Theor. Appl. Genet. 51, 97-110 (1977)

Review

Genetic Evaluation and Utilization (GEU) Program
The Rice Improvement Program of the International Rice Research Institute

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Summary. The Genetic Evaluation and Utilization (GEU) program of the International Rice Research Institute (IRRI) is an interdisciplinary program for the improvement of rice crops. Scientists trained in diverse disciplines such as plant breeding, plant pathology, entomology, agronomy, cereal chemistry, plant physiology, and soil chemistry work together and contribute their specialized skills to this joint endeavor. The program has five interrelated components: (1) germ plasm collection and conservation, (2) research in disciplinary areas, (3) development of improved germ plasm, (4) distribution, evaluation and exchange of germ plasm internationally, (5) training of young scientists.

Over forty thousand rice varieties from different countries are being maintained in the IRRI germ plasm bank. These varieties have been screened for grain quality, resistance to various diseases and insects, and tolerance to various environmental stresses such as drought, high and low temperatures and problem soils. Donor parents for resistances to each of the problem areas have been identified. These parents were utilized for developing improved germ plasm. Varieties with resistance to as many as five diseases and five insect species have been developed. These multiple resistant varieties are grown on millions of hectares of rice land. Seeds of improved breeding materials are exchanged internationally and 194 scientists from different countries have been trained in rice improvement work.

Key words: Rice Breeding - Germ Plasm Collection - Interdisciplinary Research - Disease and Insect Resistance - International Cooperation

Rice is the world's most important food crop. It is the principal food of more than half of the world's population. The world's rice production totals 330 million tons from an area of 130 million hectares. About 92 % of all the rice is grown and consumed in Asia. Yields of rice are disappointingly lower in the less developed tropical regions where most of the rice is grown as compared with yields from temperate areas. In tropical Asia, for example, the average yield is 1.5 to 2.0 t/ha as compared with average yields of 5 t/ha achieved in such temperate-zone countries as USA, Japan, Korea, Australia, Spain, Italy, and others.

In the tropics, the wide range of agroclimatic conditions under which rice is grown, the broad array of natural enemies of the rice plant, and the adverse growing conditions combine to reduce the yield of rice.

- Rice is grown across a gradient of water regimes ranging from upland hill slopes to a maximum water depth of about 6 meters in river deltas, i.e., Thailand, Bangladesh, India, and others (Fig.1).
- Rice is produced on a wide array of soils and under a wide range of solar energy regimes.
- Numerous diseases and pests severely reduce rice yields in the tropics.
- Suboptimum temperatures -- low temperatures during cooler months or high elevations and high temperatures in the drier climates -- reduce rice yields.

Additionally, grain characteristics which affect nutritive value, milling recovery, appearance, and eating quality of rice influence rice yields.

To meet the needs of a rapidly expanding world population, particularly in Asia where the majority of the rice-consuming populations are located and who are among the low income groups, rice yields must be increased. In Asia, where almost all of the available agricultural land is already under cultivation, yields per unit area of arable land will need to be increased. Thus, rice varieties tailored for specific conditions, locations, and cropping systems are needed. These new rices must have a higher yield potential than the cultivars traditionally grown in these adverse and varied situations.

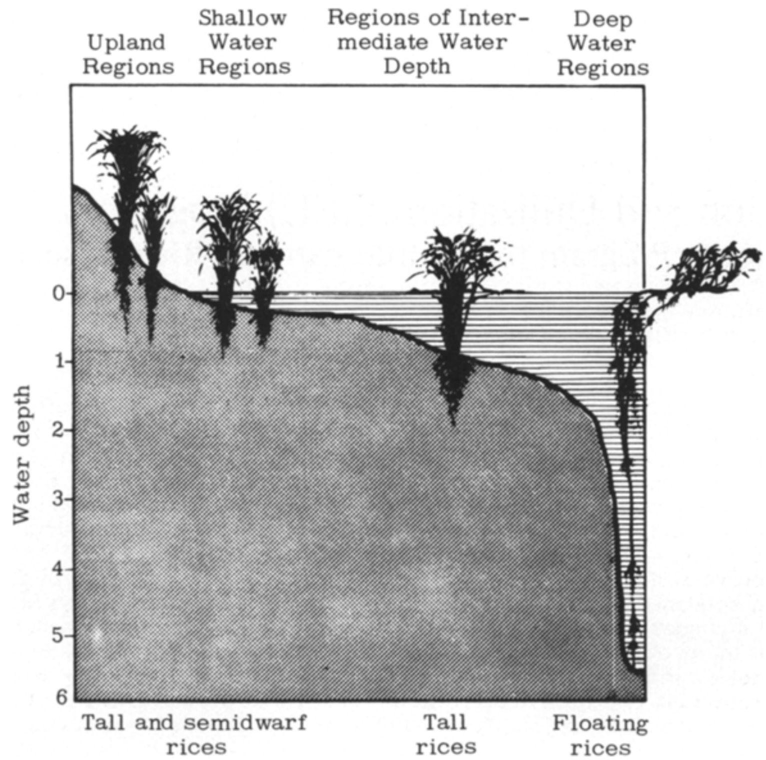

Fig. 1. The world's rice land classified by water regimes and predominant rice types

In the Genetic Evaluation and Utilization (GEU) program, interdisciplinary teams of plant breeders and problem-area scientists, such as pathologists, entomologists, agronomists, and soil chemists, work together to develop rices that are genetically adapted to each of the major types of growing conditions in which rice is produced. An integral part of the GEU program are the linkages with national rice improvement programs in rice-producing nations, particularly in Asia. The five interrelated components of the GEU program are:

- Germ plasm collection and conservation
- Research in disciplinary areas
- Development of improved germ plasm
- Distribution, evaluation, and exchange of germ plasm
- Training of young scientists

The following presentation summarizes the highlights of each of these five components of the GEU program.

Germ Plasm Collection and Conservation

Collection, conservation, and cataloguing of germ plasm is the backbone of any crop-improvement program. Since 1962, when the germ plasm collection work was initiated, cultivated and primitive varieties and wild species have been collected from different parts of the world. The collections are multiplied at IRRI and various duplicates are removed. An IRRI accession number is assigned to each collection. Seed samples (250 grams) of each accession are stored in the germ plasm bank (GPB) for long-term storage. The seeds of many improved breeding lines developed at IRRI and elsewhere are also maintained in the IRRI GPB. Over 40,000 accessions are presently maintained in the Institute's GPB.

Records of traits such as tiller number, plant height, and growth duration, and of morphological features, i.e., pigmentation and pubescence, are collected in the field. These accessions are also screened for grain quality characteristics, for resistance to various diseases and insect pests, and for tolerance to unfavorable growing conditions such as drought, low temperature, and adverse soils. Records have been completed on 37 different traits for 17,820 accessions (Chang, 1976). A catalogue summarizing the various traits and place of origin of the rices in the IRRI GPB was published in 1970.

Seeds of the rice accessions are maintained under cold storage and every 6 months the viability of seed samples of 3 control varieties is checked. The newly constructed Rice Genetic Resources Laboratory (dedicated 12 December 1977) expanded the storage facilities to include (1) long-term, (2) medium-term, and (3) short-term storage areas. Each area can accommodate 100,000 accessions.

In the long-term storage facilities, the seed samples are stored in vacuum sealed cans at -10°C. Seeds stored in this area should remain viable for about 100 years. In the medium-term storage where a 4°C temperature is maintained, the seed samples should remain viable for about 25 years. Seeds stored in the short-term storage area (20°C) should remain viable up to 5 years. As an added precaution, a 15-gram duplicate sample of each completely recorded accession is sent to the U.S. National Seed Laboratory at Fort Collins, Colorado; it now stores 18,780 accessions from IRRI.

Systematic canvassing of indigenous germ plasm in south and southeast Asia and Africa is planned to explore the germ plasm-rich areas. A 5-year plan for germ plasm collection has been developed based on original surveys of germ plasm (Chang, 1976). IRRI continues to collaborate with the national centers in the field collection of most threatened varietal types and species. Contacts have been established with other international institutes and organizations, such as IITA (International Institute of Tropical Agriculture), WARDA (West African Rice Development Association), and IRAT (Institut de Recherches Agronomiques Tropicales), for collecting indigenous rice germ plasm in Africa.

Research in Disciplinary Areas

Research in disciplinary areas is essential for a successful crop improvement program, and at IRRI, research efforts include:

- Development of screening techniques
- Identifying the donor parents for various traits
- Study of the variation in disease and insect pests
- Investigation into the basic mechanisms governing the resistance of the rice plant to diseases and insects or tolerance to environmental stresses, such as drought and high or low temperatures
- Study of the inheritance of resistance

Efficient screening techniques are essential for evaluating the germ plasm to identify the donor parents and for evaluating the segregating populations. A screening technique which allows the rapid screening of a large volume of materials, increases the efficiency of the breeding program. IRRI scientists have developed efficient screening techniques to cope with a particular problem.

The incidence of grassy stunt virus around 1967 brought about the decision to develop rice varieties resistant to this virus. IRRI plant pathologists quickly developed a greenhouse inoculation method for evaluating rice germ plasm for resistance to grassy stunt. Although over 7,000 entries from the IRRI GPB were screened, no resistant variety was found. The germ plasm of the wild relatives of rice were then screened and one accession of *O. nivara* was found to be resistant (Ling et al., 1970). Using this wild species as source of resistance, grassy stunt resistant varieties such as 'IR28', 'IR29', 'IR30', 'IR32', and 'IR34' were quickly developed (Khush et al., 1977) and made available to the farmers.

Research has continued to improve the existing techniques. For example, the pin-prick method of inoculating rice plants for screening against bacterial blight was developed in 1965 (Ou et al., 1971). However, it is a laborious method. Kauffman et al.(1973) developed a more efficient method - the clipping technique.

Once the screening technique is developed, a large number of varieties from the Institute GPB are screened. IRRI scientists have evaluated large numbers of germ plasm entries for the traits pertaining to their problem areas. Thus, a large number of rice varieties have been screened for resistance to blast (Ou, 1965), bacterial blight (Ou et al., 1971), tungro (Ling, 1969), grassy stunt (Ling et al., 1970), stemborer (Pathak et al., 1971), green leafhopper (Cheng and Pathak, 1972), brown planthopper (Pathak, 1972), protein content (Juliano et al., 1968), cold tolerance (Vergara et al., 1976), drought tolerance (Chang et al., 1974, De Datta and O'Toole, 1977), and tolerance to injurious soils (Ikehashi and Ponnamperuma, 1978). When sources of resistance and tolerance are identified, they are included in the hybridization block and are used in the crossing program.

Basic information on the virulence patterns of diseases and insects helps in the selection of the breeding strategies to be used. If the pathogen is variable and races or biotypes exist, breeding for horizontal resistance is advisable. Numerous races of blast, for example, have been identified (Bandong and Ou, 1966). Similarly, at least four biotypes of brown planthopper are known (Pathak and Khush, 1978). Because of this variability, several breeding strategies are used to develop germ plasm that is resistant to blast (Ikehashi and Khush, 1978) and to brown planthopper (Khush, 1978).

Some resources are allocated to the study of the mechanisms of resistance to diseases and insects and tolerance to environmental stresses. Recent studies on the mechanism of resistance to brown planthopper show that resistance is primarily due to antibiosis (Saxena and Sogawa, 1978). Similarly, studies on the mechanism of high temperature tolerance show that pollination of tolerant varieties is not affected, whereas in susceptible rice varieties, both pollen shedding and pollen germination are abnormal (Satake and Yoshida, 1978).

Information on the inheritance of characteristics of economic importance helps to decide upon the breeding methodology to be adopted, the population size of the segregating materials to be grown, and the breeding strategy to be used. At IRRI, investigations of the inheritance of resistance to brown planthopper, green leafhopper, bacterial blight, and grassy stunt have shown that major genes govern resistance to the diseases and insect pests. Four genes have been identified for resistance to brown planthopper (Athwal et al., 1971; Athwal and Pathak, 1972; Martinez and Khush, 1974; Lakshminarayana and Khush, 1977). Similarly, five genes for resistance to green leafhopper have been located (Athwal et al., 1971; Siwi and Khush, 1977). Five genes for resitance to the Philippine isolates of bacterial blight are known (Petpisit et al., 1977; Olufowote et al., 1977). Only one gene for resistance to grassy stunt has been identified (Khush and Ling, 1974). These genes are used systematically in the IRRI GEU program.

Development of Superior Germ Plasm

Major resources are allocated to develop germ plasm with improved characteristics. Improvement is sought in the following problem areas:

- Agronomic characteristics
- Grain quality
- Disease resistance
- Insect resistance
- Protein content
- Drought tolerance
- Adverse soil tolerance
- Deep water and flood tolerance
- Temperature tolerance

Considerable progress has been made in some problem areas, whereas advance has been slow in the others. Salient features of the research efforts in the various problem areas are summarized in the following.

Agronomic Characteristics

Improvement of the yield potential - a most important agronomic trait - has received major attention in the IRRI GEU program. The yield potential of a rice variety depends upon a set of plant characteristics collectively known as plant type. The ideal plant type varies according to the conditions under which rice is grown.

The characteristics and history of the 'IR8' plant type are well known. 'IR8' rice is short in stature (about 100 cm), has sturdy stems, high tillering ability, lodging resistance, and is highly responsive to fertilizer. Its dark green erect leaves use available solar energy efficiently. It is widely adopted in areas where there is a relatively high level of management combined with good water control.

The development of 'IR8' was a major breakthrough. By doubling the known yield potential of indica rices, 'IR8' showed that high yields could also be achieved in the tropics and subtropics with this type of germ plasm. The success of 'IR8' was convincing evidence for the merits of this new plant type. Most national and international rice improvement programs began developing varieties with a plant type similar to that of 'IR8'. Thus, 'IR8' stimulated plant breeding activities in national rice improvement programs and established new goals.

The plant type of 'IR5', which is somewhat taller than 'IR8' and competitive with weeds, is popular where the water control is undependable and where the soil fertility is low. IRRI's previous efforts in varietal improvement were focused on developing plant types similar to 'IR8' and IR5'. These two plant types are suited to about 50% of the world's rice land. Presently, IRRI is developing plant types suited to upland conditions, deep water conditions, and to lowland rainfed conditions combined with poor water control.

Early maturing varieties (100-110 days from seed to maturity) are widely adopted where irrigation is available. These rices are suitable for multiple cropping systems which involve either several crops of rice annually or one or two crops of rice in rotation with other crops. Varieties of medium duration (130 days) are preferred for rainfed areas. Most of the tall traditional varieties of tropical Asia require 150 to 170 days to mature. The first varieties developed at IRRI and many improved varieties released by national programs were about 1 month earlier (125 to 135 days).

The growth duration was reduced further in such early maturing varieties as 'IR28' and 'IR30' released by IRRI; 'IR36' released by the Government of the Philippines; 'TN73-2' released in Vietnam; 'BR7' released in Bangladesh; and 'Ratna', 'Palman 579', and 'Pusa 2-21' released in India. These varieties mature in 105 to 110 days and have gained wide acceptance by farmers in Asia. Efforts are now under way at the Institute to develop high yielding germ plasm with a maturity range of 90 to 95 days. Many breeding lines which mature in 90 days and have a high yield potential are now available.

Grain dormancy and threshability are two other agronomic characteristics requiring attention in the GEU program. Grain dormancy is important in areas of high rainfall because grain of nondormant varieties sometimes germinate in the panicle, lowering yield and grain quality. Varieties with grain that shatter readily are unacceptable because of the serious grain losses that can occur before or during harvest. Farmers hesitate to grow rice varieties which are difficult to thresh.

Grain Quality

Grain quality determines, to a large degree, the market price of a rice variety. Local preferences for grain shape, grain size, and for eating quality frequently determine the adoption of new improved varieties. Grain quality characteristics may affect production by influencing the amount of milled rice recovered from the paddy.

Rice varieties differ in the physical properties of the grain (size, shape and translucency) and the physicochemical properties of the starch. Starch, a polymer of glucose, is the major constituent of milled rice. The amount of its linear fraction (amylose), of its branched fraction (amylopectin), and its gel consistency, determine in large part, the eating quality of rice.

The majority of the rice varieties grown in tropical Asia have a high amylose content and cook dry and fluffy. However, the preferred rice varieties have an intermediate level of amylose (20 to 25%); they cook moist and remain soft when cool. Varieties with an intermediate amylose content would probably have universal acceptance in areas where indica rices are eaten. All the japonica varieties have a low amylose content and the consumer in temperate areas, where japonica rices are grown, prefer low amylose varieties which are soft cooking.

All IRRI-named varieties, except 'IR24' and 'IR29', have a high amylose content. 'IR24' has a low amylose content and 'IR29' is a glutinous rice (waxy endosperm). Glutinous rice cooks soft and sticky and is used in Asia in special preparation such as cakes and pastries.

Efforts at IRRI are under way to develop varieties with an intermediate amylose content. Many breeding lines with an intermediate amylose content are available and are being evaluated for yield potential and other desirable characteristics.

Disease Resistance

In the wet and humid tropics, the rice plant is subject to attack by such diseases as blast, sheath blight, bacterial blight, tungro virus, and grassy stunt virus. Varietal resistance is the only practical way to control diseases of rice in the tropics.

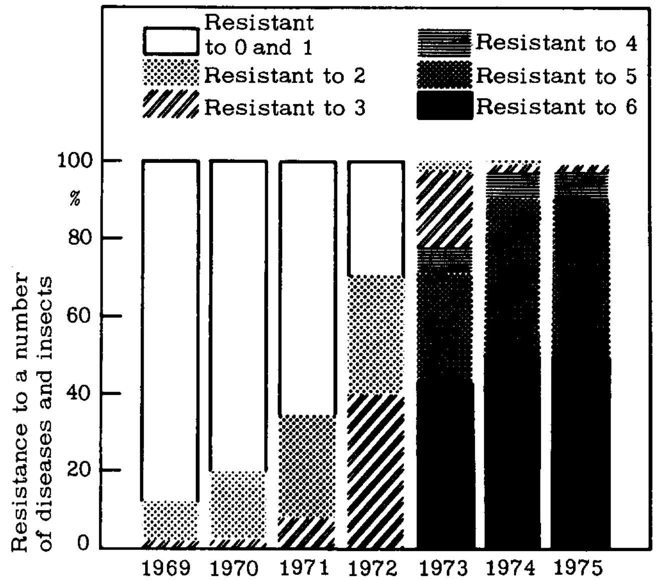

Fig.2. Changes in proportion of entries in IRRI's annual replicated yield trials with multiple resistance to important diseases and insects in the Philippines (blast, bacterial blight, tungro, grassy stunt, brown planthopper, and green leafhopper). Each year's trial consisted of at least 185 entries

IRRI plant pathologists have identified the sources of resistance to these diseases from among the accessions of the Institute's GPB. Numerous rices with resistance to blast, tungro virus, and bacterial blight have been identified. However, only one source of resistance to grassy stunt is known (Ling et al., 1970). Germ plasm with a high level of resistance to sheath blight is still being sought. Varieties with only a moderate level of resistance are known, and these are tall traditional varieties.

As a first step, the sources of resistance were transferred to an improved plant type background (Khush, 1977). This "conversion" was achieved by crossing the tall donor parents with an improved plant type parent and selecting improved plant type segregates with resistance to disease in question. The selected lines were evaluated for two or three generations for plant type, grain quality, and resistance traits. Where available, several donor parents were used as sources of resistance for each disease. In the case of primitive parents with an extremely poor plant type such as *Oryza nivara*, one or two backcrosses were made using the improved plant type lines as recurrent parents.

The improved plant type lines with resistance to different diseases were intercrossed to obtain lines with multiple resistance. Resistance to as many as five diseases was combined. Some of these multiple resistant lines were named varieties by IRRI and national programs. Thus, 'IR26', 'IR28', 'IR29', 'IR30', 'IR32', and 'IR34' named by IRRI and 'IR36', 'IR40', and 'IR42' named by the government of the Philippines are resistant or moderately resistant to blast, bacterial blight, tungro, grassy stunt, and sheath blight. The disease-resistance segment of the GEU program seeks to identify diverse genes for resistance, transfer them to a desirable agronomic background, and share these materials with scientists in the national programs in Asia and other rice-producing areas of the world.

Insect Resistance

Varietal resistance appears to be the most logical and practical way to control insect pests of rice in the tropics. Since the beginning of the IRRI program for developing rices resistant to the major insect pests of rice, considerable progress has been made to incorporate resistance to major insects into the IRRI improved germ plasm. IRRI varieties 'IR26', 'IR28', 'IR29', 'IR30', 'IR32', and 'IR34' are resistant to three of the most important insect pests of rice, namely, brown planthopper, stem borer, and green leafhopper. 'IR32', 'IR36', 'IR38', 'IR40', and 'IR42' are resistant to gall midge in India and 'IR40' is resistant to whorl maggot. Improved plant type lines with resistance to the whitebacked planthopper are now available; 'N22' is the donor for this resistance. Thus, breeding lines resistant or moderately resistant to five major insect pests of rice are now available.

The GEU program emphasizes the development of germ plasm with multiple resistance to major diseases and insects. About 87% of the entries in the 1969 wet season replicated yield trials were either susceptible to all six major diseases and insects (blast, bacterial blight, tungro virus, grassy stunt, brown planthopper, and the green leafhopper) or resistant to only one (Fig.2). Only 2% of the entries were resistant to three diseases and insects. The proportion of entries with multiple resistance gradually increased with research effort and time. In the replicated trials con-

Table 1. Disease and insect resistance reactions of varieties named by IRRI and IRRI lines named varieties by the Philippine Government

	Disease and Insect Reaction*							
	Blast	Bacterial Blight	Grassy Stunt	Tungro	Green Leaf-hopper	Brown Plant-hopper	Stem-borer	Gall Midge
IR5	MR	S	S	S	R	S	MS	S
IR8	S	S	S	S	R	S	S	S
IR20	MR	R	S	MR	R	S	MR	S
IR22	S	R	S	S	S	S	S	S
IR24	S	S	S	S	R	S	S	S
IR26	MR	R	MS	MR	R	R	MR	S
IR28	R	R	R	R	R	R	MR	S
IR29	R	R	R	R	R	R	MR	S
IR30	MS	R	R	MR	R	R	MR	S
IR32	MR	R	R	MR	R	R	MR	R
IR34	R	R	R	R	R	R	MR	S
IR36**	R	R	R	R	R	R	MR	R
IR38**	R	R	R	R	R	R	MR	R

* S - Susceptible; MS - Moderately susceptible; MR - Moderately resistant
R - Resistant. Reactions based on tests conducted in the Philippines for all diseases and insects except gall midge. Screening for gall midge was done in India
** - Named by the Philippine Government

ducted in 1975, 90 % of the entries were either resistant to five diseases and insects or to all six.

The germ plasm with multiple resistance developed at IRRI is widely used in plant breeding programs by breeders in national rice improvement programs and by farmers in tropical Asia. About 10 million hectares of rice land is now planted to multiple resistant varieties. The varieties most widely planted are 'IR26', 'IR28', 'IR30', 'IR32', 'IR34', 'IR36', and 'IR38'. The ratings of disease and insect resistance of these rice varieties as compared with earlier IRRI-named varieties are summarized in Table 1.

Protein Content

Rice protein is one of the most nutritious of all cereal proteins. It has 4 % lysine as compared with 2 % for most other cereals. However, the protein content of rice is lower (7 to 8 %) than that of most other cereals (wheat contains 14 % and more protein). Some germ plasm entries were found to contain 12 to 14 % protein as compared with 8 % for the more commonly grown rices. Since 1966, when the plant hybridization program using these high protein parents began, numerous progenies from these crosses have been evaluated. However, progenies combining the high yield capacity and a high protein content have not been obtained from these crosses.

All IRRI advanced breeding lines from the other segments of the GEU program have been screened for the combination of high yield potential and high protein content. Two breeding lines, IR480-5-9 and IR2153-338-3, have consistently shown 1.5 % higher protein content than 'IR8' and 'IR26' at comparable yield levels. However, they are not resistant to all the major diseases and insect pests. These two lines have been used extensively in the hybridization program to develop rices with a high protein content.

Drought

Drought tolerance is essential for stable yields in nearly all rice growing areas which do not have dependable irrigation. Major differences for drought tolerance have been noted among rice varieties. For example, varieties 'Salumpikit' and 'Pinursigi' from the Philippines, 'ARC 10372' from India, 'DJ29', 'DV110', 'DZ41' and 'DNJ60' from Bangladesh and 'Lua Ngu' from Vietnam are highly tolerant to drought. Most of IRRI's improved plant type advanced breeding lines are screened regularly for drought tolerance. Several have been found to have a good level of drought tolerance. 'IR36' has the best level of tolerance to drought among the named varieties.

Breeding materials developed for upland and lowland rainfed conditions are screened for drought tolerance at different stages of plant growth. Plant types with intermediate stature, early seedling vigor, and greater leafiness are preferred for these situations. Even deep water rices grow under conditions of moisture stress during the seedling stage for about 4 to 6 weeks after they are broadcast sown. Thus, the germ plasm being developed for deep water conditions is screened for drought tolerance at the seedling stage.

Adverse Soil Tolerance

Millions of hectares of land which are otherwise suitable for growing rice remain uncultivated because of soil toxicities caused by salt, alkali, acid, and organic matter. Additionally, vast areas exist where deficiencies of zinc, phosphorus, and iron and excesses of iron, aluminium, and manganese limit rice yields. Soil chemists working in the GEU program help to develop improved germ plasm suitable for growing on such adverse soils. Cultivars are screened from the IRRI GPB and advanced breeding lines and varieties from IRRI and from national rice improvement programs. To the present, 17,453 entries have been screened (IRRI, 1977), and sources of resistance to various toxicities have been identified.

Varieties 'Pokkali', 'Getu' and 'Nona Bokra' from India are the best sources of resistance to salinity. Improved plant type breeding lines such as IR2153-26-3-5-2, IR4630-22-2 and IR4763-141-2 have a good level of tolerance and are resistant to major diseases and insects. IRRI varieties 'IR30', 'IR32', and 'IR36' are fairly tolerant to salinity.

Large areas of irrigated land in the drier regions of India, Pakistan, and Egypt include alkaline soils. Rice varieties differ in their level of tolerance to alkalinity. Alkali-tolerant varieties have been crossed with high yielding genotypes. Improved plant type breeding lines with good grain quality, high yield potential, and alkali tolerance have been identified and are evaluated under alkaline conditions. The best alkali tolerant lines, IR4427-28-3-2 and IR4427-104-3-3-1, have excellent grain quality and a high yield potential.

Iron toxicity affects the growth of the rice plant when grown on strongly acid soils. Varieties and lines exhibited distinct differences in tolerance to the level of available iron in the soil. 'IR20', 'IR29', 'IR32', and many of the advanced breeding lines developed at IRRI have exhibited good tolerance to iron toxicity in the soil.

Many of the improved materials developed at IRRI are tolerant to zinc and phosphorus deficiencies in the soil. 'IR20', 'IR34', and 'IR38' are tolerant of zinc deficiency, while 'IR28', 'IR29', 'IR30', and 'IR34' tolerate phosporus deficiency.

Deep Water and Flood Tolerance

About 10 % of the world's rice area is planted with floating rice varieties which have the ability to elongate with a rising water level. On another 20 % of the world's rice areas, the water is too deep to grow successfully the semidwarf improved plant type rices. In certain areas near river basins, flash floods may submerge a rice crop for several days.

Varieties grown in deep water areas are sensitive to photoperiod. They flower and mature after the rainy season is over and the excess water has receded. The GEU program, in cooperation with scientists in Thailand, seeks to develop improved germ plasm for deep water areas, and uses floating varieties from Vietnam, Thailand, Bangladesh, and India in the hybridization program. Early generation lines from these crosses are evaluated in cooperation with scientists in national programs in Thailand, Bangladesh, and other rice growing countries in Asia.

Selections of the 'BKN 6986' cross made in Thailand are the best prototypes in which the semidwarfing gene is combined with an elongation ability. These selections yield as well as other improved varieties when grown under shallow water conditions and yield more than traditional deep water varieties when grown under deep water situations. Additionally, some lines of this 'BKN 6986' cross, such as BK6986-47, BK6986-58, and BK6986-108, have a high submergence tolerance.

Temperature Tolerance

Low temperature tolerance is important in rice grown at high elevations and at northern latitudes. Off-season rices, such as boro rices of India and Bangladesh, are exposed to low temperatures. The stage of growth at which rices are subjected to low temperatures depends upon the locale. Boro rices, for example, are exposed to low temperatures at the early vegetative stage.

In the northern latitudes, rices are exposed to low temperatures at both the vegetative and the reproductive stages. At high elevations, temperatures are suboptimal throughout the growth cycle. Germ plasm tolerant to low temperatures have been identified for various situations. Materials derived from crosses between low temperature tolerant varieties and improved plant type parents are evaluated cooperatively in various areas affected by low temperatures.

In some areas high temperatures affect the seed set and can cause sterility. The response of varieties to high temperatures varies markedly. N22 from India exhibited a good level of tolerance. Advanced generation breeding lines from the GEU program are screened for tolerance to high temperatures.

Distribution, Evaluation, and Exchange of Germ Plasm

The seeds of donor varieties, improved breeding lines and named varieties are supplied to rice scientists all over the world on the basis of requests originating from scientists working in the national programs. To date, 50,000 seed packages of rice accessions from the IRRI GPB have been sent to researchers in more than 100 countries. Similarly, over 98,000 seed packets of IRRI breeding lines have been supplied upon request from 87 countries. These include seeds of early generation segregating lines, advanced generation fixed lines, and named varieties.

These lines are evaluated for adaptation to local conditions and some become named varieties; to date, 49 IRRI lines have been named as varieties by national programs (Table 2). Many are used as donor parents in the local hybridization programs. Thus, IRRI varieties and breeding lines are the parents of many varieties named by the national programs.

Since 1975, germ plasm has been exchanged and evaluated through the international segment of the GEU program - the International Rice Testing Program (IRTP). Promising breeding lines, named varieties, and donor parents from IRRI and the national programs are grown in nurseries to test for yield potential or to evaluate the rice plants' tolerance and resistance to diseases, insect pests, or environmental stresses. On the basis of these tests, parents are identified that have a broad spectrum of resistance to diseases, insects, and environmental stresses or wide adaption to various ecological conditions.

In 1977, 545 sets of 15 international nurseries listed below, were distributed to 40 countries.

1. International rice yield nursery, short growth duration.
2. International rice yield nursery, medium growth duration.
3. International rice yield nursery, long growth duration.
4. International rice observation nursery.
5. International upland rice yield nursery.
6. International upland rice observation nursery.
7. International rice brown planthopper nursery.
8. International rice gall midge nursery.
9. International rice stemborer nursery.
10. International rice blast nursery.
11. International rice sheath blight nursery.
12. International rice tungro nursery.
13. International rice cold tolerance nursery.
14. International rice salinity tolerance nursery.
15. International rice deep water observation nursery.

These nurseries serve as an excellent means by which germ plasm can be exhanged among different national and international programs. The IRTP provides a mechanism through which breeding materials are made available from one national program to another through these nurseries. The flow of materials from the IRRI GPB to the various breeding nurseries, international nurseries, and return to the GPB is summarized in Fig. 3.

Seeds of IRRI breeding lines are also given to IRRI trainees, visiting plant breeders, and other scientists to take to their respective countries at the conclusion of their visit to the Institute.

Table 2. IRRI lines named varieties in other countries

Name	IRRI Line	Cross	Country where named	Year Named
Sinaloa A68	IR160-27-4	Nahng Mon S-4/TN1	Mexico	1968
Pankaj	IR5-114-3	Peta/Tangkai Rotan	India	1969
Bahagia	IR5-278	Peta/Tangkai Rotan	Malaysia	1969
Mehran 69	IR6-156-2	Siam 29/Dee-geo-woo-gen	Pakistan	1969
RD 2	IR253-4	Gam Pai 15^2/TN1	Thailand	1969
CS 2	IR160-25-1	Nahng Mon S-4/TN1	Ivory Coast	1970
CS 3	IR253-16-1	Gam Pai 15^2/TN1	Ivory Coast	1970
CS 1	IR262-7-1	$Peta^3$/TN1	Ivory Coast	1970
Cica 4	IR930-31	IR8/IR12-178	Colombia	1970
IR262	IR262-43-8	$Peta^3$/TN1	Sri Lanka	1971
IR532	IR532-1-18	IR262-24-3/TKM 6	Sri Lanka	1971
Chandina	IR532-1-176	IR262-24-3/TKM 6	Bangladesh	1971
Nilo 11	IR579-48-1	IR8/Tadukan	El Salvador	1971
Palman 579	IR579-48-1	IR8/Tadukan	India	1971
Tongil	IR667-98	IR8/(Yukara/TN1)	Korea	1971
Naylamp	IR930-2-6	IR8/IR12-178	Peru	1971
Mala	IR272-4-1	$(CP\ 231\text{-}SLO\ 17)^2$/Sigadis	Bangladesh	1972
Huallaga	IR442-2-50	$Peta^2$/TN1/Leb Mue Nahng	Peru	1972
Ajral	IR480-5-9	Nahng Mon $S\text{-}4^2$/TN1	Fiji	1972
Chancay	IR930-31-10	IR8/IR12-178	Peru	1972
Parwanipur 1	IR400-29-9-73	$Peta^4$/TN1	Nepal	1973
Masria	IR789-59-3-1	IR8/Muey Nahng 62M	Malaysia	1973
Variety "R"	IR1052	BG 79/IR8	Guyana	1973
Variety "S"	IR1055	BG 79//$Peta^4$/TN1	Guyana	1973
TN 73-1	IR1529-680-3-2	$Sigadis^2$/TN1//IR24	Vietnam	1973
TN 73-2	IR1561-228-3-3	IR8/Tadukan//$TKM6^2$/TN1	Vietnam	1973
ROK-6	IR5-198-1-1	Peta/Tangkai Rotan	Sierra Leone	1974
SM 1	IR5-250	Peta/Tangkai Rotan	Malaysia	1974
N.G. 6637	IR532E-208	IR262-24/TKM 6	Papua New Guinea	1974
-	IR665-4-5-5	IR8//$Peta^5$/Belle Patna	Brazil	1974
GPL 1	IR747B2-6-3	TKM 6^2/TN1	Solomon Islands	1974
Piedras Negras A74	IR837-20-3-6	IR262-43/N.S. Pah Tawng	Mexico	1974
Bomoa A74	IR837-46-2	IR262-43/N.S. Pah Tawng	Mexico	1974
Abbasi 72	IR841-36-2	IR262-43/Khao Dawk Mali	Pakistan	1974
-	IR841-63-5	IR262-43/Khao Dawk Mali	Brazil	1974
CR 1113	IR822-81-2	$IR8^2$/Pankhari 203	Costa Rica	1974
GPL 2	IR1614-138-3-1	IR22//Mudgo/IR8	Solomon Islands	1974
Pani Dhan 1	IR442-2-24	$Peta^2$/TN1//Leb Mue Nahng	Bihar, India	1975
Pani Dhan 2	IR442-2-58	"	Bihar, India	1975
IR50	IR442-2-50	"	West Bengal, India	1975
IR58	IR442-2-58	"	West Bengal, India	1975
Sakha 1	IR579-48-1-2	IR8/Tadukan	Egypt	1975
Sakha 2	IR1561-228-3	IR8/Tadukan//$TKM6^2$/TN1	Egypt	1975
BILO	IR1539-156	IR24//Mudgo/IR8	Fiji	1976
BR 7	IR2053-87-3-1	IR1416-131-5/IR22/C4-63	Bangladesh	1976
FARO 22	IR627-1-31-4-3-7	IR8/Wagwag	Nigeria	1976
IR36	IR2071-625-1-252	IR1561-228/IR1737//CR94-13	Philippines	1976
IR38	IR2070-423-2-5-6	$IR20^2$/*O. nivara*//CR94-13	Philippines	1976
PR 106	IR665-79-2-4	IR8//$Peta^5$/Belle Patna	India	1976
IR40	IR2070-414-3-9	$IR20^2$/*O. nivara*//CR94-13	Philippines	1977
IR42	IR2071-586-5-6	IR1561-228/IR1737//CR94-13	Philippines	1977

Training of Young Scientists

The training program for familiarizing rice breeders with the latest methodologies and techniques of crop improvement was initiated in 1962. Since then, 119 individuals from 26 countries have undergone training in the Plant Breeding Department. The periods of training have varied from a few months to 3 years. A large proportion of trainees participate in the nondegree programs; 28 received a Master of Sciences degree at the adjacent University of the Philippines at Los Baños with the thesis research conducted at IRRI. Six studied

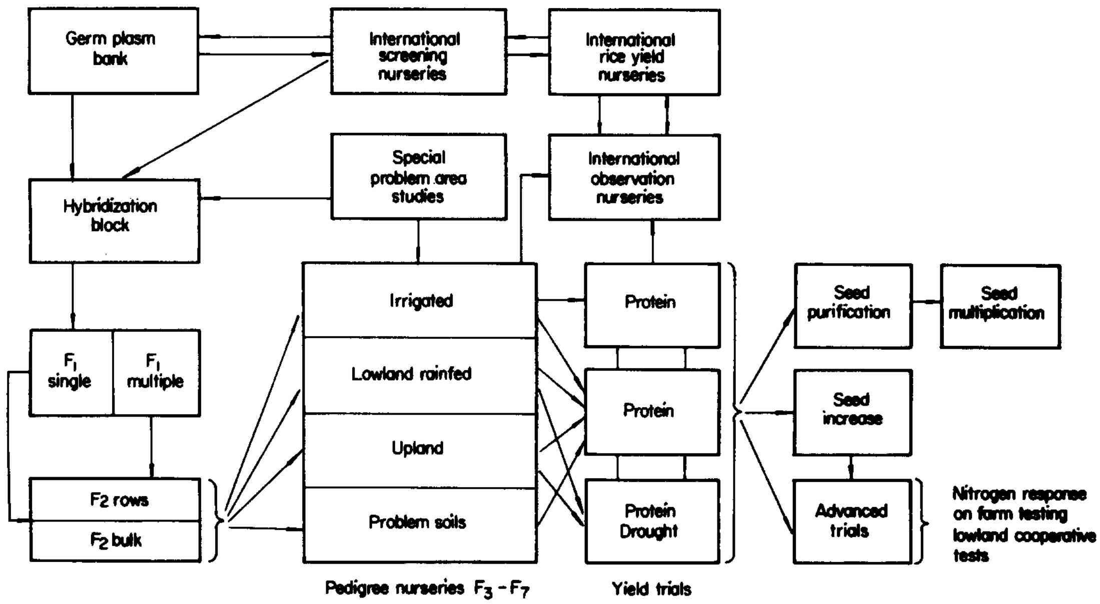

Fig.3. Flow of materials in the IRRI GEU program and to national programs through international nurseries and back to IRRI Germplasm Bank

for the Ph. D. degree under collaborative arrangements with various universities.

Since 1975, when a GEU training program was initiated for one crop season (February to June), three groups of 16, 27, and 32 trainees participated in the program. Beginning in 1978, two GEU training courses will be offered annually. Participants learn various skills and the philosophy of an interdisiplinary approach to varietal development through on-the-job training and formal lectures by GEU scientists.

The Philosophy of GEU

The GEU program uses the interdisciplinary team approach to develop improved rice varieties. Scientists trained in diverse disciplines work together and contribute their specialized skills to this joint effort. Thus, problem areas scientists (PA), such as plant pathologists, entomologists, soils scientists, and cereal chemists develop screening techniques, evaluate germ plasm entries to identify the donor parents and work closely with plant breeders (PB) in evaluating the breeding materials for specific traits in their area of specialization.

The plant breeders provide leadership in developing breeding strategies, in the hybridization program, in managing the breeding nurseries, in selecting the breeding lines, and in managing the seed materials. Integration of various traits into improved varieties through such cooperative endeavors is illustrated in Fig. 4.

Eighteen scientists from nine departments and eight disciplines are working together in the GEU program. Five plant breeders-geneticists, one plant pathologist, one cereal chemist, one agronomist, and one plant physiologist work full time in the program. Three plant pathologists, two entomologists, one agronomist, one plant physiologist, one soil scientist, and one statistician work part time in the GEU program.

Nine different teams of PA scientists and plant breeders handle the work on the various problem areas discussed previously.

Each team has at least one plant breeder and one or more PA scientists. Each plant breeder works with more than one team. Each problem area team is responsible for providing leadership for work in its particular area. Each team plans the research jointly, selects the parents for hybridization, screens the progenies, and selects the lines to be included in the various international screening nurseries. Special studies, such as genetics of resistance and genetic variation in

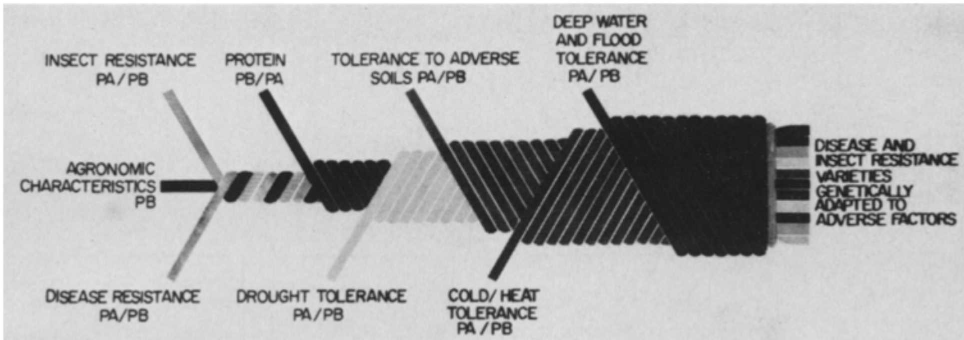

Fig.4. Plant Breeders (PB) and problem area scientists (PA) are working together as interdisciplinary teams to develop desease and insect resistant varieties that are genetically adapted to withstand a range of adverse factors

pathogens and insects, are conducted jointly by the PA scientists and plant breeders.

Operational Procedures

Breeding materials generated by different teams are grown in common nurseries managed by plant breeders. Special screening nurseries and yield trials may also be grown under the supervision of PA scientists.

One plant breeder/geneticist is in charge of the germ plasm bank and upland nurseries. Another plant breeder is responsible for growing hybridization blocks, crossing operations, F_1 nurseries and replicated yield trials. A third plant breeder handles the F_2 populations and observational yield trials. The fourth plant breeder is in charge of pedigree nurseries, seed increase, and seed purification operations.

Various teams work on the same materials, and entries recommended by different teams are grown in one hybridization block. All crosses recommended by different teams are made at one place and grown in one nursery. Similarly, all F_2 populations are grown together. Materials in the F_2 populations, pedigree nurseries, and yield trials are screened by various PA scientists. All data on GEU materials are recorded in common field books which are stored in a records room and are available to all concerned scientists. A computerized data management system was initiated and field books are printed via computer.

One plant pathologist and one plant breeder handle the operations related to assembling, dispatching, monitoring, analyzing of data, and reporting on international nurseries. Problem area teams identify the appropriate entries for each nursery from the IRRI materials. Nominations are sought from the colleagues in national rice improvement programs for each international nursery. Data received from various international locations are analyzed and made available to all the cooperators as computer printed reports.

IRRI Policy on Naming Varieties

IRRI has formally named and released 11 varieties, starting with 'IR8' in 1966 and ending with 'IR34' in 1975. Forty-nine other IRRI lines were released as varieties by national programs. In 1975, the Institute announced that it would no longer officially name and release rice varieties. Rather, the Institute concentrates its efforts on providing genetic material, including both early and advanced breeding lines, to rice scientists all over the world. The Institute encourages national programs to release IRRI selections as varieties under any name.

The modification of IRRI 's varietal release policy reflects the stronger national rice improvement programs, as well as increased international collaboration through the GEU program and the IRTP. Thus, IRRI supplies germ plasm to national programs and the IRRI breeding lines are evaluated by the national programs along with locally developed materials. When IRRI materials are found suitable, national programs are encouraged to name them and use them in the hybridizaton program.

In the Philippines, IRRI's elite breeding lines are provided to the Philippine Seed Board for evaluation and possible release. This Board has the responsibility of evaluating the breeding lines in cooperative yield performance trials. On the basis of results of these trials, during 1976 and 1977, the Philippine Seed Board recommended four IRRI lines under the names of 'IR36', 'IR38', 'IR40', and 'IR42'. The Board elected to continue to use the IR designation for IRRI selections released in the Philippines.

Conclusion

The ultimate goal of the IRRI GEU program is to develop superior germ plasm of rice with increased yield potential, good grain quality, resistance to economically important diseases and insect pests, and suited for unique growing conditions. Varieties for specific locations must have tolerance to certain stresses, such as high or low temperatures, adverse soils, drought, and excess water.

A strong interdisciplinary team approach is undertaken at the Institute to develop improved rice varieties through a dynamic plant breeding program coupled with strong research efforts in problem areas.

National GEU programs are strengthened through training of young scientists in the interdisciplinary approach. Strong linkages exist between IRRI and national programs to facilitate the transfer and exchange of ideas, techniques, materials, and personnel. This international network of cooperating scientists, trained in different disciplines, are working towards a mutual goal on an equal basis for exploiting the vast reservoir of genetic variability of rice in the development of improved rice varieties.

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Received September 13, 1977
Communicated by H.F. Linskens

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