systematic varietal evaluation is Sasaki's (1922) recognition of the variation in the varietal resistance to the pathogenicity of the blast fungus. Screening for varietal differences in stem borer infestation was initiated at the Central Rice Research Institute in India during 1951–1955 (Israel, 1967). Studies with academically oriented objectives have also contributed to the understanding of other economic traits such as growth duration, seed dormancy, and grain type (Matsuo, 1952; Chandraratna, 1955).

Intensified national efforts on systematic evaluation were markedly stimulated by IRRI's early success in finding and using valuable traits found in IRRI's collection of cultivars and wild taxa (Pal, 1972; Zaman *et al.*, 1972). Staff of the All-India Coordinated Rice Improvement Project (AICRIP) instituted regional testing of breeding lines and systematic screening for disease and insect resistance under several nurseries (Shastry *et al.*, 1971; Freeman and Shastry, 1972; AICRIP (undated)). Other Indian workers have carried out mass screening for a specific pest in its endemic areas or "hot-spot" nurseries (Shastry *et al.*, 1972; CRRI, 1980). More recently, national GEU Programs have been instituted in Bangladesh, Indonesia, and Thailand.

National efforts on multidisciplinary evaluation of breeding lines and donor parents have been further intensified since the establishment of the International Rice Testing Program (IRTP).

D. International Efforts on Dissemination and Evaluation

International exchange and collaboration on the evaluation of rice germ plasm began on a modest scale when the International Rice Commission of the FAO implemented cooperative variety trials on adaptability during the period from 1956 to 1958 (Parthasarathy, 1972). This was followed by the International Blast Nurseries which were initiated under FAO's sponsorship and turned over to IRRI in 1963 for coordination.

Shortly after the IRRI germ plasm bank began its operations, it supplied rice researchers all over the world with seed samples of Asian rices, African rices,

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wild species, and genetic testers. The total number of samples distributed during the past 20 years in response to more than 2500 requests amounted to about 80,000 seed packets. Between 1972 and 1981, the number of samples sent abroad in a year ranged between 2770 and 10,200. These statistics may indicate the magnitude of experiments for specific objectives being conducted by rice researchers in different countries.

Since the mid 1960s IRRI has supplied numerous IR breeding lines to rice researchers all over the world. The number of lines sent abroad each year ranged from 5000 to 15,000. An international yield nursery of 32 entries was composed in 1972 and distributed to 17 countries in 1973. IRRI has continued to supply rice researchers with breeding lines. The number of seed samples of IR lines sent abroad each year remains at a level between 10,000 and 17,000.

In 1966 a set of 303 varieties and breeding lines were sent by IRRI to 10 countries for testing and selection. The testing not only established the superiority of the semidwarf Indicas over other types of breeding lines but also led to the finding of many promising parents for use in various countries (Beachell *et al.*, 1972).

The International Rice Testing Program (IRTP) was established in 1975 with the enthusiastic support of rice researchers in many countries and funded by the UNDP. The types of nurseries have increased from 12 in 1975 to 37 in 1981. During 1981, 2250 sets of seeds were distributed to hundreds of workers in 50 countries. The nurseries consist of yield trials; observational trials; disease and insect nurseries; and tests for adverse soils, cool temperatures, internode elongation ability, and drought resistance. The nurseries cover different types of rice culture: irrigated, rainfed-wetland, rainfed-dryland, and deepwater.

In the beginning, IRRI breeding lines and accessions of the IRRI germ plasm bank formed the bulk of the entries in IRTP nurseries. The contributions from national programs have rapidly increased from 30% in 1975 to slightly over 50% of the total entries in 1979 (IRRI, 1980a).

Along with distribution of the seed for testing, a uniform scoring system was developed and provided to place recorded data on a standard basis (IRRI, 1976b, 1980c). The data returned by collaborators are processed, analyzed, and reported by IRRI staff.

For Latin America and West Africa, the nurseries are handled with the collaboration of the Centro Internacional de Agricultural Tropical (CIAT) in Cali, Colombia; IITA in Ibadan, Nigeria; and WARDA in Monrovia, Liberia. Some regional nurseries are individually developed to cope with the needs of local ecoedaphic environments.

On the basis of the IRTP tests, workers in entomology, plant pathology, and crop physiology have developed collaborative research projects to probe deeper into the specialized research problems. Such projects involving several countries include investigations on the biotypes of the brown planthopper and the gall

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midge, pathotypes of the tungro virus and the bacterial blight pathogen, varietal resistance to the bacterial blight pathogen, cooperative testing and breeding for tolerance to extreme temperatures, site characterization and testing rices on adverse soils, cooperative breeding nurseries for drought resistance, exchange of early-generation breeding materials, and studies on tissue culture (IRRI, 1981).

E. Problems in Dissemination and Evaluation

The process of massive and collaborative evaluation efforts was also marked by handicaps and problems in the initial stages. Gradually some of the problems were resolved by periodic workshops, exchange of visits, and cooperative efforts.

Plant quarantine restrictions of some countries and regions have slowed the flow of genetic materials among research centers. Special arrangements often were made to allow an accelerated release of the introduced seeds after appropriate inspection and observation.

For disease and insect nurseries, a light epidemic or a lack of the outbreak renders notes taken on those nurseries of little practical value. Some of the nurseries have been relocated in endemic or "hot-spot" areas. In the case of light infections, the data are adjusted on the basis of the control varieties.

For nurseries grown under the rainfed culture, vagaries of weather conditions at different locales across seasons have limited the comparative study and summarization of research data. Workers are now taking supplementary data on weather, hydrological conditions of the soil, and soil characteristics of the site, all of which will enhance the interpretative aspect of the tests.

In recent years Thailand has added and expanded field facilities to test the internode elongation ability and submergence tolerance of materials intended for deepwater rice. Korea (South) has built special fields to test for tolerance to cold water. Such specialized facilities also take in a certain amount of breeding materials generated by other centers.

V. PRESERVATION OF GERM PLASM

A. Preservation by USDA and Recent Efforts for Improvement

The rice germ plasm preservation program is centered at the Agricultural Research Center, USDA at Beltsville, Maryland. The program is conducted in cooperation with State Agricultural Experiment Station and federal personnel in

Arkansas, California, Louisiana, and Texas and with the National Seed Storage Laboratory (NSSL) at Ft. Collins, Colorado.

The varieties for the most part are grown by USDA personnel. However, state employees and personnel of the California Cooperative Rice Research Foundation (CCRRF) cooperate in many of the evaluation tests that are conducted in field and greenhouse experiments. Seed of new entries in the collection are sent to IRRI and to NSSL each year.

There is an informal cooperative arrangement between IRRI and NSSL for the conservation of all rice genetic materials in the IRRI collection. The plan is to send a small sample of each entry in the IRRI collection to the long-term storage facility at NSSL. The long-term storage at NSSL was installed in 1978–1979 (personal correspondence from L. N. Bass, Director, NSSL, November 9, 1978). The seeds are accepted for storage in the NSSL in accordance with the standard policies of NSSL which were adopted September 13, 1977.

B. Status at Other National Centers

The size of rice collections maintained by different national and regional centers has been enumerated in Section III.B. The statistics were based on recent surveys made by IRRI (1978b) and IBPGR (Toll *et al.*, 1980). Germ plasm is preserved at all centers in the form of seed. Only a few centers maintain small collections of wild species as live plants.

The viability of rice seeds seldom exceeds one year in the humid tropics when the seeds are stored in paper bags under ambient temperatures and humidity inside unrefrigerated storerooms. Rice workers found it necessary to rejuvenate the seeds by growing the whole collection every year. Such a laborious process has led not only to mixtures and errors in the rejuvenated stocks but also to serious constraints on the germ plasm workers. Under such conditions several national collections have dwindled in size, and this has reduced the capability for international exhange.

Among germ plasm-rich countries in the Asian tropics, nearly all countries have recently installed refrigerated seed storage rooms to insure that the rice stocks can last for 3–5 years (Toll *et al.*, 1980). With the help of the Japanese government a modern facility for medium- and long-term storage has been constructed in Thailand.

Japan, the Republic of Korea, and the Soviet Union have medium-term and long-term storage facilities, while China is beginning to develop such facilities at provincial and national levels.

An encouraging development is that during the last decade nearly every rice-producing country in tropical Asia has donated their rice collections to IRRI for preservation. The IRRI collection is incomplete for a few state collections of India and for the traditional varieties of China, North Korea, and North Vietnam

C. The International Network

At a 1977 IRRI–IBPGR workshop on genetic conservation held in IRRI, scientists of Japan, the United States, IITA, IRAT, ORSTOM, and 12 country programs agreed to join IRRI in an international network of conservation in which IRRI would preserve the entire (base) rice collection of all institutions concerned so that at least one duplicate set of rice seed stocks is safely stored outside the country of origin. Moreover, IRRI would continue to deposit a duplicate set of its seedstocks at the United States National Seed Storage Laboratory in Fort Collins, Colorado, providing further security to the world's rice germ plasm (IRRI, 1978b).

Staff members of IRRI, USDA, and NIAS of Japan are comparing their holdings so that redundancy among different centers can be reduced while no individual accession will be overlooked in the process of providing duplicate or triplicate sites of storage. The national centers are urged to construct medium-term storage facilities and to help the international seed banks on rejuvenation (IRRI, 1978b).

Both the National Institute of Agricultural Sciences (NIAS) of Japan and IRRI have modern facilities for medium- and long-term seed storage. At NIAS the rice seeds are dried to 6–7% moisture content at 50°C, packed in vacuum inside tin cans, and stored at −10°C (IRRI, 1978b). At IRRI the seeds are dried (at 38°C) down to 6% moisture content under a low-risk procedure, packed under partial vacuum inside aluminum cans, and kept at 2°C, and −10°C for medium- and long-term storage, respectively (IRRI, 1980d).

IRRI presently holds approximately 60,000 accessions of *O. sativa*, 2600 samples of *O. glaberrima*, 1096 populations of wild species, and 680 genetic testers.

During the last decade, several nations have lost a substantial portion of their rice collections because of civil strife or difficulties in maintaining their collections. IRRI has returned hundreds of accessions to the national centers of China, India, Indonesia, Kampuchea, Kenya, Nepal, Sri Lanka, and Thailand.

D. Problems Encountered in Preservation

Complexity in the genetic makeup of rice germ plasm and the magnitude of the operations have posed certain difficulties for the large centers. The following problems in characterization, seed multiplication, and preservation have been encountered (Chang, 1980).

1. Inviable incoming seed samples
2. Duplicate samples, morphologic variants, or ecostrains with identical varietal names

3. Inherent genetic variation within accessions
4. Incomplete information on the unique features of an incoming accession
5. Loss of the true-to-name features
6. Low seed yield of unimproved cultivars
7. Inefficient seed increase of ecologically unadapted or pest-susceptible accessions
8. Need for separate plantings for seed increase and rejuvenation of photoperiod-sensitive accessions
9. Unpredictable demand for seeds of certain accessions
10. Differential loss of seed viability among varieties during storage
11. Misidentification or errors in processing accessions
12. Lack of biochemical criteria to differentiate between morphologically similar accessions or samples
13. Insufficient field space and manpower to concurrently handle three types of seed increase: (a) seed increase of new accessions, (b) rejuvenation of exhausted stocks, and (c) rejuvenation of old stocks for storage in the new medium- and long-term facilities. Therefore, seed increase activities are expanded in number and must be conducted over a longer period of time.

IRRI staff also found it necessary to rejuvenate seed every few years for the often-requested or difficult-to-multiply accessions. On the other hand, the pitfalls of frequent rejuvenation pointed out by Chang *et al.* (1979), include:

1. Errors and mechanical mixtures
2. Loss of unadapted or susceptible accessions
3. Changes in genetic composition, especially for small populations
4. Increased workload and requirements for field and storage space

One remedial measure for the above problems is to multiply sufficient seed in one planting, confirm the varietal identity, and preserve the seed under cold storage. Such an approach has been adopted at IRRI but poor seed production of unadapted or highly susceptible accessions remains the main constraint.

VI. USE OF GERM PLASM

A. By United States Workers

Rice is not indigenous in the United States so all United States cultivars were derived by some means or another from introduced materials in the germ plasm collection of USDA. The history of the development of the cultivars grown in the United States has been documented by Chambliss and Jenkins (1923), Jones (1936), Jones *et al.* (1941, 1953), Adair *et al.* (1973), Johnston (1958), and by

other registration statements in the *Agronomy Journal* and *Crop Science*. The genetic base of the United States cultivars is somewhat narrow (National Academy of Sciences, 1972). However, concerted efforts are being made to broaden the genetic base of the United States rice cultivars (Johnston *et al.*, 1978). Several varieties in the collection are being used in the cooperative rice-breeding programs. For example, a short-grain improved variety introduced from Taiwan about 20 years ago (Tainan-iku 487, P.I. 215936) as a "Ponlai" variety has been an outstanding parent in the development of the high-yielding cultivar "Nortai" (Johnston *et al.*, 1973). Several other varieties from a number of countries have been utilized in recent years to contribute desirable genes and help to broaden the genetic base of United States cultivars being released to growers. New varieties imported from these programs will help to broaden the genetic base of available parent material. The recently released cultivar "Newrex" (Bollich, 1979) is an example of a cultivar that has a somewhat different genetic background than older United States cultivars.

Rice genetic stocks that have unique characteristics but are not suitable for commercial production can now be registered by the Crop Science Society of America. This program allows all rice breeders to get seed of these genetic stocks if they are needed (Rutger *et al.*, 1979a).

B. By Other National Centers

Nearly all of the national centers have made profitable use of the semidwarfing gene (*sd*-1) contributed by Dee-geo-woo-gen and varying numbers of the pest resistance genes derived from IRRI lines or IR varieties. Moreover, through local screening and selection, several national centers have incorporated additional resistance or tolerance genes from other sources into their improved cultivars.

Among the major rice-producing countries in Asia, researchers in India have conducted the most extensive testing of indigenous germ plasm to pests and diseases (cf. AICRIP, [undated]; CRRI, 1980). Therefore, Indian rice breeders have made effective use of the indigenous genepools which provide resistances to pests or tolerance to ecoedaphic stresses. The drought-resistant "N22" was used in breeding "Bala," "TKM6," which has multiple resistance to insects and diseases, became a parent of "Ratna," "Saket 4," "Parijat," "CR44-1," and other improved cultivars (CRRI, 1980). TKM6 was also extensively used at IRRI as a donor of disease- and insect-resistance (Khush, 1977). The gall midge-resistant "Eswarkotra" was used to breed W1251, W1256, and W1263; the latter lines were widely used inside India as well as in Sri Lanka and Thailand (Rice Division, 1976; Dalrymple, 1978; CRRI, 1980; Directorate of Extension, [undated]). The tungro virus resistance of "PTB10" has been bred into improved cultivars such as "Aswini," "Bharathi," "Jyothi," "Rohini," "Sabari," and "Triveni." Similarly, "PTB18," possessing multiple re-

sistance, has been widely used in India (CRRI, 1980) and at IRRI (Khush, 1977, 1980). For tolerance to submergence by flood waters, FR13A is an outstanding source. Indians breeders were also developing saline-tolerant varieties from Indigenous sources such as "Pokkali," "Getu," and "Dasal" (CRRI, 1980). R575, a local variety of H.P. State, was used to breed "Himdhan" which is adapted to altitudes above 1000 m (Sharma and Kaushik, 1978).

Indian workers have also made numerous exchanges with workers in other countries and benefited early from foreign introductions such as "Taichung Native 1," "IR8," "Mahsuri," "Leb Mue Nahng," and "China 1039." Taichung Native 1 and IR8 were the principal sources of semidwarfism during the mid-1960s (Hargrove, 1976). Mahsuri of Malaysia and Leb Mue Nahng of Thailand were used to develop photoperiod-sensitive varieties (CRRI, 1980). "Rajendra Dhan 20" and "Pusa 4-1-11" derived their disease resistances from "Tadukan" of the Philippines (Chaudhary *et al.*, 1979). "BG79" of Sri Lanka was extensively used by Indian breeders in Maharashtra State to develop "Satya," "Surya," and "Suhasini" (Directorate of Extension, [undated]).

Rice breeders of Sri Lanka have used the outstanding levels of resistance to insects and tolerance to adverse soil factors found in their diverse germ plasm. BG400-1 derived from OB678/IR20/H4 has resistance to gall midge, blast, and the bacterial diseases. BG276-5 originating from OB678/2/BG34-8 is resistant to gall midge and bacterial blight. BW100 selected from H501/Podiwee-A8/H5 has resistance to blast as well as tolerance to iron toxicity (Rice Improvement Program of Sri Lanka, 1980).

Malaysian breeders extensively used the germ plasm of other Asian countries to develop improved cultivars. Mahsuri is one of the few Indica Japonica hybrids that has won wide acceptance in several countries. "Sri Malaysia Dua 11" was derived from IR8/Pankhari 203 (cf. Dalrymple, 1978).

Breeders in the Philippines continued to draw heavily on germ plasm supplied by the USDA and locally improved materials (Hargrove *et al.*, 1979). Recently C1064-5 was selected from C22/IR26/C22/OS4. "OS4" came from West Africa and is known as a drought-resistant upland variety.

Rice breeders in Bangladesh and Thailand have made substantial progress in improving their deepwater rices from indigenous germ plasm (Zaman, 1977; Prechachat *et al.*, 1980). Thai breeders have retained much of the excellent grain quality of their export cultivars in the improved rices (Rice Division, 1976; Kongseree, 1979).

Two sister lines (BR51-91-6 and BR51-46-C1), both derived from IR20/IR5-114-3 and selected by the Bangladesh Rice Research Institute, have been recommended for release in Burma and India because of their promise in yield performance (IRRI, 1980a).

An Indonesian breeding line (Kn-lb-361-1-8-6) having a high level of tolerance to cool temperatures was recommended for planting in the Mt. Province of

the Philippines as "RP KN-2" (Ronduen and Villareal, 1976). The Indonesian variety "Remadja" was used to breed "BG90-2" of Sri Lanka; the latter has been renamed as new releases in Burma and Nepal (IRRI, 1980b). Improved cultivars bred by Indonesian workers in the mid 1970s involved parents coming from foreign countries such as "Latisail" of Bangladesh, "Puang Nahk 16" of Thailand, "Basmati-370" of India, and IR varieties or lines (cf. Dalrymple, 1978).

Chinese workers have made extensive use of indigenous semidwarfs, pest-resistant sources, and foreign introductions at many breeding centers. The semidwarfs were derived from "Ai-zai-shan" or "Ai-Jiao-Nan-Te," both of which were indigenous to China. A Japanese introduction led to many improved "keng" (Sinica race) varieties bred from "Nong-Kêng 58." IRRI varieties and lines have been extensively used in conventional breeding programs and in the development of recent hybrid rices (Shen, 1980).

Chinese breeders have successfully incorporated the cytoplasmic-genic male sterility found in a sterile plant (Wild Aborted) belonging to the annual weedy race, *O. sativa* f. *spontanea*, into many productive backgrounds. This sterile source proved to be highly compatible in crosses with Indica varieties of China and with IRRI varieties. Since 1977 the planted area of hybrid rices has been expanded to nearly 8 million hectares (Lin and Yuan, 1980).

Aside from the cytoplasmic sterile source found in *O. sativa* f. *spontanea*, Chinese breeders had earlier used another *spontanea* plant in developing "Yatsen 1." This variety was later used as a parent in breeding the "Bao-tan-ai" semidwarfs which are widely adapted and pest resistant (Kwangtung Agriculture and Forestry College, 1975). "Bao-tan-ai" and "Bao-xuan 2" were recently found by IRRI virologists to have a higher level of tolerance to the grassy stunt virus than other traditional varieties which do not have the *Gs* gene for resistance derived from *O. nivara* (IRRI, 1982).

Wide crosses of rice involving sorghum, maize, wheat, bamboo, and barnyard grasses also have been investigated in China (Shen, 1980), but the continually segregating progenies have yet to prove their agronomic worth.

Korean workers have made dramatic advances in yielding ability by crossing IR lines with local varieties of the Sinica (Japonica) type in a collaborative venture with IRRI. A series of high-yielding cultivars led by "Tong-il" (selected from IR667-98) dramatically increased rice yields from 3.35 to 5.01 tons/ha in the demonstration fields during 1971. Tong-il came from the cross of "Yukara"/TN1//IR8, and it was used to develop "Yushin." The next series of Milyang varieties (Milyang 21, 22, and 23) involved "Jin Heung" of Korea and IR262-43-8 and "IR24" of IRRI. The series of 15 interracial hybrids developed between 1971 and 1977 had increased the national rice yield from 3.30 to 4.94 tons/ha and achieved self-sufficiency for the country in 1975 (ORD, [undated]).

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However, serious disease epidemics made importation of rice necessary a few years later.

Grain yield of the Ponlai (Keng or Sinica) type in Taiwan was raised to a new level by the development of "Tainung 67" which involved Taichung Native 1 in its parentage (Huang., 1979). Other breeders drew on local Ponlai varieties, Taiwan's semidwarf Indicas, IR varieties and lines, and early-maturing varieties introduced from Japan to further improve both the Keng and Indica types.

However, to cope with the major virus diseases and the brown planthoppers, rice breeders in tropical Asia rely heavily on IRRI's resistant varieties and lines having a high-yielding background (Hargrove, 1978; IRRI, 1980b).

C. By International Centers

IRRI scientists have made extremely profitable use of the genepools present in the IRRI germ plasm bank. The initial and best known success is the incorporation of the semidwarf gene (*sd*-1) into the background of tropical varieties, leading to the development of IR8 (see Chandler, 1968). The dramatic advances in yield performance and range of ecogeographic adaptedness associated with the improved plant type have been described and analyzed (Chang, 1967; Yoshida *et al.*, 1972; Chang and Oka, 1976).

The second stage, improvements in grain quality, was contributed largely by TKM6 of India and Tadukan progeny of the Philippines (Beachell *et al.*, 1972). Successful improvements in disease and insect resistance were largely contributed by TKM6, a strain of *O. nivara*, "CR94-13" (derived from "PTB 18" and "PTB 21"), "Mudgo," and "N22," all of which came from India. "Gam Pai 15" of Thailand furnished resistance to the tungro virus (Khush, 1977). Earliness was derived mainly from Chinese and Indian varieties (IRRI, 1980a). Resistance to drought was transferred from "Rikuto Norin 21" of Japan, "E425," "Moroberekan," and "OS4" of West Africa, "Nam Sagui 19" and "Khao Dawk Mali 105" of Thailand; "Khao Lao" of Laos; the Gorai varieties of India; and traditional upland varieties of the Philippines (Chang *et al.*, 1982). The Kn lines of Indonesia and Chinese introductions selected in India have provided promising sources of tolerance to cool temperatures (IRRI, 1980b). Tolerance to salinity was derived primarily from varieties of South India and Sri Lanka, such as "Pokkali," "Nona Bokra," and "Getu." Outstanding sources of tolerance to alkalinity such as "Damodar" and "Dasal" also came from India. Varieties tolerant to iron toxicity in wetland soils came from Sri Lanka and Vietnam. Sources able to withstand aluminum and manganese toxicities in aerobic soils were identified from the dryland varieties of the Philippines, Latin America, and West Africa (IRRI, 1981). On the other hand, many IR lines tolerant to adverse

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soil factors were obtained from crosses involving nontolerant parents (Ikehashi and Ponnamperuma, 1978).

Breeders at CIAT in Colombia have used IR varieties and lines, selections bred at the Instituto Colombiano Agropecuario (ICA) of Colombia, blast-resistant varieties from Vietnam, and BG varieties from Sri Lanka in the breeding program.

At IITA in Nigeria, rice scientists have utilized IR varieties and lines, African upland varieties, Taichung Native 1, and "LAC 23" in the breeding program.

Varieties developed by the IRAT staff in Ivory Coast include in their parentage upland varieties from Africa, Indica varieties from Taiwan, and upland varieties from Brazil.

D. Global Sharing of Improved Germ Plasm

The rapid dispersal and adoption of IR varieties by different countries in Africa, Asia, and Latin America from 1965 to 1977 have been summarized by Dalrymple (1978). During 1976–1977 the total land area planted to IR varieties and other high-yielding varieties amounted to about 25.27 million hectares. Diffusion of the IR varities and lines into national breeding programs has been documented by IRRI staff (Hargrove, 1978; Hargrove *et al.*, 1979; IRRI, 1981).

Since late 1975 IRRI ceased to name and release new rice cultivars under the IR series—11 varieties were so named, numbering from "IR5" to "IR34." The revised policy was adopted at a time when national rice-breeding programs and international cooperation through the IRTP had reached an expanded stage which made the practice of IRRI's naming of varieties no longer necessary. This change further encourages national centers to fully utilize IRRI's breeding materials and other selections included in the IRTP nurseries. Several national centers have named selections chosen from the above sources either under their own codes or as IR varieties. Since 1975, 21 varieties have been released in 23 countries under the cooperative testing program (IRRI, 1978a, 1980a).

The establishment of the IRTP in 1975 marked a giant step in the systematic and coordinated exchange and sharing of improved germ plasm by rice researchers all over the world. The testing of a uniform set of genotypes across many environments has provided credibility to the initial experimental findings as well as information on genotype × environment interactions and growth stage-specific responses.

A 5-year report of the IRTP (IRRI, 1980b) furnished an extensive list of stress-resistant or tolerant selections confirmed by many rice researchers. Some of the outstanding performers or resistant donors in the international nurseries were subsequently released by national programs as recommended cultivars. Since 1979 more than 30 IRTP entries have been released in that manner in more than

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20 countries. The use of other promising entries as parents in national breeding programs provides an even greater potential in using the useful genetic pools of diverse origin (IRRI, 1980b).

E. Public Efforts versus Private Enterprise in Rice Breeding

Most of the rice breeding in the United States has been done at public institutions although in the early years the development of cultivars was largely by private breeders. These private breeder efforts consisted primarily in selecting true breeding lines from mixed populations, increasing the seed, and distributing it to rice growers. Using this method, S. L. Wright, an independent rice breeder in Louisiana (Jones, 1936), developed several cultivars that were widely grown from about 1912 to 1935 in the Southern States. Public rice-breeding programs were started in most rice-producing states early in this century. These programs were cooperative projects conducted by the USDA and State Agricultural Experiment Stations. Cultivars developed in these cooperative projects gradually replaced the older ones developed in private rice-breeding programs. The acreage of rice in the United States is small compared to that of other cereals so the demand for seed is limited. Because of this, and also because the public rice-breeding programs were fairly successful, there was little effort by private breeders to conduct rice-breeding programs.

In recent years rice acreage has expanded, thus there is an increased demand for rice seed. The Plant Variety Protection Act (PVPA) enacted in 1970 enabled plant breeders to retain control of the varieties they developed (Rollin, 1972). These two items gave added incentive for private breeders to initiate rice-breeding programs. There has not been a big rush of private breeders into the breeding of rices, but a few companies have entered this field, and their activity increased noticeably in 1980 and 1981.

The most active nongovernmental rice-breeding project is conducted by the California Cooperative Rice Research Foundation (CCRRF). This agency is supported by marketing-order funds raised by self-imposed rice-grower assessments. No other public funds (since the marketing-order funds are collected by the California Department of Food and Agriculture, they are considered "public funds") are directly involved in this rice-improvement project but several University of California and USDA/ARS personnel are involved in cooperative projects which provide assistance to the breeding and testing efforts of CCRRF and others. Recent varietal releases have continued to be joint, cooperative releases by CCRRF, the University of California, Davis, and USDA/ARS, with CCRRF controlling the production and sale of foundation seed.

Some privately developed rice cultivars have been marketed in recent years in

California, Louisiana, and to a lesser extent in Mississippi and Arkansas. For the most part, however, such cultivars sold in the Southern United States are still lacking in resistance to diseases, especially blast, and to date occupy a relatively small percentage of the total rice acreage.

The present system of conducting rice-breeding research with public agencies in charge of the introduction, maintenance, and evaluation of genetic stocks is working quite well. This system entails publication from time to time of reports on the material available and the characteristics of these materials. The personnel involved in these projects also continue their own genetic and breeding projects. This arrangement makes all the basic breeding material available to all breeders, but private breeders are able to control distribution of the cultivars and breeding material they develop under provisions of the PVPA.

The recent appearance of a booklet (Mooney, 1980) has led to some rather detailed discussions on the future domain of plant breeding. The principal emphasis of the booklet is that plant breeding of cash crops in the advanced countries has been largely brought under the plant breeder's rights and more recently controlled by multinational companies dealing with agricultural chemicals. The rapid acquisition of major seed companies by such industrial giants has alarmed agricultural scientists as well as many people in the public sectors.

The situation in rice is not so alarming as it is in hybrid maize or in the high-priced vegetable crops. In all rice-growing countries the breeding phase has been traditionally the responsibility of the government sector. This is even true in the major rice-growing states of the United States. Commercial rice-breeding ventures currently are found only in the United States and Latin American countries, and their percentage of the seed market to date, is insignificant. Moreover, the international and national centers are continuing the free exchange of elite germ plasm and unrestricted naming of varieties selected from such materials (IRRI, 1980b).

Since rice is largely a self-pollinated crop, the prospects of profitable private enterprise in breeding and seed production do not appear overwhelmingly attractive. Even with the recent development of hybrid rice in China, the margin of profit rests with the price differential between ordinary seed and F_1 hybrids as well as the increase in yield of the hybrids over the pureline varieties. For rice varieties of nonaromatic grain quality, the price differential likely will remain small. Moreover, the diverse rice-growing environments would require a wide array of improved genotypes to meet the needs of specific environments. China was able to expand hybrid rice production because it is a government-supported campaign. Therefore, the threat of private companies to monopolize the breeding programs does not appear eminent in rice. However, two large seed companies operating in the United States and elsewhere reportedly have obtained "exclusive rights" to the component lines of the cytosterile sources used to constitute the major rice hybrids currently being grown in China. The cooking and process-

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ing characteristics of these current hybrids are not satisfactory for the markets where United States rice is now marketed. Meanwhile, research on hybrid rice also is being conducted at public institutions of several countries and at the international centers. In addition, rice breeders of public institutions will likely continue their practice of sharing both the unimproved and improved germ plasm without the restrictions imposed by the plant breeder's rights act.

F. Problems in Using Diverse Germ Plasm

It is apparent from the preceding sections that rice researchers and particularly the IRRI staff, have been using diverse donor parents in the hybridization programs. On the other hand, wide crosses among cultivars within one species or between two species have hampered progress in breeding because of incompatibility problems.

The best known example of intervarietal sterility within *O. sativa* has been documented in the crosses between the tropically based Indica race and the temperate zone Japonica (or more appropriately Sinica) race. Early findings on the sterility and incompatibility aspects have been summarized by Chang (1964) and Oka (1964). Extensive cytogenetic investigations on the partially sterile F_1 hybrids were summarized Chang (1964). The partial sterility, weakness of F_1 seedlings, breakdowns of F_2 seedlings, disturbed segregation ratios in the F_2, and aberrant recombinations have hampered the recovery of useful progenies in the Indica × Japonica crosses. The problems associated with the interracial crosses may partly explain why only a few promising varieties were obtained from the FAO-sponsored Indica × Japonica Hybridization Project which involved several Asian countries during the 1950s (Parthasarathy, 1972). Similarly crosses between tropical Indicas and the Javanica varieties of Indonesia have shown partial sterility and chromosomal aberrations (Engle *et al.*, 1969).

The incompatibility phenomenon in Asian rice is not confined to interracial crosses. It has been demonstrated that similar difficulties showed up when crosses were made between tall tropical Indica varieties and the Chinese semidwarfs and between traditional dryland varieties and the semidwarfs (Engle *et al.*, 1969; Hung and Chang, 1976; Lin and Chang, 1981). Cytological and chromosomal abberrations of the inter- and intraracial hybrids are essentially similar (Demeterio *et al.*, 1965; Engle *et al.*, 1969, 1970).

The well-publicized findings on inter- and intraracial incompatibility have discouraged some rice breeders from attempting wide crosses, but the difficulties were not so unsurmountable as to exclude wide crosses from being used for specific objectives. Breeders in Korea, Taiwan, the United States, and at IRRI have obtained useful progenies from wide crosses, but only after long cycles of crossing and selection (Johnston *et al.*, 1972; ORD, [undated]; Chang, 1976f; Chang *et al.*, 1982).

Research in China has shown that anther culture has produced higher proportions of plantlets in Indica × Japonica hybrids than in Indica × Indica hybrids (Zhang, 1981). Tissue culture may offer an alternative approach to make more efficient use of the progenies of wide crosses.

Crosses between the Asian cultigen *O. sativa* and the African cultigen (*O. glaberrima*) have not been rewarding because of sterility and related problems. The African rices possess certain biotic resistances and ecoedaphic tolerances, but the levels were generally not superior to the Asian cultivars (Chang *et al.*, 1977). A limited amount of crossing, selection, and evaluation for insect resistance has been conducted at IRRI since 1976.

Crosses between the cultivated rices and their wild relatives generally present serious difficulties in recovering desirable progenies, especially when the genomes of the parents differ (cf. Chang, 1964; Chang *et al.*, 1977). But one strain of *O. nivara* (IRRI Acc. 101508), an annual Asian weed race, has been successfully used in incorporating resistance to grassy stunt virus into the semidwarfs (Khush, 1977). This strain, which was the only one of 40 strains in the same species that was resistant to the grassy stunt virus, appears to be an exceptional sample in the weed race. Its hybrids with the Asian cultivars showed less chromosomal aberrations than several crosses among Asian cultivars (Dolores *et al.*, 1979).

VII. ENDEAVORS FOR THE FUTURE

A. Completion of Field Collection for the Two Cultigens

The collaborative efforts of many research centers in canvassing and assembling the uncollected rice germ plasm during the last decade is a unique venture among the major crops. The total number of seed samples collected was more than 32,000, but the coverage is still incomplete insofar as the widely distributed rice cultigens are concerned. Moreover, a number of the collected samples were either obvious duplicates or nonviable.

The 5-year collection program developed at IRRI in late 1977 has served as a useful guide in implementing systematic collection in Asian countries. Although more than one-half of the accessible areas of the target countries have been covered since the 1977 workshop, vast areas in Laos, Cambodia, and Nepal remain unexplored. Field collection in Southwest China has been initiated but the area has not been completely canvassed. The northeastern states of India also remained largely unexplored. There are many pockets in West Africa which could yield rice germ plasm, if canvassed. The assemblage of the wild relatives of the two cultigens remain as the most obvious gap in the conservation efforts.

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It will require periodic workshops and vigilant communication to maintain the tempo of the collection activities. Fortunately, the IBPGR is channeling larger allocations of its resources into this phase of conservation.

B. Consolidation of Existing Major Collections

Conferences held at IRRI and elsewhere have revealed substantial duplication of conserved seedstocks at different centers. However, some of the superficial duplications may be in varietal names only because the seedstocks may represent different eco-strains of the original variety. Morphologic variants and mutants of the same varieties are also found in the duplicated samples. In addition, in at least a few cases, mislabeling apparently occurred at harvest. In the interest of efficient management, it is essential to minimize the duplications without overlooking the ecostrains, morphologic variants, and mutants. Steps have been taken by the staff of the USDA, the NIAS of Japan, IITA, and IRRI in comparing accession lists as preparations for consolidation.

This phase is a time-consuming and laborious operation because seed and plant data need to be included in the process of comparison and consolidation. On the other hand, the process would lead to a more efficient and secure preservation of all conserved stocks at two or more long-term storage sites. Working collections could be maintained in the region of collection as desired.

C. Conservation of Wild Species

The total number of wild forms being conserved by different centers is probably not more than 3000. The wild strains were collected either by botanists or explorers on specific missions or by breeding-oriented collectors while canvassing for the cultivars. More systematic efforts are needed to survey and plan for the conservation of the wild forms which are also threatened by developments in progressive agriculture and public infrastructures.

The IBPGR–IRRI Rice Advisory Committee studied the complex problem of collecting and conserving the wild species in late 1981. The conservation of the wild forms would require a synthesis of contributions from botanists, geneticists, conservationists, and government administrators (IBPGR–IRRI, 1982).

D. The Completion of Evaluating the Collected Materials

The massive scale of varietal evaluation by rice workers in different centers on a worldwide basis is unprecedented in crop history. However, the sequence and

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degree of completeness in evaluating the existing collections have not been as systematic and comprehensive as desired. Periodic reviews and discussions are needed to upgrade the coverage and usefulness of the evaluation activities.

The material in the collections should be evaluated as rapidly as funds and availability of personnel and equipment permit. The evaluation could be done at several locations. That is, reaction to disease and insects could be studied at locations where the disease or pest occurs naturally. Cooking and nutritional studies must be conducted at institutions that have the necessary equipment and personnel.

Because of the enormous diversity in the genetic makeup of the cultigens and of the environments under which they are grown, the interpretation of evaluation results obtained at one location for use at other locations would require in-depth study and analysis by teams of scientists of the several appropriate disciplines.

E. Characterization of Environments

The diverse environments under which rice is grown requires the coordinated efforts of rice researchers to concurrently describe and characterize the important ecological components so that a better understanding of the ecosystem involved would lead to an efficient use of the experimental data. The international agricultural research centers have been conducting dialogues which will eventually lead to unified and comparable systems of characterizing the rice-growing environments.

F. Innovative Breeding Techniques

The great majority of elite rice germ plasm bred at different centers has been developed through the conventional process of hybridization and selection. Induction of mutations as a breeding tool has met with varying degrees of success at different rice research centers. Rutger *et al.* (1976) reviewed the advances in rice breeding through the use of spontaneous and induced mutations. In the cooperative USDA/ARS California Agricultural Experiment Station-Rice Industry program, induced mutations of useful genes have been obtained for short-stature, early maturity, and glutinous character in adapted, cold-tolerant California germ plasm (Rutger *et al.*, 1976, 1977, 1979a,b). Rutger and his co-workers have had considerable success with induced mutation breeding in their unique situation in California where they have rather minor insect and disease problems compared to other areas of the United States and most rice-growing countries. However, they emphasize that this is only one of several breeding methods that should be used. They believe that induced mutation breeding, both on whole plants and in cell culture studies, offers the potential to eventually "generate new genes upon demand."

It has been suggested (J. N. Rutger, personal communication) that for better utilization of existing rice germ plasm, serious consideration should be given to establishing an "instant germ plasm reservoir package" which may be quickly put into use in areas with serious new disease or insect problems. Such a package could be used in situations such as the ragged stunt virus outbreak in Indonesia, the Philippines, and elsewhere. If prepackaged germ plasm reservoirs or pools were available for instant distribution, resistance to new pests might be more quickly identified. Perhaps the simplest such package might contain a few seeds from each of the accessions in the IRRI World Collection, perhaps broken down into at least three major categories. More sophisticated pools might be formed by using genetic male steriles to create composite cross populations. Efforts have been made to develop somewhat simpler gene pools but involving hundreds of crosses with a wide range of types of varieties from throughout the world (personal communications from W. R. Coffman and W. O. McIlrath). The establishment of such gene-pool composites represents a very major undertaking and the involvement of many personnel, extensive funding and coordination, and prolonged dedicated efforts.

Tissue culture has been used to a limited extent in rice breeding, often under restricted objectives. Croughan *et al.* (1980) applied cell culture techniques to selection of salt-tolerant rice in California experiments. Starting with naturally occurring haploid plants, they obtained four cell lines which exhibited salt tolerance. Their research is continuing. Chalef *et al.* (1978) working at Cornell University and Schaeffer *et al.* (1978) working at the USDA ARS, Beltsville Agricultural Research Center have been using tissue culture techniques in an effort to develop rice plants with increased lysine content in the grain. Some progress is reported and the research is continuing.

In a recent report, the National Plant Genetic Resources Board (1979) cites a "white paper" entitled "Research Priorities in Plant Breeding" by Sprague, Alexander, and Dudley which cautions against the high budgetary rating currently given research in cell culture and other forms of "genetic engineering." These well-respected researchers of long standing agree that the field holds some promise and unquestionably deserves support. However, they seriously question the high priority rating of genetic engineering if the research is to be achieved through neglect of those disciplines that continue to improve plant performance and offer promise for the future. They further state, "Even if new products are developed by genetic engineering techniques, the use of them will be accomplished through conventional crop improvement programs. Continued progress in improving the performance of crops cannot reasonably be expected unless this relation is understood and implemented."

The possibility of employing useful genes present in the wild species of *Oryza* and those of related genera have not yet been attempted extensively other than the efforts of IRRI staff. Figoni *et al.* (1981) reported on the transfer of stem rot

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resistance from a wild species (*Oryza rufipogon*) to *O. sativa*. Advanced generation lines are undergoing further testing for resistance to stem rot. Some of the lines also were tested in 1981 in Arkansas for resistance to sheath blight (F. N. Lee and K. S. McKenzie, personal communication). Similarly, screening of wild species for resistance to sheath blight is underway in California (J. N. Rutger, 1981, personal communication).

Incompatibility and a lack of controlled experimentation have impaired the reproducibility of the wide crosses. A combination of different breeding techniques such as mutation and tissue culture would lead to more efficient use of the specific gene pools to be transferred through the wide crosses.

G. Restoration of Genetic Diversity to the Improved Cultivars

It is inevitable that as breeding programs advance, there is a concurrent increase in the genetic uniformity of the elite germ plasm. The narrowing of the genetic diversity in the major commercial varieties would increase the genetic vulnerability of the relatively few cultivars to serious epidemics of pests and diseases. Recent events such as the shifts in the brown planthopper biotypes, the sudden emergence of hitherto obscure virus diseases, and the flareup of rice blast in South Korea during 1980 are associated with the rapid spread and large-scale adoption of a few genetically similar cultivars over large areas, especially under continuous cropping in the humid tropics. It is imperative that the breeders as well as public administrators recognize the need to reinstate the rich genetic diversity which was present in rice until a few decades ago.

The cooperative breeding programs in the United States in the past 10–15 years have included the use of a much wider range of parental types than in earlier years in order to broaden the genetic base for resistance to blast and other diseases and for other needed characteristics. Concerted efforts are being made in the United States, IRRI, and other rice research centers for different sources of short stature and high- and stable-yielding ability.

Seed multiplication and distribution programs may be complicated by the restoration of genetic diversity to the major production areas, but the costs involved may be a small price to compensate for the much larger potential losses due to serious pest damages. Moreover, genetic diversity should be considered both on a genic and cytoplasmic basis.

H. Training of Rice Researchers

The number of rice researchers in different national programs has been greatly expanded during recent years. But the total number and their distribution across disciplines are insufficient for the needs of the near future. Researchers in the

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areas of pathology, entomology, and physiology are more deficient in number than those in breeding and agronomy. Among many rice breeders trained in advanced countries, the graduate training was largely based on dryland crops. The semiaquatic rice requires an in-depth understanding of those peculiarities associated with the crop. On the other hand, some breeders working on dryland rice were trained under programs designed for irrigated rice. A frequent criticism of existing advanced country training programs for developing country trainees is that the training is highly basic and has little application in the student's home country. Nevertheless, it is crucial that students become cognizant of the latest techniques in order better to understand how these might be utilized in local situations.

Workers trained in genetic conservation are few in number and low on experience. Training in each of the above areas, emphasizing practical experience in handling the rice plant and its associated biotic and physical factors, is essential to developing real expertise in different aspects of rice research. Training will continue to be an equal partner to research on rice.

One important aspect in the training of rice researchers is to emphasize the need to look at the rice plant or crop as a whole. Workers in all disciplines need to be aware of the many interrelated traits such as the effect of N-fertilization on diseases and quality of the grain. Also, N-fertilization and cultural management can have profound effects on lodging of the crop, cost of harvesting, and ultimate food value or cash crop value obtained.

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