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Conservation of Rice Genetic Resources: Luxury or Necessity?

T. T. Chang

Rice shares equal importance with wheat in feeding the world's population. While wheat production exceeds that of rice, rice is milled nearly exclusively as food. In the developing world, rice ranks as the principal staple. It provides about calories to sustain a larger number of persons per unit of land than other cereals in the monsoonal areas. The crop feeds and supports millions of subsistence farmers and landless workers of the humid tropics.

Summary. There is remarkably rich diversity in the cultivated rices and their wild relatives. Substantial segments of the diverse germplasm have been collected and conserved during the past two decades by national, regional, and international research centers. Multidisciplinary and interinstitutional evaluation and use have drawn substantial rewards. However, nations in the developing world that grow and consume rice still face enormous challenges to meet the continuous growth of the human population. Further conservation efforts and improved preservation measures are needed to provide security for the irreplaceable rice germplasm. Modest inputs into conservation programs are highly justified by multibillion dollar returns from the improved varieties in the past two decades.

80 percent of the calories for the 2 billion people of Asia and one-third the caloric intake of the nearly 1 billion people in Africa and Latin America. Rice is also a major source of protein for the masses of Asia. It is the only cereal that can withstand flooding, and it produces more

T. T. Chang is geneticist and head, International Rice Germplasm Center, International Rice Research Institute, Post Office Box 933, Manila, Philippines.

From 1969 to 1971 important gains in rice production and yield were realized by most of the populous countries in tropical Asia, which had faced food crises in the droughty years 1965 and 1966. Development of the semidwarf rices and wheats and the associated production technologies spurred the food production increase. The gains continued through 1982; however, per capita food production in the developing countries has lagged since the early 1970's, mainly because of high population growth rates (*1*).

If the mid-1983 world population of 4.72 billion continues to increase at the annual rate of 1.75 percent (*2*), an increase of 1.62 billion people by the year 2000 may be projected. The population will rely on increased rice production to supply nearly one-half of the caloric intake required.

Sources of Germplasm in *Oryza*

The genus *Oryza* has 20 wild species and two cultigens, *Oryza sativa* L. and *Oryza glaberrima* Steud. The full spectrum of genetic resources in the genus consists of (i) wild species, natural hybrids between the cultigen and wild relatives, and primitive cultivars of the cultigens in the areas of diversity; (ii) commercial types, obsolete varieties, minor varieties, and special-purpose types in the centers of cultivation; and (iii) pureline selections of farmers' varieties, elite varieties of hybrid origin, F_1 hybrids, breeding materials, mutants, polyploids, aneuploids, intergeneric and interspecific hybrids, composites, and cytoplasmic sources from breeding and related research programs (*3*).

The geographic distribution of the two cultigens and their close wild relatives has been described (*1, 4*). I estimate that slightly more than 100,000 cultivars of *O. sativa* may be found in the world.

Genetic Diversity in Rice Species

The cosmopolitan rice cultigen is *O. sativa*; *O. glaberrima* is grown only in Africa. The original home of the genus is traceable to the Gondwana supercontinent before its fracture and drift. Progenitors of the present 22 species in the genus had differentiated to a considerable extent before the Cretaceous period, or about 130 million years ago. Thus, the genus has great antiquity (*1, 4*).

The prototype of *O. sativa* quickly differentiated into the present cultigen mainly in the area bordering India, Burma, and China during the Neothermal period, about 15,000 to 10,000 years ago. Through early contacts among peoples of the above areas, human movements, and water-assisted dispersal of seed, substantial plantings of the tropical ecogeographic race (indica) were already cultivated at the Ho-mu-tu site of Chekiang Province, China (about 120°E, 30°N), at least 7000 years ago. Remains of the temperate race (sinica) were found at Ch'ien-shan-yang, also of Chekiang Province, and dated at 3311 B.C. The Ho-mu-tu remains antedated the Chalcolithic samples found in India dated at 4530 B.C. (*5*). These dates indicate that cultivation of rice by the early farmers of China was not far behind that of bread wheat in the Near East (*6*).

Rapid dispersal of rice from its tropical (southern and southeastern Asia) and subtropical (southwestern and southern China) habitats to much higher altitudes and latitudes in Asia occurred as recently as 2300 years ago in the case of Japan. Introduction to points as far as West Africa, North America, and Australia took place within the past six centuries.

More important was the exposure of the tropically based semiaquatic species to new diverse environments that led to its broad adaptiveness. Inherent variability in the early forms of rice was greatly magnified after its introduction into these new environments. Subsequent differentiation, diversification, and selection (both natural and artificial) led to floating rices able to withstand 5-m-deep water, dryland rices with deep and thick roots, rices tolerant of submergence by floodwater, cultivars tolerant of high salinity, rices resistant to aluminum toxicity, and rices tolerant of cool temperatures at the seedling or ripening stage. Thus, rice is ideal for growing by subsistence farmers in low-lying monsoonal areas where no other grain crop can be cultivated (*1, 7, 8*). The land races are adapted to cultural practices involving low inputs. Rice cultivation presently extends from 53°N to 40°S (*1*).

Because rice breeding in tropical areas began largely after World War II, there was remarkable genetic diversity in the widely distributed *O. sativa* before the advent of the semidwarf rices in the late 1960's. However, the displacement of traditional varieties (land races) by improved varieties (primarily semidwarfs) or introductions has since been progressing at an alarming rate. About 40 percent of the rice areas in Bangladesh, Burma, India, Indonesia, South Korea, Nepal, Malaysia, Pakistan, the Philippines, Thailand, and Sri Lanka are now planted in the semidwarf rices (*9*). Rice areas in China are nearly entirely planted in improved varieties and hybrid rices, although precise data are unavailable.

Oryza glaberrima also exhibited diversity, but it was considerably less than that of the Asian cultigen (*7*). The *O. sativa* varieties introduced from Asia continually replace *O. glaberrima* in many irrigated and upland areas of Africa, but the rate is slower than that in Asia.

The 20 wild species comprise another reservoir of diversity. Six wild species closely related to the two cultigens are diploid and have the same AA genome. Both diploid and tetraploid forms exist in the other wild species and their genomes are CC, BBCC, CCDD, EE, or FF, or are unknown (*4*).

Conservation Efforts Before the 1970's

Major rice-growing countries in Asia assembled substantial numbers of indigenous rices during the 1930's and 1950's. The size of the national collections varied from about 1000 in the Philippines to more than 20,000 in India. China assembled about 40,000 varieties, which included some duplicates. The United States maintained about 7000 accessions. Japanese workers collected about 1300 local varieties during 1962 (*10*).

Most of the national collections in tropical Asia shared a number of features: (i) the principal commercial varieties were well represented; (ii) minor and primitive cultivars (land races) were few; (iii) many duplicates existed, especially in foreign varieties of some fame; (iv) few breeding lines were maintained; and (v) very few wild rices were conserved. The lack of refrigerated seed storage facilities forced the staff of national centers to grow and renew their stocks every year or so. Thus mixtures, losses, or mislabeling increased in frequency. The work load and lack of refrigerated storage facilities strained local capabilities and discouraged conservationists (*8*).

The rice germplasm bank of the International Rice Research Institute (IRRI) was established in late 1961. With excellent cooperation from various national centers, the IRRI collection quickly grew to 12,000 accessions by 1970. Because a medium-term storage facility was built at the start, IRRI's germplasm bank was able to serve as a major seed exchange center for many rice-growing countries by drawing on the seeds kept in cold storage.

Like the national centers, IRRI suffered from deficiencies in the coverage of land races. However, its bank was maintaining 740 wild taxa donated by botanists and geneticists of several nations. It also held a substantial number of cultivars locally known for their high levels of resistance or tolerance for diseases, insects, salinity, drought, and deep water. These land races have helped IRRI staff find useful sources for their evaluation and breeding efforts (*8*). Development of the semidwarf IR8 in 1966 was a major breakthrough based on an assemblage of useful donors.

Conservation Efforts Since 1970

When the high-yielding semidwarfs began to replace traditional varieties in South and Southeast Asia, the 100 rice breeders who were present at the 1971 rice breeding symposium urged IRRI to organize and coordinate field collection in areas threatened by the rapid spread of the new varieties. Major national rice research centers in tropical Asia and several donor agencies collaborated with IRRI in implementing intensive exploration and collection operations. Targets ranged from uncollected cultivars in threatened areas to minor varieties in remote areas to special types in adverse ecological niches. The massive collection campaign involved extension workers, missionaries, service volunteers, and anthropologists (*8*).

Planning and coordination of the worldwide field collection activities were intensified with the holding of an IRRI workshop in 1977. At this meeting a 5-year plan was developed and interagency cooperation and exchange were stimulated (*10*). By pooling financial resources and stimulating local interest, IRRI has played a catalytic role in the massive field activities that followed the workshop.

From 1971 to 1982 seven Asian countries and IRRI jointly collected 10,472 samples. Seven other countries implemented collection operations by their own staff but with financial and technical assistance arranged by IRRI. A total of 25,530 samples were assembled, but thousands of samples were either duplicated or nonviable. Among the collections, about 9000 samples were locally claimed to have one or more special characteristics, such as cool temperature tolerance or drought resistance (*8*).

During the past 5 years the International Board for Plant Genetic Resources (IBPGR) has channeled funds to IRRI to help Asian nations continue the collection activities. The activities have gradually waned, however. A second workshop held in the spring of 1983 developed a second 5-year plan for assembling the remnant germplasm (*11*).

National, regional, and international centers in West Africa have also collected *O. glaberrima*, African wild species, and Asian introductions of *O. sativa* during the past decade. About 4000 samples were assembled and a duplicate set was deposited at IRRI (*11*).

The wild species have not been intensively canvassed and collected. The IBPGR-IRRI Rice Advisory Committee conducted a special study and visited the germplasm-rich Jeypore Tract of India in 1981. The committee recommended special measures toward the conservation of wild taxa (*12*).

Since 1971 the IRRI germplasm bank has served as the central depository for the world's rices. In mid-1983 the IRRI collection included 67,000 Asian cultivars, 2600 African rices, 1100 wild rices, and 690 genetic testers. Thousands of breeding lines that have one or more desirable traits or have been used as donor parents were also preserved. IRRI has devised safe and efficient means of processing seed for long-term storage. To provide extra security, IRRI deposits a duplicate set of freshly rejuvenated seed at the U.S. National Seed Storage Laboratory in Fort Collins, Colorado (*13*).

The U.S. Department of Agriculture, the National Institute of Agricultural Sciences of Japan, and IRRI are comparing their inventories to consolidate them to reduce redundancy and to preserve the foreign accessions at the best-adapted site. Each of the three banks has storage facilities capable of preserving seed viability for more than 50 years (*10, 11*).

Thus, the massive collection efforts have not only saved the crop from a possible genetic wipeout (*14*) but also greatly enriched the germplasm available for the further improvement of the crop. In recent years IRRI has returned thousands of accessions to donor countries where the cultivars or wild taxa are no longer grown or maintained in a viable state (*15*).

Germplasm Exchange and Evaluation

International and interinstitutional exchange among rice workers was stimulated in the early 1950's when the International Rice Commission of the United Nations Food and Agriculture Organization initiated joint meetings of working groups. The coordinating role was shifted to IRRI in the early 1960's. The annual international rice research conferences, together with other symposia and workshops held at IRRI, have provided the venue for rice researchers to discuss and develop collaborative ventures in many areas of rice research. Worldwide collaborative activities on germplasm testing received new impetus in 1975 when the International Rice Testing Program was established at IRRI with funding by the United Nations Development Programme. The rice researchers drew heavily on the diverse germplasm, both unimproved and improved, for cooperative ventures.

When IRRI began research operations in 1962, its germplasm bank immediately became an active international exchange center, partly because it offered seed and technical information related to the accessions and partly because its international character enabled it to circumvent political barriers in seed exchange between national centers. Between 1962 and 1982 the bank provided more than 91,000 seed samples of the cultigens and wild species to thousands of rice scientists around the world. Seed requests totaling more than 2500 indicate the number of experiments being conducted by rice researchers in different countries. The bank has also supplied IRRI staff with nearly 350,000 seed samples, or about 30,000 samples a year during the past decade. In the past 5 years, IRRI scientists made an average of 280 seed requests per year, each request representing one experiment (*8, 11, 15*). Again, the statistics show the scope of IRRI's research activities under its Genetic Evaluation and Utilization (GEU) program, which was formalized in 1974 to expand and systematize the varietal improvement operations (*16*).

Under the multidisciplinary GEU program, several task forces, each composed of one or more plant breeders and their colleagues in the problem-oriented areas of specialization, were organized to jointly develop research objectives, evaluate potentially useful donors, plan appropriate crosses, and select and test progenies under a host of environments to identify promising ones. Each team member contributes his specialized knowledge to the complex process of screening and progeny evaluation. The major GEU problem areas include improving resistance to diseases, insects, and drought and increasing tolerance for adverse soil factors, submergence, and extreme temperatures. Concurrent goals are higher yield potentials, greater yield stability, improved grain quality, and enhanced nutritive value.

The major focus of the GEU program is to breed rices that can cope with the biological and physical constraints existing in the rain-fed unfertile production areas. Farmers in such unfavorable areas have not been benefited by the modern technology associated with high-yielding semidwarf rices and high inputs. These farmers, who represent nearly three-fourths of the rice farmers of tropical Asia (*16, 17*), also lack access to irrigation water or drainage facilities.

When one or more major production constraints cannot be tested on the IRRI farm, the staff collaborates with workers of national programs in screening and testing the improved germplasm under the targeted environments. Along with the involvement of many national centers in the International Rice Testing Program, collaborative testing has greatly expanded the scope of varietal improvement in each country concerned. It has also increased the exchange and sharing of germplasm and has stimulated local interests in conservation. IRRI's germplasm bank [recently reorganized as the International Rice Germplasm Center (IRGC)] serves as the reservoir of the necessary genetic inputs (*8, 15*).

In recent years several Asian countries have likewise organized national GEU programs to maximize rice breeding efforts (*18*).

Profitable Use of Germplasm

The adoption and spread of the semidwarf rices—Taichung Native 1, IR8, and other IR releases—in the Asian tropics during the late 1960's are well documented (*19*). Parallel developments in China, along with the release of early maturing Keng rices in the same decade, led to marked increases in national yield and cropping intensity (*20*). In the early 1970's IR8 was replaced by later IR varieties with improved grain quality, enhanced levels of pest resistance, and earlier maturity. Added tolerances for adverse soil factors or nutritional disorders were incorporated into some of the recent releases (*21*).

Many Asian countries have likewise

developed improved varieties that are adapted to local environments (*18, 22*). Another major breakthrough was the development of F_1 hybrid rices on mainland China during the late 1970's. Hybrid rices now cover about 6 million hectares in China (*23*).

Wild species have made significant contributions to rice improvement. Resistance to the grassy stunt virus coming solely from a strain of *O. nivara* collected from Uttar Pradesh State of India has reduced the incidence of that destructive disease on millions of hectares. Several Asian wild relatives of *O. sativa* furnish resistance to the ragged stunt virus, which flared up in 1977. One of the highly resistant sources came from Taiwan, where wild rices are now extinct (*15*). The hybrid rices of China derived their cytoplasmic male sterility from a wild rice plant (Wild Abortive) found on Hainan Island. A few Asian and African wild taxa have long anthers or prominently protruding stigmas that facilitate natural crossing in the production of hybrid rice (*23*). Two Chinese pest-resistant varieties derived their genes for insect resistance from an *O. sativa* f. *spontanea* population in Kwangtung Province (*15, 20*). Other potential uses of the wild taxa have not been fully explored (*7*).

Recent estimates show that the total area planted in improved modern rice varieties in 11 Asian countries excluding China, Japan, and South Korea during 1980 and 1981 was 32.94 million hectares, or 39.5 percent of the rice area. Between 1965 and 1980, rice production in eight Asian countries (Bangladesh, Burma, China, India, Indonesia, the Philippines, Sri Lanka, and Thailand) increased by 65 percent to 117.38 million metric tons of grain worth $19.367 billion. The contribution of improved varieties to the increase amounted to 27.37 million tons or $4.516 billion. These estimates exclude data from countries such as South Korea, Nepal, Pakistan, and Vietnam, where the impact of improved varieties has been impressive but variable (*9*).

The preceding developments were due in part to the collection and use of unimproved germplasm by rice breeders. Outside mainland China, the bulk of the genetic materials was supplied by IRGC. The extensive use of the land races and wild species by many rice breeders may be attributed to the systematic evaluation efforts by scientists in related disciplines, rapid dissemination of evaluation results on a worldwide scale in the *International Rice Research Newsletter* (published by IRRI), the free supply of seeds by IRGC at IRRI, and the relative ease in crossing and selection. The extensive use of exotic germplasm also reflects effective communication between the genetic conservationists and the users of genetic resources (*8*).

Vulnerability of Genetic Uniformity

A narrowing of the genetic base in semidwarf rices became obvious when rice breeders in tropical Asia and those in China were independently and unknowingly using the same sd_1 gene that conferred short plant stature on Taichung Native 1 (of Taiwan), IR8 and its derivatives (of tropical Asia), and Ai-jiao-nan-te and Kwang-chang-ai (of China) at the start of the Green Revolution in rice. The genetic base was further reduced by the extensive use of cytoplasm from Cina (Tjina), which went into IR8 and many other semidwarfs bred between 1962 and 1972 (*24*). The widely grown hybrid rices of central and south China all have the Wild Abortive cytoplasm (*23*).

Paralleling the above developments were the increased use of nitrogen in irrigated areas and the continuous or overlapping plantings of rice, frequently of the same variety in double-cropped areas of the tropics. The heavy and compact tillering pattern of the semidwarfs has modified the microclimate around the plants and made them more attractive to insects, especially leafhoppers and planthoppers (*25, 26*).

Although the changes toward genetic vulnerability and epidemic-prone environments have not led to such devastating yield losses as those experienced by the United States during the southern corn leaf blight epidemics of 1970 to 1971, there have been ominous incidents. One was the 1969 rice tungro virus epidemic in India, which appeared on the vector- and virus-susceptible Taichung Native 1. Another incident was the flare-up of tungro in Central Luzon in 1971 and 1972, when large areas were planted in IR8. IR8 is virus-susceptible, although it has moderate resistance to the vector, the green leafhopper (*Nephotettix virescens* Distant). The tungro problem subsided when the virus-tolerant IR20 and other improved Philippine varieties replaced IR8 (*27*). The tungro virus has also inflicted serious damage in Indonesia, especially on Sulawesi during 1972 and 1973 (*27*).

In 1973 the brown planthopper (*Nilaparvata lugens* Stål), vector for the grassy stunt virus, quickly dominated the scene in Southeast Asia. The prevalent population—brown planthopper biotype 1—was suppressed by the release of IR26 beginning in 1973. The insect also caused much damage in Indonesia from 1974 to 1978. This was a significant development because the insect had been considered a minor pest in earlier years (*28*).

During 1975 and 1976, almost simultaneously in North Sumatra and East Java of Indonesia and Mindanao of the Philippines, where intensive double-cropping was practiced, the brown planthopper populations shifted to biotype 2, which attacked IR26. Planting of the resistant IR36 in 1977 and 1978 stopped the epidemic, but, beginning in 1982, new hopper populations dominated both areas. IR56 was multiplied in Indonesia to replace IR36, and IR60 was released in 1983 for use in Mindanao. Both Indonesia and the Philippines rank high in the proportion of rice area planted in semidwarfs: 60 and 77 percent, respectively (*9*). With the drought of 1976, Indonesia's annual rice imports during 1976 to 1980 were nearly twice those of 1972 to 1974 (*1*).

Similar if less severe events occurred in Sri Lanka, Taiwan, and Vietnam during 1974 to 1975 (*28*). The above sequence fits the "boom and bust" cycles postulated by Robinson (*29*). The total loss due to the brown planthopper and grassy stunt virus in 11 affected countries from 1974 to 1976 amounted to $312 million (*28*).

Sequential release of varieties having new monogenic resistance was effective in suppressing the epidemics, but the Indonesian farmers suffered heavy losses under the cyclic events. As a consequence of poor weather and epidemics, the growth rate of Indonesian rice production declines in some years (*1*).

South Korea has also experienced serious reverses in rice production. Dramatic advances in rice yield were obtained when Korean breeders cooperated with IRRI scientists in crossing IR varieties and lines with Korean and Japanese varieties. A series of high-yielding cultivars, led to Tong-il, raised rice yields in the demonstration fields from 3.35 to 5.01 tons per hectare during 1971. The 15 interracial hybrids developed between 1971 and 1977 increased the national rice yield from 3.30 to 4.94 tons per hectare and helped achieve self-sufficiency for South Korea in 1978. The new varieties were planted on 44 to 76 percent of the rice land from 1976 to 1979. However, a high incidence of blast (*Pyricularia oryzae* Cav.) and cool weather in 1980 made the importation of large amounts of rice necessary during 1981 (*1*). The area planted in the indica × japonica varieties dropped to 32 percent in 1982 (*8*).

In contrast, rice farmers of Thailand grew the semidwarfs only in the dry season on 10 percent of the total planted area. During the main (monsoon) season most of the fields were planted in hundreds of traditional varieties. During the past two decades no major epidemic in the monsoon season has been reported except for an outbreak of the brown planthopper in the 1974 dry season (*26*). Thailand was able to sustain its position as a leading exporter during 1979 to 1983 despite a population increase of 18.4 million people between 1965 and 1983 (*1*). Bangladesh and Burma also experienced light pest outbreaks because the new varieties occupied only 22 and 29 percent of the total rice area in 1980 and 1981 (*8*).

After the semidwarfs replaced the traditional tall varieties of the Asian tropics, another perceptible change in insect prevalence was a shift from stem borers to sucking insects, mainly leafhoppers and planthoppers, and their associated viruses.

Need for New Gene Sources and Reinstatement of Genetic Diversity

With about 230,000 rice accessions, including many duplicates, stored at major national and international centers (*11, 30*), the conserved germplasm still falls short of the full spectrum necessary to meet future needs. Genes particularly needed are those expressing resistance to an ever-increasing number of rice disease pathogens and insect pests. Padwick's (*31*) list of 24 parasitic diseases in 1950 did not include a single virus disease. Ou (*32*) described 59 diseases in 1972. Since then the ragged stunt virus, a new strain of grassy stunt virus, and the rice gall dwarf virus have appeared and caused considerable damage in Southeast Asia. Three new virus diseases have been reported from West Africa (*33*). Other new diseases will certainly be reported as rice workers become more alert to emerging diseases.

In addition to rapid shifts in insect populations, equally rapid shifts in the races of the rice blast pathogen have been documented in Japan (*34*). New genes need to be identified and used to cope with such changes.

The bulk of new land for rice cultivation may be found through denudation of forests or development measures in Brazil and the humid regions of Africa. Surviving native fauna and flora as well as the little known ecosystems in such areas will require new gene sources to sustain rice growth and production (*3, 8*).

For many marginal areas where rice has been produced or will be produced at the subsistence level, ecological constraints will persist. Such areas include low-lying and flood-prone areas, rain-fed and drought-prone lands, saline tracts, tidal swamps, cool regions, and blast-endemic upland areas with acid soils and associated toxicities. Prospects for dramatic yield increases in these areas are slim, but subsistence farmers would certainly benefit from stable or moderately enhanced yields. Again, diverse rice germplasm may furnish most of the desired genes.

Recent pest-related ravages of semidwarf rices point to the need for reinstating genetic diversity in the improved cultivars. This will call for breeders' conscientious efforts to use diverse parents at the expense of rapid production of similar and closely related cultivars. Rice farmers in many parts of tropical Asia intentionally plant a mixture of different varieties in the same field to forestall epidemics. In field collection activities by IRRI in Cambodia it was noted that each rice farmer planted five to seven varieties of different maturities and grain types, not only for different household needs but also as insurance against vagaries of the weather and pest outbreaks.

Recent experiments by IRRI researchers showed that growing a mixture of resistant and susceptible genotypes markedly reduces the incidence of blast on the susceptible genotypes in blast-prone upland fields (*35*). While other breeding approaches, such as gene deployment, gene pyramiding, and multilines may alleviate the ravages, the use of genetic diversity either within a crop or through intercropping has been the most effective long-lasting means of stabilizing yields (*25, 36*).

Cost Versus Necessity

Recent lessons learned from tropical Asia and South Korea stress the need for a broad genetic base for the rice crop so as to slow genetic changes in major pests, prevent minor pests from evolving into major pests, counterbalance the vulnerability to epidemics associated with continuous monoculture, and provide the potential for further genetic improvement (*3*).

It is imperative to complete field canvassing and assemblage of uncollected rice germplasm while such resources are still available. Meanwhile, alternative conservation measures, such as the establishment of both in situ and ex situ genetic reserves and the use of in vitro cultures, may be explored. Fortunately, the seed of all *Oryza* species belong to the orthodox type and can be preserved for long periods under dry and cold conditions (*13, 37*).

The world's total investment in the conservation of crop germplasm has been estimated at \$55 million annually (*30*), of which \$13 million was provided by the U.S. Department of Agriculture (*38*). The direct and indirect outlays of operating IRGC have been increased from about \$150,000 per annum in the early 1970's to about \$500,000 in 1983. For all the other rice research centers, the total expenditures probably do not exceed \$750,000.

Some scientists have expressed concern about the low use of the bulk of resources in crop germplasm collections and the cost of maintaining duplicates. More intensive evaluation and research efforts have been urged (*39*). One suggested approach is to assemble for plant breeders a core collection which could represent the genetic diversity of a crop species and its wild relatives (*40*). While this is a logical proposition for a well-researched crop with a narrowing genetic base, for rice the more urgent task is to save those resources accumulated by the growers through several millennia and now threatened by replacement or extinction. The consolidation phase should follow effective evaluation and genetic analysis.

At present, the world's rice crop totals about 400 million metric tons a year and feeds more than 2.3 billion people. Between 1968 and 1981 rice production in Asia rose 42 percent and the area planted in rice increased 9.5 percent. Average rice yields rose about 30 percent, whereas the population increased at the same rate. A larger increase in yield will be needed in the future, as there is little prospect of expanding the rice area in Asia.

The \$1.25 million invested in the conservation of rice germplasm will continue to yield large monetary and humanitarian returns. It appears only logical to encourage and support conservation measures. The wealth of genetic resources as found in rice will provide the base for further progress in crop improvement in the face of shrinking resources, both biological and physical. Crop germplasm is surely one of man's most important biological treasures.

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RESEARCH ARTICLE

Expression of Cellular Oncogenes in Human Malignancies

Dennis J. Slamon, Jean B. deKernion
Inder M. Verma, Martin J. Cline

Most acutely transforming RNA tumor viruses contain genomic sequences that appear to be responsible for the induction of neoplasia. These genes have been termed viral oncogenes (v-onc) (*1*). The exact mechanism by which v-onc gene products mediate the transformation of normal to neoplastic cells remains unclear.

Nineteen v-onc genes have been identified and isolated (*2–4*), and DNA sequences homologous to the transforming genes of certain retroviruses have been found in normal untransformed cells (*5*, *6*). DNA sequences homologous to most of the known v-onc genes have been identified in a variety of normal uninfected cells, including those of man (*2–7*). These genes—termed cellular oncogenes (c-onc)—appear to have been the evolutionary progenitors of the v-onc genes (*3*, *4*, *8*). Viral acquisition of the genes is believed to have occurred by recombinational events between the genome of the infecting retrovirus and that of the host cell (*8*).

The structural similarity between c-onc genes and their viral homologs suggests that the former may also possess an oncogenic potential. Three lines of evidence support this idea. First, two cloned c-onc genes, c-*mos* and c-ras^{Ha}, when coupled to a retroviral long terminal repeat (LTR) and transfected into NIH 3T3 cells, induce transformation (*9*, *10*). Second, the avian leukosis viruses (ALV), which lack an identifiable onco-

Dennis J. Slamon is assistant professor of medicine, Jean B. deKernion is professor of surgery, and Martin J. Cline is professor of medicine at the Center for the Health Sciences, University of California, Los Angeles 90024. Inder M. Verma is at the Salk Institute, San Diego, California 92138.