RICE IMPROVEMENT IN CHINA AND OTHER ASIAN COUNTRIES

International Rice Research Institute and
Chinese Academy of Agricultural Sciences

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FOREWORD

The People's Republic of China is the world's largest producer and consumer of rice. Many scholars feel that rice originated in China. Therefore, the holding of the first International Rice Research Workshop and monitoring tour in the People's Republic of China on 22-30 October 1979 had special significance. Thirty rice researchers from eight countries participated in this workshop and monitoring tour jointly sponsored by the Chinese Academy of Agricultural Sciences (CAAS) and the International Rice Research Institute (IRRI). Financial support for the workshop/tour was provided by the United Nations Development Programme (UNDP). IRRI has sponsored 28 previous monitoring tours and workshops in 31 rice-growing countries.

From 22 to 26 October, the group met at the Guangzhou branch of CGAS. Papers were presented on current rice research progress in China and other Asian nations; future collaborative research and testing programs were discussed. Emphasis was on the breeding of varieties with genetic resistance to insects and diseases, and on cultural practices to enable farmers to control pests without costly chemicals.

During the monitoring tour, the participants visited rice-growing communes and rice research centers in the southern province of Guangdong, then traveled by train to Ch'angsha, central China, to observe research sites, communes, and progress made at the Hunan Province branch of CAAS. The participants also observed part of the more than 5 million hectares of hybrid rice being grown in China. The workshop program was developed jointly by a group of leaders from the two sponsoring institutions, headed by Mr. Ren Zhi, secretary general of CAAS, and Dr. Marcos R. Vega, deputy director general of IRRI. Dr. Harold E. Kauffman, joint coordinator of the International Rice Testing Program, was monitoring tour coordinator. The

workshop papers were edited by Dr. Thomas R. Hargrove, a workshop/tour participant; Ms. Gloria S. Argosino; and Ms. Corazon V. Mendoza of IRRI's Office of Information Services.

The historic meeting in China is further evidence that scientists from many nations can pool their efforts to help farmers everywhere produce more and better food from the land.

He Guang-wen
Vice President
Chinese Academy of Agricultural Sciences

N. C. Brady
Director General
International Rice Research Institute

Some of the participants in the International Rice Research Workshop and Monitoring Tour, at the Guangdung Academy of Agricultural Sciences.

WELCOME ADDRESS

He Guang-wen

Mr. President, ladies and gentlemen. The International Rice Research Workshop is now open.

Cosponsors of the workshop are the International Rice Research Institute (IRRI) and the Chinese Academy of Agricultural Sciences (CAAS). This workshop signifies the further development of friendly cooperation among CAAS, IRRI, and scientists in national rice improvement programs across Asia.

The workshop provides Chinese agricultural scientists an opportunity to establish and develop friendly collaboration with rice scientists from Bangladesh, India, Indonesia, Sri Lanka, and Thailand. We are pleased to gather here to talk to one another, to exchange research experiences, and to discuss future cooperative programs. We expect the workshop to be a great success.

On behalf of the CAAS and Chinese rice researchers, I extend a warm welcome to peer scientists from South and Southeast Asia and from IRRI, and to all Chinese representatives.

Rice is perhaps the world's most important food crop. The main problem facing both the governments and the people of rice-growing countries is to continuously increase rice production and improve rice quality. That is a glorious and arduous challenge for rice scientists.

To increase rice production, not only must we synthesize and exchange advances in rice improvement and popularize those findings within our own countries; we must also make a common effort to strengthen international cooperation and information exchange. We believe that this workshop will enable us to know each other better, to further strengthen our friendly cooperation, to advance rice research, and to make immediate contributions to rice production.

Vice president, Chinese Academy of Agricultural Sciences, People's Republic of China.

China is an old agricultural country. Agriculture is the foundation of our national economy. After the founding of the new China, we carried out agrarian reforms in the countryside and abolished feudal landownership to develop our agriculture. Through mutual aid and cooperation, we have transformed a private farm economy into a socialistic system of collective ownership that we now call the People's Communes. Because of changes in the production relationships, great productive forces were unleashed, opening a wide road for the development of agricultural production. Relying on the collective forces of the People's Communes, we have carried out -- and we continue to carry out -- full-scale capital construction on China's farms.

Following the principle of having agriculture as the foundation, and industry as the developing force of the national economy, under extremely difficult conditions we built an integrated industrial system and a citizens' economic system through our own efforts. Lin Piao and the Gang of Four sabotaged those efforts. But the Gang of Four was smashed; our economy was restored and is once again rapidly developing. Our industry now produces an increasing flow of chemical fertilizers, pesticides, and farm machinery to support agriculture. We now have a foundation for the reconstruction of agricultural technology.

We are now starting a new *long march* -- a march to modernize agriculture, industry, national defense, and scientific technology.

China also has a long history of rice growing. Rice production occupies an important position in Chinese agriculture, and we are emphasizing its development. We have launched a mass movement for scientific experiments and have combined that professional research with mass movements in technical reform. Agricultural science has been implemented widely.

We have made much progress in the use of heterosis in rice breeding. Today, hybrid rice is grown in about 5 million ha in China. Double-cropping has been adopted in the main rice-growing areas of the southern Yangtze River. Two crops of rice, interplanted with a green manure crop, are now grown there. Through such efforts, rice production is continuously increasing.

But even such progress in rice research and production does not yet meet the needs of our national economic development. We are relatively behind in scientific technology. To realize agricultural modernization, we must not only work hard, we must also seriously study and learn from the advances and

experiences of other countries. The International Rice Research Workshop, held in Guangzhou, China, provides such an opportunity.

The foreign friends attending the workshop have brought their friendship to us. I sincerely thank you for attending and for bringing with you reports of your scientific achievements and experiences.

OPENING REMARKS

N. C. Brady

I am pleased to join my friend Mr. He Guang–wen in welcoming you to the First International Rice Testing Program (IRTP) Workshop held in China. The workshop is jointly sponsored by the Chinese Academy of Agricultural Sciences (CAAS) and the International Rice Research Institute (IRRI) with financial support provided by the Rockefeller Foundation and the United Nations Development Programme.

This is a historic occasion. For the first time, rice scientists from South and Southeast Asia are meeting with distinguished scientists from the People's Republic of China (PROC) in this great country. This workshop provides the first opportunity in recent times for rice scientists throughout Asia to inform each other of their research findings and to develop plans for future cooperation.

Dr. Vega, Dr. Pande, and I, along with members of the IRRI Board of Trustees, have just completed a 12-day visit to important rice-growing areas of China. We are impressed by the high production levels we have seen and by the excellent technology being used. We are also pleased with the evidence of cooperation that has begun between CAAS and IRRI scientists. You will have the privilege of seeing such evidence in Kwangtung and Hunan Provinces in the hybrid rices that are the progeny of IRRI and local Chinese varieties. Apparently, the Chinese varieties ensure high yields and reasonably short growing seasons while the IRRI varieties provide good insect and disease resistance.

The emerging cooperation between IRRI and PROC scientists is matched by similar cooperation among scientists from other rice-growing countries. The IRRI rices used in Chinese crosses are, in fact, crosses of rices from India, Indonesia, Bangladesh, Sri Lanka, Thailand, China, and other countries. In the past decade the IRTP -- a network of cooperating scientists who

Director general, International Rice Research Institute, Manila, Philippines.

freely exchange both scientific information and genetic resources -- was developed. You scientists here today represent a few of the cooperating countries that developed this network. You are here to share your rice research findings and to observe the research under way in China, the world's largest rice-producing country.

The first challenge you face during the coming week is to share with each other all that you have learned about the rice plant, particularly its genetic potential to resist or tolerate constraints on its production. The second challenge is to develop concrete plans to remove those constraints through cooperative research efforts.

The IRTP provides an ideal framework for such international cooperation. It is based on the concept of free exchange of genetic resources and of scientific information. The IRTP's ground rules are determined, not by IRRI but by the scientists in all countries who participate in the worldwide testing effort. We are all pleased that this workshop will help to strengthen the ties that the IRTP has helped develop. We are most pleased to see the demonstrated interest of PROC scientists in IRTP participation. This workshop is tangible evidence of such cooperation.

I would be remiss if I did not express my sincere appreciation to the Chinese Academy of Agricultural Sciences for arranging these fine meeting facilities. We are indebted to officials of Guangdong Province for making local arrangements. Special recognition should be given to the Academy of Agricultural Sciences of Guangdong Province for the attractive workshop seal and for detailed facility arrangements. The Guangdong Academy has cooperated with the CAAS in making these arrangements.

I trust that this workshop will give all of us an opportunity to fully evaluate the potential for international cooperation. Each country whose scientists are here today has something to gain from the papers and discussions that this workshop permits. Likewise, each of the scientists here has something to contribute to his colleagues.

As you listen to the research papers to be presented in the next 2 days, I hope you will constantly think of the cooperative and collaborative research that you can plan during the open discussions that follow.

The IRTP provides an opportunity for broad cooperation in rice improvement. Field nurseries to evaluate the world's rices, for resistance to and tolerance for constraints on rice

production are being implemented throughout the world. You will help plan such nurseries during this meeting. But you will also have an opportunity to plan more specific collaborative research efforts on such topics as brown planthopper, blast, and drought resistance. Small-group discussions will give you the opportunity to plan such collaborative research.

As requested by the Chinese Academy of Agricultural Sciences, the IRRI staff stands ready at all times to help organize and implement cooperation that you feel is necessary and important.

May I wish you success in this important and historic workshop and thank you all for attending.

RICE BREEDING IN CHINA

Shen Jin-Hua

Rice has been cultivated in China for more than 6,700 years. During that period it has differentiated into ecotypes adapted to different environments and cropping systems. Rice is now grown from Hainan Island in the south (18°N) to Hei-ho River in the north (50°N) and at elevations ranging from sea level to 2,600 m.

On the basis of rice types, the Chinese rice-cropping area is divided into the keng (sinica or japonica) rice region, and hsien (indica) rice region, and the mixed region. On the basis of cropping systems, varietal distribution, and natural environmental conditions, the rice area falls into the South China rice belt, the central China belt, the southwestern China belt, the north China belt, the northeastern belt, and the northwestern belt.

The major types of cultivated rice are hsien and keng, early (first)-season and late (second)-season, wetland and dryland, and zhan (nonglutinous) and nuo (glutinous).

The widespread rice-growing areas necessitated the establishment of research units at the state, province, prefecture, and county levels. Units of each level have their specific research responsibilities.

During the first 10 years after the Liberation, varietal improvement centered on purification of local varieties and pure line selection. The first semidwarf was developed in 1959. Semidwarf varieties spread rapidly in the early 1960s to most

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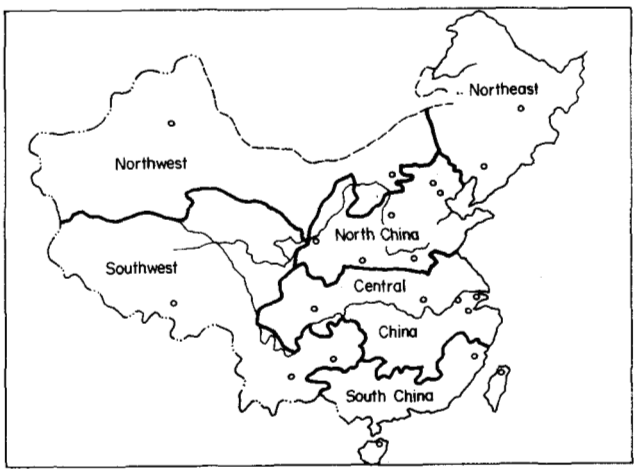
areas in the south. In the 1960s, radiation breeding gained acceptance. At present conventional breeding is the most common method and important breeding objectives are the development of semidwarfs and varieties with varying maturity dates, and resistance to pests. Hybrid rice work was initiated in 1964, and with the identification of vigorous restorer lines in 1973, hybrid rice was first grown in communes in the mid-1970s. In some regions, hybrid rices of certain combinations have yielded promising results: stable high yields, and resistance to some diseases and insects. Since 1970 anther culture has been used to develop some new varieties, which are now in production.

OBJECTIVES

The Chinese rice-cropping area can be categorized according to the distribution of types of rice varieties:

- the *keng (sinica, japonica) rice region,* north of the Huang-ho (Yellow River);
- the *mixed region,* where hsien and keng rices are cultivated simultaneously, in the Huai-ho (Huai) and the Chang-Jiang (Yangtze River) basins; and
- the *hsien (indica) rice* region around the Zhu-jiang (Pearl River) and the Xi-jiang (West River) basins.

If categorized according to cropping systems, varietal distribution, and natural environmental conditions, the country might be divided into six rice belts (Fig. 1).



1. *Rice belts of China.*

The South China rice belt

The South China rice belt (Fig. 1) is south of Nan-ling (South Mountain): It includes Guang-dong (Kwangtung), Fu-jian (Fukien), and Taiwan Provinces, to which the Guang-xi (Kwangsi) autonomous region and islands belong. Twenty-seven percent of the total cropping area of China, which produces 22% of the total yield (not including Taiwan), is in this belt. The temperature is the highest in China; the rainfall, the heaviest; and the rice cropping season, the longest (usually more than 270 days, but as long as 365 days on Lei-Zhou Peninsula and Hai-nan Island). The lowest mean temperature is higher than 10°C in January, higher than 19°C in April, and higher than 22°C in October. During the cropping season the mean temperature is 22-26°C; the temperature difference between day and night is 5.4-8.1°C. The annual rainfall is more than 1,500 mm, and the relative humidity, about 80% during the rice-growing period.

The chief cropping system is two successive rice crops; the new systems are rice-rice-wheat, rice-rice-peanut, and rice-hemp-rice. Most varieties are hsien, but in mountainous districts keng or dryland rice are grown, and in low-lying waterlogged fields, deepwater varieties are cultivated. In this belt, special stress is put on important rice yield characters such as cold tolerance at the seedling stage of the first crop and in the blooming period of the second crop. Because diseases and insects are serious, varieties with multiple resistance are needed.

The Central China rice belt

The Central China rice belt lies north of Nan-ling and south of Hai-ho and Chin-ling (Chin Mountain). It includes eight provinces and municipalities along the Chang-jiang basin -- Jiang-su (Kiangsu), Shanghai, Zhe-jiang, central and southern An-hui, Jiang-xi (Kiengsi), Hu-nan, Hu-bei (Hupeh), Si-chuan (Szechwan) (Ganzi Jang autonomous prefecture excluded) -- and southern Shan-xi (Shensi) and Ho-nan Provinces. Sixty-three percent of China's total rice cropping area, which contributes about 66% of the total yield,is in this belt. The cropping season is usually from mid-March to October (220-240 days). The mean monthly temperature is higher than 14°C in April, and higher than 17°C in October. Temperatures are somewhat lower in northern Jiang-su and An-hui Provinces, Hu-bei Province, and northwestern Si-shuan. Annual rainfall is higher than 1,000 mm, and the relative humidity is about 80% during the growing period. Formerly, only one rice crop was grown in this belt, but now a comparatively large area is double-cropped. In recent years a three-crop system of rice-rice-rape or rice-rice-wheat has developed and spread rapidly. Varieties for the first and second crops should have high yield potential with early maturity. Because temperature during the second crop is low, varieties for the first crop should be hsien

and those for the second, keng. Varieties resistant to diseases and insects, particularly to virus diseases transmitted by leafhoppers, are needed.

Southwestern China rice belt

The southwestern rice belt includes Gui-zhou (Kweichow Province), Yun-nan and Xi-zang (Tibet) Autonomous Regions, and the Ganzi Autonomous District of Si-chuan Province. Most of the rice fields are in the Yun-nan Gui-zhou plateaus, from 100 to 2,600 m above sea level. These rice fields represent 6.1% of China's total rice cropping area and produce 8.8% of the total yield. The cropping season is from March to October. The monthly temperature means for April and October are 17.7° and 15.5°C for Kun-ming and Yun-nan, and 16.5° and 15.5°C for Gui-yang and Gui-zhou. Annual rainfall is more than 1,000 mm and there are obvious dry and wet seasons. Rainfall is plentiful, humidity high, and temperature comparatively low during the rice season.

The major cropping system has been a single crop of rice, but rice-wheat, rice-broad bean, rice-rape, and rice-green manure patterns are also followed. Double-cropping of rice has recently been initiated in the south and the valley plains near the Hongshui-ho of Gui-zhou as well as in areas lower than 1,400 m above sea level in southern Yun-nan and in the Jin-sa-jiang valleys in the north. Both hsien and keng rices are grown simultaneously in this belt, with keng in areas higher than 1,750 m above sea level in Yun-nan, and higher than 1,400 m in Gui-zhou. For those climatic conditions, varieties with short stems, cold tolerance, and adaptability to highly fertile soils are needed. In mountainous regions with insufficient water, varieties need strong drought tolerance. On the plateaus of Yun-nan and Gui-zhou where the humidity is high and diseases and insects are serious problems, high yielding varieties with multiple resistance are necessary.

North China rice belt

The North China rice belt is north of Chin-lin and Huai-ho, and south of the Great Wall. It includes Bei-jing (Peking), Tian-jin (Tientsin), Ho-bei (Hopeh), Shan-dong (Shatung), Shan-xi (Shensi); the northern parts of Ho-nan, Jiang-su (Kiangsu), and An-hui; and the central and northern parts of Shan-xi (Shensi). The cropping area is 1.5% of that of the country, and paddy rice production is 1.3% of the total. The cropping season is from April to October, and the growing period lasts from 150 to 180 days. In the southern part (Ji-nan through Cheng-zhou to Xi-an), the mean temperature is 21.4-22.6°C. The difference in temperature between day and night is 11.3-13.3°C. The temperature in the northern part (Taiyuan through Bei-jing to Tian-jin) is lower

than that in the southern. Annual rainfall averages more than 500 mm, usually concentrated in June-August. The relative humidity during the growing period i.s 60-75%. Except in hang-ho and Huai-ho, where a rice-wheat system is practiced, one rice crop has generally been grown. In recent years, however, a rice-wheat system has rapidly spread in parts of Rei-jing and Tian-jin. Early maturing high yielding varieties suitable for growing after a wheat crop must be selected. Because rice blast, bacterial blight, and rice stripe transmitted by gray planthoppers are becoming more serious, disease-resistant varieties have become the top priority. In some areas it has become necessary to breed for varietal resistance to gray plant-hoppers. Varieties with strong salinity resistance are also needed because many rice fields in this belt, particularly along the coast of Bohai Bay, have soils with comparatively high salt content.

Northeastern rice belt

The northeastern rice belt includes Liao-ning, Ji-lin (Kirin), and Hei-long-jiang (Hei-lungkiang) Provinces. Its rice cropping area is 2.6% of that of China, and its output is 2.7% of the total. The cropping season is usually from May to September, and the growing period 110-170 days. The mean monthly temperature is higher than 10°C in May and in September. The difference between day and night temperatures is 12-14°C. Annual rainfall is 500-700 mm, concentrated in July-August. The cropping system is a single crop of rice. The growing period is short. Early sown seedlings are susceptible to cold damage, and low temperature in the later growth period hinders normal seed setting. Rice blast and bacterial blight are severe.

Land is plentiful but the population is comparatively low in regions of this belt. Rice field mechanization is a pressing need. Varieties must be high yielding, resistant to blast and bacterial blight, strongly resistant to cold in the seedling and blooming stages, and stiff culmed to adapt to the requirements of mechanization.

Northwestern rice belt

The northwestern rice belt includes Gan-su Province and fin-jiang and the western part of Inner Mongolia autonomous region. Its cropping area and yield constitute 0.3% of the country's total. The single-crop season is usually May to September. The mean temperature during the rice-growing period is 18.3-19.8°C. The difference between day and night temperatures is more than 14°C. The climate is dry -- the annual rainfall is generally less than 200 mm -- but with sufficient irrigation, rice grows well. Rice breeding focuses primarily on the selection of early maturing varieties that are resistant to rice blast, bacterial blight, and cold temperature, and tolerant of saline and alkaline soils and of drought.

CHINESE RICE BREEDING ORGANIZATIONS AND RESEARCH ACTIVITIES

The Chinese rice cropping regions are widely distributed. They differ greatly in climate, soil, topography, irrigation facilities, and cropping systems. Chinese breeding organizations were established to carry out rice breeding and basic research.

Agricultural research organizations

Agricultural research units are located at the state, province, prefecture, and county (Xian) levels. The Chinese Academy of Agricultural Sciences (CAAS) is responsible for coordinating rice research projects for all of China, for organizing joint investigations on important national topics, for arranging the exchange of experiences in scientific investigations, and for summing up research findings. The Academy's Crop Breeding and Cultivation Institute and the Crop Germplasm Resources Institute are engaged in rice breeding, collecting rice genetic resources, sifting basic research, and organizing national and special cooperative scientific activities.

The provincial academies of CAAS are in 27 major rice-producing regions. Each academy has a rice breeding program with its own breeding objectives. The provincial academies also organize inter-prefectural research cooperation, and arrange for the exchange of breeding experiences.

Prefectural institutes of agricultural sciences are established according to the administrative divisions of the provinces. In prefectures with comparatively large rice cropping areas, the institutes are responsible for the selection of varieties. Usually, county (Xian) institutes of agricultural sciences work on the certification, demonstration, and multiplication of rice varieties. Such county institutes and farmers with breeding experience cooperate closely with the provincial and prefectural agricultural science institutes.

Educational agriculture organizations

Also engaged in rice breeding work and the study of related subjects such as plant diseases, insects, physiology, and genetics are the agricultural universities and colleges of the provinces, municipalities, and autonomous regions, as well as some agricultural middle schools and university biology departments.

Institutes of the Chinese Academy of Sciences

The affiliate Institutes of Genetics, Botany, and Plant Physiology cooperate with agricultural research organizations in rice breeding and basic studies of genetics and physiology.

The following rice breeding activities have been carried out since the liberation.

National network of rice varietal tests. In 1957 CAAS initiated China-wide tests to determine the adaptability of new varieties and the expressions of their varietal characteristics. The country was divided into northern and southern sectors. The southern sector includes the South China, Central China, and Southwestern China rice belts; the northern sector, North China, Northwestern, and Northeastern China rice belts. The seven categories of varietal testing in the southern sector, according to nature of the varieties to be tested are:

1. first crop hsien, early maturing varieties;
2. first crop hsien, medium-early maturing varieties;
3. first crop hsien, medium-maturing varieties;
4. first crop hsien, late-maturing varieties;
5. single crop (intermediate) keng (including glutinous) varieties;
6. second crop keng (including glutinous) rice varieties; and
7. second crop hsien, early-maturing varieties.

The six categories of testing in the northern sector are:

1. first crop keng, early-maturing varieties;
2. first crop keng, medium-maturing varieties;
3. first crop keng, late-maturing varieties;
4. single crop (intermediate) keng, early-maturing varieties;
5. single crop (intermediate) keng, medium-maturing varieties;
6. single crop (intermediate) keng, late-maturing varieties.

The participating units provide test varieties. Each cooperating sector meets every 1 or 2 years to summarize joint test results, exchange breeding experiences, and discuss working plans.

Tests at the provincial, prefectural, and sectoral levels are coordinated to form a national varietal testing network that expedites the exchange and extension of new varieties.

Specialized rice breeding cooperating groups. CAAS has organized a few specialized research cooperating groups to investigate difficult breeding problems such as photoecology and thermoecology of rice, breeding for hybrid rice, and resistance to blast, bacterial blight, and planthoppers.

National plant breeding meetings. CAAS has organized three national plant breeding conferences since 1957 to summarize breeding results, orient future breeding work, and arrange joint research tasks. A meeting was held in 1973 to develop new ways and techniques of rice breeding -- wide crosses, photoefficiency breeding, and anther culture.

Establishment of a breeding base in South China. Rice breeding progress in the past 10 years has been comparatively rapid. A major reason is the acceleration in breeding of hybrid progenies. Soon after liberation, farmers in the southern regions began to plant the first-crop variety as the second crop (called "a spring variety planted in autumn" in Chinese) to accelerate propagation. Subsequently, Ya-xian, on Hai-nan Island, where natural environmental conditions allow year-round rice planting has been used for breeding medium- and late-maturing varieties for the south, and early- and medium-maturing varieties for the north. Raising a rice crop in the winter allows the breeding of 3 generations/year of first-crop rice varieties and of 2 generations/year of intermediate and second-crop rice. Farm bases have also been established on Hai-nan Island to shorten the conventional breeding period and to accelerate breeding of three lines (male sterile, maintainer, and restorer) for hybrid rice.

Participation in international rice breeding activities. We attended the 4-country (China, Soviet Union, Korea, and Vietnam) rice meeting in Hankou, China, in October 1957 and the Peking Symposium in October 1964. We exchanged scientific information with rice breeders in Japan, Korea, and Indonesia. Recent contacts with foreign rice research organizations, especially IRRI, led to the development of joint research projects. We have also exchanged rice varietal resources with Japan, Korea, USA, Indonesia, Thailand, and IRRI.

MAJOR ACCOMPLISHMENTS

Of the 96 Chinese varieties released from 1950 to 1960, 41% were purified local varieties, 42% were pure line selections, 10% were introduced from abroad, and only 8% were developed by hybridization (Table 1). During the 10 years after liberation, varietal improvement centered on the purification of local varieties and pure line selection. In the southwestern plateaus, 69% of the cultivars were purified local varieties; pure line selections amounted to 31%.

Of the varieties in the Central China rice region, 49% were pure line selection and 42% were purified from local sources. In the South China region 41% were from pure line selection and 39% were purified from local sources. In the Northwestern and North China rice regions, 60% of the recommended varieties came from pure line selection, and

Table 1. Rice varieties developed by different breeding methods. People's Republic of China, 1950-70.

Period	Rice varieties (%) by method of development or acquisition					Varieties (total no.)
	Introduced	Local	Pure line selection	Developed by hybrid-ization	Developed by radiation breeding	
1950-1960	10	41	42	7	0	96
1961-1970	1	0	38	54	7	104

20% were introduced. The Northeastern China rice region was comparatively poor in varietal resources; about 50% of the cultivars there were introduced from Japan and Korea, and 30% were developed by crossbreeding.

From 1961 to 1970, Chinese rice breeding underwent a great change. The percentage of varieties developed by crossbreeding increased from 7.3% to 54%; however, the varieties developed by pure line selection constituted 38% -- about the same as in 1960 (Table 1). Radiation breeding is becoming accepted (7% of the recommended varieties were developed by radiation breeding) (Table 1).

We have developed a large number of short-statured, high yielding, improved varieties adapted to various environmental conditions. Simultaneously, hybrid vigor has been successfully exploited and many hybrid rices are now being grown. Major research on new breeding methods and basic studies in rice genetics, cytology, and physiology are outlined next.

Investigation and use of rice varietal resources

A vast range of wild and cultivated varieties of the genus *Oryza* is found in China. The rich and varied ecotypes have characters that adapt them to various environmental conditions.

More than 30,000 local rice varieties have been collected and are being used directly and indirectly for varietal improvement.

Among the superior varieties selected from local cultivars after liberation were Lu-cai-hao, Sheng-li-xian, Lao-lai-ching in the Central China rice region; Zhen-zhu-zao and Tang-pu-ai in the South China region; and Luan-jiao-long and Qian-nong 5782 in the south-western region.

The late director of the Chinese Academy of Agricultural Sciences, Professor Ding-ying, crossed a wild rice from Guang-zhou (Kwangchow) with cultivated rice and selected Zhong-shan 1 (second-crop rice), which was grown successively in Guang-dong and Guang-xi. From Zhong-shan 1, the stable yielding varieties Zhong-shan-hong and Bao-tai-hong, with resistance to adverse soils and wide adaptability, were selected. The recent introduction of the gene for cytoplasmic sterility from a wild rice in Ai-xian, Guang-dong Province, into cultivated rice produced a wild abortion-sterile line and thus paved the way for the use of hybrid vigor in a vast rice production area.

The major types of cultivated rice in China are: hsien (indica) and keng (sinica, japonica) rice; early season (first crop) and late-season (second crop) rice; wetland and dryland rice; and Zhan (nonglutinous) and Nuo (glutinous) rice.

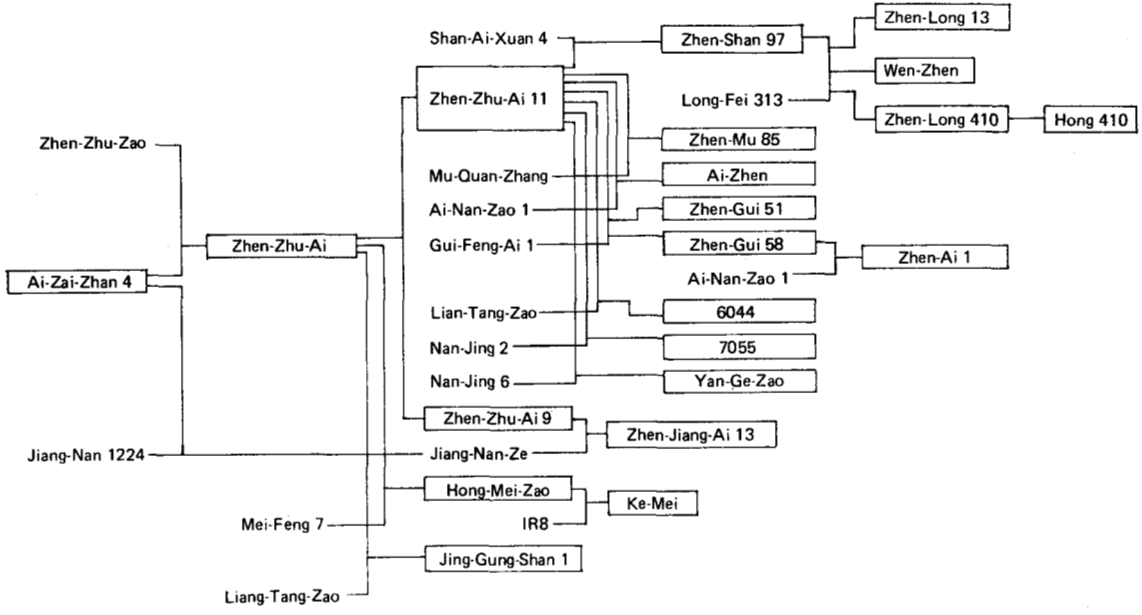
In a 1961-64 investigation of the photoecotypes and thermo-ecotypes of Chinese rice varieties, led by Professor Ding-ying, the Chinese varieties were divided into 13 climatic ecotypes:

1. The South China late-season hsien type
2. The Yun-nan late-season hsien type
3. The Central China late-season hsien type
4. The South China, Yun-nan winter rice hsien type
5. The South China, Yun-nan, Gui-zhou, Central China medium-season hsien type
6. The South China, Central China early-season hsien type
7. The South China, Yun-nan, Gui-zhou late-season keng type
8. The Central China late-season keng type
9. The South China medium-season keng type
10. The keng type found in the plateaus of Yun-nan and Gui-zhou
11. The North China and Central China medium-season keng type
12. The Northeastern and North China early-season keng type
13. The Northwestern early-season keng type.

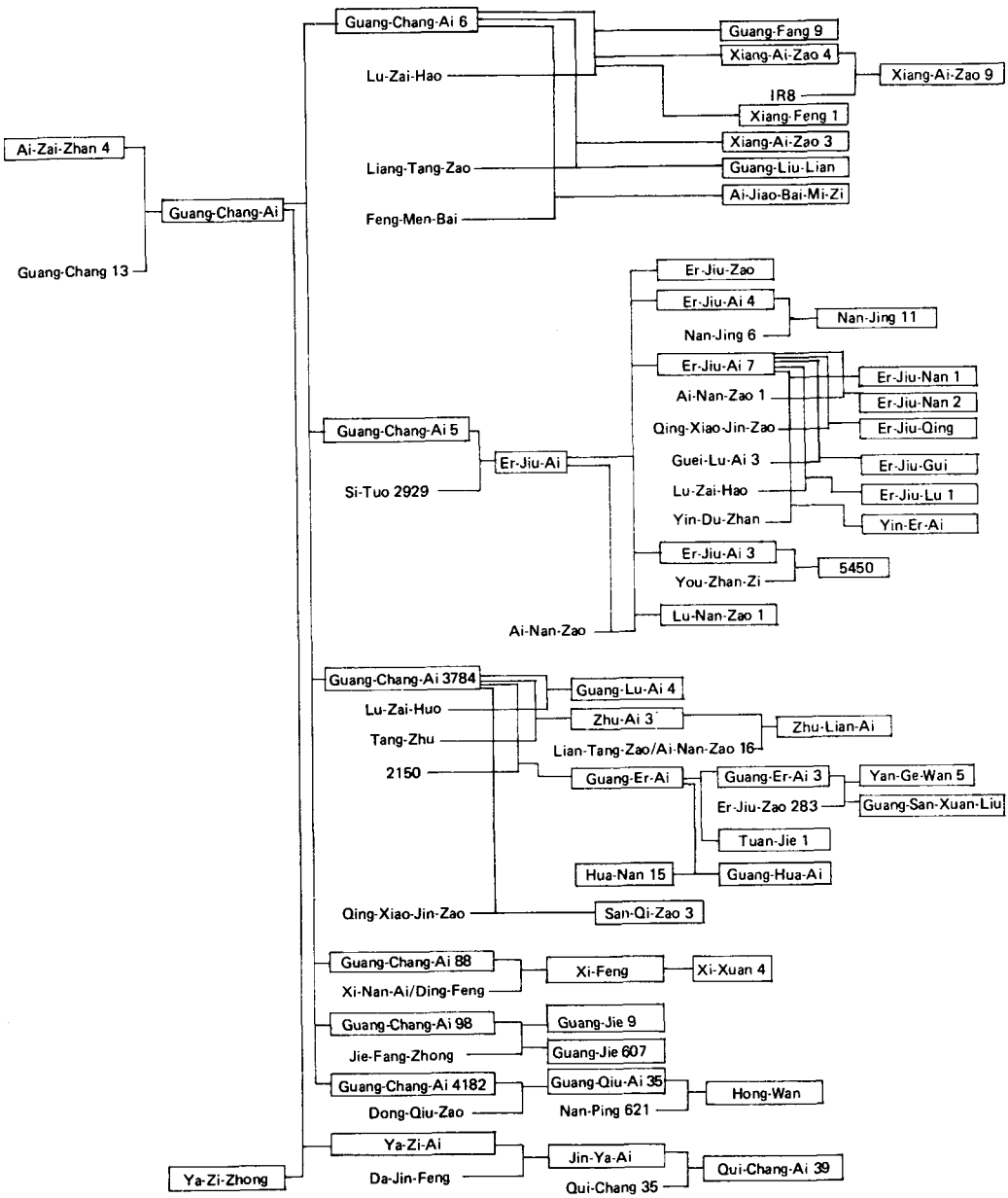
Chinese rice varieties have not only the complex characters of climatic ecotypes, but also the special characteristics of cultivated varieties: some are adapted to highly fertile soils, others to infertile soils; some have resistance to cold temperature, drought, waterlogging, diseases, and insects; some are shade tolerant. The Chinese varieties also vary in panicle, grain, and plant type, and in grain quality.

After liberation, a large batch of valuable germplasm such as the dwarf gene sources Ai-zai-zhan, Ai-jiao-nan-te, Di-jiao-wu-jian, and Hua-long-shui-tian-gu, was collected locally and from abroad. Those materials were used to develop improved short-statured varieties for the southern rice regions (Fig. 2, 3). Other local varieties have wide adaptability. For example, Nan-te-hao, the first-crop variety that is extensively grown along the Chang-jiang Basin has good combining ability in hybridizations. Many superior varieties grown in the southern rice regions are Nan-te-hao derivatives (most of China's short-statured varieties were developed from crosses involving Nan-te-hao or Hui-yang-zhen-zhu-zao).

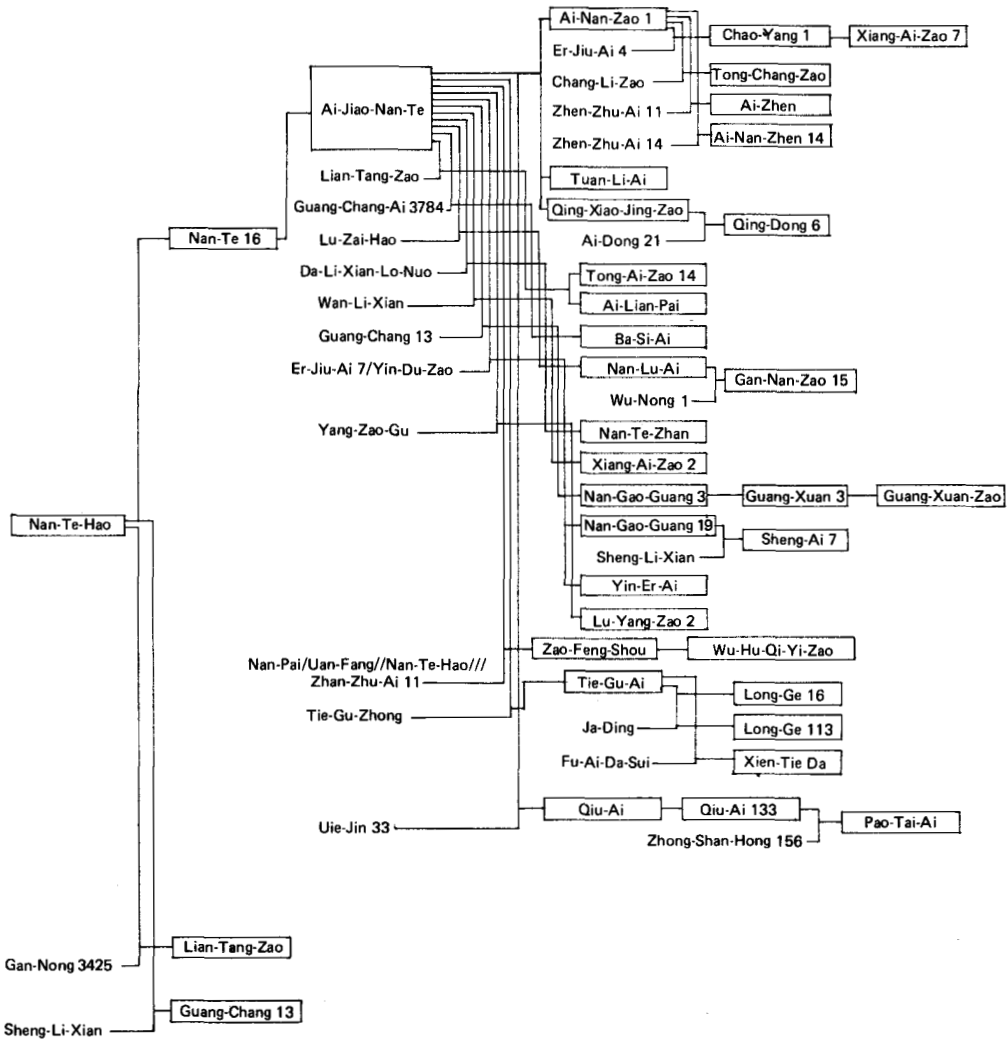
The hsien rice Cai-tang and the keng Dong-nong 363 are resistant to rice blast disease. Tests of 3,000 varieties in Jiang-su Province in 1975-78 show that keng rices generally are more resistant to bacterial blight than hsien rices. Although no variety is immune, some varieties are highly resistant. Work to identify varieties resistant to common dwarf and yellow stunt virus diseases and to leafhoppers and planthoppers, which are becoming serious pests in the southern rice regions, was launched. Of 4,700 materials tested in Ho-nan Province, some local varieties proved highly resistant to leaf-hoppers, common dwarf, and yellow stunt. In various provinces most IRRI varieties are resistant to highly resistant to blast, bacterial



2A. *Lineage of short-statured varieties derived from Zhen-Zhu-Ai, which originated from Ai-Zai-Zhan.*



2B. *Lineage of short-statured varieties derived from Guang-Chang-Ai, which originated from Ai-Zai-Zhan.*



3. *Lineage of short-statured varieties derived from Ai-Jiao-Nan-Te, a mutant of Nan-Te-Hao.*

blight, Common dwarf, yellow stunt, planthoppers, and leafhoppers in China. Some of those IRRI varieties are now grown in China, and used as crossbreeding parents. Many local varieties with strong cold tolerance -- such as Mi-chuan-tu-mang from Xin-jiang (Sinkiang) and Zhao-tong-maxian-gu from Yunnan Province -- are also resistant to cold in the seedling stage. In parts of Yun-nan some varieties are cold tolerant in the blooming stage and at monthly mean temperatures of 16.7°C (September in Kun-ming). South China has salt-tolerant varieties in tidal flooded fields as well as varieties adapted to waterlogging and iron toxicity. Floating rice grows along the shores of Xi-jiang in Guangdong. Varieties that tolerate waterlogged, low-embankment fields are found in An-hui, Hu-bei, and Fu-jian. All of those varieties are valuable parents for crossbreeding. Our collection has many varieties with early maturity, large grains, large panicles, and superior grain quality.

Progress of conventional breeding

Conventional breeding (varietal crossing and pure line selection) is the most common breeding method in China.

Rice hybridization in China was initiated in 1926 by Professor Ding-ying, who developed Zhong-shan 1 and Xian-xue 9 for South China. Afterwards, Gan-nong 3425 was crossed with Nan-te-hao in Jiang-xi Province, and Lien-tang-zhao, a first-crop hsien rice, was developed. Lien-tang-zhao's 100-day growth duration in the middle and lower reaches of the Chang-jiang Basin makes it suitable for double-cropping. In Jiang-su Province, Shen-li Hsien was crossed with Chong-nong 4 to develop the hsien Nan-jing 1, which is extensively used for medium-season double cropping in provinces along the Chang-jiang Basin. In Guangdong Province, the cross Shen-li-hsien/Nan-te-hao produced Guang-chang 13, the leading first-crop rice variety in South China in the 1950s.

In the northern rice regions, the Ji-lin Province Academy of Agricultural Sciences began varietal crossing in 1950, and selected early maturing, cold-tolerant keng varieties adapted to the Northeastern, Northwestern, and North China rice belts. Among them are Chang-bei-hao and Song-liao-hao.

In the late 1950s when Chinese rice production was changing from single to double cropping, rice breeding objectives were adaptability to fertile soils, lodging resistance, early maturity, cold tolerance, pest resistance, and wide environmental adaptability. Since then rice breeders have worked successfully with specialists in plant protection, soils and fertilizers, and physiology.

Selection of semidwarf varieties. Lodging was China's largest yield problem. Scientists at the Guang-dong Province Academy of Agricultural Sciences crossed Ai-zai-zhan with Guang-chang 13 in 1956. From

that cross, the first-crop rice Guang-chang-aiwas selected in 1959. Meanwhile, Guang-dong farmers had selected Ai-jiao-nan-te from Nan-te 16.

Guang-chang-ai was China's first short-statured variety developed by crossbreeding. It is about 90 cm tall (more than 20 cm shorter than Guang-chang 13) and has extensive roots, vigorous and healthy tillers, even stems, and erect leaves. It does not lodge, even in typhoons. Later, the Academy bred Zhen-zhu-ai (Ai-zai-zhan/Hui-Yang-Zhen-zhu-zao), which is more widely adapted than Guang-chang-ai. It generally yields from 6 to 7.5 t/ha.

In 1963, a first-crop rice was crossed with a second-crop rice to develop Guang-chiu-ai, a short-statured second-crop variety. In about 1960 semidwarf varieties were introduced from Guang-dong into various provinces, where their high and stable yields were demonstrated. Thus, Guang-chang-ai, Zhen-zhu-ai, and Ai-jiao-nan-te have become the major varieties for extension and for use as parents in the Southern China rice regions. The first-crop varieties Zhen-zhu-ai, Guang-lu-ai 4, Xian-fang 1, Er-jiu-qing, and Lu-shuang 1011, and the second-crop varieties Bao-xuan 2, Nan-jing 11, and Dong-ting-wuan-xian are being released for large scale production in the Southern rice region.

The major characteristics of the Chinese semidwarf rice varieties are 80-90 cm plant height and strong stems to avoid lodging in coastal areas. The semidwarf indicas are responsible for the greater rice yields in the south. Their superiority is attributed to their flourish ing root systems, leaf arrangement, vigorous stems, and a seed-setting rate of more than 85%.

The keng rice Nong-ken 58 was introduced into the Tai-hu region of the Chang-jiang basin in 1957. Its high yields made it one of the major second-crop keng rices in the South. The Prefectural Institute of Agricultural Sciences of Jie-Xing, Zhe-jiang Province, crossed Nong-ken 58 with the local variety Lao-hu-dao to develop Nong-hu 6, another second-crop keng. This variety is 80-90 cm tall and has stout, vigorous stems. It tolerates low temperature in later growth and may yield as high as 7.5 t/ha. Rice breeders in Shanghai and Jiang-su have selected from Nong-ken 58 early maturing second-crop keng varieties such as Hu-xuan 19 and Wu-nong-zao. These keng rices, which are a little more than 80 cm tall, tiller profusely, adapt to fertile soils, and tolerate low temperature.

The development of semidwarf varieties is also an important breeding objective in the North, where varieties shorter than those originally released are being developed. Ji-keng 60 (bred by the Ji-lin Academy of Agricultural Sciences) and Jing-yue 1 (bred by the CAAS Institute of Crop Breeding and Cultivation) are for large-scale production in the North and Northeastern China belts.

Selecting varieties of varying maturity. Different provinces have bred early-, medium-, and late-maturing hsien and keng varieties for both the first and second rice crops.

In some regions where multiple cropping has expanded, early maturity is particularly stressed. The first-crop indica variety 7025 was developed from a cross of Ai-jiao-nan-te with a local early-maturing variety Liang-tang-zao in the lower Chang-jiang River area of An-hui Province. It matures 3 to 5 days earlier than the extension variety Gui-lu-ai 4, and yields 15% more. In the Wu-jin Xian area of Jiang-su Province, the variety Wu-nong-zao was selected from the second-crop keng variety Nong-ken 58. Its yield is approximately the same as that of its parent, but it matures 10-15 days earlier. In 1973 the Guang-dong Province AAS crossed the second-crop hsien rice Gui-yang-ai 49 with the first-crop hsien rice Chao-yang-zao 18. In 1976, they developed Gui-chao-2, a first-crop hsien rice with medium-late maturity. If sown as a second crop, Gui-chao-2 heads late in September, avoiding the harmful Cold Dew wind. It yields about 6 t/ha.

Varietal resistance to pests. The most common rice pests in China are rice planthoppers, leafhoppers, and stem borers. In recent years, rice breeders and plant pathologists have successfully bred disease- and insect-resistant varieties in different localities. Zhai-ye-qing 8, a first-crop rice variety bred by the Guangdong AAS, was developed by crossing Hua-long-shui-tian-gu with a selection of the variety Tang-zhu. Scientists then crossed the progeny with Ji-dui-lun. Because both parents -- Tang-zhu and Ji-dui-lun -- are highly resistant to blast, Zhai-ye-qing 8 has shown high blast resistance in South and Central China. Its resistance has decreased in certain localities, however, because of changes in the blast race. The Wen-shou Institute of Agricultural Sciences (IAS) in Zhejiang crossed Zhen-shan 97 with Long-fei 313 to develop Zhen-long 13, which is also highly blast resistant. Those varieties have increased production markedly in seriously affected areas.

Nan-keng 15 is resistant to bacterial blight in Jiang-su Province. Scientists in Hu-bei Province crossed the highly resistant 72-11 with the semidwarf varieties Er-jiu-ai 7, Guang-lu-ai 4, Hong-mei-zao, and Ai-nan-zao to develop some superior lines with high resistance. The variety Mei-she 2 is moderately resistant to sheath blight. In Yu-lin of Guang-xi autonomous region, Bao-xuan 2, a late-maturing, second-crop hsien rice, was selected from Bao-tai-bai. It resists bacterial blight and sheath blight,and is moderately resistant to brown planthoppers and yellow stunt. Rao-wan 6, bred by the Shang-rao IAS of Jiangxi Province, is resistant to the brown planthopper. The Bo-luo-ai and Guang-chiu 4309-2, released in Yun-nan and Guang-xi Provinces, have relatively high resistance to virus diseases transmitted by the green leafhopper.

Use of hybrid vigor in rice

Research on three lines of hybrid rice. Research on three lines of hybrid rice in China began in 1964 when a male sterile plant was discovered at the Qian-yang Agricultural School, Hu-nan Province. In 1970 a wild rice plant with aborted pollen (hereafter referred to as WA for wild aborted) was found in Hai-nan Island; it was introduced into other provinces in 1971. The use of hybrid vigor was declared a major research thrust for all of China at a 1972 meeting on scientific work in agriculture and forestry, sponsored by the Ministry of Agriculture and Forestry. The CAAS and Hunan Province AAS were assigned to coordinate joint investigations in 14 provinces, municipalities, and autonomous regions. WA was used for breeding that same year in Jiang-xi and Hu-nan Provinces; hsien male-sterile lines and maintainers of Er-jiu-ai Zhen-shan 97, and Er-jiu-nan 1 were developed. In 1973, a restorer with strong hybrid vigor was discovered in Guang-xi; later that year the restorer lines IR24, IR661, and Tai-yin 1 were tested in Guang-xi, Jiang-xi, and Guang-dong, respectively. The College of Agriculture of Si-chuan developed a Gam-type male-sterile line by crossing a Gambiaca variety from West Africa with Chao-yang 1. Two superior combinations have since been identified and released in Si-chuan Province. The Yun-nan Agricultural University has also developed a Dian-type male-sterile line by crossing the native variety E-shan-ta-bei-gu with the keng rices Ke-ching 3 and Toride 1. They are now screening to identify a restorer.

In 1972, the Northern regions introduced three lines of Boro-Taichung 65 (BT) from Japan. By using the BT male-sterile line as the female parent, the CAAS Institute of Crop Breeding and Cultivation and the Liao-ning Province Institute of Rice have developed promising new male-sterile lines. Some comparatively satisfactory restorers were developed by screening the filial generations of F_1s of hsien and keng hybrids backcrossed with keng. These three line combinations are being tested in Northeastern and North China.

Major combinations of hybrid rice. Hybrid rice was planted on about 4.7 million ha in China in 1978. Production has increased markedly in most regions.

Many superior hybrid rice combinations have recently been developed in the South and Central China rice belts. Comparatively good performance has been shown by Shan-You 2 (Zhen-Shan 97A/IR24), Shan-You 3 (Zhen-Shan 97A/IR661), Shan-You 6 (Zhen-Shan 97A/IR26), Wei-You 2 (V20A/IR24), Wei-You 3 (V20A/IR661), Wei-You 6 (V20A/IR26), Si-You 2 (V41A/IR24) Si-You 3 (V41A/IR661), Si-You 6 (V41A/IR26), Nan-You 2 (Er-Jiu-Nan 1A/IR24), Nan-you 3 (Er-Jiu-Nan A/IR661), Nan-you 6 (Er-Jiu-Nan A/IR26), and others. Those combinations are grown as the first or second rice crops in the Southern China double-cropped regions. They generally adapt to the regional growing periods. Shan-you and Wei-you have shown

good seed setting and stable yields. They are generally grown as a second crop along the Changjiang Basin. In some areas of comparatively high temperature, high yields have resulted from raising seedlings in protected nurseries, and using them as the first rice crop. Their growth duration, however, exceeds 130 days. Provinces along the Chang-jiang Basin, and regions in northern Guang-dong, Guang-xi, and Fu-jian use restoring line No. 6 (IR26) crossed with Wei A (V20 male-sterile, or MS line), Nan A (Er-jiu-nan 1 MS line), Shan A (Zhen-Shan 97 MS line), and Si A (V41 MS line). Those combinations mature 3 to 5 days earlier than combinations of restoring lines No. 2 (IR24) or No. 3 (IR661), but their photoperiod sensitivity is low and they have little flexibility in seedling age at transplanting. It is, therefore, necessary to determine the transplanting stage to avoid tangling of seedling roots.

The single-crop rice combinations Nan-You, Shan-You, and Si-You No. 2 and No. 3 produce large panicles and high yields in regions 400-1,200 m above sea level along the Chang-jiang Basin, and southern Shanxi, Honan, and Guang-dong Provinces to the southern Huang-ho River.

Large-area plantings in different regions show that combinations of Shan A are generally strongly resistant to rice blast, and combinations of restorer line No. 6 (IR26) resist bacterial blight and tolerate the brown planthopper. Combinations of Wei-A/Gui 630, Wei-You 4 (V20A/GU 154), and Shan-You 4 (Zhen-shan 97A/GU 154) are resistant to common dwarf and yellow stunt.

In North China, the primary hybrid rice combinations are Honishiki A/C57, Rei-mei A/C57, and Jing-yin 66A/Bei-jing 300.

Chemical emasculation. Although neither male-sterile lines nor restoring lines are needed to produce hybrid seeds, either allows parental plant combinations to be freely selected in accordance with breeding objectives.

Because the F_2 does not segregate for fertility, F_2 hybrid seeds can still be used if the parents do not differ greatly in maturity. Some hybrid combinations emasculated by chemicals have been released for large-scale production or have performed well. They include Gang-hue-da-jian, Gan-hua 2, and Bei-hua-gu 67. The cost of chemical emasculatory preparations -- Emasculants 1 and 2 -- is low, their effects are stable, and their residual toxicity, both in the soil and in the seeds, is low.

Radiation breeding

Radiation was first used for rice breeding in China between 1958 and the early 1960s. The common radiants were gamma rays of Co^{60} and X-ray. Among the radiation-induced varieties is the first-crop keng rice Xiong-yue 613, which was grown on more than 40,000 ha in Lioning

Province in 1971. More than 330,000 ha were planted to the radiated hsien rice Yuan-feng-zao in Zhe-jiang Province in 1978.

Treating dry seeds with radiation can induce various mutations; short-statured and early-maturing mutants are the most easily obtained. In 1965 the Zhe-jiang Province AAS used a dose of 15 r units of Co^{60} gamma rays to treat the hsien Er-jiu-ai 7, a late-maturing semidwarf used as a second crop. In 1968 Fu-yu 1, an early-maturing semidwarf with fine grain, was developed. It matures about 15 days earlier than its parent, and is used as first crop in Zhe-jiang. In Guang-xi, Zhen-fu 1 was selected from the progeny of Zhen-zhu-ai after treatment with 30,000 r units of Co^{60} gamma rays. The semidwarf yields high, has a high seed-setting rate, and matures 10 days earlier than Zhen-zhu-ai. The Zhe-jiang Agricultural University treated the tall but high-yielding first crop variety Lien-tang-zao with 20,000 r and developed Fu-lien-ai, Fu-lien-ai is 70 cm tall -- 35-40 cm shorter than the original variety. Although its growth duration is 5 or 6 days longer than that of the original variety, its yield may be more than 750 kg/ha higher.

The Si-chuan Province AAS treated the variety Cheng-du-ai 8 with 20,000 r units of Co^{60} and selected Fu-she 58 in 1969. Fu-she 58 is more than 10 cm shorter than the original variety, its growing period is 7 days shorter, and its blast resistance is higher. It has 20% more protein than the original variety and yields more than 15% higher.

The efficiency and use of radiation breeding have improved in recent years. In Guang-dong, P^{32} was used for internal-exposure treatment of hybrid seeds of Guang-chang-ai and IR8. The seeds were soaked in a P^{32} solution of 1.25 curies/grain radiation intensity. The high-yielding variety Fu-lu-zao was developed from that treatment. It matures early and has high seed setting.

Besides new radiants, treatments of multiple physicochemical factor combinations have been used. Irradiating different organs of the rice plants in various growth periods has enhanced the rate of induced mutation.

New plant breeding methods

Anther culture. Since 1970, work on tissue culture of rice in China has been mainly by in vitro culture of anthers. The research approaches focused on plant inductivity and mechanisms of seedling differentiation. The anther-induced green seedling rate, on the basis of anthers, is more than 0.4% for hsien rices and may reach 5% for keng rices. Three comparatively good basic culture media -- N_6, Ho 5, and SK_3 -- have been formulated through screening. Simplified culture media that have given good results are boiled liquid of potato, sap of corn grain, and liquid pressed from sorghum stems.

Some new varieties now grown, such as Mu-hua1 (Hei-long-jiang), Sin-Siu (Shanghai), and Wan-dan 7 (Guang-xi), were developed from anther culture of hybrid progeny of varietal and intersubspecific crosses.

Wide crosses of rice. Specialized Chinese research organizations, together with farmer-breeders, have worked on wide crosses of rice for years. Rice has been crossed with Kaoliang (sorghum) at the CAAS Institute of Crop Breeding and Cultivation. Many hybrid progeny of those wide crosses vary markedly in characteristics. Kaoliang-rice progeny have large grains and bacterial blight resistance. They have become valuable parental material for further breeding. Backcrossing and anther culture have also been used to develop special lines still under investigation.

Rice has also been used as the female parent in crosses with maize, bamboo, barnyard grass, and other crops by units in Shanghai, Guangdong, and Yun-nan. Although there are academic disputes about some cytological phenomena of wide crosses, the technique for physiological, biochemical, and cytological research areas shows promise.

Selection for high photosynthetic efficiency. The semidwarf variety Guang-lu-ai 4, a high-yielding variety of intermediate maturity, is grown along the Chang-jiang Basin. It yields about the same as the late-maturing Zhen-zhu-ai. Guang-lu-ai 4 has erect stems with straight, thick, and dark-green blades. It also uses solar energy efficiently. When Guang-lu-ai 4 was compared with the late-maturing Zhan-zhu-ai and Guang-er-ai under high temperature (35°C) at the South China College of Agriculture, Guang-lu-ai's adventitious roots grew faster, and the photosynthetic intensity of its leaves was stronger. Testing with ^{32}P radiation proved that under high temperature and strong light conditions, Guang-lu-ai 4 has weak glycolate oxidase activity. That implies that the amount of carbon dioxide it releases in photorespiration is small and its photosynthetic efficiency is high.

Breeding for rice varieties with high photosynthetic efficiency is encouraged in China. In experiments, C_3 and C_4 plants have been grown in the same chamber to screen the comparatively strong rice plant (C_3) under low carbon dioxide conditions. The Jiang-su AAS selected two dwarf plant lines with compact plant type and resistance to bacterial blight from Ji-bang-dao. The Jiang-xi Province AAS selected from Guang-lu-ai 4 a line that had 7.8% more tillers and 23.3% higher net photosynthetic rate than the original variety. From Zhen-zhu-ai, the Fu-jian Province AAS selected 7 plant lines that mature 13 days earlier than the original variety, have more effective tillers, and 13% more grains per panicle. We are just beginning research along this line and many theoretical and practical problems are doubtlessly ahead.

Studies on autotetraploidy of rice. The CAAS Institute of Crop Breeding and Cultivation has studied autotetraploidy for more than 20 years. It has found that the outstanding characters of tetraploids are the markedly enlarged seeds, about 50% higher 1,000-grain weight, and from 5 to 16% more protein content. But the autotetraploid has serious defects: the seed-setting rate greatly decreases, the number of half-filled grains increases, the grains per panicle decrease, and tillering ability decreases.

Various autotetraploid rice materials were developed to overcome some of the defects. Some progeny with comparatively high seed-setting rates or good economical characters such as compact plant type, erect blades, and strong tillering ability were selected. Another problem in autotetraploid rice breeding is the difficulty of stabilizing the segregation of characters.

FUTURE DIRECTIONS

In the past 30 years, rice breeding in China has produced many superior varieties, significantly contributing to the improvement of per-unit area yields and expediting the intensification of cropping. But to fully modernize agriculture, more rice breeding work is necessary.

First, we must further collect genetic resources, both indigenous and foreign cultivars and wild species, and strengthen our genetic evaluation and utilization program. The search for genetic resources with pest resistance and tolerance for adverse weather and problem soils is urgent.

Second, we must strengthen theoretical research on topics such as genetic resistance to diseases and insects, cold tolerance, high yields with better grain quality, and the formation of physiological characteristics and their genetic regularities.

Third, we must further strengthen cooperation with international agencies such as the International Rice Research Institute, with Japan, and with Southeast Asian countries to expand the scope of scientific discussions, technical cooperation, and exchange of genetic material and experiences. Such cooperation will enhance the development of rice breeding and rice production, both in China and the rest of the world.

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IRRI'S RESEARCH, TRAINING, AND INTERNATIONAL ACTIVITIES

N. C. Brady and M. R. Vega

IRRI conducts research on all aspects of the rice plant, disseminates research findings, distributes improved plant materials, trains promising young scientists in rice research, maintains an information center and library, and organizes periodic conferences on current problems.

The research and training efforts are organized into nine interdisciplinary programs: genetic evaluation and utilization, control and management of rice pests, irrigation water management, soil and crop management for rice, climatic environment and its influences, constraints on rice yields, cropping systems, machinery development, and consequences of new technology.

Training consists of production-oriented short courses and research-oriented on-the-job training programs that may be either short courses or degree-oriented programs.

IRRI's international program involves technical assistance to research organizations, cooperation through international networks, collaboration on specific research projects, and training of young scientists.

International agricultural research centers provide an innovative approach to the effective use of science in solving the world's food supply problem. They are sharply focused scientific establishments located in developing countries but are as well-equipped and manned as the best in the more developed world.

Director general and deputy director general, International Rice Research Institute, Manila, Philippines.

From its inception, the International Rice Research Institute (IRRI) has performed a dual role as 1) an emerging center of excellence, and 2) a collaborator with rice-producing countries.

IRRI's charter lists our objectives:

1. To conduct basic research on the rice plant, on all phases of rice production, management, distribution, aad utilization with a view of attaining nutritive and economic advantage or benefit for the people of Asia and other major rice-growing areas through improvement in quality and quantity of rice;

2. To publish and disseminate the research findings and recommendations of the Institute;

3. To distribute improved plant materials to regional and international research centers where they may be of significant value or use in rice breeding or improvement programs;

4. To develop and educate promising young scientists, primarily from South and Southeast Asia, along lines connected with or related to rice production, distribution, and utilization through a resident training program under the guidance of well-trained and distinguished scientists;

5. To establish, maintain, and operate an information center and library that will provide interested scientists and scholars everywhere with a collection of the world's literature on rice;

6. To organize or hold periodic conferences, forums, and seminars -- international, regional, or local -- to discuss current problems.

MAJOR CORE PROGRAMS

The research and training efforts at IRRI are organized into nine interdisciplinary programs:

- Genetic evaluation and utilization (GEU)
- Control and management of rice pests
- Irrigation and water management
- Soil and crop management for rice
- Climatic environment and its influence
- Constraints on rice yields
- Cropping systems
- Machinery development
- Consequences of new technology

A brief description of each program follows.

GENETIC EVALUATION AND UTILIZATION (GEU)

The primary goals of the interdisciplinary GEU program are to collect the world's rice cultivars, to systematically evaluate their abilities to resist or tolerate natural enemies, and, through selective breeding, to incorporate into new rice varieties as many as possible of such desirable genetic characters as high yields, disease and insect resistance, and high protein. Most of the screening to identify such favorable characters is performed at the IRRI headquarters, but an increasing amount is done in cooperation with scientists in national programs. Through the International Rice Testing Program (IRTP), promising genetic materials from IRRI and from national programs are furnished to cooperators who evaluate them as potential varieties or use them as parents in breeding efforts.

CONTROL AND MANAGEMENT OF RICE PESTS

Cultural, biological, and chemical measures are used in combination to manage rice pests (insects, diseases, and weeds). Efforts to develop integrated methods of pest control are increasing. The field evaluation of low-cost control and management techniques is emphasized. A major consideration is the potential ability of the farmer and village processors to adopt new practices.

IRRIGATION AND WATER MANAGEMENT

Our irrigation program stresses the development and testing of improved systems to deliver irrigation water to rice farmers, and research on socioeconomic factors to ensure the systems' continued performance. The program is important because water management is a critical limiting factor in rice production, especially during the dry season.

SOIL AND CROP MANAGEMENT FOR RICE

The soil and crop management program is concerned with soil characteristics that affect rice and with the effect of soil management, nutrient inputs, and crop culture practices on rice yields. The current concern for efficient fertilizer use by rice plants, coupled with the high cost of such chemicals, makes soil and crop management a priority area. Additionally, algae, azolla (water fern), and organisms within the rice rhizosphere are examined as potential sources of biologically fixed nitrogen for the rice plant.

CLIMATIC ENVIRONMENT AND ITS INFLUENCE

Environmental factors -- solar radiation, humidity, and light -- that affect rice plant growth and response to environmental differences and changes are studied. We investigate the effects of microclimatic differences on rice insects and diseases, and the comparative responses of rice varieties to environmental changes.

CONSTRAINTS ON RICE YIELDS

We evaluate the socioeconomic, management, institutional, and policy constraints that prevent rice farmers from adopting improved practices, and the methods for removing such constraints, particularly those that research can help remove. A network of collaborators in national programs use standardized techniques to ascertain constraints on rice yields in each cooperating country.

CROPPING SYSTEMS

Components of cropping systems research include the development of productive and practical cropping systems involving rice in the different agroclimatic zones of the world's rice-growing areas. Rice-based cropping systems have a great potential for increasing world food production. Among the systems studied are those that, with simple changes, permit farmers to grow one or more crops in addition to rice, and the more complex systems that involve intercropping, sequential cropping, and integrated pest control.

MACHINERY DEVELOPMENT

The machinery development program tests machinery for small farmers and considers the local capabilities to manufacture, market, and use the products developed. Primary emphasis is on the design and development of machinery for 1) crop production, 2) postharvest handling of rice on farms and in villages, and 3) crops grown in systems that include rice. Encouragement of timely operations both to increase the amount of food delivered to the consumer and to maximize labor inputs is of top priority.

CONSEQUENCES OF NEW TECHNOLOGY

The social and economic consequences of the new rice varieties and the associated new technology are evaluated. We assess the effects of the new rices and technology on income distribution, labor requirements, changes in size of landholdings, and on overall economic development. This program is new; however, previous research was done under the category *Constraints on rice yields.*

IRRI'S TRAINING PROGRAM

Training is an integral part of IRRI's programs and complements IRRI research. IRRI training supplements national program training and is of two types: 1) *production–oriented short courses* focused on either rice production or rice–based cropping systems, and 2) *on–the-job research training* short courses, or longer ones that lead to academic degrees.

Since the initiation in 1962 of IRRI's training program, about 2,460 trainees, scholars, and fellows have participated; more than 2,340 have taken the 1– or 2–week short courses on rice production. Practical field problems are emphasized in both the 6–month and the 2–week training courses.

Most of the 1,330 IRRI scholars or fellows who participated, did their academic work at the University of the Philippines at Los Baños (UPLB) and their thesis research at IRRI. By late 1978, 195 postdoctoral fellows had participated in IRRI's training program. The quality of research in national programs is evidence of the effects of such training.

Training is an essential component of the expanded international networks, which include cropping systems, GEU, agro–economic constraints, and farm machinery development. GEU training is now offered twice a year. In 1979 we initiated a new training course for participants in the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) and are continuing the new 6–week short course on irrigation and water management.

INTERNATIONAL PROGRAMS

The two ultimate measures of IRRI's contributions are 1) the extent to which the technology and research methodology developed by IRRI scientists –– either independently or in collaboration with other scientists –– have been or are used to help increase rice production in national programs; and 2) the role IRRI–trained rice scientists play in their rice research and production programs.

IRRI's international program is the mechanism through which we attempt to help countries produce more rice. Individual rice–growing nations have a wide range of research capabilities and requirements. Therefore, our interaction with those nations involves any one or a combination of factors including technical assistance to research organizations, collaboration through international research networks, collaboration on specific research projects, and training of young scientists and production specialists.

IRRI continues to vigorously disseminate research information to scientists and administrators of rice research and production programs. IRRI now publishes the Annual Report, the annual Research Highlights, the International Rice Research Paper Series, the IRRI Reporter, and the International Rice Research Newsletter through which scientists of many nations can publish concise summaries of their research. IRRI also publishes the proceedings of important conferences and symposia and makes them available to scientists everywhere.

In 1979 IRRI scientists resided in Bangladesh, Burma, Indonesia, Sri Lanka, Pakistan, Philippines, and Thailand to implement collaborative country projects. But IRRI's emphasis has shifted decidedly from technical assistance to cooperative country projects to active collaboration in research and network activities.

IRRI's liaison scientists facilitate the planning and implementation of collaborative research between IRRI and institutions within their spheres of responsibility. The liaison scientists also have major responsibility for facilitating the operation of the international research networks -- particularly the IRTP -- and for organizing regional services. Other research networks are the International Rice Agro-Economic Network (IRAEN) to study constraints on high yields in farmers' fields, the Cropping Systems Network (CSN), the Farm Machinery Development and Evaluation Network, and INSFFER.

Regional liaison scientists are now in Indonesia-Malaysia, Africa, and Latin America. Positions are planned for liaison scientists for Thailand-Burma-Bangladesh and the Middle East (the Thailand-Burma-Bangladesh position has been temporarily filled on a part-time basis by a Rockefeller Foundation scientist). A Ford Foundation staff member continues to serve part-time as IRRI liaison scientist in India.

Collaborative relations with national research programs are essential to IRRI's core research programs and are in IRRI's interest in moving technology to rice farmers. In turn, IRRI plays the unique role of providing assistance to national programs as they develop their own internal capacities to do rice research and to put those research findings to work in rice farmers' fields.

RICE RESEARCH AND TESTING PROGRAM IN INDIA

H. K. Pande and R. Seetharaman

Until the 1950s, India's rice improvement program was aimed mainly at improving the popular local varieties through pure line selection. The Central Rice Research Institute (CRRI) established at Cuttack in 1946 identified problems of national importance and undertook research activities on various aspects of rice improvement. It initiated in 1950 an indica-japonica hybridization program for tropical Asian countries. Although not highly successful, the program led to the development of two popular and widely grown varieties: ADT27 in India, Malinja and Mahsuri in Malaysia.

The introduction of the *improved plant type concept* in the mid-1960s opened new horizons in rice improvement. The potentials and problems of the first two semidwarf varieties -- Taichung Native 1 and IR8 -- called for a crash breeding program in India. By 1979,142 improved varieties had been released, and many promising location-specific lines were in the final stages of testing.

The All India Coordinated Rice Improvement Project (AICRIP), initiated in 1965 at Hyderabad, is the national agency that coordinates rice research and multilocation testing of improved material and technology developed at national and state rice research centers -- 45 research centers and 80 test sites -- across India. The International Rice Testing Program (IRTF), initiated at IRRI in 1975, provides another avenue for the international testing of promising national varieties and lines in different countries, thereby helping spread improved genotypes and diversifying the genetic base. India plays a key role in the IRTP; it grows 15 types of nurseries at 35 locations.

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RICE RESEARCH ACTIVITIES

Rice, India's most important cereal crop, contributes almost 40% of the country's food production. Rice improvement programs have been in operation across India since the early 1900s. Over time, a chain of rice research centers were established and today India has 120 rice research stations dealing with problems specific to regions or states.

The Indian Council of Agricultural Research (ICAR) was established in 1929. In its early stages, ICAR as a funding agency promoted research on various crops across India. With time, new institutions and commodity committees were set up to cater to the needs of the crop improvement and development programs. The overall responsibility for agricultural research in India was entrusted to ICAR in the early 1960s and changes of far-reaching effect were introduced. The commodity committees established earlier were abolished and new institutes initiated.

The Central Rice Research Institute (CRRI) was established at Cuttack by the Government of India in 1946. Its mission is to conduct research on all aspects of rice culture, to investigate problems that have wide application in India, and to serve as an information center for rice improvement. CRRI and the state research centers under the department of agriculture and agricultural universities have since made invaluable contributions to Indian rice improvement.

Early varietal improvement work sought primarily to improve popular local varieties by pure line selectlon. In 40 years, the rice research stations developed more than 500 such improved varieties. Many remain popular with farmers because of their good performance under *low risk and low management* conditions (Shastry et al 1973). Simultaneously the direct introduction of exotic varieties was attempted. Some varieties that performed well were China 1039 and China 988, Chinese indica varieties that spread widely in the Kashmir Valley and other temperate hill regions.

The second half of this century witnessed a significant change in approaches to rice breeding to increase production in major Asian rice-growing countries. The International Rice Commission (IRC) was established in 1949 to formulate and finance rice improvement projects in various countries within the framework of the United Nations Food and Agriculture Organization (FAO). At the first meeting of the IRC working party, it was realized that tropical rices had low productivity because their fertilizer response was low. Therefore, an

indica-japonica hybridization project was initiated in 1950 with CRRI as its international center. All the Southeast Asian countries participated. A large number of crosses of japonicas with the best local varieties of each country were made. The F_1 was grown at CRRI, then F_2 seeds were sent to the participating countries which selected the best nonlodging, fertilizer-responsive lines under their own agroecologic conditions. The notable contributions of the project were the development of ADT27 in India and of Mahsuri and Malinja in Malaysia (Parthasarathy 1972).

A program to develop nonlodging, stiff-strawed varieties using javanica (bulu) varieties was initiated at CRRI in the mid-1950s. From that program, the cultivar CRl014 (T90/W113) was developed. Because of its excellent grain quality, CR1014 is still popular in the wetlands of Orissa, Andhra Pradesh, and West Bengal states (Balakrishna Rao et al 1971).

The introduction of the *improved plant type* concept and the rapid spread of high yielding, nonlodging semidwarf varieties in the mid-1960s opened new vistas for rice improvement. The cultivation in India of the semidwarf variety Taichung Native 1 (TNl) introduced from Taiwan raised both hope and fear -- hope, from the realization that yields of a level previously unknown were possible under good conditions; fear, from the suspected varietal susceptibility to major insects and diseases.

The *miracle rice* as IR8 is sometimes called, was developed at IRRI, Philippines, and released in India in 1966. Indian farmers preferred it to TN1 because of its higher yield potential and much wider adaptability. Its drawbacks, like those of TN1 but only at a lesser degree, were its susceptibility to diseases and insects and its poor cooking quality.

The potentials and problems of IR8 and TN1 called for an aggressive, coordinated research program to develop local varieties with improved plant type and a wide range of growth durations, grain types, cooking qualities, and pest resistance. Through a *crash breeding program* coordinated by the All India Coordinated Rice Improvement Project (AICRIP), the Central and State Variety Release Committees have released 142 high yielding varieties, including 20 for nationwide cultivation (Table 1). The varieties have yield potential of 5 to 10 t/ha under proper management. Among Indian farmers, the most popular of the varieties are Ratna, IR20, Pusa 2-21, Bhavani, and Annapurna of the early-maturing group; Jaya and IR8 of the intermediate group; and Jagannath and Pankaj from the late group.

Table 1. High yielding varieties released by the Central Variety Release Committee, India, 1966-78.

Variety	Origin	Cross	Year of release	Growth duration (days)	Remarks
IR8	IRRI	Peta/DGWG	1966	135	Bold grain, intermediate growth duration, wide adaptability, moderately resistant to leafhoppers and blast.
Jaya	AICRIP	TNl/T141	1968	130	Bold grain, intermediate duration, wide adaptability, resistant to blast, moderately resistant to leafhoppers.
Padma	CRRI	T141/TN1	1968	110	Bold grain, early duration, susceptible to diseases and insects.
Pankaj	IRRI	Peta/Tongkai Rotan	1969	150	Bold grain, long duration, suitable for lowlands.
Jagannath	OUAT[a]	T141 mutant	1969	155	Medium slender grain, long duration, suitable for lowlands.
Bala	CRRI	N22/TNl	1970	105	Bold grain, short duration, moderately resistant to Helminthosporium.
Cauvery	TNAU[b]	TKM6/TN1	1970	110	Bold grain, short duration, moderately resistant to Helminthosporium.
Kanchi	TNAU[b]	TNl/CO 29	1970	115	Bold grain, mid-early duration.
Ratna	CRRI	TKM6/IR8	1970	120	Fine grain (long slender), mid-early duration, good cooking quality, wide adaptability, tolerance for stem borers and tungro.

Table 1. Continued.

Variety	Origin	Cross	Year of re1ease	Growth duration (days)	Remarks
Krishna	CRRI	GEB24/TN1	1970	120	Medium-fine grain, mid-early duration.
Sabarmati	IARI[c]	TNl/*5 Basmati 370	1970	125	Medium-fine grain (moderately scented), moderately resistant to blast.
Jamuna	IARI[c]	TN1/*5 Basmati 370	1970	130	Medium-fine grain, medium duration.
IR20	IRRI	IR262/TKM6	1970	135	Medium-fine grain, medim duration, moderately resistant to stem borers, leafhoppers, and tungro.
Vijaya	CRRI	T90/IR8	1970	135	Medium-fine grain, mid-late duration, moderately resistant to leafhopper and blast.
Sona	AICRIP	GEB24/TNl	1973	125	Fine grain (long slender), medium duration, moderately resistant to leafhoppers and tungro.
Jayanti	CRRI	T90/IR8	1973	135	Fine grain (long slender), medium duration, moderately resistant to bacterial blight.
Vani	CRRI	IR8/CR1014	1975	120	Fine grain (long slender), mid-early duration.
Rasi	AICRIP	TNl/CO 29	1977	110	Bold grain, short duration, suitable for drylands.
Akashi	AICRIP	IR8/N22	1977	100	Bold grain, short duration, suitable for drylands.
Prakash	AICRIP	TN1/T90	1977	130	Fine grain (long slender), medium duration.

[a]Orissa University of Agriculture and Technology. [b]Tamil Nadu Agricultural University.
[c]Indian Agricultural Research Institute, Delhi.

The major problem of today's high yielding varieties is that most have either TN1 or IR8 as a parent (because of plant type) and therefore are derivatives of one genotype, the Chinese dwarf Dee-geo-woo-gen (DGWG). This narrow genetic base has caused alarming uniformity in the improved varieties and was largely responsible for a widespread epidemic of brown planthoppers (BPH) in Kerda state in 1973-74 (Kulshreshtha et al 1974) and a BPH problem in the Philippines and Indonesia from 1974 to 1976 (Dyck and Thomas 1979).

Besides their genotypic uniformity and resulting vulnerability, most of the released improved varieties are also not suitable for the stress situations -- dryland or ill drained areas -- that exist in more than 75% of India's total rice area. Therefore, they are not yet grown in substantial areas. Specific breeding programs to develop location-specific varieties have been intensified.

India, a major part of cultivated rice's primary center of origin, has a rich and diverse genetic wealth. Most of the donors for resistance to major biotic and abiotic stresses and for grain quality are from India (Table, 2). Such varieties serve as major raw materials for location-specific breeding programs (Roy et a1 1977). Hybridization programs using these donors are under way in most of India's leading rice research stations to develop 1) suitable wetland types, 2) rainfed dryland types, 3) insect-resistant, disease-resistant, and multiple-resistant types, and 4) varieties tolerant of specific stress situations such as cold temperature, high altitudes, floods, and deep water. Table 3 shows situation-specific promising cultures that are in advanced national and international testing programs to study their suitability and adaptability (Balakrishna Rao 1978, Roy et a1 1978, Seetharaman 1979).

NATIONAL TESTING PROGRAM

The need to sustain an increasingly higher production potential emphasized the need for an agency to coordinate the activities of the rice research programs and to facilitate proper testing of varieties and quick assessment of new technology. Thus, the AICRIP program was initiated in 1965, with headquarters at Hyderabad, Andhra Pradesh. AICRIP conducts annual workshops to discuss ongoing rice research results and to formulate coordinated programs for the future. Scientists at 45 Indian research centers conduct various coordinated trials as integral parts of AICRIP. State departments of agriculture and the agricultural universities also conduct AICRIP trials. The

Table 2. Donor parents from India and other countries that impart resistance to biotic and abiotic stresses.

Stress condition and traits	Donors identified
Gall midge	PTB18, PTB21, Leuang 152, Eswarakora, Siam 29, ARC5959, ARC13516, ARC14787
Stem borers	TKM6, CB1, W1263, ARC10443
Brown planthopper	PTB33, ARC6650, ARC14766, Leb Mue Nahng
Green leafhopper	PTB18, PTB21
Blast	Tetep, Tadukan, Zenith, IR8
Helminthosporium	Ch 13, Ch 45, Bam 10, AC2550
Stem rot	Basmati 370, Bara 62
Udbatta	CB2
Bacterial blight	LZN, BJ1, Vase – Aikoku, TKM6, UPRB30
Rice tungro virus	Kataribhog, Latisail, ARC14766
Grassy stunt	*Oryza nivara*
Dryland (drought tolerance)	N22, MTU17, Lalnakanda 41, JBS508
Wetland	T90, Bam 6, Mahsuri, NC1281, T1242
Cold tolerance	Dhunghansali
Flood resistance	FRl3A, FR438
Salt resistance	SR26B, Getu, Dasal, Patnai 23
Deep water	HBJ1, Nagari Bao
High altitude	Ch 1039, Ch 988
Scented	Basmati 370, Kaminisaru, Randhuni, Pagal, Badshabhog, AC609
Alternate source of dwarfism	Baok, Jukkoku

national AICRIP grid consists of more than 100 test locations across India. Figure 1 shows the number of AICRIP trials in various disciplines from 1966 to 1979.

Coordination in different disciplines

Breeding. The main breeding thrust is the rapid testing program on a multitier basis. The system consists of the Initial Evaluation Trial (IET) – National Screening Nursery (NSN), Preliminary Variety Trial (PVT), and Uniform Variety Trial (UVT). The IET is primarily intended to eliminate inferior lines. The NSN, which is grown in as many locations as possible, including "hot spots," provides useful information on the

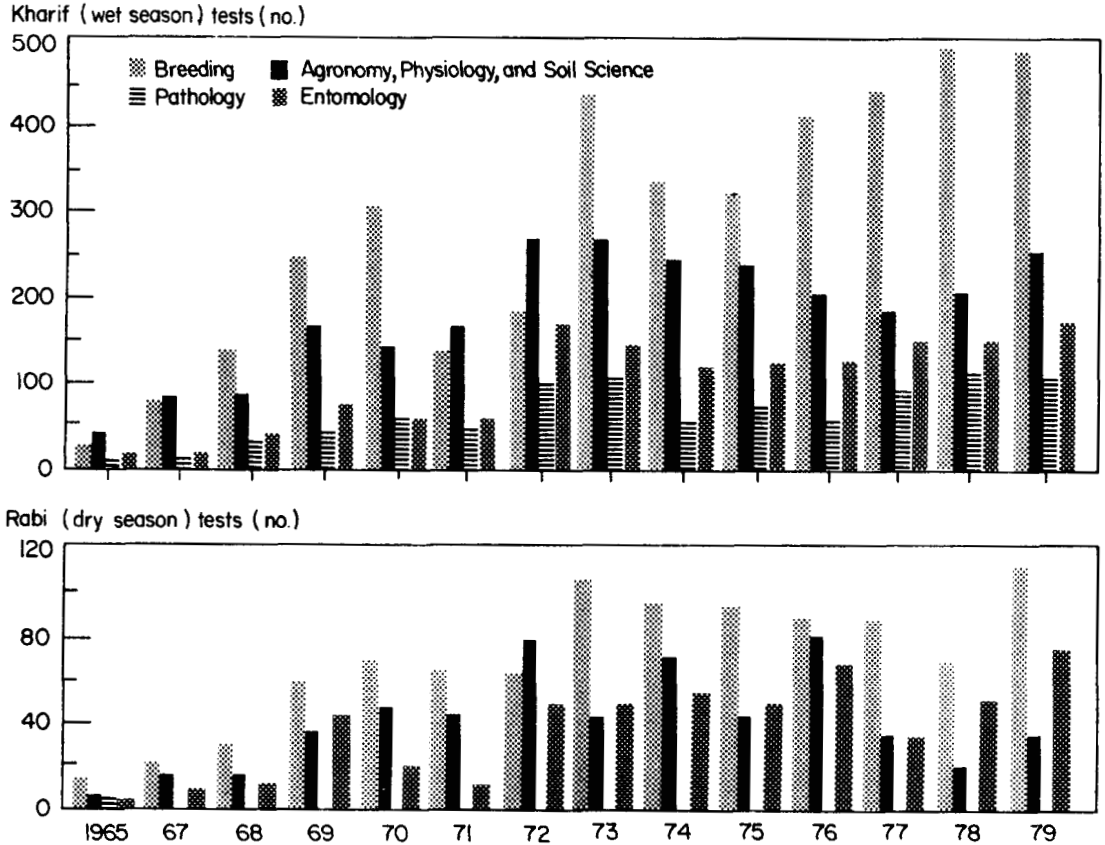
Table 3. Promising cultures against specific stress situations.

Culture no.	Cross combination	Resistance or tolerance[a]
CRM13-3247	CRl13 (mutant)	Dryland, rainfed
CR143-2-2	Bala/Lalnakanda 41	Dryland, rainfed
CR210-1009	Pankaj/Jagannath,	Wetland situations
CR211-1016	Pankaj/Kada	"
RPlOl7-76-1-4-3	Sona/Mahsuri	"
RP975-109-2	RPW6-13/Sona	"
CR94-721-3-1	PTB21/PTBl8//IR8	GM, GLH
CR95-952-1	Leuang 152/IR8	GM, GLH, BL, RTV
CR401-7	CR94-1512-6/Vijaya	GM, GLH, RTV
CRl88-10	IR20/Shakti	GM, GLH, BL, RTV
CRl89-32	CR129-118/RPW6-13	GM, BL, BPH
CR199-1	RPW6-13/Supriya	GM, BL, BB, SB
RP825-24-7-1-1	Vijaya/PTB21	BB, RTV, GM, BPH
RP825-82-1-6-6	"	BB, RTV, GM, BPH
RP825-71-4-11-2	"	GM, BPH
RP894-61-1-3-7-2	CR44-35/W12708	BL, SB
RP974-56-3-3-1	Sona/RP9-4	BB, SB
RP974-113-4-15	"	BB, RTV

[a]GLH = green leafhopper, GM = gall midge, BL = blast, RTV = rice tungro virus, BB = bacterial blight, SB = sheath blight, BPH = brown planthopper.

reaction of varieties to stresses such as pests or soil problems. The more promising nominations from the IET-NSN are promoted to the next stage of testing, the PVT. The best PVT entries at different regions are promoted to UVT. The PVT and UVT are subdivided into four or five trials based on growth duration. A few of the most promising UVT entries are included in minikit programs for large-scale testing in farmers' fields. The minikit results and data from the coordinated trials are discussed at annual workshops that then recommend lines for the CVRC Subcommittee or the State Variety Release Committees to consider for release as varieties.

Agronomy. The development of improved semidwarf varieties for different soils and environmental conditions makes improved crop management practices even more relevant than before because the new varieties are relatively more responsive to improved management. Advances in management practices can increase rice production substantially. The agronomy program includes trials on nitrogen-variety management, fertilizer efficiency, biofertilizers, and herbicide screening.



1. *Number of coordinated trials conducted through the All India Coordinated Rice Improvement Program, India. 1966–79.*

The nitrogen-variety trials have clearly shown that the semidwarf varieties respond more to nitrogen than the traditional varieties do. The trials show that fairly good yields are possible from the semidwarfs even with moderate fertilizer levels of 50-60 kg N/ha. The nitrogen-variety trials also show that no more than 20-35% of the potential yield is sacrificed at such moderate nitrogen levels (although the semidwarfs can respond to applications as high as 120-125 kg N/ha). The economic optimum dose is about 80-100 kg N/ha in the wet season, but could be 100-120 kg N/ha in the dry season.

Because of leaching and volatilization, nitrogen losses in paddy fields are greater when nitrogen is applied as urea. Application techniques that reduce urea losses by conditioning before application have been developed. Successful work in the improvement of nitrogen use efficiency under a variety of soil and water environments includes the use of urea as *supergranules* to facilitate placement and the coating of urea with indigenous materials such as neem cake, lac, asphalt, or coal-tar to reduce the dissolution rate and to effect slow release.

Split application of nitrogen at planting, tillering, and panicle initiation is suggested for most situations where water is not a physical barrier to nitrogen topdressing. Deep placement of nitrogen as modified urea materials at planting has been found beneficial for uncontrolled water situations, although practical application processes remain to be developed.

Pathology. Besides screening trials, pathologists also conduct control trials and pathogenic variation studies of the major rice diseases blast, bacterial blight, sheath blight, and tungro virus.

Multilocation coordinated screening trials enable Indian pathologists to identify varieties or selections that yield high and have high resistance to major rice diseases. Several entries with multiple resistance have been identified. Based on the multilocation fungicidal trial on blast control, 0-ethyl-S-S-diphenyl-dithiophosphate (edifenphos) and methyl-2-benzimidazole-carbamate (carbendazim) effectively controlled both leaf and neck blast in the early stages of infection. Carbendazim also effectively checked the spread of sheath blight. Results from studies on the pathogenic variability of *Xanthomonas oryzae* indicated that high- and low-virulence populations of the bacterium were present in each location surveyed. Location-specific races of clear-cut physiology were absent.

Entomology. Entomology research includes trials for varietal screening, insecticide control, biotype studies, and maximum protection for major pests such as the stem borer, gall midge, and brown planthopper.

After extensive varietal screening, entomologists identified various selections that resist one or more major rice pests. In chemical control, a technique involving seedling root dip with isofenphos (Oftanol) or chlorpyriphos (Dursban) at 0.02% + 1% urea shows the possibility of reducing the period of root dipping from 12 to 3 hours, and of controlling the insect for 20–25 days after transplanting. Insecticides such as terbufos, encapsulated carbofuran, granular MIPC, and monocrotophos and phosalone as sprays were effective at low doses.

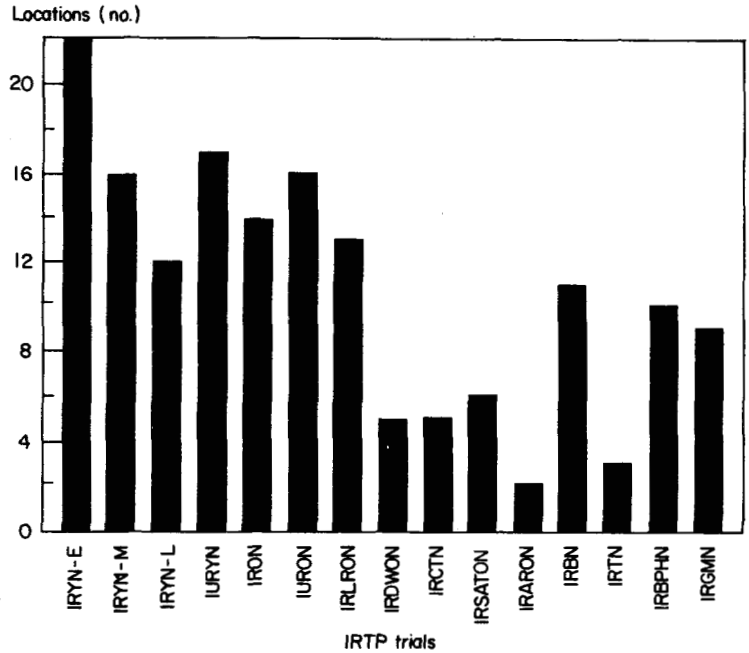
Physiology. The physiology trials include factors such as the analysis of canopy photosynthetic ability, translocation potential, the influence of environmental factors, and sterility. They are conducted on a limited scale.

The results indicated that lower light intensity reduced rice yields particularly when light levels at the reproductive and ripening stages were low. The varieties Vijaya and RP4–14 performed better than others under low light intensity. A combination of moderate temperature and moderate light intensity increased productivity.

IRTP in India

The International Rice Testing Program (IRTP) is an appropriate mechanism for testing promising national varieties and lines and helps to spread genotypes with more diverse genetic bases. IRTP testing also helps identify different insect biotypes and disease races. As a major part of this international testing program, India conducts 15 trials in about 35 locations (Fig. 2).

By active participation in IRTP India makes a substantial contribution not only to herself, but also to other countries. Many promising Indian cultures have performed well in various nurseries; scientists in other national programs either use them as parents in hybridization programs or release them as varieties. As many as 67 promising Indian breeding lines were used in state, national, or regional trials in other countries in 1978. Several other Indian lines or varieties were released as varieties in other countries. Jaya, the most promising Indian variety, has been released for wide cultivation in



2. *Number of International Rice Testing Program nurseries and their test locations in India.*

several African countries: Ivory Coast, Mali, Senegal. Vijaya has been recommended in Upper Volta. IET2938 (Durga) and IET2885 have been released as varieties in Nepal and Mali (Kauffman and Seshu 1979).

Similarly promising breeding lines from other countries are performing well in local, state, and AICRIP trials in India and are used in Indian breeding programs.

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THE GEU CONCEPT IN INDONESIA

B. H. Siwi and H. M. Beachell

New high yielding rice varieties are needed in Indonesia to solve problems brought by constantly changing farm practices and the development of important insects and diseases. Such varieties should possess grain and eating qualities preferred by Indonesian consumers and meet the requirements of wetland irrigated, wetland rainfed, dryland, tidal swamp, and high-elevation cultures. Efforts are being made to produce such varieties through the Genetic Evaluation and Utilization (GEU) program.

Trained manpower is essential for a successful GEU program. Graduate training to provide adequate qualified senior staff for all disciplines in the program is in progress. A number of technical support staff have participated in IRRI's GEU training.

Indonesia has collaborative and cooperative programs with IRRI and other country programs. It also participates in the International Rice Testing Program (IRTP).

Progress in developing new varieties for all types of culture is being made. Field and greenhouse screening techniques are widely used to screen early generation material. Improved milling and eating qualities also receive high priority.

The Government of Indonesia (GOI) places high priority on the development of improved rice varieties for all rice-farming sectors. Rice in Indonesia grows in wetland irrigated, rainfed wetland, dryland, tidal swamp, and high elevation (both wetland and dryland) areas.

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More than 70% of the total is wetland irrigated and rainfed rice, but dryland and tidal swamp cultivation are increasing in importance because the GOI promotes transmigration to such areas of the outer islands, particularly Sulawesi, Kalimantan, and Sumatra.

Indonesia has a long and enviable history of rice varietal improvement. Most of the improved varieties grown all over the world trace back to at least one and, sometimes, several Indonesian varieties (Hargrove et al 1979).

The current varietal improvement program has a strong capability and potential. It services more than 8 million ha of rice, much of which is among the most intensively cropped (2 crops/year) in the humid tropics.

DEMAND FOR NEW VARIETIES

The introduction of the high yielding semidwarf varieties IR5 and IR8 from the International Rice Research Institute (IRRI) in the late 1960s coincided with the initiation of the GOI's First Five-Year Development Plan, which strongly emphasized increasing food crop production, particularly rice.

The demand for new varieties stems from the intensification of production to meet the ever increasing need for rice.

But intensification has contributed substantially to the evolution of insect and disease problems. Crops are often devastated by the brown planthopper (BPH) and the associated ragged stunt and grassy stunt viruses. Because little warning preceded the epidemics, yield losses were substantial.

Furthermore, varieties to combat the pests were not available. Indonesia relied heavily on IRRI-developed BPH-resistant varieties, which are now grown in a high percentage of the land. Unfortunately, IRRI varieties do not possess the eating qualities preferred by Indonesian consumers, so farmers are reluctant to grow them. Thus after a successful year when the BPH was reasonably contained, the farmers returned to their traditional (but susceptible) varieties. Such practices encourage the buildup of BPH populations to devastating proportions.

It is imperative that national varietal improvement programs meet the varietal needs of their countries. The Indonesian varietal improvement program is developing the capability and staff to meet this challenge and responsibility.

THE GEU PROGRAM

A modern varietal improvement program requires the full cooperation and coordination of plant breeders and problem-area scientists -- pathologists, entomologists, agronomists, and other biological and social scientists. During the past several years, plant breeders and problem-area scientists at the Central Research Institute for Agriculture (CRIA) have worked as teams in a *Genetic Evaluation and Utilization* (GEU) program, an extremely effective means of orienting all rice improvement scientists toward a common goal. CRIA scientists from Bogor, Sukamandi, Maros, Padang, Banjarmasin, and Malang; and rice scientists from other Indonesian agencies engaged in varietal improvement cooperate in the GEU program.

An adequate germplasm bank of local and introduced cultivars is maintained at Muara as a source of new varietal characteristics for incorporation into the new varieties. After varietal objectives are formulated, plant breeders select suitable parental varieties and make the crosses. Problem-area scientists develop screening techniques for evaluating breeding material for the specific genetic traits that the new varieties must have. Teams of GEU scientists screen breeding material for the required resistances, tolerances, yield-increasing morphological traits, and milling and eating qualities. Economists and social scientists contribute in determining the feasibility of introducing new varietal characteristics from an economic and social point of view. A GEU coordinator channels the efforts of the several disciplines to ensure reliable, timely, and concise results.

THE NEED FOR TRAINED MANPOWER

Like many developing nations, Indonesia has had to carry on the GEU program with limited manpower. One of the most serious constraints on the GEU program has been the heavy work load of the senior staff. It is often difficult for them to provide the day-to-day guidance needed in the program and to obtain the greatest efficiency from the skill-oriented support staff. An accelerated graduate training program to provide qualified senior staff in all disciplines is in progress.

The technical support staff has been strengthened through GEU training at IRRI. To date 40 individuals who have participated in the training have been assigned to the various disciplines (Table 1). The support staff has also received training in other donor countries such as Thailand, Japan, and the Netherlands. The senior staff have received invaluable in-

Table 1. Number of CRIA staff receiving GEU training at IRRI, 1974-79.

	CRIA personnel (no.) assigned to given site					
Discipline	Bogor	Sukamandi	Malang	Maros	Padang	Banjarmasin
Breeding	9	3	3	1	2	1
Agronomy	3	1	1	1	1	2
Entomology	2	1	-	2	-	1
Pathology	1	1	-	4	-	-
Total	15	6	4	8	3	4

service training through participation in international conferences, symposia, workshops, and travel sponsored by IRRI.

Eventually it may be desirable to establish a GEU training program within Indonesia to guarantee the availability of trained support staff.

VARIETAL IMPROVEMENT STRATEGY

It is essential that varietal improvement objectives anticipate and project farmers' varietal requirements well into the future. The genetic resources of rice must not only be exploited, but also be applied in close relationship to projected crop management techniques and feasible chemical control measures. The Indonesian program is attempting to do this.

Optimum varietal requirements for Indonesia are overwhelming. To better meet the varietal needs of the country, five broad varietal target areas that encompass the country have been defined: wetland irrigated, wetland rainfed, dryland, tidal swamp, and high-elevation areas (Table 2). It is argued that in view of the shortage of senior scientists, Indonesia should not attempt to have a major research effort in all areas of rice improvement. But the geographic and political nature of the country dictates that attention be given to all. Through cooperative and collaborative efforts among CRIA's national rice program, regional stations, the agricultural universities, IRRI, and programs of other countries, it should be possible to meet minimum varietal requirements.

Collaborative and cooperative programs with IRRI and with other countries have expanded in recent years. Cooperative efforts involve IRRI screening of Indonesian breeding lines for

Table 2. Present and projected areas and desirable characteristics for future Indonesian rice varieties.

Varietal type	Estimated area planted (million ha) Present	Potential[a]	Important agronomic characters	Resistant to or tolerant of Disease[b]	Insect[b]	Miscellaneous
Wetland irrigated - includes reliable rainfed areas. Not flood prone.	3.70	4.65	Acceptable eating quality, strong seedling vigor, moderately high tillering, erect leaf, Pelita ht and shorter, lodgingresistant, 90 to 135 days maturity range, intermediate threshability, 90 to 135 kg N/ha.	RTV RSV BB GSV BL BLS SHB CER BL	BPH GLH SB WBPH GM	Salinity Moderately cold temp-erature Nonshattering
Wetland rainfed - less reliable irrigated areas. Flood prone or drought prone or both.	2.30	2.85	Acceptable eating quality, strong seed1ing vigor, high tilering, moderately erect leaf, Pelita ht or taller, lodging resistant, 100 to 135 days maturity range, intermediate threshability, 60 to 90 kg N/ha.	RTV RSV BB GSV BL BLS SHB CER	BPH GM SB GLH WBPH	Salinity Fe toxicity Drought

Table 2. Cont.

Varietal type	Estimated area planted (million ha)		Important agronomic characters	Resistant to or tolerant of		
	Present	Potential[a]		Disease[b]	Insect[b]	Miscellaneous
Dryland	1.20	vast	Acceptable eating quality, strong seedling vigor, moderate tillering, moderately long, slender, drooping leaves, Pelita ht or taller, lodging resistant, 90 to 125 days maturity range, intermediate threshability, 45 to 90 kg N/ha.	BL BB BLS	SB GLH	Moderately cold temperature Aluminum toxicity Iron deficiency Low P Drought tolerance
Tidal swamp, inland swamp (*lebak*), etc.	0.40	2.00	Acceptable eating quality, very strong seedling vigor, high tillering, strong vegetative vigor, slender, drooping leaves, slightly taller than Pelita, lodging resistant, early and photoperiod-sensitive maturity types, nonshattering	RTV BB BL	SB GLH	Elongation ability Submergence tolerance Drought

Table 2. Cont.

Varietal type	Estimated area planted (million ha) Present	Potential[a]	Important agronomic characters	Resistant to or tolerant of Disease[b]	Insect[b]	Miscellaneous
High elevation (cold-tolerant)	0.70	0.90	Acceptable eating quality, strong seedling vigor, moderate tillering, moderately erect leaves, Pelita ht, lodging resistant, 120 to 140 days maturity range, intermediate threshability, 90 to 135 kg N/ha, good panicle exsertion.	BL BB	BPH SB GLH	Cold temperature (strong)

[a] Includes potential expansion in areas that could be readily developed.

[b] RTV = rice tungro virus, RSV = ragged stunt virus, BB = bacterial blight, GSV = grassy stunt virus, BL = blast, BLS = bacterial leaf streak, SHB = sheath blight, CER = Cercospora, BPH = brown planthopper, GLH = green leafhopper, SB = stem borer, WBPH = whitebacked planthopper, GM = gall midge.

diseases, insects, and grain quality. In turn Indonesia contributes valuable assistance to IRRI by field screening of breeding lines for rice tungro and ragged stunt viruses.

The International Rice Testing Program (IRTP) provides valuable assistance. Breeding lines from many nations, including Indonesia, are evaluated internationally for many characteristics through the IRTP nurseries. Indonesia is also cooperating with programs in other countries in screening for blast resistance, cold tolerance, deep water, and problem soils.

Collaborative projects with IRRI on insect and disease resistance are in progress. They include studies on BPH and gall midge biotypes, blast, bacterial blight, and tungro virus. Projects in adverse soils, drought, and rainfed wetland rice have been initiated.

BREEDING OBJECTIVES AND RESULTS

An extensive screening program is being developed for the early-generation evaluation of breeding material. It requires the mass screening of many bulk populations (usually F_2 and F_3) and thousands of breeding lines. Table 3 shows the screening techniques that have been or are being developed.

Through these screening techniques, the desired characteristics are identified for combining in single varieties.

Varieties for wetland irrigated and rainfed areas

Wetland irrigated and rainfed varieties include early, midseason, and late maturing types varying in growth duration (seed to seed) from 109 to 145 days. Both semidwarf and intermediate height varieties are grown. Where reliable irrigation systems exist and high yields are economically feasible, farmers require early maturing semidwarf varieties. Farmers in some risk-prone areas need both early and late maturing varieties of intermediate height.

It is important that stronger disease and insect resistance and improved eating quality be incorporated into all varieties grown in Indonesia. As shown in Table 4, many of the leading varieties (Pelita I-1, PB5, C4-63, IR26, IR32, and IR36) although high yielding lack other needed traits.

Many promising breeding lines for wetland irrigated and rainfed conditions are now available. They combine resistance to BPH biotype 1 and 2, tungro virus, and bacterial blight, and have satisfactory eating qualities. Both early maturing and medium-

Table 3. Screening tests now conducted in Indonesia and other tests that are needed.

Problem area	Type of screening test	Where located	Level of development
Diseases			
Blast			
Nursery bed	Nurseries	Tamanbogo, Muara, Sukamandi, Maros, others	Good
Neck stage	Field	Tamanbogo	Developing
Bacterial blight	Field, inoculated	Muara, Sukamandi, Maros	Very good
Bacterial leaf streak	Field, natural infection	Where pedigree or yield plots are grown	Strengthening
Sheath blight	Field	Bogor, Sukamandi, Maros	Strengthening
Tungro virus	Field	Lanrang, Maros	Good
Grassy stunt virus	Greenhouse	-	Should be developed
Ragged stunt virus	Greenhouse	Bogor	Strengthening
Insects			
Brown planthopper biotypes 1 and 2	Greenhouse	Bogor, Sukamandi, Maros	Good, strengthening for biotype 2 and developing for other biotypes
Green leafhopper	Greenhouse	Bogor, Maros	Strengthening
Whitebacked planthopper	Greenhouse	Bogor, Maros	Strengthening
Gall midge	Greenhouse, field	Bogor, Pusakanegara, Sukamandi	Good, strengthening
Stem borers	Field	Maros, Pusakanegara	Strengthening
Drought resistance	Field	Tamanbogo	Strengthening
Cold tolerance	Field	Sukarami, Ciwalen	Strengthening

Table 3. (cont.)

Problem area	Type of screening test	Where located	Level of development
Submergence tolerance	Tank	Sukamandi, Kalimantan, Bogor	Should develop
Elongation ability	Tank	Sukamandi, Kalimantan, Bogor	Should develop
Problem soils tolerance			
Alkalinity	Field, greenhouse		Should develop
Iron toxicity	Field		Should develop
Zinc	Field		Should develop
Organic soil	Field		Should develop
Photoperiod response	Field	Banjarmasin, Sukamandi, or Bogor	Developing
Milling and eating quality			
Amylose content	Laboratory	Bogor	Should enlarge, developing at Sukamandi
Alkali digestion (gel temp)	Laboratory	Bogor	Good but should develop tests at other locations (Sukamandi, Maros)
Gel consistency	Laboratory		Should develop at Bogor
Taste panel for evaluating promising lines	laboratory	Bogor	Good

Table 4. Characteristics of important rice varieties grown in Indonesia.[a]

Variety	Seeding to maturity (days)	Plant ht (cm)	Disease reaction				Insect reaction					Amylose content[b] (%)
			BB	BLS	RTV	GSV	BPH biotype 1	BPH biotype 2	BPH biotype 3	GLH	GM	
Lowland irrigated and rainfed production												
PB5	135	130	MR	MS	S	S	S	S	S	MR	S	27
C4-63	125	115	MR	S	MR	S	S	S	S	MR	S	22
Pelita I-1	135	130	MR	MR	S	S	S	S	S	MR	S	23
Gati[c]	120	75	R	R	S	S	S	S	S	S	S	23
Gati[c]	115	80	R	MR	S	S	S	S	S	S	S	26
Adil[d]	135	101	R	R	S	S	S	S	S	S	S	28
Makmur[d]	135	100	R	MR	S	S	S	S	S	S	S	27
Gemar[d]	145	125	R	R	S	S	S	S	S	S	S	24
Brantas	127	109	R	S	MR	R	R	S	R	S	S	27
Serayu	126	105	MS	S	S	R	R	S	R	S	S	27
Asahan	130	90	R	MR	R	R	R	S	MR	S	S	16
Citarum	129	110	MS	S	MR	MS	R	S	MR	MR	S	22
IR20	120	90	R	MS	MR	S	S	S	S	R	S	25
IR26	125	85	MR	MR	MR	S	R	S	R	R	S	27
IR28	109	80	R	MS	R	R	R	S	5	R	S	27
IR30	112	73	MR	MS	MS	MS	R	S	S	R	S	27
IR32	140	88	R	MR	R	R	R	R	S	R	S[f]	27
IR34	130	117	R	MR	R	R	R	S	S	R	S	28

Table 4. Cont.

Variety	Seeding to maturity (days)	Plant ht (cm)	Disease reaction				Insect reaction					Amylose content[b] (%)
			BB	BLS	RTV	GSV	BPH biotype 1	2	3	GLH	GM	
IR36	118	81	R	R	R	R	R	R	S	R	S[f]	27
IR38	128	97	R	R	R	R	R	R	MR	R	S	25
Tidal swamp production												
Lemo	*e*	>130	S	-	S	S	S	S	S	-	-	I
Bayar Kuning	*e*	>130	S	-	S	S	S	S	S	-	-	I
Bayar Putih	*e*	>130	S	-	S	S	S	S	S	-	-	I
Bayar Melintang	*e*	>130	S	-	S	S	S	S	S	-	-	I
Siyam Halus	*e*	>130	S	-	S	S	S	S	S	-	-	I

[a] R = resistant, MR = moderately resistant, S = susceptible, MS = moderately susceptible.
[b] I = intermediate amylose (22 to 24%). [c] Also recommended for drylands. [d] Also recommended for high elevation. [e] Photoperiod sensitive. [f] Resistant to gall midge in Sri Lanka and in India, but susceptible in Indonesia.

late (Pelita maturity) lines are in the final stages of evaluation, as are several promising wetland irrigated lines with gall midge resistance. Programs of seed increase for those lines were conducted in the 1978–79 wet season.

Dryland varieties

Strong blast resistance is required for improved dryland varieties for the intensive cropping systems being developed for the transmigration areas of Sumatra and elsewhere. Several early maturing breeding lines superior to Gati are in final evaluation. Several lines developed in other countries were obtained through IRTP nurseries grown in Indonesia.

Swamp varieties

Several improved tidal swamp varieties have been developed from traditional varieties by pure line selection and are being grown in Kalimantan. Their eating quality is excellent and they are photoperiod sensitive. The expanding varietal improvement program for swamps stresses the development of shorter varieties and the incorporation of tolerance for problem soils and submergence, and, in some cases, of elongation ability. Both early maturing photoperiod–insensitive and later maturing photoperiod–sensitive types are being developed for the tidal swamps, inland swamps (Zebak), and flood–prone areas.

Several Thai breeding lines with elongation ability and submergence tolerance are being evaluated as new varieties for the deepwater areas.

Cold–tolerant varieties

At least one very promising cold–tolerant variety was grown in seed–increase fields in the 1978–79 wet season. It combines resistance to BPH biotypes 1 and 2 and bacterial blight, and has satisfactory eating quality. If final evaluation is favorable, it can replace Gemar, Adil, and Makmur.

Milling and eating quality

Improved milling and eating qualities are important breeding objectives. Through the quality laboratory at Muara the milling and eating qualities of rice strains are determined. Large numbers of breeding lines are screened for amylose content and gelatinization temperature of grain starch. Indonesians prefer rice with intermediate amylose and low gelatinization temperature. Both traits are being incorporated into new varieties.

Aroma similar to that of Cianjur rice is a preferred trait that we are incorporating into some of the new varieties that we expect to release soon.

Yield potential

Breeders must constantly look for morphological characteristics associated with yield potential: plant height, tillering ability, stiffness of stems, growth duration, and other less obvious characters. A highly developed program to test the yield of new strains at strategic locations is required.

We recognize that a sound and adequate seed production and distribution program is essential to achieve maximum yield potential.

A varietal improvement program must be continuous to solve new varietal problems brought about by constantly changing farm practices and development of new pest problems. The rice varieties that Indonesian farmers will require in the years ahead must be tailored to fit precise farming systems developed through a dynamic cropping systems and farming practices research effort. If these farming systems are put into practice and suitable site-specific rice varieties not now in existence become available to farmers, a *breakthrough* in Indonesian rice production will take place during the next decade. Without the essential farming systems, however, the benefits from new rice varieties will be less significant.

REFERENCE

Hargrove, T.R., W.R. Coffman, and V.L. Cabanilla. 1979. Genetic interrelationships of improved rice varieties in Asia. IRRI Res. Pap. Ser. 23.

THE INTERNATIONAL RICE TESTING PROGRAM

H. E. Kauffman and D. V. Seshu

The International Rice Testing Program (IRTP) is a global network of more than 600 rice scientists working in 75 countries. It is coordinated by IRRI with funds from the United Nations Development Programme (UNDP). It provides the basic inputs that allow network scientists to cooperatively and individually develop a *critical mass* of genetic technology. International testing helps disseminate advanced breeding material and donors of resistance to various stresses among scientists in different rice-growingcountries. Nine IRTP yield and observational nurseries are designed to identify improved breeding materials for irrigated and rain-fed rice. Seven stress screening nurseries identify donors for resistance to major diseases and insects, high and low temperatures, and soil stresses. Through the screening nurseries breeders can have their breeding lines evaluated and pathologists and entomologists can monitor the variations in pathogens or insects. Entries nominated to the IRTP nurseries may be evaluated through a worldwide range of international, regional, national, and state or provincial testing programs. The IRTP organizes monitoring tours that enable national scientists to travel together to observe their own and other genetic materials in IRTP nurseries, as well as local rice genetic materials in IRTP nurseries, as well as local rice research. Planning workshops conclude most monitoring tours. The IRTP regularly prints and distributes reports and publications to cooperating scientists and administrators to keep them abreast of network activities and to provide the latest research information for scientists in national and international rice improvement programs.

Joint coordinators, International Rice Testing Program, International Rice Research Institute, Manila, Philippines.

Multilocational testing permits the rapid evaluation of varieties and breeding materials under many diverse environments each season. Because years of testing can be crammed into a single season, superior varieties can quickly be identified and made available to farmers. High-yielding varieties developed through multilocation testing by national research programs and by the international agricultural research institutes have contributed significantly to increases in worldwide cereal production during the last decade.

IRRI has coordinated individual rice testing nurseries since 1963 when the first global screening effort, the Uniform Blast Nursery, was initiated. Other nurseries were later established. They included the International Rice Bacterial Blight Nursery (1972), the International Rice Sheath Blight Nursery (1973), the International Rice Yield Nursery (1973), and the International Upland Variety Nursery (1974).

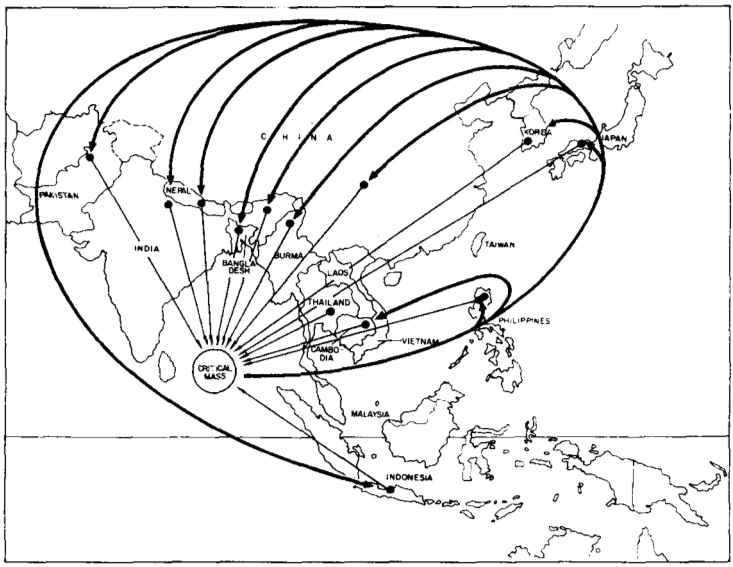
ESTABLISHMENT OF THE PROGRAM

In 1975 the United Nations Development Programme (UNDP) pledged funds to help IRRI coordinate the International Rice Testing Program (IRTP) for 5 years. This commitment was recently renewed for 1980 through 1984.

The specific IRTP objectives are:

- to exchange and test diverse germplasm and breeding lines,
- to rapidly identify germplasm that can be used as donors of resistance to pests and environmental stresses, and to identify elite breeding lines best adapted to the diverse rice-growing regions of the world,
- to evaluate genetic variations (strains and biotypes) of pathogens and insects that damage the rice crop,
- to develop a worldwide rice improvement network for transferring genetic technology and strengthening national and regional varietal improvement programs,
- to identify research and operational leads and initiate followup action for national, regional, and IRRI's rice improvement program, and
- to conduct forums to exchange research information among rice scientists around the world.

Cooperators participate in planning and revising the IRTP program regularly through monitoring tours, the annual International Rice Research Conference, regional and subject-matter workshops, and IRTP advisory group meetings. During field visits and participation in national workshops IRRI scientists



1. *How the program works for cold tolerance research: By participating in the International Rice Testing Rogram, scientists in many rice-producing nations can help develop and can draw from a critical mass of genetic technology. Thin arrows represent nations contributing cold-tolerant genetic materials, testing results, and breeding information to help develop the critical mass effect. Thick arrows represent a flow of improved rices and accompanying technology back to all cooperating nations.*

also discuss ways of improving rice and of implementing its testing. Correspondence and questionnaires provide additional opportunities for involving national-program scientists.

By participating in the IRTP network scientists can cooperatively develop a critical mass of genetic technology that feeds improved genetic materials and breeding information to scientists across the rice-growing world (Fig. 1).

The IRTP works closely with the Genetic Evaluation and Utilization (GEU) programs around the world and at IRRI. International GEU activities include making crosses for specific rice-growing environments; exchanging segregating materials; composing and exchanging nurseries, elite breeding lines, and stress-resistant donors; and conducting collaborative in-depth research on specific problem areas.

TYPES OF NURSERIES

The nurseries are divided into the following subject matter areas: yield nurseries (irrigated and dryland), observational nurseries (irrigated, rainfed dryland, rainfed wetland, and

Table 1. Types of IRTP nurseries, 1979.

Nursery	Description[a]	Entries (no.) in 1979: Donors	Entries (no.) in 1979: Varieties, lines	Maturity range (days)
Yield				
Irrigated	Early maturing (IRYN-E)	-	27	100-120
	Medium (IRYN-M)	-	27	120-140
	Late (IRYN-L)	-	24	140-160
Rainfed	Upland (IURYN)	-	24	100-140
Observational				
Irrigated	General (IRON)	3	339	95-150
	Arid (IRARON)	12	222	95-130
Rainfed	Upland (IURON)	1	140	100-140
	Lowland (IRLRON)[b]	10	239	100-160
	Deepwater (IRDWON)[b]	11	51	120-160
Stress screening				
Temperature	Cold (IRCTN)	87	150	
Soil	Salinity-Alkalinity (IRSATON)	4	69	
Diseases	Blast (IRBN)	59	288	
	Tungro (IRTN)	16	384	
Insects	Brown planthopper (IRBPHN)	41	121	
	Gall midge (IRGMN)	19	85	
	Stem borer (IRSBN)	11	69	

[a] IRYN-E = International Rice Yield Nursery - Early; IRYN-M = International Rice Yield Nursery - Medium; IRYN-L = International Rice Yield Nursery - Late; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IRARON = International Rice Arid Regions Observational Nursery; IURON = International Upland Rice Observational Nursery; IRLRON = International Rainfed Lowland Rice Observational Nursery; IRDWON = International Rice Deep Water Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRBN = International Rice Blast Nursery; IRTN = International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSBN = International Rice Stem Borer Nursery.

deepwater), and stress screening nurseries (cold tolerance, heat tolerance, problem soils, and disease and insect nurseries) (Table 1).

The type of nursery influences the information collected. Yield and maturity are the major data collected for the yield nurseries, but stress reactions are also often reported. Observational nurseries generally yield data on maturity, phenotypic acceptability, and stress reaction. The pest-screening nurseries collect varietal reactions to specific diseases and insects. All nurseries provide information on important environmental factors pertaining to individual test sites.

Instructional fieldbooks are enclosed in the seedboxes. Each fieldbook has 3 sections: 1) general instruction about the nursery, 2) general information pertaining to the trial and test sites (to be filled by the cooperators), and 3) experimental data recording sheets. The experimental data sheets are generated by computer, which prints the list of entries and appropriate column headings for relevant notes for each nursery. Each sheet in sections 2 and 3 has three copies, one each for the experimenter, the national rice coordinator, and the IRTP headquarters.

A booklet, *Standard Evaluation System for Rice,* was developed in collaboration with rice scientists from the national programs to facilitate standardization of the system of reporting various observations. Copies are made available to all cooperators and other interested scientists. Cooperators are encouraged to inform the IRTP headquarters when information is not available from a nursery because of a particular stress or when for some reason a trial was unsuccessful.

HIGHLIGHTS, PHASE I (1975–79)

In the past 5 years the global IRTP network has established working contact with more than 600 rice scientists at about 250 rice research stations and institutes in more than 70 countries.

The international nurseries provide opportunities for the free exchange of the best breeding lines and of a few donor parents. The number of nurseries increased from 11 (dispatched to 40 countries) in 1975 to 15 (dispatched to 61 countries) in 1979 (Table 2), including regional nurseries dispatched to South and Central American countries. Scientists from 72 countries participated in the 1979 IRTP program.

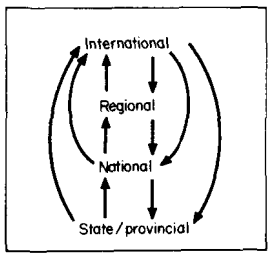
Table 2. Types and number of nurseries coordinated by the IRTP, 1975-79.

Year	Nurseries (no.) Yield	Observ-ational	Stress screening	Sets dispatched (total no.)	Participating countries (no.)
1975	3	2	7	457	40
1976	3	3	8	573	42
1977	4	3	8	577	42
1978	4	5	6	852	52
1979	4	5	6	886	61

Most IRTP nurseries are dispatched to Asia but an increasing number go to other regions (Table 3).

A four-tier system to disseminate and evaluate IRTP entries has evolved (Fig. 2).

1. *International.* IRRI sends entries directly to national programs for distribution to national scientists.
2. *Regional.* IRRI sends entries to regional centers in Latin America and Africa where the nurseries are evaluated and recomposed with only those entries that have desirable qualities for specific regional requirements.
3. *National.* Cooperating countries place the best-performing entries in national program nurseries for direct comparison with the best being developed within the national research system.
4. *State or provincial.* The entries that perform best locally are entered in state or provincial trials.



2. *The two-way movement of the best International Rice Testing Program entries in the world's rice testing network.*

Table 3. Percentage of IRTP nurseries dispatched from IRRI to various regions, 1975 to 1979.

	Nurseries dispatched (% of total)				
Region	1975	1976	1977	1978	1979
East Asia	4	3	4	2	6
Southeast Asia	27	24	29	29	16
South Asia	39	44	36	42	46
West Asia & North Africa	4	5	4	2	5
Sub-Sahara Africa	15	11	15	12	14
Latin America[a]	9	12	12	13	13
North America	1	-	-	-	-
Europe	-	-	-	1	1
Oceania	1	1	-	1	1

[a]Additional nurseries were dispatched.

Thus, IRTP entries are tested in wide range of environments by a series of agricultural research organizations to select varieties for diverse rice-growing conditions.

The IRTP trend has been to compose and dispatch more regional and target environment nurseries so that cooperators can best use their limited resources to evaluate germplasm suited for their regions.

Countries with active breeding programs use the outstanding IRTP entries as parents in hybridization work or release them as farmer varieties. Countries with small breeding programs often promote the best entries to their national testing programs for eventual release.

IRTP entries have been used in thousands of crosses made by national and IRRI scientists. Hundreds have been further tested in national testing and production programs. By 1978 at least 21 IRTP entries had been released as varieties in 9 countries (Table 4).

RICE IMPROVEMENT MONITORING PROGRAM

Monitoring tours have been the key component of the IRTP program (Table 5). Monitoring tours involve scientists from various countries who travel together to observe the IRTP nurseries and other rice research activities. The monitoring tours have helped improve the quality of the IRTP trials and

Table 4. IRTP entries named as farmer varieties in different countries. 1978.

Region or country	Designation	Origin	Named as
Southeast Asia			
Burma	BG90-2	Sri Lanka	Sinthiri
	BR51-91-6	Bangladesh	Sintheingi
	IR34	IRRI	Sinshwethwe
Vietnam	IR2071-625-1	IRRI	NN3A
	Jaya	India	
	Pelita I-1	Indonesia	
	Biplab	Bangladesh	
South Asia			
Bangladesh	IR2061-214-3-8-2	IRRI	BR6
	IR2053-87-3-1	IRRI	BR7
Indiaa	BR51-46-C1	Bangladesh	-
	IR30	IRRI	IR30
	IR34	IRRI	IR34
	IR36	IRRI	IR36
Nepal	BG90-2	Sri Lanka	Janaki
	IET2938	India	Durga
	IR2061-628-1-6-4-3	IRRI	Laxami
	IR2071-124-6-4	IRRI	Sabitri
West Africa			
Ivory Coast	Jaya	India	-
Sierra Leone	Cica 4//IR665/Tetep	CIAT[b]	ROK 11
	Cica 4 //IR665/Tetep	CIAT[b]	ROK 12
Latin America			
Bolivia	IR1529-430-3	IRRI	V5
Cub a	IRl529-430-3	IRRI	IR1529

[a]The varieties were named in certain states. [b]International Center for Tropical Agriculture, Colombia.

have given incentives to cooperating scientists through their involvement in regional and international programs. Regional workshops are usually tied into the monitoring tours. The workshop and monitoring tour reports are published and distributed to relevant scientists and administrators.

During the past 5 years (1975-79) 208 rice scientists from 30 countries (mostly tropical developing countries) participated in the monitoring programs. They visited 114 stations and institutes in 27 countries (Table 5).

Table 5. Number of monitoring tours, participants, and research stations visited from 1975 to 1979.

Year	Tours (no.)	Participants No.	Participants Countries represented (no.)	Research centers No.	Research centers Countries represented (no.)
1975	4	37	6	12	2
1976	7	56	15	20	6
1977	3	26	13	48	14
1978	10	78	20	84	14
1979	4	66	14	20	5

Table 6. IRTP publications from 1975 to 1979.

Publication	Number 1975	1976	1977	1978	1979
Fieldbook	12	14	15	15	15
Nursery report					
• Preliminary	2	8	14	15	15
• Final	-	12	13	-	15[a]
• Highlights	-	-	-	1	1[a]
Activities report	1	1	1	1	-
Planning and review	1	2	2	3	1
Monitoring tour report	2	1[b]	3	9	4[a]
Standard Evaluation System for Rice	1				
Master fieldbook				1	1

[a]To be printed. [b]Combined report for 7 monitoring tours.

REPORTS AND PUBLICATIONS

Preliminary and final nursery reports of results and activities (working documents) are prepared annually for each IRTP nursery. Such reports, along with summaries of monitoring tours and workshops, are disseminated to national cooperators and administrators (Table 6).

PLANNED ACTIVITIES, PHASE II (1980-84)

The IRTP global network will continue to be strengthened. The major focus will continue to be on the exchange and testing of germplasm and on monitoring tours and workshops.

In 1980 a yield nursery for very early maturing varieties (90-100 days) will be initiated. A small screening nursery for ragged stunt resistance will also be established. More sets of donor varieties resistant to various diseases, insects, and problem soils will be prepared and made available to interested scientists.

Monitoring tours and workshops will continue to focus on the major rice-growing systems and problem areas. The IRTP workshops and tours will be used as a major planning and review tool.

Future IRTP activities will be oriented toward further strengthening of individual, regional, national, and state or provincial rice improvement programs. Increased attention will be on the followup of research leads that are identified through the IRTP program. Scheduled to receive increased IRTP focus are collaborative work with national breeding programs (e.g. cooperative crossing, early generation testing, and rapid generation advance), collaborative disciplinary research programs, and production programs (through increased on-farm testing).

WILD RICE IN BOLUO COUNTY

Chen Wei-qin, Liang Neng, and Yu Jian Rui

Common wild rice is widely distributed in Boluo County, probably because the region has much unproductive land, few people, and frequent floods -- conditions that favor the plant's growth. The extent of wild rice distribution and the number of disseminating points are closely related. Most of the sources are located at 200–300 m above sea level and in the upper reaches of reservoirs. Yearly, floods wash wild rice away. The seeds drift from higher to lower elevations. Hilly areas favor the growth of wild rice. But during floods, water cannot flow into the East River because its water level is higher than that of the two other rivers in the county. Many drifting seeds settle lower than 20 m above sea level. It is practically impossible for living creatures to carry wild rice seed from lowlands to high mountains. The authors deduce that in ancient times wild rice seed drifted along the rivers and settled in mountain ponds. This could explain the multitude of disseminating points. Many sources of wild rice dissemination remain unaltered by man in Boluo County despite many new ditches, roads, and farmlands. Man seems destructive to the habitats in which wild rice grows; wild rice grows luxuriantly in places with Little man–made interference.

Guangdong Province is rich in wild–rice genetic resources. The three species found there are *Oryza sativa* L. f. *spontanea*, *O. officinalis* Wall., and *O. meyeriana* Baill (Ting 1961). Merrill (1917) first discovered the common wild rice in Changling, at the foot of the Luofu Mountain, and in the vicinity of Fujian and Shilong. Then Ting discovered wild rice in the swamp area at Sinuwei in the suburb of Guangzhou

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in 1926 (Ting 1949). Later, wild rice was discovered in the vast area extending from Yinde in the north of Hainan Island in the south, and from Puling in the east to the Leizhou Peninsula in the west, as well as in the Jian River Valley (Agricultural Science Academy of China 1964).

In 1933 Ting developed a variety, Yatsen No. 1, from Guangzhou wild rice germplasm. It was widely adaptable, tolerated adverse environmental conditions, and resisted major diseases and insects (Ting 1933). Several other varieties were derived from Yatsen No. 1 through pure line selection. Two of them, Baoshuan No. 2 and Guangerxuan No. 2, became the leading varieties for the late-maturing crop in Guangdong, Guangxi, and Fujian Provinces.

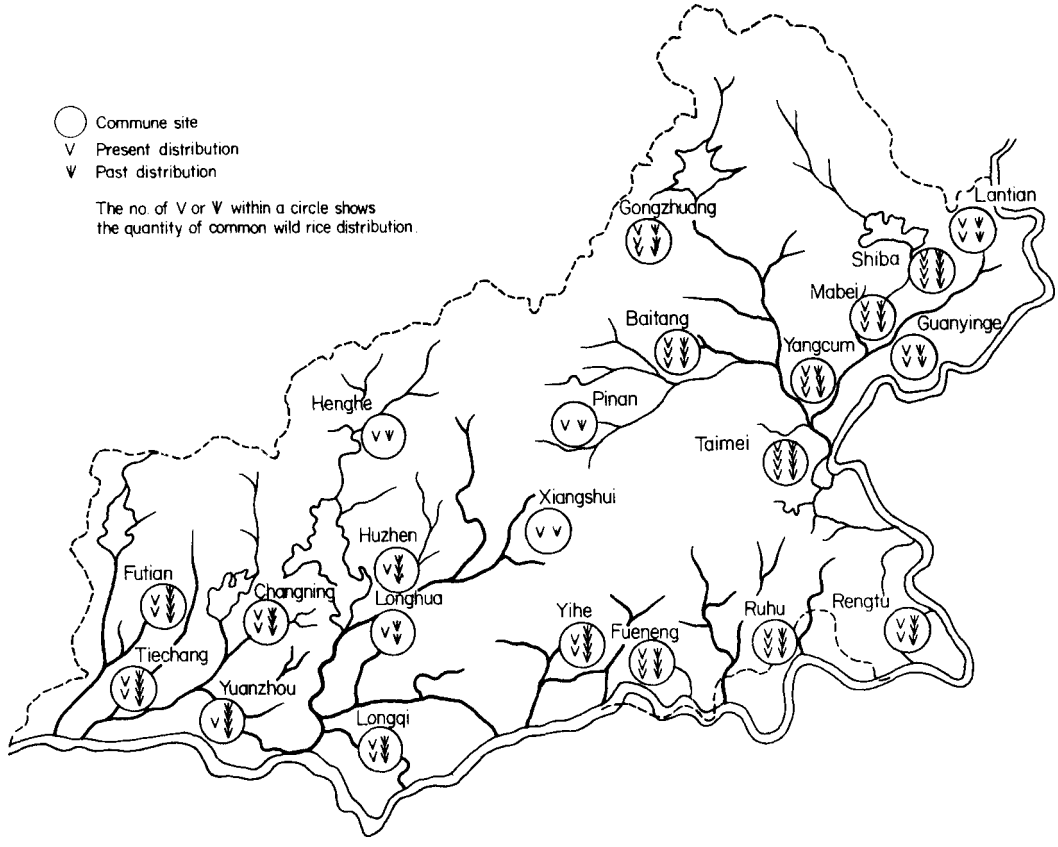
On the basis of the extensive distribution of common wild rice in Guangdong Province and in all of South China, research on relationships between wild and cultivated rice varieties, and historical records, philology, and etymology, Ting in 1949 proved that South China was the origin of China's rice species (Ting 1961). We recently studied wild rice in Boluo County to provide new germplasm and to accumulate scientific data for further basic rice research.

GEOGRAPHY OF BOLUO COUNTY

Boluo County is located 23.1° to 23.8°N and 113.9°-114.8°E in the middle reaches of the Dongjiang (East River). Its topography can be summarized as "three mountains and three rivers." The Luofu Mountain (elevation 1,296 m) is in the northwest, the Kwui Mountain (1,048 m) in the northeast, and the Shiangtou Mountain (1,029 m) in the midsouth. The Sha River originates on Luofu Mountain and partly on Shiangtou Mountain. The Gongzhuang River originates on Kwui Mountain and partly on Luofu and Shiangtou Mountains. The two other rivers flow from north to south into the East River. Elevation in the region varies greatly. Boluo County has a total area of 276,656 ha, of which 172,141 ha are mountainous. The rivers, roads, and dikes account for 51,028 ha. The farmlands, mostly in the hilly region, total 53,487 ha. The climate is subtropical. The yearly mean temperature is 21.9°C: the lowest -- 13.2°C -- in January and the highest -- 28.5°C -- in July. The annual rainfall, mostly May-August, is 1,800 mm. Hours of sunshine is 2,100/year. Two crops per year are harvested.

RESULTS

An extensive study of the wild rice growing in different ecological environments in mountains and river valleys yielded



1. *Distribution of common wild rice in communes of Boluo County.*

132 samples. Initial identification shows that all belong to *Oryza sativa* L. f. *spontanea*. The wild rice in that county has the following peculiarities:

Extensive distribution

Wild rice is widely distributed in mountains, hills, plains, and flooded areas in the County's 22 communes (Fig. 1, Table 1). In Shihpa Commune, for example, wild rice was found in all 16 production brigades. Land along a 3-km stream in Ruhu Commune has a luxuriant overgrowth of wild rice (Fig. 2). Such wild plants are also found along a 19-km irrigation canal that passes through 9 brigades of Gongzhuang Commune (Fig. 3). It also grows on about 0.6 ha in Tantien Brigade of Shihpa Commune and on 3.41 ha in the Tienkwan production team of Taimei Commune. Wild rice in Boluo County is usually distributed in areas 0.1-4.0 m above sea level (Table 2).

Table 1. Distribution of common wild rice samples collected in various ecological areas in Boluo County.

Type of area	Samples	
	No.	%
Mountainous	5	4
Hills	103	78
Plains	6	5
Waterlogged	18	14

Table 2. Common wild rice samples distributed at various altitudes in Boluo County.

Altitude (m)	Samples	
	No.	%
0.1- 10.0	24	18
10.1- 20.0	36	27
20.1- 30.0	37	28
30.1- 40.0	21	16
40.1- 50.0	8	6
50.1- 60.0	1	1
200.1-250.0	5	4

2. *Wild rice growing along the Xiao Jin stream, Ruhu Commune.*

3. *Wild rice along an old canal of Gongzhuang Commune.*

Drifting spread

The two rivers and their tributaries, which originate on the three mountains, spread over the county. Usually wild rice is found in the lower reaches as well as in the upper reaches. But if there is no wild rice in the upper reaches, none is found in the lower reaches. More wild rice is found along the tributaries than along the main streams. Small rivers have more wild rice than large rivers; rivers with slow current have more than rivers with fast currents.

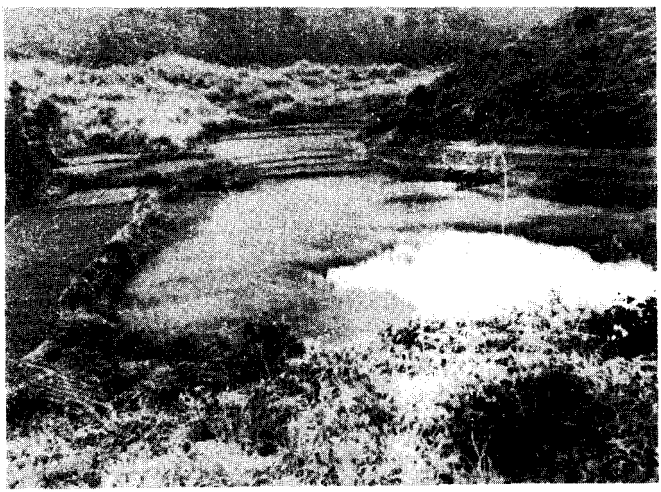
Multiple dissemination points

On Changlong Mountain, 220 m above sea level, 2 ponds with a total surface area of 0.43 ha had a 0.25-ha area overgrown with wild rice (Fig. 4). We found a thick layer of peat or

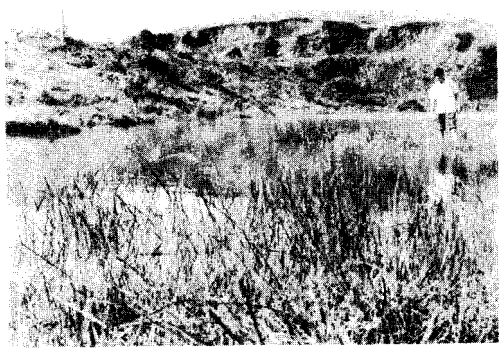
stubble massed at the bottom of the ponds. An 80-year-old peasant said that his ancestors spoke of wild rice growing there, so we deduced that wild rice had existed there for more than 100 years. The pond had often been flooded and ripe grains were washed downstream past Fuchen and Yiho Communes and finally into the East River.

Wild rice was also growing in Ku Pond at the foot of Yakungchi Mountain (Fig. 5). The local peasants confirmed that wild rice grew luxuriantly in the pond, whose water was 1 m or deeper before 1973. Some of the stems were creeping and interwoven. Each year floodwater sends the ripe grains drifting into the Liangtian River. Wild rice was also found in the areas through which the two rivers and their tributaries flowed.

Wild rice could also be traced in the lower reaches of the Lienho, the Motung, the Shuidongbei, and the Huangshantung Reservoirs. The reservoirs were also sources of wild rice



4. *Wild rice growing by an old mountain pond, Tangaebei, Changlang Mountain.*



5. *Wild rice in a pond at the foot of the Yakungchi Mountain, in Taimei Commune.*

dissemination. Some of the reservoirs are on different mountains and as far as 100 km apart -- further evidence of multiple disseminating points (Fig. 6).

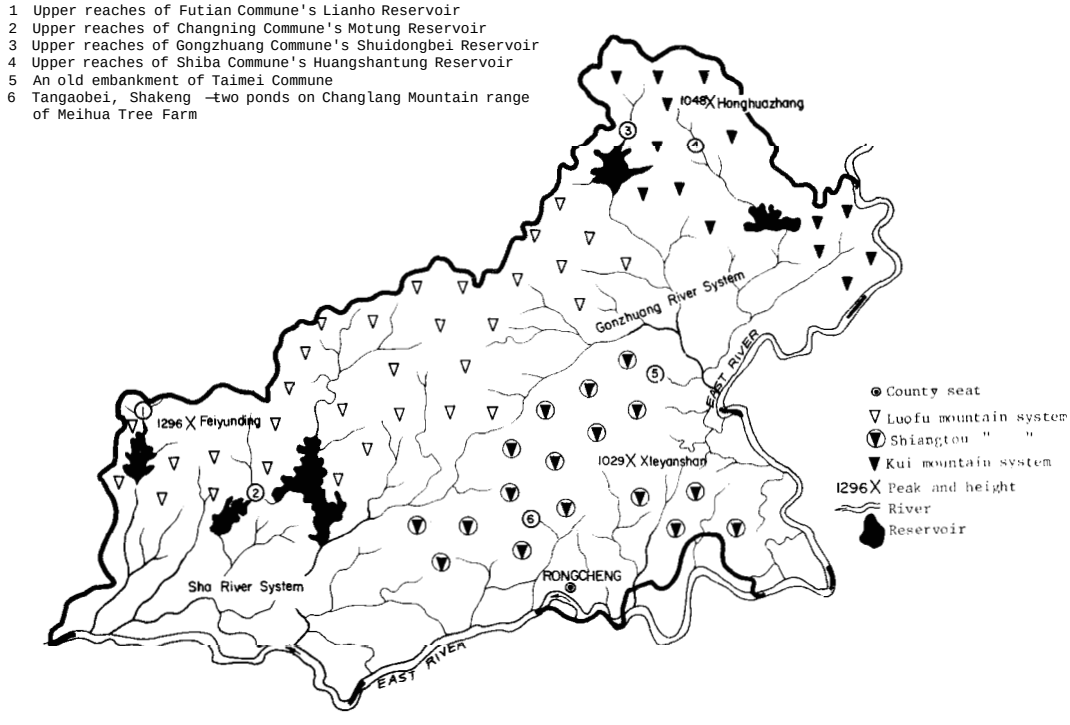
Complexity of habitat

Most of the wild rice grows in abandoned mountain ponds (Fig. 7, 8); in ditches along old roads (Fig. 9); in old streams (Fig. 10), and in small streams, river banks, wasteland, and ditches in the fields. The areas where wild rice grows vary: mountains, hills, plains, and flooded areas, at elevations ranging from 2 to 220 m above sea level. Wild rice grows in water from about 1 m to 3.5 m deep and in both drought-prone and waterlogged areas where cultivated rice cannot grow. Wild rice also grows in acid or infertile soils and in fertile soils; in abundant sunlight and in spots shaded by trees and bamboo. It grows side by side with aquatic plants such as *Cyperus difformis* L. *Hygroryza aristata* (retz) Nees, *Cyperus iria* L., *Potygonum hydropiper* L., *Lemma paucicostata* Hegelm, *Leersia hexandra* Swartz, *Echinochloa crus-galli* (L.) Beauv., and *Hymenochne aurita* (Presl) Bolansa.

The ecological environment mainly determines the presence or absence of wild rice. Man and domestic animals threaten its existence. Drainage of water is unfavorable for the development of natural communities that include wild rice. The exact conditions necessary for the formation and development of such natural communities remain to be studied.

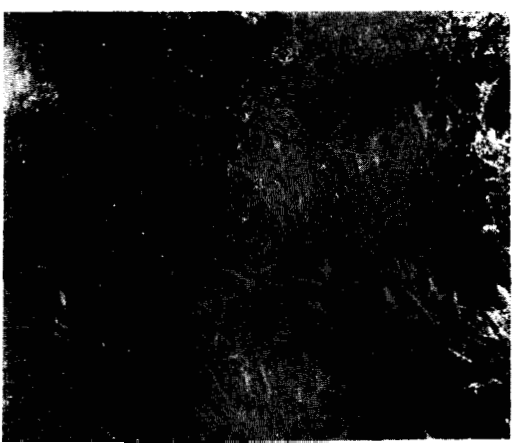
Diversity of ecotypes

The 132 samples that we collected came from diverse ecological environments and were disseminated in different ways. For example, most of them did not flower when replanted. Some flowered normally and set seeds, and some flowered only on the main stem or lower tillers. Some had dark-green leaves with long blades and thick stems, and many tillers; others had pale-green leaves with narrow short blades, slender stems, and few tillers. Some appeared dark violet or grass green; others were colorless in the emergents, auricles, ligulates, and leaf sheaths. Some were creeping plants with subterranean stems and heavy branching, but others had erect or semierect leaves, and few subterranean stems, and branches. The wild rice plants were injured by *Nephotettix bipunctatus cincticeps* Uhler, but in a few ecological environments, they were seldom affected by *Cochliobolus miyabeanus* (Ito. et Kurib) Drechsl ex. Daetur, *Pachydiplosis oryzae* Woodmason, *Cnaphalocrocis medinalis* Guenee, or *Hydrellia griseola* Fallen. The wild rice was not affected by *Piricularia oryzae* Cav., *Xanthomonas oryzae* (U. et I.) Dowson, *Pellicularia sasakii* (Shirai) Wei, *Nilaparvata lugens* Stal, and



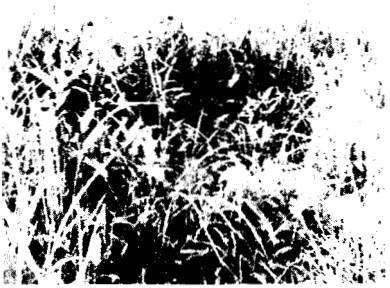
6. *Disseminating starting points of common wild rice in Boluo County.*

7. Wild rice growing in Shakeng, an old pond on Changlang Mountain.



8. Wild rice in an old pond of Taimei Commune.

9. Wild rice in an old highway ditch of Fucheng Commune.



10. Wild rice in a stream in Changning Commune.

Tryporyza incertulas Walker. Wild rice growing in different ecological environments appears to produce different ecotypes by natural selection year after year.

Wild rice collection

In 1974 Chang noted that *Oryza nivara, O. fatua, O. rufipogon, O. perennis, O. perennis* sp. *balunga,* and cultivated rice have the same genome AA (Chang 1976). The crossbreeding of common wild rice and cultivated rice has given positive results. Yet characters differ notably among the various species. In Boluo, different ecotypes can be found even within the same species. Therefore, the philosophy for wild rice collection should be that unique ecotypes can be found in various habitats.

The common wild rice that is widely distributed in various habitats is a valuable genetic resource. Collection of and research on this germplasm will contribute to rice breeding.

This investigation was conducted jointly by the Rice Research Institute of the Guangdong Academy of Agricultural Sciences (AAS), the Boluo County Bureau of Agriculture, and the Huiyang District Agricultural Research Institute. The diagrams were drawn by the Soil and Fertilizer Research Institute of the Guangdong AAS. We thank all who participated in the work.

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THE RICE GENETIC RESOURCES PROGRAM OF IRRI AND ITS IMPACT ON RICE IMPROVEMENT

T. T. Chang

IRRI's Genetic Resources Program has seen three landmarks: in 1961 IRRI began to assemble rice accessions from national centers for its germplasm bank (GB); in 1971, at the suggestion of 100 rice breeders, IRRI launched and coordinated the field collection of unimproved rices in tropical Asia; in late 1977, IRRI built the Rice Genetic Resources Laboratory (RGRL) and developed a 5-year collection plan at the Workshop on the Genetic Conservation of Rice.

The three developments were timely. From 1972 to 1978, numerous rice workers and extension officers in 7 Asian countries collaborated with IRRI staff to canvass the remote areas and collected 9,728 samples. Many agencies pooled their financial or technical resources to support the field operations. From 1971 to 1979, rice workers sent another 18,592 samples to IRRI. West African agencies provided IRRI with 4,493 samples. Participating in the massive collection activities were 14 Asian and 10 African nations.

Most of the collected samples were unimproved minor varieties and special types. In the last 7 years, IRRI's collection of *Oryza sativa* accessions has quadrupled to almost 60,000; the collection of *O. glaberrima* samples has increased by 10 times. Local workers claim that almost 7,970 samples have pest resistance to or tolerance for ecoedaphic stresses. The combined field collection efforts have counter-balanced the replacement of indigenous germplasm with improved varieties, and simultaneously enriched the IRRI collection with old land races and special types.

Expansion of systematic screening for desirable traits through IRRI's Genetic Evaluation and Utilization

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(GEU) program accompanied the growth of the GB. Many sources of resistance or tolerance have been channeled into the International Rice Testing Program (IRTP) for use by rice researchers in 46 nations.

The usefulness of the GB led many national centers to conserve, evaluate, and use their indigenous rice germplasm. IRRI's Genetic Resources Program has served as a model for other crop genetic resources centers.

Improvement of the drying-and-packing process, along with expansion of storage space in the RGRL, assures a longer shelf life for the conserved stocks and reduces the need to frequently rejuvenate seed. Collaboration with other centers will provide duplicate or triplicate seedstock storage sites. Computerized data systems will help in data retrieval and other GB-GEU operations.

The following areas of international and inter-institutional collaboration deserve immediate attention: 1) implementation of field collection in unexplored and germplasm-rich areas, 2) strengthening of interinstitutional collaboration on seed and data exchange, 3) improving storage facilities at national centers, and 4) training more and better genetic conservation workers. IRRI joins the collaborating rice-producing countries in looking forward to even greater levels of collaboration from Chinese rice researchers in working toward fuller conservation, evaluation, and use of the world's rice genetic resources.

Planning for the establishment of a rice germplasm bank (GB) began in 1960 before IRRI's physical facilities at Los Baños were built (IRRI 1960, Wortman 1962). The first 266 rice cultivars were planted in the 1961-62 dry season. Since then the GB has steadily grown in both holdings and seed distribution (Chang 1970). From the beginning the GB has served as the principal source of desirable genes for IRRI's varietal improvement program and many national breeding programs (IRRI 1972, Chang, 1972, Beachell et al 1972, Pal 1972, Chang et al 1975a, b, Khush 1977, Hargrove 1978, Seetharaman and Rani 1979).

The GB's activities began to expand significantly shortly after the 1971 Rice Breeding Symposium at which 100 plant breeders urged IRRI to initiate and coordinate field collection of rice germplasm (IRRI 1972). With a grant from The Rockefeller Foundation, IRRI began extensive field collection in 1972 with the collaboration of germplasm-rich countries in South and South-

east Asia (Chang and Perez 1975). In 1977 the Rice Genetic Resources Laboratory (RGRL) building was constructed to meet the expanding needs of IRRI's Genetic Resources Program. A Workshop on the Genetic Conservation of Rice Germplasm, held in late 1977, led to the development of a 5-year plan and further expansion of collaborative field conservation (IRRI 1978b).

This report reviews recent progress in the activities of IRRI's Genetic Resources Program, assesses its impact on rice improvement, and suggests areas for future collaboration toward fuller use of the world's enormous rice germplasm.

FIELD COLLECTION

Bangladesh, Bhutan, Burma, India, Indonesia, Kampuchea, Laos, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam collaborate in field collection. IRRI staff have participated directly in field collection in Bangladesh, Burma, Indonesia, Kampuchea, Philippines, Sri Lanka, and Vietnam. Technical assistance has been extended to operations in the other countries. IRRI's *modus operandi* under varying arrangements in different countries has been described by Chang and Perez (1975) and Chang et al (1975b).

Priority for IRRI's participation in a country 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 germplasm areas to field collectors,

5. the extent of local (in-country) support for collection, and

6. funding from an outside source.

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

IRRI's direct participation in 7 countries has led to the assemblage of 9,728 samples; efforts of national centers and volunteer workers have resulted in the collection of 18,592 samples (Table 1). India exerted the greatest national effort in 1978; it assembled 3,478 samples. Such collections, however, included thousands of duplicate samples and dead seeds.

Because most past collection efforts were concentrated on readily accessible, major rice-producing areas, the teams of IRRI staff and national workers made special efforts to collect the minor, unimproved varieties in remote areas and the special types in unusual ecologic niches. About 7,970 cultivars reputed to have tolerance for environmental stresses were assembled on

Table 1. Indigenous rice varieties collected with IRRI's direct or indirect participation in 14 collaborating Asian countries, 1971 to August 1979.

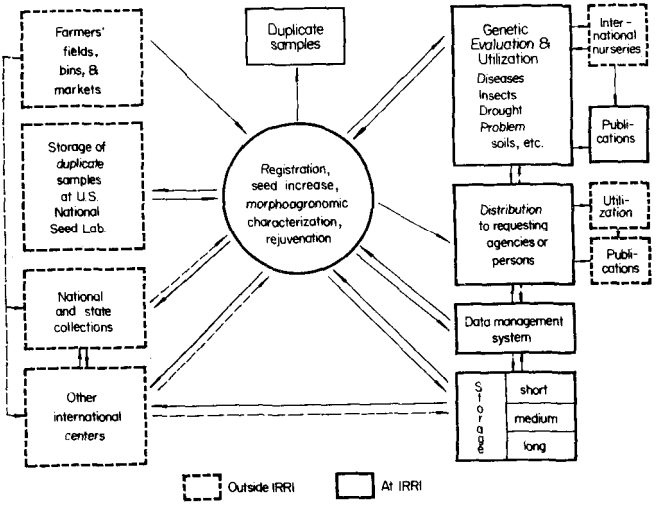
Country	Years	Indigenous varieties collected (no.) with IRRI's	
		Direct participation	Indirect participation
Bangladesh	1973-79	2,130	2,348
Bhutan	1975-76	--	121
Burma	1973-74, 1976	225	406
India	1976, 1978-79	--	3,940
Indonesia	1972-76, 1978-79	4,799	3,964
Kampuchea	1973	280	--
Laos	1972-73	--	898
Malaysia (E.)	1973-77, 1979	--	754
Nepal	1971-72	--	952
Pakistan	1972-73, 1976	--	771
Philippines	1973-76, 1977-79	510	1,927
Sri Lanka	1972, 1975-76, 1978-79	1,676	399
Thailand	1973, 1975-76, 1978-79	--	1,463
Vietnam	1972-75	108	649
	Total	9,728	18,592

Table 2. Indigenous rice varieties with special traits collected and preserved in national programs and in the IRRI germplasm bank, 1972 to mid-1979.

Reported features	Samples (no.)
Tolerance for salinity	343
Tolerance for aluminum toxicity	290
Tolerance for acid soils (wetland)	216
Tolerance for alkaline soils	324
Tolerance for iron toxicity	16
Tolerance for iron deficiency	3
Tolerance for phosphorus deficiency	3
Dryland and drought-resistant types	2781
Floating and flood-tolerant types	776
High-elevation and cool-tolerant types	671
Resistance to nematodes	5
Disease resistance	1634
Insect resistance	619
Aromatic types	120
Multiple tolerances	62
Semidwarfs	84
Nonpreference by rodents	10
Medicinal purposes	13
Total	7970

such collection trips (Table 2). Such samples are routed to the IRRI GEU scientists concerned for evaluation and verification.

A separate report (Chang and Vaughan 1979) briefly describes examples of the collaborative field collection operations from IRRI's joint ventures with Bangladesh, India, Indonesia, and Sri Lanka.



1. *Flow chart of the different IRRI operations in acquiring and increasing seed; and cataloging, preserving, evaluating, and utilizing rice germplasm, with the collaboration of other agricultural research centers.*

Field collection in 10 West African countries has been implemented by the Food and Agriculture Organization (FAO)-United Nations Development Programme (UNDP) Project in Liberia, the International Institute of Tropical Agriculture (IITA), Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT), Vest Africa Rice Development Association (WARDA), and Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM). Brazil's Centro Nacional de Recursos Geneticos (CENARGEN) has surveyed and collected indigenous varieties. Each of those institutions has provided IRRI with duplicate sets of collected samples (about 4,741) for preservation (IRAT-ORSTOM 1978; IITA /1978/; IRRI 1978a, 1979a, 1980).

EXPANSION AND IMPROVEMENTS IN GENETIC CONSERVATION OPERATIONS

Figure 1 shows the operational aspects of the IRRI Genetic Resources Program. The following summary focuses on the expansions and improvements.

Inventories

By early September 1979 the GB contained 47,674 distinct accessions, morphologic variants, and ecostrains of *O. sativa.* Another 11,454 newly received samples wait to be sown and registered. The GB also has 2,273 accessions of *O. glaberrima,*

908 populations of wild taxa, and 644 genetic testers and mutants.

Field and greenhouse plantings

Because field plantings are much larger (6.25 ha) now, we plant 2 or 3 times in the dry and wet seasons. Another planting in early November initially increases seed of the strongly photoperiod-sensitive accessions from tropical Asia. Most of the old or exhausted seed stocks are rejuvenated in the dry season. Accessions that have few seeds or that are highly pest susceptible are initially grown in a heavily screened nursery. It is now feasible to grow *O. glaberrima* strains in the hydromorphic soil on the new IRRI upland (dryland) farm in the wet season.

Acceleration of GEU tests

Newly harvested seeds of accessions reputed to have special characteristics (ecoedaphic tolerances and biotic resistances) are channeled to the concerned IRRI GEU scientist to speed evaluation. In 1978-79 we offered 309 accessions for testing for cold tolerance, 303 accessions for comparison of elongation ability, 194 samples for alkali-tolerance experiments, 202 for iron toxicity evaluation, and 540 deepwater rices for drought tests. 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.

Uniform descriptors and descriptor states

A meeting held in conjunction with the 1977 Genetic Conservation Workshop at IRRI, followed by a late-1978 meeting of the International Board for Plant Genetic Resources (IBPGR)-IRRI Rice Advisory Committee at Beltsville, Maryland, USA, led to the development of a set of uniform descriptors and descriptor states for rice germplasm (FAO-IBPGR 1979) that IRRI and IBPGR will jointly publish as a bulletin.

Storage procedures

The short-term stocks were moved into the new Rice Genetic Resources Laboratory in early 1978, and the seed stocks in two other medium-term storerooms, in early 1979.

Table 3 describes the storage conditions in different areas in the new building. There is sufficient storage space in the short- and medium-term rooms for valuable seed stocks of other research departments. Each medium- or long-term room can hold 130,000 accessions.

Table 3. Storage conditions and projected seed longevity.

Area	Temperature (°C)	Relative humidity (%)	Longevity (years)
Seed processing	20–22	50–70	2–3
Short–term	19–21	45–60	3–5
Medium–term	2–4	40–50	20–25
Long–term	–10	40–50	more than 50

Before fresh seeds are placed in medium– and long–term storage, they are dried to 6% moisture content by a new procedure; then 60–g lots are sealed under partial vacuum in aluminum cans. We are now fabricating the dehumidifier–cooler-oven assembly.

Computerized data management

We have streamlined the GB data management system using marked improvements in computerized data management made by the IRRI Statistics Department in recent years. We now have up–to-date minifiles of the registered accessions, country files, and a basic GB file of 38 morphoagronomic traits. The GB basic file is linked to the 37–item GEU file, the hybridization records, and records of other breeding nurseries.

We have increasingly moved to computerized data retrieval to meet the highly specific needs of national and IRRI rice researchers. The Statistics Department has also developed a computerized data system for seed storage, distribution, and rejuvenation.

Characterization of wild taxa

We are rejuvenating the seeds of wild taxa through a series of plantings. Meanwhile, we are systematically recording their botanical characteristics and entering them into a computer program; 91 morphologic traits are recorded in the system.

Seed dissemination

The GB has markedly increased the quantity of seed samples provided to IRRI researchers and foreign scientists since 1973

Table 4. Progress of the IRRI Genetic Resources Program in field collection, preservation, and seed distribution of *Oryza sativa* cultivars, 1970 to August 1979.

Year	Samples collected (no.) in Asia	Distinct accessions (no.) in GB	Samples distributed (no.) Within IRRI	Samples distributed (no.) To national programs
1970	--	12,800	16,000	5,600
1971	--	14,712	10,600	2,300
1972	732	16,893	2,740	2,500
1973	1,405	24,162	8,275	9,777
1974	2,982	26,818	19,236	2,603
1975	566	30,332	22,155	4,043
1976	1,466	34,229	40,200	4,819
1977	696	36,956	49,778	4,089
1978	1,134	40,768	31,941	7,316
Jan-Aug 1979	576	47,674[a]	14,013	2,869

[a] About 11,454 recently received seed samples are yet to be registered; 4,839 duplicate accessions and 3,391 nonviable seed samples were removed from the registry from 1972 to August 1979.

when the GEU program was formalized (Table 4). The increases were concurrent with the initiation and expansion of the IRTP nurseries, indicating worldwide expansion in breeding and evaluation activities.

The seeds to be sent abroad are placed in clear plastic film envelopes that show not only the seeds' physical features but also the agricultural chemicals dusted on them. The sealed envelopes are airtight.

Seed experiments

Our experiments on efficient and safe ways to dry and pack seeds for storage include different ecogeographic races and insecticides. Different seed containers and storage units are also compared. The information from such studies will be useful to many national centers.

Training

We continually provide short-term training for genetic stock officers of national centers and for GEU trainees who wish for specialized education in genetic conservation. We are also developing slide sets to aid trainees from Bangladesh, China, India, Malaysia, Pakistan, Thailand, and Vietnam.

Network of international collaboration

At the 1977 Rice Genetic Conservation Workshop and at two Rice Advisory Committee meetings, staff members from different centers developed a collaborative plan to share responsibilities in the conservation of the world's rice germplasm (IRRI 1978b). We are working toward the exchange and comparison of accession lists. Our goal is to establish duplicate or triplicate storage sites for each conserved accession and, simultaneously, reduce redundancies in holdings.

OPERATIONAL PROBLEMS AND DIFFICULTIES

It would be unrealistic not to mention the operational problems and difficulties for the largest crop-specific genetic resources program of the world. We often encounter the following problems in characterization, seed multiplication, and preservation:

1. Inviable incoming seed samples;
2. Duplicate samples, morphologic variants, or ecostrains with identical varietal names;
3. Inherent genetic variousness 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; and

13. Insufficient field space and manpower to concurrently handle three types of seed increases: 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 is expanded in number and conducted over a longer period.

We also find it necessary to rejuvenate every few years seed for the often-requested or difficult-to-multiply accessions. We are keenly aware of the pitfalls of frequent rejuvenation (Chang et al 1979):

1. Errors and mechanical mixtures,

2. Loss of unadapted or susceptible accessions,

3. Changes in genetic composition, especially for small populations, and

4. Increased workload and requirements for field and storage space.

IMPACT ON RICE IMPROVEMENT

The contributions of the IRRI GB to recent advances in global rice breeding, initially through the improvement of plant type by use of semidwarf genes, are well documented (Chalam 1965, Shastry 1966, Chandler 1968, Athwal 1971, Chang 1977, 1979a, Hargrove 1978, Seetharaman and Rani 1979). When promising sources of resistance or tolerance are identified, the GB furnishes the initial seeds for systematic screening by IRRI and national staff; IRRI disseminates the information. Such sources comprise most of the resistant or tolerant parents that rice breeders in many countries use to incorporate disease or insect

resistance, drought resistance, flood tolerance, cool tolerance, and tolerance for adverse soils into high yielding or locally adapted genetic backgrounds. Although workers in India, Japan, Sri Lanka, Taiwan, Thailand, and USA have earlier reported a number of resistant sources, the use of resistant genes from such sources received impetus from publications, conferences, and the exchanges of visits, sponsored largely by IRRI. Major publications that list promising sources are those by IRRI (1965, 1969), Ou (1972, 1977), and Chang et al (1975a) for disease resistance; IRRI (1967, 1979a, 1979c), Pathak (1972, 1977), and Chang et al (1975a) for insect resistance; and Chang et al (1972, 1974), IRRI (1975) and De Datta and O'Toole (1977) for drought resistance; BRRI (1975) and IRRI (1977, 1979b) for deep water tolerance; Vergara et al (1976) and IRRI (1979d) for cool tolerance; and Ponnamperuma and Castro (1972) and Ikehashi and Ponnamperuma (1978) for adverse soils.

In response to about 2,000 requests from rice researchers everywhere, the GB has supplied more than 63,000 seed samples of *O. sativa* accessions and more than 10,500 samples of other species. It has provided about 246,000 seed samples to IRRI GEU scientists. Table 4 summarizes the receipt and distribution of *O. sativa* cultivars. In recent years we note an increasing number of foreign requests for cultivars adapted to drought, cool temperature, deep water, and adverse soils, and for wild taxa.

GB's other contributions follow:

1. Serving as an example for rice germplasm conservation and utilization in national programs (Seetharaman et al 1972, Frankel 1975, 1977, Harlan 1977, IBPGR 1978a);

2. Serving as a model for the operations of other crop genetic resources centers (Frankel 1975, IBPGR 1978a, 1978b, 1979);

3. Publishing manuals on field collection and on conservation operations (Chang et al 1972; Chang 1974, 1976a);

4. Assisting or advising other centers on collection, characterization, and storage (Chang and Perez 1975, Varnell and McCloud 1975, Chang 1976b, IBPGR 1976, Chang et al 1977a, b, IBPGR-PCARR 1977, Anon. 1977, IBPGR 1978c, IRRI 1980).

5. Training young workers at IRRI and elsewhere; and

6. Implementing the directions set by the IBPGR Rice Advisory Committee.

AREAS FOR FUTURE COLLABORATION

The preceding survey of activities show that IRRI has made a good start in conserving enormous rice genetic resources by pooling human and financial resources. Because of the broad geographic distribution of the two rice cultigens *O. sativa* and *O. glaberrima*, the IRRI GB probably now has about half of the world's existing rice cultivars. We recognize that tens of thousands of seed samples have already been collected in China, India, and West Africa, but have not been deposited in the GB. The most urgent matter is to collect in threatened areas and to ensure the proper preservation of the conserved stocks.

Four areas in genetic conservation deserve immediate attention:

1. Completion of field collection. We should investigate the conservation status of countries and areas not covered by the 1977 Workshop on Genetic Conservation and develop collaborative collection programs. The wild species should be the next topic of discussion.

2. Strengthening of interinstitutional collaboration. The 1977 Workshop outlined broad areas for interinstitutional collaboration. We should implement the time-consuming task of comparing conserved stocks in different collections so we can establish duplicate or triplicate storage sites and reduce redundancy in preserved samples. IRRI needs the help of regional and national centers in the rejuvenation of the poorly adapted or pest-susceptible accessions.

3. Improvement of national seed storage facilities. We should develop inexpensive and efficient means of preserving seed at the national centers. Small ready-made refrigerated units, improved drying procedure, and better packaging materials will augment the national centers' capabilities and reduce their financial burdens.

4. Training of conservationists. More genetic stock workers are needed at all centers. Regional training programs could be expanded to provide more and better workers. Continuity in personnel is another important consideration in the manning of crop genetic resources programs.

We now turn to the host country of this workshop, China. We all recognize that China has had 7,000 years of rice

cultivation history and possesses enormous diversity in rice gemplasm (Ting 1957, Kwangtung Agricultural and Forestry College 1975, Liu 1975, Chang 1976c, 1979c, Ming 1978). The *keng* ecogeographic race (synonymous with japonica, sinica) was differentiated in China. Because of China's long rice history and varied ecologic conditions, rice workers in other countries have, for example, found a number of Chinese *hsien* (indica) varieties such as Leng Kwang and China 1039 to be cool tolerant (Ghose and Butany 1959, Richharia and Misro 1961, Hargrove 1977, Satake and Toriyama 1979). Moreover, the recessive gene of the Chinese semidwarfs Dee-geo-woo-gen, Ai-chiao-nan-te and Ai-tze-chuan has been the principal source of the improved plant type (IRRI 1978a, Lu 1979). We believe that the Chinese rice germplasm has many more valuable genes, but intensive evaluation must be conducted at more sites around the world to identify them.

IRRI now has in the GB about 3,000 Chinese accessions of which 569 were recently donated by Chinese scientists. We would like to offer to China's rice researchers services similar to those IRRI provides to other rice-producing countries: IRRI's assistance and collaboration in providing duplicate storage, more comprehensive evaluation of conserved stocks, exploration and collection in those areas not canvassed earlier, and training of technical personnel. We believe that other countries participating in the IRTP network would also enthusiastically work with Chinese scientists in conserving, evaluating, and using all the world's available rice genetic resources for mankind's benefit. Such a sentiment was expressed at the 1977 Workshop on Genetic Conservation (IRRI 1978b).

From the Chinese scientists, we wish to learn more about China's rice germplasm and how IRRI can further extend its role in genetic conservation. The IBPGR and IRRI would also welcome a Chinese scientist to serve as a member of the Rice Advisory Committee.

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FUNGUS DISEASES OF RICE IN CHINA

Sun Shuyuan

Rice blast and sheath blight are the most widespread and destructive fungus diseases in China. Stem rot, narrow brown leaf spot, leaf scald, and brown spot are less significant but have been increasing in intensity in recent years. In disease control the "prevention first" principle has always been carried out. The minor diseases and sheath blight have been controlled mainly through modifying cultural practices complemented by chemical measures where necessary.

Blast has been most widely studied. Although the selection of resistant varieties began many years ago, national coordinated research on the disease started in the mid-1970s when blast nurseries were established in various regions. Local breeding lines and high yielding varieties from the various rice-growing regions as well as varieties introduced from abroad have been used in resistance breeding programs.

Pyricularia oryzae from the different rice regions in China have been identified in differential varieties. Of the 24 races identified, race CGl -- the most dominant -- is found in 11 provinces. Other important races are CF1, CE3, and CA57.

Studies on blast control have shown the use of resistant varieties as the core of control, cultural practices as the foundation, and chemical application as a complementary measure. Farmers take an active part in the experiments.

There are about 50 fungus diseases of rice in China, according to incomplete records (Dai et al 1956, Wei 1975). Rice blast and sheath blight, the most destructive, cause severe crop

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damage. Other fungus diseases, such as stem rot, narrow brown leaf spot, leaf scald, and brown spot are present but are not as important (Ministry of Agriculture Plant Protection Bureau 1959).

Sheath blight is distributed mainly in the rice regions of South China and the Yangtze Valley. Its incidence has recently increased with the growing of broadleaved semidwarf varieties and the adoption of close planting. The disease is usually controlled by removing the sclerotia on the water surface before rice transplanting. During late tillering, the field is checked; if 5-10% of the hills are infected, chemicals such as organic arsenic compounds are applied once or twice.

Stem rot, prevalent in the South, has occasionally been reported from Jilin Province. It occurs both in nursery beds and in transplanted fields with excess water. Its incidence varies with season and variety. Generally, late rice is more severely damaged than early rice. Recommended for sheath blight control are the adoption of resistant varieties, good water management, and one or two applications of Topsin at the elongation stage.

Narrow brown leaf spot is usually found in the late rice crop in the Yangtze Valley and South China. Pathogens from diseased seed and straw cause primary infection. Infection is not serious until after the rice elongation stage, when the stem of the infected plant gradually becomes soft and rotten. The disease severity differs with variety and amount of organic fertilizers applied. Heavy topdressing induces disease incidence. Heavy fertilization such as basal application with proper top-dressing increases the plant's resistance. Narrow brown leaf spot is controlled through the use of resistant varieties and spraying Topsin or benlate compounds once or twice at the early and late tillering stages.

Leaf scald is not important but its incidence in some rice-growing areas has increased in recent years. It is more severe when temperature is low and humidity high. Indicas are more susceptible than japonicas; glutinous rice appears more resistant. Chemical control by spraying Topsin or IBP emulsion is effective.

Brown spot is widespread in almost all rice regions in China. It usually occurs at the seedling stage and in some areas causes panicle blight on late rice. Losses from the disease vary with site. Chemicals and rational fertilization are used for control.

Blast is a major rice disease found in almost all rice-growing areas of China. Its occurrence and severity vary with year, site, season, and rice type. It is generally more severe in the mountainous areas than on the plains and more destructive to the second rice crop than to the first, and to japonicas and glutinous types than to indicas. It occurs almost yearly in certain areas because of the complexity of environmental conditions, cultural practices, and varieties, all of which influence blast development.

Blast studies have been conducted for decades and some disease control has been achieved (Chin and Chin 1959, Wang 1961). Studies have focused on variety screening for sources of resistance, breeding for improved resistant varieties, and identification of pathogenic races. In disease control, we have always been guided by the principle of prevention first. This report deals briefly with previous work on blast.

SCREENING VARIETIES FOR SOURCES OF BLAST RESISTANCE

The discovery and use of sources of blast resistance from China's abundant varietal resources have encouraged the breeding and development of new varieties.

Although varietal selection for resistance has been conducted for years in some areas, screening on a national scale began only in the mid-l970s, when national coordinated research was initiated and blast nurseries were established in the rice-growing areas.

Resistance sources

Highly resistant stable varieties that can be used as blast resistance sources for breeding are Hong-jiao-zhan, Jin-wei-ai, Wen-Xuan No. 10, Cai-tang, Fu-bao-ai No. 22, IRl544-238-2-3, IR2061-427-1-17, IR2061-427-1-17-7-5, Toride No. 1, and Nan No. 56 (Zhejiang Academy of Agricultural Sciences, Plant Protection Research Institute 1976-77).

High yielding resistant varieties

In South China the high yielding varieties with blast resistance are Zhen-long No. 13, Wen-xuan No. 10, Zhu-ko No. 2, Hong No. 410, Jin-wei-ai, Zhao-yang No. 18 xuan, Zhai-xie-qing No. 8, Xiang-ai-zao No. 9, Bao-tai-ai, Bao-Xuan No. 2, and Fu-bao-ai No. 22. In North China the high yielding resistant rices are Zhong-xi 7609, Huojiang No. 742, 752, Jing-yin No. 127, and r-71-11-6-1 (Zhejiang Academy of Agricultural Sciences [AAS] Plant Protection Research Institute 1976-77).

Blast and varietal combinations

Our early breeding material comprised breeding lines from local varieties and varieties introduced from abroad. Because it was not always possible to properly identify the parental varieties, the genetic expression of resistance in the progeny varied with the combinations. Some newly bred varieties or lines were discarded soon after farmer release because of inherited susceptibility, others had resistance that lasted for years, and still others were persistently resistant in most rice-growing areas.

Tracing back the genetic sources among the ancestors of varieties developed during the past 30 years, we found that the early indica varieties grown in Zhejiang Province were derived from Nan-te-hao and Ai-zi-zhan, and the late indica varieties in South China came from Chong-shen-zhan and Qiu-bu-liao (Zhejiang AAS, Crop Research Institute 1972, Guangxi AAS 1975). Amng the progeny of those parents, Zhen-long No. 13, from the cross Long-fei No. 313/Zhen-shen 97 (which is a derivative of Ai-zi-shan), and Bao-tai-ai, from the cross Qin-Chang-ai No. 133/ Chung-shen-hong No. 156 (a derivative of Chong-shen-zhan), have shown persistent and stable blast resistance.

Recent blast resistance tests of a large number of entries from different combinations indicate that, regardless of breeding method, it is difficult to gain any blast-resistant progeny if the parents are susceptible. But a high percentage of the progeny of resistant local varieties and resistant varieties from IRRI or Japan are resistant, and their resistance is less variable (Zhejiang AAS, Plant Protection Research Institute 1976-77, Lin and Shen 1978).

PATHOGENIC RACES OF BLAST FUNGUS

Studies on races of *Pyricularia oryzae* in China began in the eaqly 1960s (Yang et al 1959, Wei and Zhang 1962). In recent yeap, such studies have been nationally coordinated. Data from the screening of Chinese differential varieties have been used in national screening tests. The pathogenic races of *P. oryzae* were differentiated on the differential varieties with 476 isolates collected from the different rice areas of China to determine the distribution and prevalence of pathogenic races (National Coordination Group of Pathogenic Races of Rice Blast 1977).

These differential varieties are used for the race studies.

1. Tetep (key variety, Group A): a Vietnamese variety with stable, resistant reaction.

2. Zhen-long No. 13 (key variety, Group B): from Wenchow District Agricultural Research Instiitute, Zhejiang Province; resistant to most isolates.

3. Si-feng 43 (key variety, Group C): developed by the Rice Research Institute, Zhejiang AAS; has different resistance sources and is resistant to northeastern China races.

4. Dong-nong No. 363 (key variety, Group D): a resistant genetic source in the Northeast, released by the Northeast Agricultural College.

5. Kanto No. 51 (key variety, Group E): from Japan, susceptible to some races.

6. He-jiang No. 18 (key variety, Group F): developed by the He-jiang Province Rice Research Institute; susceptible to most races.

7. Li-jiang-xin-tuan-hei-gu (key variety, Group G): local variety grown in Yunnan Province; highly susceptible to almost all races and a good indicator variety for testing viability of isolates.

Two hundred and fifty-seven isolates from 21 provinces were tested on the Chinese differential varieties. The isolates can be categorized into 7 groups with 24 races: CA25, CA29, CA49, CA55, CA57, CA59, CA61, CA63, CB12, CB15, CB17, CB25, CB29, CB31, CC1, CC7, CC13, CC15, CD7, CE1, CE3, CF1, CF2, and CG1. Among the 24 races, race CG1 is widely distributed in 11 provinces, which indicates that it is the dominant race in China. It is followed by races CF1, CE3, and CA57 (National Coordination Group of Pathogenic Races of Rice Blast 1977, Atkins et a1 1967).

INTEGRATED CONTROL

Research on the control of rice blast disease can be summarized into three stages.

1. The *chemical control research stage* began with the application of mercuric fungicides for blast control in the mid-1950s.

2. The *studies on cultural practices for disease control* were undertaken in the late 1950s. Emphasis was on field management, including rational fertilization and scientific irrigation to improve plant health.

3. *Research on integrated control* features the selection

and use of high yielding, resistant varieties and other blast-control measures.

The studies in most areas were initiated in the 1960s. Since the mid-1970s, the relation of disease development to the host-pathogen interactions and the influence of environment have been studied. Use of resistant varieties proved to be the core of control, cultural practices the foundation, and chemical application a complementary measure (Zhejiang AAS 1975). After extensive screening at different sites, improved blast-resistant varieties were identified, and the areas planted to them gradually increased. Such area in Xin-huang County, Hunan Province, for example, expanded from 2,933 ha in 1974 to 8,587 ha in 1977 (76% of the total double-cropped rice area).

Farmers take an active part in the scientific experiments and have themselves established effective control measures. Most of the area in Van-jia, the brigade of Zhen-hai County, Zhejiang Province, was planted to susceptible varieties before 1972 and the crops were seriously damaged by blast each year. In 1972 the brigade established an observational nursery to screen resistant varieties. Farmers adopted the measures of introduction in the first year, multiplication in the second, and popularization in the third. All of the brigade's growing areas in the early 1977 crop were planted to resistant varieties that the farmers developed. The farmers are also responsible for blast control (Zhejiang AAS, Plant Protection Research Institute 1978). They apply chemicals to susceptible or moderately susceptible varieties that cannot be discarded because of their favored agronomic characters. The application of IBP emulsion at the booting and heading stages is considered desirable (Zhejiang AAS 1975).

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RICE BACTERIAL DISEASES IN THE PEOPLE'S REPUBLIC OF CHINA

Wu Shang Zhong

Bacterial blight, bacterial leaf streak, rice brown spot (sheath rot), and brown stripe occur in rice in the People's Republic of China.

Bacterial blight, the most destructive, has become severe because of extensive cultivation of susceptible semidwarf rice varieties and heavy application of nitrogen fertilizers. The major sources of inoculum are diseased seeds, straw, and stubble, and infected tillers that regenerate in the field; and weeds. Their relative importance varies with region. Rice seedlings may be infected through hydathodes and wounds in the leaves, stems, and roots. Disease severity correlates closely with seedling age, bacterium density, varietal susceptibility, and times and duration of seedling submergence.

Three groups of bacterial phages have been identified. The phage technique is used for seed inspection and disease forecasting.

Most foreign rice varieties are highly resistant to bacterial blight across China. Japonicas are generally more resistant than indicas. Because three or four strains of the pathogen exist, the same variety may not show the same reaction in different districts.

Integrated control involves the use of resistant varieties, dapog or dry seedbeds, light application of nitrogen, proper irrigation and drainage, and spraying of recommended bactericides.

Four bacterial diseases of rice occur in the People's Republic of China. Bacterial blight is the most common and most

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destructive, followed by bacterial leaf streak. Rice brown spot (sheath rot) and brown stripe appear sporadically and are less important.

BACTERIAL BLIGHT

Bacterial blight has existed in China for centuries but has become more severe in the past 20 years because of extensive cultivation of high-yielding but susceptible semidwarf rice varieties, and heavy application of nitrogen fertilizers. Bacterial blight has spread rapidly throughout almost all of China, except the Xin Jiang, "Wei-wu-er" Tribal Autonomous Region.

The Chinese rice cropping area may be divided into three: the triple-cropped area, the midseason or double-cropped and mixed culture area (in central China), and the single-cropped area (in North China).

Bacterial blight often infects the triple-cropped area in tropical Hainan, and severely attacks the double-cropped area in South China and the midseason rice in Young-tze District. But in North and Northeast China, bacterial blight occurs only in the rainy season, at the heading stage of rice.

The two main syndromes of bacterial blight in China are leaf blight and kresek. Severe kresek on rice hybrids was reported in 1976-78. The pale yellow syndrome has not yet been encountered in China.

Disease surveys and research were initiated in China in 1954 (Anonymous 1957, 1958). This paper presents some research results on the disease cycle, including the source of inoculum and mode of infection, bacteriophage and phage technique, varietal resistance, pathogenic strains, chemical control, kresek disease, and integrated control of the disease in China.

Source of inoculum and mode of infection

The major sources of inoculum (primary and secondary) are diseased seeds, straw, and stubble; infected young tillers that regenerate in the fields; and wild grasses. As the crop cultural systems, rice varieties, and geographic and climatic factors vary considerably from the south to the north of China, there are different opinions and concepts as to how the disease

is transmitted, and the sources of inoculum. In tropical Hainan, disease infection and transmission through the diseased plants, and regeneration of infected young tillers from diseased stubble left in the field, occur year round. Thus diseased seed and straw, which are important as sources of overwintering bacteria in the temperate zones, are less important in tropical Hainan. Bacterial blight outbreaks in previously nondiseased regions after the introduction of seed from diseased plants lead us to suspect that the disease is transmitted through seeds. Isolation and the phage-technique methods have shown that the bacteria may survive easily on diseased seed and straw, especially in outdoor piles, for 5 to 7 months. The bacterium causing kresek infection is harbored in diseased straw which may survive until the next summer when stored indoors. The bacterium was detected in the straw both by the needle pricking and the submerged seedling methods developed by Jiangsu Agricultural College and the Agricultural Research Station of Liu-Hop County (1974). The bacterial exudate from the diseased stubble of transplanted rice inside the greenhouse may also directly infect the regenerated young shots.

Opinions on infection of weed hosts also differ. There is no evidence that weeds can be infected naturally. Weed infection has only taken place by artificial inoculatrion. Further investigation is in pogress. Experimental results on the mode of infection of rice seedlings indicate that the bacterium may ingress through the hydathodes and wounds in the leaves, stems, and roots (Wu et al 1965, Wu et al 1979a). Experiments in inoculation by the submerged seedling method indicate that the severity af the disease correlates closely with seedling age, bacterium density, varietal susceptibility, and times and duration of seedling submergence. The three-leaf seedling stage is the most susceptible. The ^{32}P labeled tracing method was used to investigate the ingress and rate of movement of the bacterium. Both propagation and moving rate were higher in highly susceptible than in resistant varieties regardless of the inoculation method. From the point of infection the bacterium tends to extend upward. Systemic infection is often observed when the ingressing bacterium passes through the vascular bundle in the midrib by the needle pricking method. Local infection is often observed when the leaf needle pricking or the leaf tip dipping method is used (Wu et al 1979a).

Studies of pathological anatomy have also indicated that the mode of infection determines the resulting systemic or local infection in rice plants. Kresek symptom is usually caused by systemic infection and leaf blight symptoms by local infection (Wu et al 1979a, Hunan Academy of Agricultural Sciences 1978).

Bacteriophage and phage technique

Research on the bacteriophage of *Xanthomonas oryzae* was initiated in 1960. On the basis of morphological, physical or serological characteristics, and host range, three groups of bacterial phages were identified (Table 1) (Jiangsu Agricultural College 1978).

Phage group 1 has a narrow host range and is much more specific; it only infects *Xanthomonas oryzae.* Phage group 2 may attack *X. oryzae, X. oryzicola,* and *X. leersiae.* Phage group 3 attacks not only the above three, but also *X. protypus* (a weak pathogen parasitic on gramineae), *X. juglandis, X. malvacearum, X. nakatae,* and *X. campestris.* Bacteriophage group 1 is only used for practical phage technique work.

The phage technique is used mainly for seed inspection and disease forecasting. It is simple, fast, and accurate for seed inspection and quarantine, and is also used to detect the presence of bacteria in infected straw or other materials (Jiangsu Agricultural College 1978). The accuracy of the method was recently improved by substituting a ferric ion compound for antiserum.

Disease forecasting is also used to detect the bacteria in the irrigation water. If the number of plaques exceeds 500/ml in the early and middle crops, focal points of disease will appear in the field 10 to 15 days later, when conditions are favorable for disease development. A disease outbreak can be expected when the plaque counts exceed l,000/ml (Jiangsu Agricultural College 1978).

Varietal resistance

Cultivated, domestic, and foreign varieties have been screened for resistance to bacterial blight across China. The clipping and needle puncture methods are used for artificial inoculation in greenhouses and fields. Most of the foreign varieties are highly resistant; japonicas are generally more resistant than indicas. The difference in reaction of the same variety in different districts may be explained by the existence of strains. In Guangdong the pathogenicity of 60 bacterial isolates was identified on 46 varieties; bacterial blight resistance was generally classified as broad spectrum, nonbroad spectrum, and no resistance (Wu et al 1979b).

Most of the foreign varieties belong to the first group. Moderately resistant or moderately susceptible varieties classified as nonbroad spectrum included Zhai-Ye-Qing No. 8, Fu-Bao-Ai No. 22, Zao-Jin-Feng No. 5, Qiu-Er-Ai, Er-Bai-Ai,

Table 1. Main characteristics of the 3 bacteriophages of bacterial blight. Jiangsu Agricultural College, 1975.

Phage group	Diameter (mm)	Incubation period (min)	Thermal deathpoint (°C/10min)	Serial neutralization reaction[a]					
				Antiserum 1 treatment		Antiserum 2 treatment		Antiserum 3 treatment	
				Before	After	Before	After	Before	After
1	7-13	80-90	56	25	0	105	95	24	22
2	2-3	210-240	68	114	106	143	0	472	446
3	1-1.2	300-330	76-78	27	25	230	216	13	0

[a] No. of phages: n x 10^7 (individual).

Tong–Pu-Ai, Tetep, and Zenith. In the third group are IR8, Zhen–Shu-Ai, Guang–Liu-Ai No. 4, and Jing–Gong No. 30.

Resistant varieties now grown in China are Nan–Gang No. 11, Nan–Geng No. 15, Hongqi No. 16, Suang–Feng No. 4, 3303, Guang–Er–Ai No. 3, Zao–Jin-Feng No. 5, Zai–Yed-Qing No. 8, and Qiu–Er-Ai.

Resistance sources carrying the *Xa4* gene are generally used in the rice breeding programs. Some promising breeding lines are under selection.

The mechanisms of varietal resistance have been studied. Resistance is correlated with the biochemical constituents of the plant (Fang et al 1963a, 1963b, Ching and Fang 1965). Susceptible varieties generally have higher sugar contents, some free amino acids, and low contents of polyphenols and reduced sugar. The free amino acid contents of the susceptible varieties evidently increase with increased nitrogen fertilizers; their levels are low in resistant varieties.

Pathogenic strain

A network of studies on pathogenic strains has been conducted. Inoculation is by clipping method on a uniform set of differential varieties in both field and greenhouses. The differential varieties include two japonicas and four indicas: IR26, Nan–Geng No. 15 (resistant); Zhai–Ye-Qing No. 8, and Nong–Ken No. 57 (moderately resistant to susceptible); Zhen–Zhu Ai and Jing–Gang No. 30 (susceptible). The test results indicate three or four groups of pathogenic strains. The difference in isolates' pathogenicity is quantitative only, not qualitative.

Chemical control

Many chemicals have been tested for bacterial blight control: mercury, mercuric copper, organic sulfur and arsenic, sulfuric–cyanamide aniline diazole, organic phosphorate compounds, and agricultural antibiotics, including phenagen, F–849, S–258, MD–3, TF–114, TF–128, Chuan–5105, Cellocidin, Agri–Streptomycin, Chloromycin, 7012, oryzemate, 771–20, and SF7402. Diazole compound is most effective but it is not used commercially because it has residual toxicity. Instead, a moderately effective chemical, phenagen, is used. 7012 and Agri–Streptomycin are used in the seed–dip treatment. Considering the importance of bactericides for disease control in seedlings, more work should be done to find new and more effective systemic bactericides.

Kresek disease

Epidemics of kresek disease have broken out in Hainan in recent years as well as in hybrid rice in the middle and late crops in other districts. The main factor that induces serious kresek outbreaks seems to be the planting of highly susceptible hybrid rice.

Tests on the mode of kresek infection in Guangdong indicated that the pathogen may attack the foliage in young seedlings and ingress through wounds and hydathodes (Wu 1978). The occurrence of kresek symptom, late or early, depends on the mode of infection and environmental conditions. Kresek symptoms will appear in the seedbed and rice field. At the 25-30°C range, the pathogen's incubation period for the given ingress point is 6 days through the wounded stem by the needle prick method, 11-17 days through wounded leaves, 25-30 days through water pores or hydathodes and from stems and roots wounded during pulling. Plants with kresek are detected in nature 14 days after seedling submergence in contaminated water. Kresek and leaf blight symptoms are observed individually or simultaneously on the same plants whether artificially inoculated or in nature. In the winter and spring in Hainan, leaf blight symptoms usually occur in the field 30 days after the kresek symptoms appear, and then spread as leaf blight severely at the heading stage. In the middle and late crops, both symptoms often simultaneously occur in the tillering and the booting stage. Kresek can also be seen at the heading stage of spring rice when highly susceptible varieties are flooded or have excess nitrogen. Kresek is not observed at lower temperatures during the early spring sowing and tillering stage because low temperature is unfavorable to bacterial growth. Varietal differences in kresek resistance and strain virulence are conspicuous as are differences in the virulence of kresek strains. Application of effective systemic bactericides, accompanied by proper water management, gives good control in seedbeds. Some disease-resistant hybrid rices such as San-Yue 6, Wei-Yue 6, and Nan-Yue 6 that retard kresek have been released.

Integrated control measures should be used because of the complex nature of the source of inoculum, its mode of infection, varietal differences, cropping systems, and cultural practices used.

The main points of integrated control are: planting resistant varieties, using dapog or dry types of seedbed to reduce primary inoculum in the seedlings, not using excess nitrogen, proper manipulation of irrigation and drainage (especially to drain off irrigation water at the booting stage), and finally, spraying a recommended bactericide. Plant quarantine should be undertaken to protect districts unaffected by the disease.

The two main thrusts for future research are breeding resistant varieties and screening new systemic bactericides..

RICE BACTERIAL LEAF STREAK

Bacterial leaf streak was one of the most serious rice diseases in Guangdong, Guang Xi, Si Chuan, Jie Jaing, and Fujian Provinces from 1950 to 1960. It is now the second most important bacterial disease. The disease was first discovered in Guangdong and a detailed study has been made on its infection cycle and control measures (Fang et al 1957; Faan and Wu 1965a, 1965b). Fang et al (1957) distinguished bacterial leaf streak from bacterial leaf blight and identified the organism as *Xanthomonas oryzicola.*

The source of inoculums of bacterial leaf streak is seed of the diseased plant and straw. Seed transmission of the disease was identified by the artificial inoculation method with bacterial suspension spraying during the flowering stage. Quang Dong proved that bacteria might remain latent by the reisolation method inside the tissue of the kernel and the embryo might be an overwintering host (Faan and Wu 1965b).

BACTERIAL BROWN SPOT

Bacterial brown spot is the same as the bacterial leaf spot (sheath rot) reported by Klement in Hungary. The bacterium is *Pseudomonas oryzicola* Klement. The disease was first reported in Eastern and Northeastern China and was later reported in Zhe Jiang Province. It attacks the leaves, sheaths, stems, nodes, panicles, and seeds, and even kills tillers. The bacterium attacks both wetland and dryland rice, wheat, millet, sorghum, and more than 30 species of gramineae wild grass (Wu and Pai 1960, Wu and Tsao 1962, Wu 1963).

BACTERIAL BROWN STRIPE

Bacterial brown stripe occurs in the seedling or tillering stage of the early and late-season crop and the single middle crop in Central and South China. It often spreads rapidly after heavy rains in the lowlands near the banks of rivers and streams, and in waterlogged areas in valleys. The pathogen was identified as *Pseudomonas panici* Stapp (Fang, personal communication). The disease starts from the junction of the lower part of the leaf sheath where water-soaked, dark-green longitudinal stripes are formed, and finally turn light brown or brownish black. Heavy damage to the young unfolding leaves results in bud rot, or the so-called *heart rot,* whose foul odor pervades

the field. Prolonged flooding causes heavy damage from plant stunting or seedling death. Spraying with chemicals and flood prevention are the current control measures.

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A REVIEW OF RICE VIRUS DISEASE STUDIES IN CHINA

Chen Sheng-Xiang

Rice yellow dwarf, rice dwarf, rice yellow stunt, rice black-streaked dwarf, rice stripe, dwarf-like diseases, rice transitory yellowing, and grassy stunt have been reported in China.

Research on rice virus diseases started in the 1960s. Studies on rice yellow stunt gave information on the nature of the virus causal agent, the vector insect and host range, symptoms and nature of disease development, sources of varietal resistance, and control measures including an antiserum for the virus. The rice yellow stunt virus, which is widespread on the mainland, is apparently identical to transitory yellowing reported in Taiwan.

Extensive investigations have led to recomendations for effective and practical control of virus diseases, such as elimination of vector insects and consideration of their threshold population, changes in the cropping system, use of resistant varieties, improved cultural techniques, and appropriate management of fertilizer and water.

The virus and virus-like diseases of rice that have been recorded in China are rice yellow dwarf, rice dwarf, rice yellow stunt, rice black-streaked dwarf, rice stripe, dwarf-like diseases, rice transitory yellowing, and grassy stunt.

The first recorded rice virus disease was yellow dwarf, observed in Taiwan Province in 1924. The disease became a large-scale problem in 1932. In 1967 it prevailed on the Wen-Wang plain, Zhejiang Province.

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Rice dwarf was first noted in 1939 (Zhou 1941). In 1957, Wei Jing-chao reported the disease in Zhejiang and Jiangsu Provinces. It became severe in the late 1960s and was widespread in the Yangtze Valley from the early to mid-1970s.

The earliest record of rice yellow stunt was in late 1950. The disease later prevailed in southern Yunnan, Guangxi, and Guangdong Provinces. Along with rice dwarf, it appeared along the middle and lower catchments of the Yangtze River from 1970 to 1975.

Rice black-streaked dwarf and rice stripe were first reported in 1963 (Zhu et al 1964) in Zhejiang and Jiangsu Provinces. They broke out in East China in l965. Rice stripe has sporadically damaged crops in North China since 1970.

Dwarf-like diseases were reported in Fujian Province in 1978 (Chen et al 1978). Rice transitory yellowing and grassy stunt diseases have been reported in Taiwan.

RESEARCH ON VIRUS DISEASES

Research on rice virus diseases in mainland China began in the 1960s. Studies on rice yellow stunt were initiated at the agricultural research institutes of Xi-shunag-Ban-Nain and Si-Mao Districts. Fan Huai-zhong in 1965 (Fan et al 1965) suggested that the virus was primarily transmitted by *Nephotettix nigropictus.* The disease development was ascertained and control methods were successfully developed by scientists at the Zhejiang Academy of Agricultural Sciences (AAS) from 1968 to 1972 (Zhejiang AAS 1972, 1973). After 1972 further studies in rice yellow stunt control, the nature of the virus causal agent, and sources of varietal resistance were undertaken by scientists involved in the national coordination of rice virus research.

In 1976 the rice yellow stunt pathogen was identified and the virus particles were shown to be bullet shaped (Acad. Sin. 1978b, Fu-Tan Univ. 1966). A tentative antiserum to the virus was obtained (Zhejiang Univ. Agric. 1978). Of the varieties screened, Be Lou Ai and IR29 seem resistant. Those varieties have been distributed and adopted in disease-prone areas of southern Yunnan.

Cooperators from eastern China studied rice black-streaked dwarf and rice stripe from 1964 to 1966, under the regional coordination of the rice and wheat virus disease researchers Professars Wang Min-jie and associates. On the basis of disease symptoms, the vector insect, and the shape of virus particles,

the two diseases were recognized as identical to the virus reported in Japan (Zhu et al 1964, Acad. Sin. 1974). Disease studies were continued by researchers at the Zhejiang AAS and the Shanghai AAS, as well as by other workers (Zhejiang AAS 1977).

The nature of rice yellow dwarf disease development and control measures were ascertained in 1967-68 at the Zhejiang AAS, with the cooperation of the Agricultural Bureau of Zhejiang Province (Zhejiang AAS 1977). The vector insect, host range, and development characteristics were discovered and control measures established.

Research on rice dwarf was initiated by cooperators in Zhejiang Province from 1968 to 1972 and was continued by a national group that coordinates rice virus research. Disease development was traced, control methods were established (Zhejiang AAS 1977), and a high-titer antiserum to the virus was prepared. Meanwhile, a method that uses blood and carbon aggregation to effectively examine the viruliferous rate of insects was developed (Acad. Sin. 1978a, Zhejiang AAS 1978).

Research to forecast the incidence of rice yellow stunt and rice dwarf, and to screen for varieties resistant to them has recently been emphasized. Simultaneously, we have attempted to diagnose and identify new virus diseases. In disease forecasting, the populations of viruliferous vector insects in the first crop directly influence disease severity in the second crop. Studies of the interactions of factors related to disease development are under way. Varietal improvement has been confined to the screening and use of resistant varieties; not much hybridization to develop virus-resistant varieties has been done.

Furthermore, disease symptoms, vectors, transmission passages, and virus particle shapes indicate that rice yellow stunt, which was found in Mainland China, is similar to rice transitory yellowing disease, reported in Taiwan (Su 1969, Chen and Shikata 1971). Further studies are needed to confirm that the diseases are identical.

RICE YELLOW STUNT

Rice yellow stunt virus has recently become important and widespread in China. It causes 20-30% yield losses in areas where it prevails.

Symptoms

The main symptoms of yellow stunt are yellowing of the second and third youngest leaves and a mottling stripe along the leaf

interveinal area. Later, the diseased leaves form a wide angle from the stem.

Numerous bullet-shaped virus particles were observed from ultrathin sections of infected leaf cells through electron microscopy. The virus particles were 150-180 mm long and 70-90 nm wide, with a wall thickness of 20-25 nm. Many were between the inner and outer nucleus membranes, and many were distributed in both the cytoplasm and the nucleus. Partially purified virus preparations from infected plants show that most virus particles 100-140 x 80-120 nm in dimension were also bullet-shaped, with hollow centers 40-50 run in diameter and 6-11 nm in depth.

Observations of the crude extracts of freshly infected leaves indicated that the virus particles had thick walls with projecting edges and hollow centers. Some masses of 5 to 10 virus particles were coated with membranes.

Vectors and disease transmission

Yellow stunt can be transmitted by only three species of green leafhoppers; it cannot be transmitted by seed, soil, or any other means. In the middle and lower catchments of the Yangtze River the primary yellow stunt vector is *Nephotettix cincticeps;* in South China, the vectors are *N. nigropictus* and *N. virescens.* There has been no evidence that *Recilia dorsalis, Nilaparvata lugens, Laodelphax striatellus,* or *Sogatella furcifera* are vectors of the virus.

The yellow stunt virus is persistent in the vector without transovarial passage. Its incubation period in *N. cincticeps* is 7 to 39 days, and correlates negatively with temperature. For example, when the mean day temperature in Hangzhow was 22.2°C, the incubation period averaged 31.5 days. As the temperature rose to 30.3°C, the incubation period dropped to 13.2 days. The shortest acquisition feeding period is 10 minutes (5 min for *N. nigropictus*).

The proportion of active transmitters ranges from 17 to 50%. The earliest initial transmission occurs at the 4th nymphal stage. In most individuals, transmission occurs at the adult stage; the latest transmission time is from 4 days (30°C mean day temp) to 13 days (at 22°C) after emergence. An experiment on daily serial transmission showed that infectivity is usually intermittent. The number of effective-transmission days ranged from 23.6 to 45.4%. Temperatures higher than 14°C allow the overwintering generation of the vector insects to transmit the virus. Under artificial conditions, however, infection can be induced at

temperatures lower than 6.7°C (4-9°C) in 3 days. Each green leafhopper can simultaneously acquire and transmit two of the diseases rice dwarf, yellow stunt, and yellow dwarf. The diseases with shorter incubation periods are usually acquired and transmitted first. *Oryza sativa* is the only yellow stunk host discovered. The rice crop's reaction to the disease varies with growth stage and environmental conditions. When the variety Ai Geo Nan Dai was infected at the 3-, 5-, 7-, and 9-leaf stages under the same environmental conditions, the virus' latent period was 18.2, 20.7, 24, and 24.3 days, respectively. The latent period varied from 11 to 54 days, but was shorter with higher air temperature. The negative correlation (r = 0.983, p = 0.01) between the latent period and air temperature was formulated on Ai Geo Nan Dai infected at the 2- to 3-leaf stages.

The latent period is also related to the characters of the rice varieties. Under identical conditions of infection, the latent period was 12.5 days in Quan Luo Ai No. 4, and 18.5 days in Bu Luo Ai. Host susceptibility also varies with cultivar and growth stages. Inoculation of seedlings at the 2- to 3-leaf stages and under similar natural conditions indicated that disease incidence ranged from 57.l% to 89.5% on varieties Quan Luo Ai No. 4, Nonken 58, and Dai Bai Nuo, but was less than 5% on Bu Luo Ai, Shui hun, and Hong Oing Ai No. 1. A test to determine disease resistance at various growth stages of Ai Geo Nan Dai gave these results: 16.7% at the 3-leaf stage, 24% at the 5-leaf, 33.3% at the 7-leaf, and 11.5% at the 9-leaf. The most susceptible growth stage is from full to late tillering. Infection is reduced remarkably after the elongation stage.

The effect of yellow stunt on plant growth is determined by cultural practice and the susceptible growth stages. The recovery rate of the diseased plants is as high as 26-38% in the early indica variety Quan Luo Ai No. 4 when grown as the first crop. But if that variety is grown as the second crop, few diseased plants can recover; those that recover produce no ears. The recovery rate of diseased plants of Quan Luo Ai No. 4 increases if the susceptible growth stage is delayed. The plants infected at the seedling, tillering, and elongation stages had 8.6%, 10%, and 38.1% recovery, respectively.

The yield loss from infected crops differs in the susceptible growth stages. Infection before the tillering stage causes 74-100% yield loss; infection at tillering, 20 to 58% loss; at late tillering, 10 to 20%; and at elongation and booting stages, less than 10%.

Infection cycle

The yellow stunt virus overwinters in the vector insect in the rice-growing areas of the Yangtze River's middle and lower catchments. In South China, it survives on ratoon or volunteer rice and on winter rice. The first infection caused by the overwintering adult vector insect on the early rice crop becomes the primary source of infection. The two to three generations of vector insects acquire the yellow stunt virus from the diseased plants of the early crop and migrate from the early crop -- after its harvest -- to the late crop. The nymphs of five to six generations of insects acquire the virus from the infected late rice crop and migrate to weeds in the field to overwinter. Because the virus is not transovarial, the latent and incubation periods are relatively long. Repeated infection is, therefore, not important along the Yangtze River.

The correlation between field disease incidence and the number of vector insects that migrate to the field before tillering is positive. Disease incidence on late rice is usually higher than that on early rice because the migration of vector populations is greater at the tillering stage.

VIRUS DISEASE CONTROL

Effective and practical virus disease control measures have been formulated from extensive investigations. The elimination of vector insects is most important.

Cultural measures

Changes in the cropping system are recommended for disease-prone areas. In areas where rice black-streaked dwarf prevails, the winter crops wheat and barley (alternative hosts of the virus) are replaced with other crops such as rape or broad beans.

To control insect immigration, crops with the same growth duration are planted in adjacent fields.

The use of resistant varieties is considered the most effective and economical control measure. Yellow stunt has been successfully controlled since the resistant varieties Bai Kuo Ain and Bo Lu Ain became popular in southern Yunnan Province.

Improved cultural techniques can make the natural conditions favorable for plant growth and suppressive of the development of vector insects. Fields grown with green manure are usually plowed over before the insects migrate; the shorter the plowing period,

the better the insect control. Other desirable control measures include planting of resistant varieties before susceptible ones; beginning the harvest of early rice in the nearest fields with green seedlings, and continuing the harvest in a direction away from those fields; and cleaning weeds from the ridges and adjacent areas.

Good fertilizer and water management is advisable to stimulate early tillering and elongation, which can compensate for the disease-damaged seedlings, and to help diseased plants recover.

Disease prevention by vector control

To control virus diseases by eliminating their vectors, it is important to determine the proper time for initiating control measures in the fields and to know which insect population should be controlled. Virus diseases transmitted by the green leafhopper can be controlled during the 2 weeks after the late crop is transplanted in double-cropped areas. Virus diseases transmitted by the small brown planthopper can be controlled by eliminating the insects at the late nursery stage or before tillering in the single-cropped areas, and a few days after transplanting in the double-cropped areas. Because rice black-streaked dwarf and rice stripe can infect wheat, control measures should be applied at harvest of the late rice crop.

The threshold population of the insect to be controlled is critical. Repeated field and screenhouse experiments give the threshold for insect control at the initial growing period of late rice: if one wishes to reduce the percentage of diseased plants below 1, 3, or 5%, insects with a viruliferous rate of 2.5% should be controlled when they number 5, 10, or 16/100 seedlings, respectively. When the viruliferous rate is 5%, control should be applied when the insects number 2, 5, or 7/100 seedlings.

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STUDIES ON RICE DISEASES

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Rice diseases are caused by viruses, bacteria, fungi, and nematodes. Some are major biological constraints to rice production. The knowledge of rice diseases accumulated by investigators in various parts of the world has led to their control by three fundamental measures -- use of resistant varieties, chemical control, and field sanitation or manipulation of cultural practices. Integrated control of rice diseases can best be achieved through use of resistant varieties and of schemes based on knowledge of epidemiology for attacking or avoiding pathogens and their vectors at as many vulnerable points as possible. Such aspects as genetics and mechanism of resistance, variability and distribution of pathogen, criteria and methods of disease forecasting, and effectiveness and schedule of chemical application require extensive and collaborative study by more rice pathologists. More effective means of controlling rice diseases must be found if rice production is to increase and keep pace with the world's population growth.

Control measures and rice disease epidemiology are discussed.

Rice is an ancient grain, but the earliest record of a rice disease can be traced back only to Soong's *Utilization of Natural Resources* published in 1637 (Ou 1972). Rice is cultivated annually on 135 million ha in about 109 countries and territories, but an available list (Mao 1968) cites only 235 stations and institutions in 44 countries and territories devoted to the improvement of the crop (the list was neither complete nor up to date). Rice, the annual production of which is about 320 million t, is the staple food of about half of the world's population, but only a few thousand scientists (1,133 scientists included in the *World List of Rice Workers* by Mao 1968) study its various

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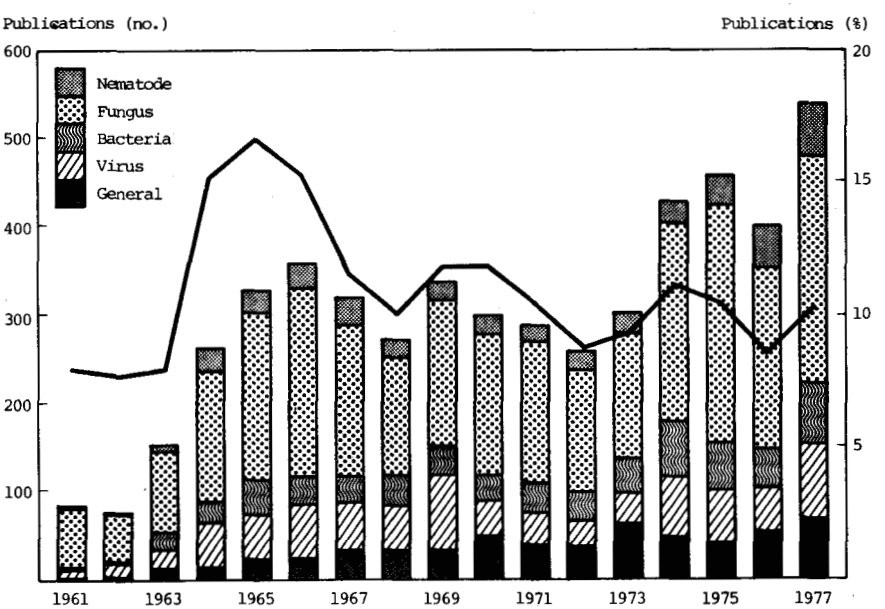
aspects. More attention should be given to rice studies because increasing rice production is essential to keep pace with the world's population growth.

One major biological constraint to rice production is rice diseases. Although there are no precise figures to illustrate the economic importance of diseases -- the incidence varies among locations annually -- an estimate of 10 to 15% average rice losses due to diseases is probably not exaggerated.

A profitable way to increase rice production is to reduce disease incidence. The methods used must be developed through detailed study by researchers. Of the estimated 12,000 plant pathologists in the world, only 1 to 2% devote studies to rice diseases; most are in Japan. Of rice scientists, about 10% study rice diseases. Articles on rice diseases contributed by rice pathologists were about 10% of the annual rice literature during the last 17 years (IRRI 1965a, 1965b, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, [1977], 1978) (Fig. 1). The main objective of studies on rice diseases is to find effective measures to minimize rice yield losses by disease control.



1. *Number (bars) and percentage (line) of publications on rice diseases that appeared in the International Bibliography of Rice Research (IRRI 1965a, 1965b, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, [1977], 19781.*

Rice diseases are caused by viruses, bacteria, fungi, and nematodes. Under the electron microscope mycoplasma – likebodies have been observed in association with rice diseases such as yellow dwarf. The causal relationship between the mycoplasma and the disease is still being investigated to fulfill Koch's postulates. The term *virus-like diseases* is, therefore, tentatively used to include such diseases.

Determination of the exact number of rice diseases in the world is difficult because of the uncertain nature of some and misidentification of others. However, 15 virus and virus – like diseases (Ling 1979), 10 bacterial diseases (Goto 1979, Hashioka 1969, Ou 1972), and 45 fungus diseases (Hara 1959, Ou 1972, Phytopathological Society of Japan 1975, Wei 1975) are well characterized. The late Dr. Wei, my former major professor, listed 28 species of Phycomycetes, 50 of Ascomycetes, 7 of Basidiomycetes, and 144 of Fungi Imperfecti in his *Manual of Rice Pathogens* (1975). Six nematode diseases are caused by 32 species of nematodes (Birchfield et al 1978, Ou 1972). More than 50% of the articles on rice diseases deal with fungus diseases (Fig. 1).

Rice diseases vary in economic importance. Some are distributed worldwide, others are localized. The major ones, which often cause great yield losses, are rice blast *Pyricularia oryzae* Cavara, sheath blight *Thanatephorus cucumeris* (Frank) Donk., bacterial blight *Xanthomonas oryzae* (Uyeda et Ishiyama) Dowson, and virus diseases. Among the virus diseases, tungro is the mst important in South and Southeast Asia.

Three fundamental control measures for rice diseases are applicable: use of resistant varieties, chemical control, and field sanitation or the manipulation of cultural practices. Even with the availability of resistant varieties the battle with rice diseases continues because new diseases may appear; new races, pathotypes, or strains of pathogens may attack the resistant varieties; changes in cultural practice may enhance disease incidence; and other problems may occur in the future.

RESISTANCE TO DISEASES

During the past decades, the use of resistant varieties to control rice diseases has been emphasized because it is the simplest, most effective, and least expensive measure for rice growers. To develop resistant varieties we first develop a screening and testing method to evaluate varietal resistance to the disease. Methods for evaluating varietal resistance to major rice diseases by natural infection in the field, or by artificial inoculation in the field or in the greenhouse, have

been developed and improved (Jennings et al 1979). Their use depends on the nature of the pathogen and the development of the disease. Each of the several methods of testing resistance to a disease has its advantages and disadvantages. The fundamental criteria for evaluating a method are accuracy and consistency of the results, and capacity and efficiency of the testing.

Varietal resistance to blast, sheath blight, and tungro have been tested annually in international nurseries by collaborators across the world. International scales for evaluation of resistance to most rice diseases have been standardized through the *Standard Evaluation System* (SES) for Rice (IRRI 1979).

Sources of resistance to rice diseases have been identified through varietal screening and testing by various investigators in different parts of the world (Ou 1977). The only variation among the diseases is in the number of resistance sources identified – more for some diseases and less or none for others. In the case of virus diseases transmitted by vector insects, a variety can be resistant to both the virus and the vector, or to either. When a viruliferous insect does not prefer to feed on a variety, inoculation access time for each plant is short because the insect becomes restless and moves more frequently among the plants. When the time is not long enough, the plant may not become infected or may have less virus infection (Ling and Carbonell 1975). The resistance of a variety that has less virus infection due to its resistance to the vector insect often does not last long because the insect can develop *adaptation* to the variety.

Rice breeders have tried combining most of the genes for resistance to diseases in the newly developed varieties in various parts of the world. Some have been successful, others have not. The most unusual case, perhaps, was transferring a gene for grassy stunt resistance from the wild rice *Oryza nivara* to cultivated varieties of *O. sativa* (Khush et al 1977). Perhaps it is also one of the most successful cases in controlling rice diseases through resistance because the increases in cultivated hectarage of the newly developed resistant varieties since 1974 have reduced the incidence of grassy stunt disease to a negligible level in the Philippines.

Two drawbacks of controlling rice disease through varietal resistance are the difficulty of combining genes from some resistance sources, particularly between cross–sterile materials, and the breakdown of varietal resistance due to the appearance of new races, pathotypes, or strains of pathogens. Besides,

variation in varietal resistance to a disease among locations or regions has been encountered. The variation may be due to either differences in pathogenicity or virulence of the pathogen, or differences in environmental conditions. The problem can best be solved by collaborative investigation among locations or regions to determine the pathogen's variation and distribution.

CHEMICAL CONTROL

Chemicals that are known to be effective for rice disease control have been applied extensively in some countries in the form of dust, emulsion, granule, or fumigant. Organomercury compounds, organophosphorus compounds, organochlorine compounds, and antibiotics (e.g., Blasticidin S and Kasugamycin) are effective in controlling rice blast. Organoarsine compounds (e.g., iron methanearsonate) and antibiotics (e.g., polyoxin and validamycin) are effective in controlling sheath blight. Organonickel compounds and phenazin, although inferior in effectiveness, are used to control bacterial blight (Yamaguchi 1976). Although no viricide is yet available, some chemicals are applied to control vector insects and reduce the spread of viruses. Organophosphates (e.g. malathion), carbaryl and several other carbamates, phenyl-substituted carbamates (e.g. Bassa and Tsumacide), pyridaphenthion (Ofunack) and propaphos (Kayaphos) are effective in controlling leafhoppers and planthoppers (Iwata 1976). Often, however, the insects develop resistance to the insecticide after it has been applied for wme time. Systemic insecticides may not completely protect a rice crop from virus infection -- although they reduce disease incidence in the crop -- because the time they need to kill a viruliferous leafhopper feeding on a treated rice plant is often longer than that required by the insect to introduce the virus into the plant.

Two application schedules of chemicals for disease control are known. One is *prophylactic:* the chemicals are applied in a predetermined schedule according to the crop's growth stages, or on specific dates. The other is *remedial:* The chemicals are applied whenever the crop needs them, hence the schedule is irregular. The latter has its advantages, particularly in view of production costs, but it requires epidemiological knowledge to determine when chemical application is essential.

EPIDEMIOLOGY OF RICE DISEASES

Epidemiology is the science that deals with the incidence of disease in a population, particularly with the factors that affect the outbreak and spread of the disease. Epidemiological studies seek to 1) forecast the disease, particularly its

outbreak, 2) predict yield losses, and 3) recommend control measures. Available epidemiological data on rice diseases follow:

Rice blast

Kiyosawa (1972) analyzed the data on the cumulative spore number of *P. oryzae* at Toyoshima, Japan, from 1938 to 1949, and proposed a method of forecasting blast incidence by using the equation $Y = Y_0 e^{rt}$, where Y is the total number of lesions or cumulative spores, Y_o is the number of lesions at the initial time of infection, r is the disease increase or daily infection rate, and t is time. The equation is fundamentally identical with $X = X_0 e^{rt}$ given by van der Plank (1963), where X is the amount of accumulated disease at time t, X_o is the initial amount of disease (the amount at zero t), e is 2.718, r is the average infection rate, and t is the time during which infection occurs. Later, a study on the relation of the occurrence of blast disease to the number of spores adrift in the air and to the meteorological conditions revealed that the number of spores trapped during a certain period could help predict disease abundance (Hori et al 1976). The physiological aspect of susceptibility to blast infection was also studied and was integrated into the procedure for forecasting blast.

El Refaei (1977) studied rice blast with emphasis on environmental conditions. He suggested that the number of blast lesions per seedling (Y) may be predicted by using either $\hat{Y} = 0.1948e^{0.413D}$ when spores are less than 250/28 liters of air, $\hat{Y} = 0.9787e^{0.318D}$ when spores are equal to or greater than 250/28 liters of air, or $\hat{Y} = 2.9 - 0.945D - 0.0098S + 0.152D^2 + 0.004DS - 0.00000008D^2S^2$, where D is dew period or period of leaf wetness in hours and S is concentration of spores per 28 liters of air.

Bacterial blight

Mizukami and Wakimoto (1969) described several methods of forecasting bacterial blight: studying early disease development, observing climatic conditions, and periodically examining the population of the pathogenic bacteria or phages in the plant or in irrigation water. None of those methods are completely satisfactory at present.

Rice dwarf

In a study of rice dwarf in Japan, Nakasuji and Kiritani (1977) suggested that the percentage of infected rice hills (I) can be estimated by $I = 0.113 \log N P + 0.491$, where N is the number of adult insects of *Nephotettix cincticeps* per hill, and P is

0.6 × the percentage of infective insects among the vector population of the overwintering generation determined either by the serological method or by feeding tests.

Rice tungro

Ling (1974) suggested two approaches for investigating the epidemiology of rice tungro disease -- experimental and field (previously known as statistical). A cage method for study of the experimental epidemiology of rice tungro disease was developed (Ling 1974). Ling (1975b) considered the *vector insect* as an independent factor rather than as part of the environment in the disease triangle (host, pathogen, and environment) when the disease incidence in a population is studied. Consequently, tungro incidence is a function of 1) population and activity of the vector insect, 2) quantity and quality of the virus source, 3) susceptibility of the rice variety to the vector and to the virus, 4) biotic and abiotic environmental conditions, and 5) time. The effects of vector insect and virus source on tungro incidence in terms of percentage of infected seedlings were determined by the cage method (Ling 1975a, 1975b). The information serves as foundation in the study of the field epidemiology of tungro.

The field epidemiology of tungro has been studied in 37 farmers' fields in Luzon, Philippines, since 1973. Because the susceptibility of the rice plant to tungro infection decreases with increasing plant age (Ling and Palomar 1966), emphasis was on the early stages of plant growth. The tungro incidence from June to October (the wet-season rice crop) seemed to be correlated with the number of tungro vectors and the percentage of infective insects from April to June (before or at the beginning of the wet-season crop) (Table 1).

Forecasting the outbreak or the exact incidence of tungro disease is difficult. There are two kinds of predictions -- positive and negative. Positive prediction indicates a disease outbreak in the near future; negative prediction indicates no outbreak or very low disease incidence. The former is complicated because an outbreak needs the presence of all factors required for increasing disease incidence. It involves guessing about the unpredictable weather and speculating about incoming uncontrollable factors that favor increasing disease incidence. On the other hand, negative prediction is simple and reliable; if any one of the factors required for increasing disease incidence is absent, inadequate, or unfavorable, the disease cannot flourish hence, no outbreak can occur. The distinct dry season in Luzon limits the population of vector insects. The vector population from April to June determines

Table 1. Tungro vectors [a] in study fields in Luzon, Philippines, from April to June, and incidence of rice tungro disease in paddy fields in Luzon from June to October.

Year	Tungro vectors (Apr – Jun)				Tungro incidence (Jun – Oct)		
	Collection (no.)	No./10 sweeps	Tested (no.)	Infective (%)	Observations (no.)	Infected fields (%)	Incidence (%)
1973	68	5.8	1028	0	151	1 [b]	0.60
1974	166	11.0	2425	1.77	244	45 [c]	2.38 [c]
1975	181	9.8	3319	0.69	234	72	3.32
1976	149	3.9	2244	0.18	267	25	0.33
1977	172	3.0	1578	0	253	15	0.03
1978	170	2.3	1844	0	241	0	0

[a] The vectors are *Nephotettix virescens, N. nigropictus,* and *Recilia dorsalis.*

[b] Excludes rice fields with only a few tungro – infectedplants. [c] The Philippine Government launched a green leafhopper program in the area in July and August.

the vector population in the early stages of rice growth in Luzon. If none or 1 to 2 insects/20 sweeps are observed in the early stages of rice growth, the insects will not be able to build up to a population large enough to cause tungro outbreak in the wet-season crop. Because tungro virus is categorized in the transitory group (Ling and Tiongco 1979b), the virus source is essential to maintain insect infectivity. A survey of infected plants and tests of insect infectivity are used to determine virus sources in the field. If both the infection of regenerated growth and volunteer plants, and the percentage of infective insects are extremely low during the early stages of plant growth, no tungro outbreak can occur. To summarize, vector insect population, virus source, and insects' infectivity are used for negative prediction of tungro outbreaks (Ling and Tiongco 1979a).

FIELD SANITATION AND CULTURAL PRACTICES

Sanitary measures, e.g. roguing diseased plants, eradicating alternate and overwintering hosts, and using pathogen-free seeds, are aimed at reducing pathogens in the field. Such cultural practices as crop rotation, selection of proper site for seedbed, timing of sowing or planting, and regulation of water and fertilizer are intended to protect the crop from infection or to minimize disease incidence. These measures can be applied principally for disease control. They are not, however, intensively studied nor adopted widely by rice growers.

Changes in cultural practices may initiate new disease problems. For instance, seedlings for mechanical transplanting are grown in seedboxes. Because the seed are sown thickly in the seedboxes (200-250 g/60- x 30- x 3-cm seedbox), seedling blight, caused by pathogens belonging to 8 genera of fungi and bacteria, may become a major problem, as it has in Japan (Yamaguchi 1976, Ohata et al 1978).

CONCLUSION

Information on rice diseases has been accumulated by investigators in various parts of the world. But many aspects -- genetics and mechanism of resistance, variability and distribution of pathogens, criteria and methods of disease forecasting, and effectiveness and schedule of chemical application -- still need thorough study. Rice pathology requires further development in terms of increased and improved manpower, sharing and exchange of information, and intensive and collaborative studies to meet the challenge of rice diseases. Integrated control of rice diseases can best be

achieved by the use of resistant varieties and a knowledge of epidemiology in devising schemes for eliminating or avoiding the pathogens and their vectors at as many vulnerable points as possible.

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THE BROWN PLANTHOPPER AND ITS CONTROL IN CHINA

Tu Cheng-Wen

Incidence of the brown planthopper (BPH) has gradually increased in China during the last decade because of the extensive double-cropping system. The BPH in China thrives in several regions extending north to the Great Wall. The regions form three belts delineated by characteristic temperature and rainfall patterns: the belt of year-round development, the dormant winter belt, and the immigrant multiplication belt. The number of BPH generations is highest in the first belt (10-ll/year) and lowest in the third (2-5 generations/year). The BPH generally does not over-winter north of 25°N latitude. In addition to climate, factors such as cultural conditions, varieties, time of immigration, and number of immigrant population affect the level of damage after 1-2 generations in each area. In 1979 a national organization to coordinate investigations and to forecast BPH migration was formed. The BPH are carried northward from March-July and southward after August. Current practices for BPH control are application of chemicals before pest outbreaks, planting of resistant varieties, and use of natural enemies of the pest.

Twenty-two species of planthoppers have been identified in China; the most important are *Nilaparvata lugens* Stal, *Sogatella furcifera* Horvath, and *Laodelphax striatella* (Fallen). Incidence of the rice brown plant-hopper *N. lugens* gradually increased during the last decade. Damage has been serious, particularly because rice cropping systems have changed from a single- to a double- or multiple-crop system and from interplanting to successive planting.

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REGIONAL DISTRIBUTION

The brown planthopper (BPH) is distributed as far north as the Great Wall, and is occasionally found in Pan-shan County, Liaorning Province, Yia-an County, and Szechuan Province (Fig. 1). It is also common in the southern Hai Ho River and is quite destructive in the southern Yangtze River area.

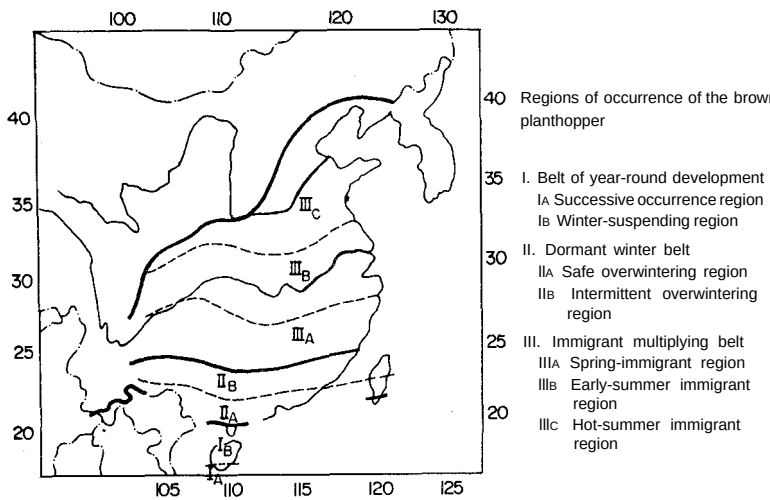
To thrive, the BPH requires at least 15 days with mean day temperature of 10°C or higher. The area of distribution can be divided into three belts, consisting of seven regions.

The belt of year-round development

The areas in which BPH develop throughout the year are located mainly between 17° and 22° north. The average yearly temperatures range from 22° to 26°C; rainfall averages 1,500 to 2,000 mm/year. Rice grown in this belt throughout the year assures the BPH of a constant food supply.

The belt has two subregions:

- In the *successive-occurrence region,* the climate is warm and frost-free throughout the year and the BPH develop 10 or 11 generations/year in multiple population peaks. The area includes Yia County and Ling Suei County in southern Hainan Island, Kwangtung Province.



1. *Regions in China where the brown planthopper occurs.*

- In the *winter-suspending region,* 9 or 10 generations/year develop in multiple-population peaks. The subregion comprises central and northern Hainan Island, Lueichou Peninsula, and Mongla, Chinghung, and Mekuo Counties, Yuanjiang Valley, and southern Yunnan Province. In those regions the lowest 10-day temperature is from 15° to 18°C, and in some years the mean day temperatures are lower than 15°C.

The dormant-winter belt

The dormant winter belt lies between 22° and 25° north, covering southern Fuchien and Yunnan Provinces and the catchment of the Pearl River. The winter is short, and the summer long and hot, with abundant rainfall. The mean yearly temperature is from 18° to 22°C, and rainfall varies from 1,100 to 2,700 mm/year. Two rice crops per year are normally grown. BPH overwinter on ratoon and on volunteer rices (less of which is found in the north). They develop 6-8 generations/year, and damage all the summer and autumn rice crops. The infestation, however, varies with year and location. The two subregions of the belt are:

- The *safe-overwintering region,* which includes southern Kwangtung, Kuangsi, and Yunnan Provinces. The lowest 10-day mean temperature in the subregion is about 13°C. Two crops of rice per year are grown and 6 to 7 BPH generations/year develop. The BPH overwinters on the ratoon and volunteer rice that survive the winter. The population distribution peaks twice each season.

- The *intermittent-overwintering* subregion, along the coastline of southern Fuchien, the hilly areas of Yunnan, and the Pearl River Basin. The temperature may be as low as -3° to -5°C, but the lowest 10-day temperature is usually higher than 10°C. Frost sometimes occurs in this double rice-cropped subregion. BPH develop 6-7 generations/year. In warmer years they overwinter on the ratoon and volunteer rice. The population distribution peaks twice each season.

The immigrant multiplication belt

The immigrant multiplication belt is in the vast rice-growing areas covering northern China, at about 25° north latitude. The yearly mean temperature is between 10° and 20°C, and rainfall varies from 600 to 1,800 mm/year. Because the BPH cannot overwinter in this belt in the cold winter, they migrate to the southern rice-growing areas. The belt has three subregions.

- The *spring-immigration region* occupies the rolling land along the coastline, the hilly area of Nanling Ridge, and the highlands of Yunnan and Kueichou Provinces. The winter is warm and the summer wet. The region has four yearly seasons. The lowest 10-day mean

temperature is 4°C in the north and 10°C in the south. The lowest absolute temperature may be -9°C in the northern rolling land and -3°C along the southeast coastline. Usually 2 crops of rice/year are grown. Planthoppers can overwinter in the fields. BPH migrate from the south into this belt with the movement of the warm, wet air current in April and May and develop 5 or 6 generations/year. In normal years, they cause heavy damage on the intermediate and late rice in the single-cropped areas and the second crop in double-cropped areas. Occasionally, they infest early rice. Population distribution peaks twice each season.

- The *early-summer immigration region* covers land in the basin of Szechuan Province and the vast plain between the Huei-ho and Yangtze Rivers. The climate is warm in winter, hot in summer. The lowest 10-day mean temperature is -4° to 0°C. One or two crops of rice per year are grown. BPH immigrate into the region from mid-June to mid-July and develop 4-5 generations/year. They often infest the intermediate and late rices in the single-cropped areas and damage the late rice at the heading stage in the double-cropped areas. Their seasonal population is of the *staircase* type.

- The *hot-summer immigration region* includes the catchment of Wei Ho River, the North China Plain, Shantung Peninsula, and Liaotung Peninsula, where the frost period may last 130-150 days. In early October, the temperature may fall below 15°C. The growing season is short and BPH develop only 2-3 generations/year. The seasonal population is of the staircase type. Because only 1 rice crop/year is grown and BPH immigrate to the region rather late, the insect multiplication is slow and damage is slight.

The destructive generations of the BPH differ with location; extensive investigations in different regions show that BPH damage is determined not only by climate, cultural practices, cultivars used, time of immigration, and immigrant population, but also by the population level after 1 or 2 generations of multiplication in an area. Usually, the rice heading stage is the most destructive period.

SEASONAL IMMIGRATION

In the south, the extreme boundary for safe overwintering of BPH is 25° north. No BPH can overwinter further north. But being more cold tolerant than nymphs and adults, BPH eggs can.

The presence of ratoon and volunteer rices, and climatic conditions usually determine whether BPH can develop in the safe overwintering zone. During warmer winters, the growth of ratoon rice extends further north, and insects' overwintering zone extends northward. Large BPH populations lead to extensive crop damage. Although ratoon and volunteer rices cannot survive the winter in most areas,

the population of macropterous insects that migrate from the year-round developing belt increases rapidly in the following spring and summer.

Because China is in the monsoon zone, the following factors determine BPH immigration.

Movement of the polar front

In northeast China, the monthly air currents moving northward increase from March to July. After August the southwest air current is pushed back by the cold air current from the northeast. In the highlands of Yunnan, Kueichou, and the Szechuan Basin, southeastern air currents in spring and summer cause the BPH to migrate north. In autumn, the BPH migrate back south with the northeast air current. Temperature fluctuations do not affect BPH migration.

In a national-scale experiment in 1978, individual BPH were marked with red color. One such marked planthopper was caught more than 300 km away, at the Pinchou District Agricultural Experiment Station, Hunan Province. Another was caught at the Kwangtung Academy of Agricultural Sciences 200 km away. Thus, we know that BPH in China migrate.

Thermal state of the lower atmospheric layer

A Summary of findings from a BPH catch from an airplane follows:

1. The temperature favorable for long-distance BPH migration ranges from 10° to 20°C.

2. The height of migration flight increases monthly as the temperature increases from spring to summer; the areas of migration extend northward; and BPH migrate from coastal areas to outer islands. The temperature along the seacoast in March is comparatively higher; so is the height at which the insect flies. For example, many insects were caught at a height of 1,500 m; a few were caught at 2,500 m. None could be found in the inner continent atmosphere before April because the temperature was unfavorable for migration. The population of BPH migrating inland increases rapidly after April, when the temperature increases from 10° to 16°C isothermal surface in the low atmosphere. The height of migration flight gradually decreases from 1,400 m at the Haikuo County coast, Kwangtung Province, to 600 m inland at Enshih County, Hupei Province.

3. The frontal weather affects northward-migrating BPH; stationary fronts are particularly favorable for BPH settlement, according to 40 observations made from 1975 to 1978. BPH were observed at the initial stages of migration and during sudden increases in migrant populations. The observations were supplemented by

systematic analyses of meteorological data for the period. Cold fronts occurred 13 times; stationary fronts, 18 times; subtropical ridge lines, 6 times; typhoons, 2 times; and shear lines, 1 time.

NATIONAL COORDINATION FOR BPH OBSERVATION AND FORECASTING

A national organization to coordinate investigations on the BPH's migration and to forecast its development was formed in seven developing regions in 1979. It is made up of 108 institutions and stations in 20 provinces, municipalities, and autonomous regions. The objectives are:

1. to investigate the total development of the BPH and the whitebacked planthopper *Sogatella furcifera* Horvath by trapping them with lights in fields and with nets on mountains;

2. to collect information on the local rice cropping systems, the cultivars and their growth durations, and meteorological data; and

3. to comprehensively analyze the data to develop methods for forecasting the times of migration from a location and into new areas, and to estimate the crop damage such migration would cause. The work involves:

- Forecasting migration on the basis of the time of emergence of the macropterous form and the growth stage of the rice crop;
- Observing the migrating populations of the macropterous form by surveying the remaining population after migration;
- Determining the migration routes according to the direction of the air currents during migration; and
- Forecasting the location where the immigrant population will settle by analyzing the weather situation in the new area.

Control measures can be based on the organization's forecasts.

CONTROL MEASURES

Chemicals play a major role in BPH control in China. The key to successful chemical control is to apply chemicals before the pest outbreak. The use of chemicals 2 times within 10 days has proved most effective in extensive experiments.

The screening and selection of improved BPH-resistant varieties have been emphasized in recent years. Sources of resistance have been found among more than 10,000 rice varieties extensively screened for

BPH resistance in different locations. Biochemical analysis of cross combinations of Nan Yu No. 2 and Wei Yu No. 6 shows that the leaf sheaths of resistant varieties contain only 25-33% as much aspartic acid, asparagine, valine, alanine, and glutamic acid as the sheaths of susceptible combinations and varieties do. The resistant cross combinations, however, contain about four times more amino-n-butyric acid than the susceptible and conventional varieties. The hybrid combinations made with IR26 and IR28 as restorers usually show BPH resistance.

Studies on biological control are also under way. More than 70 natural enemies of BPH have been identified. Among them, *Erigonidium graminicolum* Sundevall and *Theridion octomaculateem* Boes et Str effectively control both the BPH and the green leafhopper. *Lycosa pseudoannulata* Boes et Str, *Clubiona japonicala* Boes et Str, and *Cyrtorhinus lividipennis* Reulev are also useful in some areas. Parasitic enemies of the hopper are *Oligosita nephotettica* Mani, *Oligosita shlibuyae* Ishic, *Oligosita* sp., *Paracentroba andei* (Ishi), and four types of *Anagrus* spp. *Panstonon* sp. is believed to be an egg parasite. The nematode *Amphimeris* sp. parasitizes both BPH adults and nymphs. Raising ducks in the rice fields is a practical and economic approach widely adopted in Hupei and Hunan Provinces.

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STUDIES ON THE CONTROL OF THE YELLOW RICE STEM BORER

Lin Yu

The yellow rice stem borer is a widely distributed rice pest that is most destructive in middle and southern China. Its development, reproduction, and infestation are influenced markedly by the rice plant's growth stages and growing conditions. Rice plants at the tillering, booting, and late booting stages are attractive to the insect; those at the seedbed, transplanting, prebooting, heading, and ripening stages are not. Multiple cropping favors pest outbreaks. Yellow borer control is more effective when insecticides and cultural control measures are integrated. Cultural control is used to regulate the growth stages of rice so that the vulnerable stage does not coincide with the insect's hatching period. Insecticides are used to protect rice at vulnerable growth stages. A promising insecticidal control technique is to destroy second-generation insects, thereby decreasing the initial population of the third generation, and ultimate rice damage.

FACTORS RELATED TO PEST POPULATION FLUCTUATIONS

The yellow rice borer has high host specificity. Its host is strictly the rice plant and its habitat is the paddy fields. Therefore, the stages and conditions of rice growth and the cropping systems markedly influence the pest population and infestation.

Oviposition and infestation

The growth of rice in relation to yellow borer activity may be divided into six stages: tillering, prebooting, booting, late booting, heading, and ripening. Rice plants at the tillering, booting, and late booting stages are attractive to the moths for oviposition. They often have several or even 10 times more egg masses than those at the other stages (Table 1). The moths also prefer to lay egg masses on rice plants in fields that contain high levels of nitrogen. There are far more egg masses in the field than in seedbeds.

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Table 1. Distribution of egg masses of yellow rice stem borers, People's Republic of China.

Growth stage of rice	Egg masses (no./1,000 hills)
Second generation[a]	
Tillering	45
Late booting	14
Prebooting	10
Third generation[a]	
Booting	79
Late booting	114
Heading	2

[a] Generation refers to the appearance of moths in China. *First generation* refers to the moths emerging from the overwintering larvae; *second generation,* to moths from the larvae of the first generation, and so forth.

The infestation by newly hatched larvae is closely related to the plant's growth stages. Plants at the tillering and late booting stages are more vulnerable to larval attack than those at other stages. Most newly hatched larvae take about 30 minutes to bore into the tillering stem 5 to 10 cm above the water level and longer at the prebooting stage, when the stem is tightly wrapped in two layers of leaf sheaths. A considerable number of larvae die outside the stems; only 5% of the original number successfully bore into the stem within 50-180 minutes after hatching.

Table 2. Relationship between time of larval invasion and growth stage of rice.

Growth stage of rice	Larvae (%) that enter stems at indicated times after hatching					
	30 min	60 min	90 min	120 min	150 min	180 min
Tillering	56	34	0	0	0	10
Prebooting	0	0	5	15	0	70
Early booting	20	27	0	7	7	40
Late booting	75	26	0	0	0	0

At the booting stage the stem is penetrated more rapidly because it is loosely enclosed by a single layer of the flag sheath. During late booting, the flag sheath opens to a narrow slit, through which the larvae easily enter the stem (Table 2). Penetration is quickest when the top of the rice ear has just emerged above the flag sheath. After the panicle has emerged, the stem becomes so hard that few larvae can penetrate it. Thus, the infestation rate of newly hatched larvae is higher at the tillering, booting, and late booting stages of rice than at the prebooting, heading, and ripening stages (Table 3). But after the second instar, the larvae become strong enough to attack rice at all growth stages and the growth stage no longer affects infestation.

Table 3. Percentage of living larvae in rice stems at different growth stages.

Growth stage of rice	Larvae inoculated (no.)	Living larvae (%) in the rice stem
Tillering	160	53
Prebooting	240	4
Booting	240	39
Late booting	240	54
Heading	240	0

Temperature also influences the survival and the infestation rate of newly hatched larvae. Temperatures lower than 40°C do not affect larval activity. But as temperatures rise above 42°C, the larvae's death rate gradually increases; at 46°C most larvae die immediately. The infestation rate gradually decreases with increased temperature. At 46°C few larvae are able to enter the stem (Table 4).

Table 4. Relationship between larval infestation and temperature.

Temperature (°C)	Larvae inoculated (no.)	Living larvae (%) in the rice stem
34-35	31	45
40	25	64
42	29	40
44	39	26
46	36	6

Larval development

Experiments in 1953-56 demonstrated that the insect molts because it fails to either develop or adapt itself to unfavorable conditions (Yu et al 1964). More than 80% of the larvae that fail to develop undergo 4 instars to become fully grown; fewer than 10% undergo 5 instars or more. The number of moltings depends on at least two factors: temperature and food. Most of the larvae reared at higher temperature (29-35°C) undergo 3 moltings. those reared at lower temperature (23-29°C) molt 4 or more times. In Jiangsu Province, the overwintering larvae molt several times before pupating in December. Most of the larvae that feed on tillering rice molt 3 times, but most of those on the prebooting plants molt more than 3 times (Table 5) (Yu et al 1959).

In the vegetative stage of rice, the plants' growing conditions affect the survival and fecunditv of the pest. The larvae in the seedbed migrate, often because of food deficiency that causes high mortality (Table 6). Larvae that are transferred from the seedbed to the field when seedlings are transplanted also suffer high mortality (Table 7). The rate of moth emergence decreases considerably. Furthermore, the moths lay fewer eggs than those in the fields (Pathak 1968).

Insects that feed on rice at the late tillering stage develop better than those on rice at the early tillering stage. In a single middle rice field in the lower Yangtze Valley, the first-generation borers appear after the rice is transplanted and the second-generation borers, from the late tillering stage to the early prebooting stage. The female moth in the second generation lays about 20% more eggs than that in the first generation. But the rate of moth emergence is higher in the first generation than in the second (Table 8). The factors responsible for the results are not fully known and should be investigated further (Table 9).

Hibernation

In the lower Yangtze Valley, the yellow rice borer begins to overwinter in October, when the daily temperature is lower than 16°C and unfavorable for the insect's development. Most of the insects hibernate in the rice stubble and a few in the straw. The overwintering larval population depends on the rice growth stage in relation to period of larval hatching. When larvae hatch during the rice plants' vulnerable stages, larval density increases significantly and winter mortality is lower. The insects that attack the plants at the booting stage have heavier bodies and lay more eggs the next year than those that attack at other growth stages (Table 10).

As in other insects, the yellow borer's hormones govern its hibernation. Fukaya and Mitsuhashi (1958) pointed out that the essential characteristics in the diapause of the rice stem borer

Table 5. Relationship between number of instars of yellow rice borer and environment.

Temp (°C)	Insects observed (no.)	Female insects (%) 3 instars	4 instars	5 instars	6 instars	Insects observed (no.)	Male insects (%) 4 instars	5 instars	6 instars
Tillering stage of rice									
29 – 35	48	2	90	6	2	21	95	5	0
23 – 29	22	0	59	36	4	12	42	58	0
29 – 35	12	8	83	8	0	3	100	0	0
23 – 29	11	0	18	72	9	5	20	80	0
Prebooting stage of rice									
29 – 35	11	0	94	6	0	7	44	43	14
23 – 29	7	0	86	14	0	2	100	0	0

Table 6. Larval survival in the seedbed and in the field.

Days after hatching	Living larvae[a] (%)	
	Field	Seedbed
3	41	58
15	22	7
24	23	3

[a] $\frac{\text{Number of living insects}}{\text{Number of inoculated insects}} \times 100.$

Table 7. Effects of transplanting on larval mortality, rate of moth emergence, and oviposition.

Year	Insects in field			Insects transferred from seedbed to field through transplanting		
	Mortality (%)	Emerging moths (%)[a]	Eggs (no./ female)	Mortality after trans- Panting (%)	Emerging moths (%)	Eggs (no./ female)
1953	0	25	232	90	2	173
1954	25	13	203	80	2	157
1955	55	12	251	87	2	178

[a] $\frac{\text{Number of emerging moths}}{\text{Number of larvae inoculated}} \times 100.$

Table 8. Comparison of the development of the first and second generations of yellow rice borer. Lower Yangtze Valley, 1953-55.

Year	Borer generation	Time from larval invasion until moth emerges (days) Female	Male	Mean	Eggs (no.)	Emerging moths (%)
1953	1st	35	35	35	232	26
	2d	31	30	30	297	2
1954	1st	41	40	40	203	13
	2d	40	31	31	253	10
1955	1st	36	35	36	251	12
	2d	33	34	34	299	3

Table 9. Effect of transplanting time on the development of yellow rice borer in the second generation.

Rice system	Date of trans-planting	Days (no.) from larval invasion to moth emergence Female	Male	Mean	Eggs (no./female)	Emerging moths (%)
Transplanted	22 Jul '54	31	30	30	275	9
Direct-seeded	1 Jun	34	31	32	326	44
Direct-seeded	17 Jun	32	30	31	311	41
Direct-seeded	10 Jun	29	28	28	301	15
Transplanted	7 Jul '55	33	32	33	264	2
Transplanted	15 Jul	32	32	32	290	10
Transplanted	23 Jul	30	29	30	261	9
Transplanted	2 Aug	31	29	29	187	12

Table 10. Effect of rice growth stage on insect hibernation.

Growth stage of rice during larval hatching	Larvae (no./400 stubbles)	Body wt (mg) of hibernating larvae	Eggs (no./female)	Mortality in next spring (%)
Heading to ripening	215	42.7	88.4	27.83
Booting to late booting	596	45.5	108.6	-
Prebooting to booting	77	46.6	121.1	19.17

Chilo suppressalis seem to be the inactivity of the brain and of the prothoracic glands, and the high activity of the *corpora allata.* But in the yellow borer, the brains and prothoracic glands seem to be continuously active in winter.

About 1,000 diapausing yellow borer larvae were ligatured or extirpated in 1956-57. Of 426 headless larvae, 57 pupated and 12 molted but did not pupate. Of 668 larvae that were ligatured between the thorax and the abdomen, 12 molted in both the anterior and the posterior halves of the ligature and 44 molted only in the anterior half.

In another experiment, diapausing larvae were collected from the field and incubated at 30°C at intervals of about 10 days beginning in September 1956. At the beginning of diapause, the larvae molted several times before pupating. Molting decreased as diapause development advanced. During the postdiapause period, the diapausing larvae pupated without molting. It has therefore been suggested that the yellow rice borer has a facultative diapause. Whenever the conditions are favorable, diapause ends immediately.

The pupation of hibernating larvae is governed principally by temperature, moisture, and photoperiod. The minimum temperature for pupation is 16°C; below that the larvae molt but do not develop further. The critical relative humidity for pupation seems to be 96%; above that pupation occurs and below it, only molting. Larvae that are in contact with water pupate more rapidly than those exposed to 96-100% relative humidity. Long day length (14-16 hours) favors a high percentage of pupation.

EFFECTS OF RICE CROPPING SYSTEM

The yellow paddy borer is monophagous; its development, reproduction, and infestation are governed by the growth stage and growing conditions of rice. Feeding on rice at the tillering, booting, and late booting

stages is advantageous to the newly hatched larvae, but feeding at the seeding, transplanting, prebooting, heading, and ripening stages is disadvantageous. That serves as an important theoretical ground for research on population fluctuations and pest control strategies.

Generation and damage

In the Lower Yangtze Valley the yellow paddy borer has 3 to 4 generations/ year. The first generation emerges from mid-May to early June and reproduces and builds up an initial population at the tillering stage of the early transplanted rice. The second generation appears in July and usually oviposits at the tillering stage of the single late rice crop -- the source fields of the third generation. The third generation occurs from early August to mid-September; it often damages late rice seriously. The fourth generation appears from early September to early October. Its population usually declines drastically in October. When the third generation appears early in a warm year, the fourth generation has a significant peak of moths. In the multiple-cropped areas where rice is transplanted early in spring and harvested in fall, the insect has four or more generations because food is available throughout the year.

During the vegetative phase of rice, the newly hatched larva crawls between the leaf sheath and leaf blade and bores into the basal part of the stem 5 to 10 cm above water level. It then feeds on the inner surface of the stem wall, causing the base of the plant to break. The central young leaf fails to unfold, becomes whitish, and dries, but the lower leaves remain green and healthy. The affected tiller -- known as a *deadheart* -- bears no panicle. The larvae emerging from one egg mass usually infest adjacent rice plants, causing a group of 40-50 deadhearts.

During the rice reproductive phase, most of the newly hatched larvae enter the booting stem and feed on the floret in the spikelet. After 4 or 5 days, after molting once to become second instar, the larvae leave the affected plants and migrate to adjoining plants, on which they bore into the nodal region of the panicle rachis or the lower part of the stem. The affected stem is severed and the panicle dries. Such panicles are called *whiteheads.* The whitehead appears about 2 days after the entrance of the second-instar larva. When the panicle is barely above the flag sheath, the newly hatched larvae often enter the sheath through a fissure. The whiteheads appear 7 to 8 days after the larvae hatch. The larvae from one egg mass usually cause a group of 10-15 whiteheads.

Infestation and rice cropping systems

In the Lower Yangtze Valley, an outbreak of yellow borers occurs when the initial population in the first generation is large, the pest sources are abundant in the second generation, and rice is at the vulnerable

growth stages during the period of third-generation larval hatching. In short, an outbreak occurs if the multiple cropping system is favorable (Wu 1978).

The size of the first generation's initial population depends on the pest source and the oviposition of the moths emerging from the overwintering larvae. Larvae that overwinter in winter-fallowed fields and in fields of wheat and green manure crops grown for seed can safely develop into moths. Increases in field area result in an abundance of moths. After rejuvenating in the field, a large number of moths deposit egg masses on the plants, increasing the populations of subsequent generations. For instance, in areas where both early and late rice crops are grown or both single and double rice cropping systems are practiced, the early transplanted rice plants become the source of subsequent pest generations and are greatly damaged. Otherwise, as in the single late-rice area, the oviposition of most moths in the seedbeds reduces the pest population, and the insect becomes a minor pest.

Coincidence of the hatching period of the second generation with the vulnerable growth stages of rice determines the degree of infestation of the second generation and the initial population of the third generation. Larval density increases considerably when hatching coincides with the tillering stage of rice, as in the areas where an early and a late rice crop are grown. A high population in the second generation means that the third generation may be particularly destructive to the rice crop. But in areas where double rice cropping is predominant, the hatching period occurs after the first crop is harvested and before the second is transplanted. The population of the third generation decreases markedly and rice yield loss is negligible.

The time of larval hatching determines the degree of infestation by the third generation. For instance, when larvae hatch at the vulnerable stages of the single late rice, rice is damaged heavily. But yield loss is negligible when panicles of hybrid rice or of a single early rice crop emerge before larvae hatch.

Alternation of the rice cropping systems influences the pattern of predominance of the rice stem borer and the degree of damage. During the single late rice crop in Soochow district, Jiangsu Province, the lack of suitable host plants for the first generation resulted in slight damage because the rice was transplanted late. The striped stem borer was dominant. When the fields of early, middle, and late rice crops are present or both single and double rice cropping are practiced in a locality, rice at vulnerable growth stages is available throughout the year. The insect population increases from generation to generation, and sudden pest outbreaks often occur. But in areas where double rice cropping is predominant, the plowing of barley field in spring may destroy the overwintering larvae and reduce the first-generation population. The lack of suitable host plants for the second generation

also drastically decreases the initial population of the third generation, so yield losses in that generation are negligible.

EFFECT OF CLIMATE

Climate may play a role when rice cropping systems are favorable to pest infestation in Jiangsu Province. When the pest population is controlled, climatic fluctuations do not markedly influence infestation. In southern Jiangsu, the high precipitation from late April to mid-May results in the high mortality of insects parasitized by microorganisms. Therefore, the density of the subsequent generations significantly decreases. In 1962, a considerable decrease in rainfall during the same period resulted in increased insect population. Yield losses were high because the early appearance of the third generation caused by warm summer coincided with the vulnerable stage of the single middle rice crop. In 1954, a cool summer delayed the appearance of the third generation until late August. The single late rice crop, whose vulnerable growth stage coincided with the pest's hatching period, was seriously infested.

CONTROL TACTICS

Chinese peasants have fought the yellow rice borer for centuries. Control was successful only after liberation. Many investigations and extensive observation of practices have shown that the pest can be controlled satisfactorily by keeping the initial population of the third generation below the tolerable injury level, and by insecticide application as needed. That may be achieved by integrated insecticidal and cultural control.

Cultural control

Cultural control must be judiciously carried out according to local conditions. Cultural practices such as the rational arrangement of rice varieties, careful seed selection, manipulation of planting dates, and proper fertilizer application, cause the rice to reach vulnerable stages outside the peak hatching period. The resulting pest population is low. But natural and agricultural conditions often limit the use of cultural control methods. Supplementary insecticidal control methods may be necessary.

Insecticidal control

Insecticidal control appears to be the only effective method for protecting the rice crop from pest attacks. But some conventional insecticides are toxic to mammals and fish. The large-scale and long-term use of the same insecticide enables the borer to develop resistance to it. An extensive experiment on techniques of insecticidal control in 1966 showed that the destruction of the pest in the second or in the first generation decreased the population of the following generation.

Table 11. Effect on infestation by third-generation yellow rice borers of insecticide application in the first or second generation.

Treatment	Insects (no./ha)			Egg masses (no./ha)				Fields to be controlled in 3d generation	Whiteheads in untreated fields (%)
	After hibernating	At end of 1st generation	At end of 2d generation	Middle rice	Late middle rice	Late rice	Mean		
Experimental area	54,915	613	220	300	717	3,498	3,158	17	3
Conventional control area	1,183	6,435	8,812	183	2,973	11,298	7,966	44	19

Table 12. Systemic effects of insecticides.[a]

Insecticide	Corrected mortality of insects (%)			
	1 day after application	3 days after application	5 days after application	7 days after application
Methyl 1605	25	19	87	83
γ-BHC	35	19	36	80
Dimethoate	100	100	92	31
Check	11	7	0	9

[a]When 20 – 30%of the plants were at the booting and late booting stages, insecticides were poured on the paddy water at 3.75 kg a.i./ha. The panicles cut at 1, 3, 5, and 7 days after application were inoculated with newly hatched larvae in the laboratory; mortality was observed 24 hours after inoculation.

When that practice was followed experimentally, the area of rice fields that needed third-generation pest control was 62% lower and the percentage of whiteheads in the untreated fields was 88% lower than in the conventional control area (Table 11). Those results have been confirmed in practice. But the method should suit local conditions. In southern Jiangsu recommendations include insecticide application to control deadhearts in the first generation, to destroy second-generation insects in the pest source fields, and to effectively protect rice from third-generation insects.

Insecticidal control protects rice from attack at the tillering stage. Rice fields containing 300 to 450 egg masses/ha should have more than 1% deadhearts. That is a criterion for determining if a rice field needs insecticidal control.

The proper time to apply insecticide is 1 or 2 days before hatching peaks. The conventional insecticides are M-BHC (1.5% methylparathion + 3% γ-BHC) at the rate of 15 kg/ha and fenitrothion, chlordimeform, or similar insecticides at 750 g a.i./ha. Such pesticides are applied by toxic earth casting (for example, mix 1 kg 6% γ-BHC with 15 kg slightly moistened, fine earth) or by splashing (dilute the toxicants with 250-300 kg water) in 1 or 2 treatments at 6- to 7-day intervals.

Insecticide use is recommended to protect rice at booting and late booting stages. The larvae emerging from 1,500 egg masses/ha may cause more than 1% whiteheads. Because no more than half of the egg masses can generally be found, the presence of more than 600-750 egg masses/ha is recommended as the criterion to determine if rice fields need insecticide treatment. The proper application time depends on the rice growth stages and conditions. During the insect's hatching period, γ-BHC should be applied at 5- to 6-day intervals when 20-30% of the plants are at the booting and late booting stages. In fields where rice growth stages are not uniform, insecticide must be applied several times during the insect's hatching period. Splashing and spraying are popular methods of applying γ-BHC in the rice reproductive phase.

The systemic dimethoate prevents whiteheads more effectively than other conventional insecticides. When 20-30% of the rice plants are in the vulnerable growth stages, dimethoate is poured on the paddy water at 3.75 kg a.i./ha. It is rapidly transferred acropetally to the floret in the spikelet. All the larvae in the floret begin to die 24 hours after application. The insecticide's residual effect is about 5 days (Table 12). Dimethoate can be synergized with γ-BHC.

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THE RICE GALL MIDGE – VARIETAL RESISTANCE AND CHEMICAL CONTROL

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The rice gall midge *Orseolia oryzae* is a serious pest across South and Southeast Asia, except in the Philippines. Mass-rearing and screening procedures based on data on the insect's biology have been developed. For effective field screening, the seasonal population peaks of the insect must first be determined. Several resistant varieties have been identified and used in breeding programs. Five improved gall midge-resistant varieties have been released in India. Four gall midge biotypes have been identified through the trials of the All India Coordinated Rice Improvement Project (AICRIP), the International Rice Gall Midge Nursery (IRGMN), and the gall midge biotype study. AICRIP's extensive insecticide testing program has complemented the work on host resistance. Several effective chemicals have been identified for use in the nursery as a seedling root dip or foliar spray, as granules applied in paddy water, or for root-zone application.

The rice gall midge *Orseolia* (*Pachydiplosis*) *oryzae* Wood-Mason is a serious pest of rice in China, Vietnam, Laos, Cambodia, Thailand, Burma, Bangladesh, India, Sri Lanka, and Indonesia (Reddy 1967, Hidaka et al 1974). It is also reported in Sudan, Cameroons, and Nigeria (Khush 1977). In India, gall midge is found in Orissa, Andhra Pradesh, Madhya Pradesh, Kerala, Bihar, Karnataka, and Maharashtra states. Earlier, the insect was found only in the monsoon season, but in recent years it has damaged the summer crop in parts of India (Kalode and Kasiviswanathan 1976).

The main external symptom of gall midge damage is *silver shoots* or galls -- damaged leaf sheaths with an *onion-blade* appearance (Deoras 1945). Early gall midge infestation results

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in stunting and profuse tillering, but few tillers bear panicles. Literature on gall midge (Reddy 1967, Hidaka 1974), host plant resistance (Shastry et al 1972), and breeding for resistance (Khush 1977, Roy et al 1978) has been reviewed.

BIOLOGY AND SEASONAL BEHAVIOR

Biology and gall formation

Gall midge biology was reviewed by Leaumsang et al (1968), Hidaka et al (1974), Perera and Fernando (1969), Fernando (1972), and Kalode et al (1977). The males generally emerge between 1800 and 2400 hours but most females emerge after 2400. During their life span the females lay an average of 124 eggs, singly or in small groups. The percentage of eggs was greater on the leaf sheaths (44%) than on the leaf blades (42%) or auricles (14%). Eggs hatch after 72 hours, and the first-instar maggots enter the apical buds of terminal and auxiliary rice shoots within 1 day. After 3 or 4 days the insects molt into the second instar; they remain at that stage for 3 or 4 days, then enter into the third instar. As the third-instar insect stops feeding, it enters the prepupal stage, which lasts for 24 hours. The pupa is characterized by a series of heavily chitinized adaptive spines that help the insect move up the gall cavity and escape from it. The pupal period lasts for 2 to 8 days.

The first-instar maggot starts feeding on the growth cone (Perera and Fernando 1970, Fernando 1972); gall primordium is initiated within 4-6 days after infestation. A ridge of cells proliferates on the inner side of the youngest leaf primordium. This ridge of tissues grows and fuses, forming a primordial gall that encloses the first-instar maggot.

Seasonal behavior

The period of gall midge incidence was mid-August to October in West Bengal, India, and May to September in Bihar (Banerjee 1971). In those states peak infestation fluctuates from August to late November. Gall midges were collected in light traps at Maruteru and Warangal, Andhra Pradesh, from July through December, in the wet (kharif) season. Peak catches were from the third week of September to the fourth week of October (AICRIP /All India Coordinated Rice Improvement Project/ 1975, 1976, 1977, 1978). Interestingly during the 1978 dry (rabi) season (Jan-Apr), large numbers of adult gall midge were caught, with peaks in the second week of February and the fourth week of April (AICRIP 1978). At Cuttack, Orissa, gall midge was observed from late August to early December, and peaked in late September and mid-October (Hidaka and Rajamani 1977).

In northern Thailand, gall midge appears from March to May, peaks late in September, and disappears in mid-November (Hidaka et al 1974). In Sakorn Nakorn, northeastern Thailand, peak infestation was late in August (Hidaka 1974).

Climatic factors such as temperature, rainfall, and relative humidity are correlated with the seasonal fluctuation of gall midge populations. At Maruteru, Andhra Pradesh, the maximum temperature ranged from 32.2 to 33.5°C and relative humidity was 43 to 90% from 1975 through 1978. A peak weekly rainfall of 94 to 250 mm was recorded 4 to 6 weeks before peak incidence. At Warangal, the maximum and minimum temperatures during incidence were 35° and 15°C. Peak incidence there was preceded 4 to 7 weeks earlier by weekly rainfall peaks of 50-140 mm. Sunshine during peak incidence ranged from 1.5 to 9.7 hours/day (AICRIP 1976, 1977, 1978). More data are needed before such climatic factors can be correlated with duration and peak of incidence.

According to Reddy (1967) gall midge infestation was highest in years when early rains make the flies active but subsequent dry periods delay planting. Under those conditions the pest multiplies on grasses; the flies then migrate in large numbers to the late rice crop. Prakasa Rao et al (1971) also reported that early rains (more than 300 mm) in May and June promote the growth of ratoons and other host plants on which the gall midge develops before it attacks the first rice crop. Continuous rainy and cloudy weather and high humidity from July to September favor outbreaks.

OCCURRENCE ON WILD HOSTS

In India, 11 species of weeds and wild rice have been reported as alternate hosts of the rice gall midge. *Mnesethia laevi* and wild rice are the primary wild hosts for population buildups (Israel et al 1970).

In Thailand five species of graminaceous plants -- wild rice, *Ischaenum aristatum, Paspalum distichum, Leersia hexandra,* and *Echinochloa colonum* -- have been reported as alternate gall midge hosts. In summer the gall midge remained in the first and second instars on those hosts. Although reciprocal infestation between rice and wild hosts was successful, the adults emerging from larvae bred on wild hosts were significantly smaller than those from larvae on rice (Hidaka et al 1974).

ECONOMIC THRESHOLD FOR GALL MIDGE

Israel et al (1959) correlated gall midge damage with yield of variety GEB24, by the regression equation $Y = 4720.18 - 23.71X$ (Y = yield in pounds per acre, X = percent damage at the peak infestation period). They reported a 0.5% yield loss -- 23.71 lb/acre -- for every 1% increase in gall midge incidence.

A trial conducted in 1973 kharif at Cuttack and Warangal with 4 predetermined infestation levels showed that the economic threshold values vary. The threshold was less than 5% silver shoots at Cuttack, but at Warangal, even a 10% level did not significantly reduce yields.

CONTROL PRACTICES

Progress has been made in the development of varieties resistant to gall midge and the identification of insecticides to suppress its population.

Varietal resistance

Mass rearing and screening procedures. To facilitate rapid screening of material under artificial conditions, a technique to rear large populations of gall midges has been developed in Thailand (Leaumsang et al 1968), Sri Lanka (Perera and Fernando 1969), and India (Kalode et al 1977). The technique involves infesting rice plants with adults or eggs, then placing plants with eggs in a moist chamber with more than 90% humidity. After 4 days under high humidity, the pots are placed in cages for symptoms to develop. The adults are collected as they emerge from silver shoots. Seedlings 10-14 days old were used in Sri Lanka; in India, 20-day-old seedlings were found more suitable for high adult recovery.

Varieties in the greenhouse have been rapidly and effectively mass screened for resistance. Ten test entries are grown in rows spaced 4 cm, along with resistant and susceptible checks, in flat wooden trays 52 x 28 x 14 cm. After 12-15 days the seedlings are infested with 10 female and 5 male adults. The observations on the test varieties could be summarized by the 25th or 27th day in August-September and the 37th or 38th day in December-January (Kalode et al 1977).

Identification of donors. Indian researchers have identified the following varieties as resistant to gall midge -- PTB10, PTB18, PTB21, Nato, Bhainsa, Ratnachudi, Maskaty 1315, HRl4, HR42, HR63, Siam 29, Eswarakora, and Leuang 152. Table 1 lists other resistant donors.

Table 1. Donors reported as resistant to gall midge in different countries.

Donors resistant to gall midge				
India		Thailand	Indonesia	Sri Lanka
PTBl0	AC355	Eswarakora	ARC10494	PTB21
PTBl8	AC1368	Muey Nawng 62	ARC10520	Leuang 152
PTB21	HR42	Muey Nawng 62M	ARC10817	
PTB27	HR63	Dok Putdor	ARC10932 – 2	
PTB28	Siam 29	W1251	Siam 29	
PTB32	Leuang 152	W1253	Eswarakora	
ARC6202	Eswarakora	W1257	Muey Nawng 62M	
ARC6221	Peykeo P129	W1263	W1263	
ARC7317	Peykeo E53			
ARC10494	JBS446			
ARC10817	JBS673			
ARC10932 – 2				

Table 2. New germplasm reported by the All India Coordinated Rice Improvement Project (AICRIP) as resistant to gall midge from various locations in India.

Assam Rice Collection		Pattambi, Kerala	Coimbatore, Tamil Nadu
ARC5833	ARC6619	PTB12	T405
ARC5834	ARC6632	T10	T1162
ARC5848	ARC7255	ADR52	T1426
ARC5911	ARC7292	Veluthachera	T1479
ARC5912	ARC7293	Kurutha	T2587
ARC5918	ARC10040	Vellathan	
ARC5939	ARC10227	Parakulam	
ARC5984	ARC10331	T16	
ARC5988	ARC10360	Channinayakan	
ARC6001	ARC10377	Vellathilcheera	
ARC6103	ARC10460	Vellachenipan	
ARC6157	ARC10557	Pandi	
ARC6158	ARC10654	710	
ARC6605	ARC10659	Chennellu	
ARC6606	ARC10660		
ARC6607	ARC10627		
ARC6618	ARC11704		

AICRIP tested 2,128 entries from the Assam Rice Collection (ARC) in the field of Warangal; 182 were identified as resistant (AICRIP 1971). With greenhouse facilities built in 1974 at AICRIP, several new donors from different sources (Table 2) were identified, and the resistance of Siam 29, Leuang 152, Eswarakora, PTB18, and PTB21 was confirmed.

Breeding for resistance. In the early breeding program at Warangal the resistant donor Eswarakora was crossed with MTUl5, and four selections with gall midge resistance were identified: W1251, W1253, W1257, and W1263. At Cuttack, PTB18, PTB21, and Leuang 152 were used and the selections CR55 and CR56 were more resistant than the parents. After the semidwarf varieties were introduced, several crosses with resistant donors were made. On the basis of their regional performance through the AICRIP program, the following resistant varieties were released for commercial cultivation: Kakatiya, Surekha, and Phalguna in Andhra Pradesh; Vikram in Karnataka; and Shakti in Orissa. Other promising rices (Table 3) are now in minikit trials.

Table 3. Cultures found promising for gall midge resistance in minikit trials in India.

IET number	Designation	Cross	Total growth duration (days)	Grain type
6131	CRl57-380-55-11-303	Vijaya/PTB10	127	Medium slender (red rice)
6724	OR132-3-1	Rajeswari/CR57	134	Long bold
6187	RP825-71-4-11	Vijaya/PTB21	123	Long bold
5715	RP825-24-7-1	Vijaya/PTB21	130	Short bold
3356	RP352-28-1-1-4	IR8/PTB18// Eswarakora/IR8	135	Long bold

Some selections from Eswarakora were used in Thailand's breeding program; the resistant RD4 was subsequently released. W1263 and RP352 are being effectively used in Sri Lanka's breeding program; CR94-13 is used extensively at IRRI.

IRRI initiated in 1975 the International Rice Gall Midge Nursery (IRGMN), through the International Rice Testing Program (IRTP), to identify new varieties and breeding lines with broad-spectrum resistance. More than 100 entries are included both from advanced breeding material and donors nominated by various countries. They have been tested for 4 years in India, Indonesia, Sri Lanka, and Thailand under uniform management practices. Table 4 lists entries showing resistance.

Table 4. Promising breeding material found resistance to gall midge in the International Rice Gall Midge Nursery (IRGMN), 1975-78.

Entry	Cross
Resistant in all countries tested except Thailand	
IET2911 (RPW6-17)	IR8/Siam 29
IET3356 (RP352-28-1)	IR8/PTB18//Eswarakora/IR8
IET3362 (RP9-10-3-2-1)	IR8/W1251
IR4744-10-2-3 (and other sel.)	RPW6-13/IRl721-11-8-8-3-2// IR2061-464-2
75-163	OB 677/BG90-2
75-203	OB 678/BG66-1
75-159	OB 677/BG90-2
CR95-JR-46-1	Leuang 152/IR8
CR189-4	CRl29-118/RPW6-13
cRl99-1	RPW6-13/Supriya
CR200-1	RPW6-13/Vijaya
Resistant at all sites in India and Thailand	
R35-2749	
Resistant in Thailand	
BRl030-3-2	BKN6625-109-1/RD9
BR1031-3-6	
R7-2257 (and other R7 sel.)	W1263/CR10-4011
R35-2739 (and other R35 sel)	IR22/W1263

Inheritance of resistance. Studies conducted by Narasimha Rao (personal communication) of two crosses, IR8/W1263 and IR8/PTB21, show that although two genes were responsible for gall midge resistance in W1263, four were responsible in PTB21 (Shastry et al 1972). Susceptibility is inhibited, however, by one dominant inhibitor gene. Later workers found no association between the inhibitor gene and susceptibility (Sastry and Prakasa Rao 1973, Sastry et al 1975, Sastry et al 1976). Satyanarayanaiah and Reddy (1972) and Venkataswamy (1974) postulated that only one dominant gene governs resistance. The cytoplasmic influence in the expression of resistance was also reported by Prasad et al 1975). Studies in Thailand involving W1263 and Muey Nahng 62M indicated that only a few genes are responsible, but that the environment strongly affects the expression of resistance (Hidaka 1974).

Biotypes. The existence of gall midge biotypes is suspected because of the differential performance of varieties at different sites (Roy et al 1969, Fernando 1972, Shastry et al 1972, Kalode 1974). Furthermore, the results of collaborative gall midge biotype studies conducted by AICRIP and of the IRGMN indicate that varieties react differently in Thailand, Indonesia, Sri Lanka, and different sites within India. Most of the breeding materials tested displayed reaction patterns mainly in relation to the source of resistance. The main groups used to study those patterns were derivatives of Eswarakora or of W1263, PTB, Siam 29, Leuang 152, OB 677, and Muey Nahng 62M.

The main reaction patterns were observed at different sites in India (Table 5). At Cuttack, Orissa, Eswarakora

Table 5. Reaction of cultures involving different donors of resistance to gall midge in different states of India.

	Reaction[a]			
Donor	Orissa	Andhra Pradesh	Madhya Pradesh	Manipur
Eswarakora	S	R	R	R
Siam 29	R	R	R	S
Leuang 152	R	R	R	S
PTB21	R	R	S	S
Jaya (susceptible check)	S	S	S	S

[a]R = resistant, S = susceptible.

derivatives were susceptible while other groups were resistant, but at Hyderabad, Andhra Pradesh (A.P.), Eswarakora derivatives and other groups showed resistance. Reactions at Warangal (A.P.) and Raipur (Madhya Pradesh) resembled those at Hyderabad. But at Manipur (Tripura), Siam 29, PTB21, and Leuang 152 were susceptible.

Results of the international collaborative study on gall midge biotypes indicate that at least four biotypes exist. Eswarakora derivatives from the Thai breeding program were susceptible in Indonesia and Sri Lanka but resistant in Thailand and India. Siam 29 was susceptible in Thailand, Indonesia, and Sri Lanka but the Siam 29 derivative IET2911 (RP6-17) was resistant in India, Indonesia, and Sri Lanka. The PTB18 and PTB21 derivatives IR32 and IR36 were susceptible in Indonesia and Thailand but resistant in India and Sri Lanka. Muey Nahng 62M was resistant in Indonesia and Thailand but susceptible in Sri Lanka. Leuang 152 was resistant in Indonesia but susceptible in Thailand.

Mechanisms of resistance. Reports have associated gall midge resistance with hairy leaves, compact leaf sheaths, broad and thick sclerenchymatous hypodermis (4-5 cell layers), and numerous air spaces (Israel et al 1961). But studies with W1263 at AICRIP (1969) and in Sri Lanka by Modder and Alagoda (1971) showed no ovipositional preference for resistant or susceptible rices. The first-instar larvae entered the growing points of resistant and susceptible varieties. But on resistant varieties, they died without molting to the next instar, apparently because antibiosis inhibited molting.

Several researchers noted the same essential nature of resistance in other donors including PTB18 and PTB21 (Prakasa Rao, personal communication), and W1263 (Hidaka 1974). In a recent AICRIP study the resistance of donors Siam 29, PTB18, PTB21, Eswarakora, and Muey Nahng 62M was studied. Although the number of eggs laid on resistant and susceptible varieties differed, the percentage of eggs that hatched on those varieties did not. There seemed to be no mechanical barriers to maggot entry: the maggots entered the varieties 5 days after oviposition. But 18 days after oviposition the susceptible checks had many maggots and pupae and later manifested silver shoots.

Studies on the chemical basis of gall midge resistance showed that susceptible varieties had high phenol contents in their growing points before infestation, but phenol decreased during infestation. The phenolic contents of resistant

varieties increased during early infestation (CRRI 1975). Guru and Roy (1974) correlated amino acid content with the degree of gall midge resistance.

Chemical control

Most available insecticides have been tested for gall midge control in nursery beds as seedling root dips, foliar sprays, and granules applied in standing water and in the root zone.

Seed and nursery treatment. Because gall midge infestation often begins in the nursery, the possibility of controlling it through seed treatments with wettable powers (WP) and by seed soaking was explored. Isofenphos WP applied at 16 g a.i./kg of sprouted seed in the greenhouse protected the nursery for 30 days and substantially reduced gall midge infestation in the transplanted crop (AICRIP, unpub.). Prakasa Rao (1974) observed that soaking seeds in 100 ppm streptocycline + 50 ppm aureofungin + 0.02% solution carbofuran before sowing and spraying 0.1% parathion 15 days after germination were also effective. Hidaka (1973) demonstrated that diazinon 3%G was the most effective for gall midge control when applied at 2.0 kg a.i./ha 10 days after germination. But extensive AICRIP testing of 15 insecticides for 5 years (1971-75) led to the identification of 1.25 kg a.i. phorate/ha in the nursery, 1.0 kg a.i.fensulfothion/ha, and 1.0 kg a.i. MIPC/ha as the best when broadcast at 10 days after sowing and again at 7 days before transplanting.

Seedling root dip. Fernando and associates in 1970 (cited by Hidaka 1974) observed that chlorfenvinphos 24% EC, azinphos ethyl 25% EC, phorate 10%G, phosmet 50 WP, thia-diazinthion 5%G effectively reduced gall midge incidence when seedling roots were dipped in 15 to 30 ppm solutions of those insecticides. Prakasa Rao (1974) reported that 0.05% solutions of chlorpyriphos, phorate, diazinon, carbofuran, and mephosfolan substantially reduced gall midge incidence as long as 40 days after planting. Since 1972 AICRIP has tested 54 insecticide formulations (WP, EC, granules) at low concentration (0.02%) with exposure periods of 12 hours (AICRIP 1972-78). Chlorpyriphos, chlorfenvinphos, and isofenphos consistently gave the best results (Table 6).

Foliar sprays. Early work on chemical control of gall midge was initiated in the early 1950s after the introduction of synthetic organic insecticides. Several insecticides -- including DDT, BHC, toxaphene, dieldrin, parathion, chlordane -- were tried as foliar sprays but were only moderately effective (Patel and Bhat 1954, Patel et al 1957, Israel et al 1959,

Table 6. Effectiveness of selected insecticides as seedling root dip for gall midge control. All India Coordinated Rice Improvement Project (AICRIP), India, 1974-78, kharif.

	Silver shoots (%)					
Insecticide	1974	1975	1976	1977	1978	Mean
Chlorpyriphos	0.8	0.7	4.2	13.0	7.0	5.14
Chlorfenvinphos	4.3	4.3	7.0	-	-	5.20
Isofenphos	-	-	-	6.6	5.3	5.95
Untreated control	10.7	19.0	16.5	21.6	13.6	16.28

Katarki and Bhagavat 1960). Fernando (1962) reported that endrin, dieldrin, diazinon, parathion, and chlordane were promising, but more accurate timing of application was necessary. Israel et al (1963) concluded that four weekly sprayings with 0.08% parathion at 21 to 45 days after transplanting (in the crop's vulnerable phase) resulted in 49% reduction in gall midge incidence. Other effective insecticides reported were phosphamidon 100, dimethoate 40, fenitrothion, EPN, endrin, trichlorfon, and isobenzan. Insecticides that were later reported effective include endrin (Prakasa Rao 1970); fenitrothion (Sathpathy 1970); parathion and endrin (Banerjee 1971); cyanofenphos (Leeuwangh 1971); dicrotophos (Prakasa Rao 1971); trichlorfon 95% WP, diazinon 60% EC, and fenitrothion (Fernando 1971 cited by Hidaka 1974). AICRIP tested as many as 55 spray formulations (wettable powders and emulsifiable concentrates) at several locations from 1970 to 1978. Sprays were generally less effective than other methods. Only fenvalerate, BPMC, mephosfolan, and leptophos were moderately effective.

Granular application in standing water. Israel et al (1969) stated that application in standing water of diazinon, phorate, and lindane granules at 1.25 kg a.i./ha and at 15-day intervals efficiently reduced gall midge infestation. Prakasa Rao (1970) found endrin (0.625 kg a.i./ha) and diazinon (1.25 kg a.i./ha) better and more economical than lindane and carbaryl-lindane. Later studies showed that 2 applications Of diazinon granules at 1.5 kg a.i./ha at the first appearance of gall midge in light traps, and another application 15 days later were effective (Prakasa Rao 1971). Vellayutham et al (1971) tested insecticides at 1.25 kg a.i./ha and reported that diazinon granules gave best results; Wickremasinghe (1971) confirmed the effectiveness of diazinon in Sri Lanka. Further studies with other insecticides revealed that mephosfolan at

2.0 kg a.i./ha (Lindley 1973), and endrin and fensulfothion at 0.75 kg a.i./ha (Regupathy and Jayaraj 1974) were effective. Alam (1973) reported that dieldrin, fenitrothion, diazinon, fenthion, dicrotophos, and phosphamidon controlled gall midge in Bangladesh. Hidaka (1973) noted that diazinon (3%), phorate (10%), and thiadiazinthion (5%) are more effective when applied at 2 kg a.i./ha 14 and 28 days after transplanting.

In AICRIP multilocation tests, about 40 granular insecticides were tested by broadcasting on standing water at 1.5 kg a.i./ha (AICRIP 1972-78). From 1972 to 1974, MIPC, chlorfenvinphos, phorate, fensulfothion, mephospholan, quinalphos, and chlordimeform were found promising. From 1975 to 1978, isofenphos, AC 64,475, disulfoton, carbofuran, and terbuphos were moderately to highly effective. But AC64,475 and carbofuran gave slightly higher yields than even maximum protection treatments with other insecticides.

The effective insecticides were reevaluated from 1972 to 1978 to identify the minimum effective dose. Mephosfolan at 0.5 kg a.i./ha; fensulfothion, carbofuran, quinalphos, and chlorfenvinphos at 0.75 kg a.i./ha and terbufos and MIPC at 1.0 kg a.i./ha effectively controlled gall midge and increased yields (Table 7).

Further AICRIP studies showed that carbofuran and mephosfolan applied in standing water could kill maggots inside the plant as late as 7 days after insect entry, while isofenphos, phorate, fensulfothion, chlorfenvinphos, and mipcin broadcast 1 day after the entry of maggots checked silver shoots (AICRIP, unpubl.).

Root-zone application of insecticides. Granular insecticides at 2.0 kg a.i./ha placed into the root zone at the 2.5-cm depth were effective for more than 100 days against some insects of transplanted rice (IRRI 1972). We tested that application method at three sites with six granular insecticides. Carbofuran and mephosfolan were very effective against gall midge even at 60 days after transplanting (Table 8); diazinon was moderately effective.

Biological control

Investigations on biological control of gall midge have so far been limited to recording its natural enemies and population fluctuations.

As many as 11 parasites and 8 predators have been recorded in different countries. The parasites are *Platygaster oryzae,*

Table 7. Effects of selected granular insecticides on gall midge control and consequent yield increase. All India Coordinated Rice Improvement Project (AICRIP), India, 1972-78.

Insecticide	Rate (kg a.i./ application per ha)	Silver shoots (%)	White-heads (%)	Yield (t/ha)
	1973–74			
Fensulfothion	0.75	6.3	2.4	3.1
	0.50	9.4	0.6	3.1
Chlorfenvinphos	0.75	10.5	1.4	2.0
	0.50	6.8	2.1	2.1
Carbofuran	0.75	6.1	1.7	2.0
	0.50	7.3	2.2	2.1
Mephosfolan	0.75	2.0	1.0	4.3
	0.50	6.7	3.1	2.7
Quinalphos	0.75	8.9	1.1	3.0
	0.50	6.5	4.5	3.0
MPT[a]	--	3.0	0.7	2.6
Check	--	29.9	8.0	1.4

Insecticide	Rate (kg a.i./ ha)	Silver shoots (%)	Dead-hearts (%)	White-heads (%)	Yield (t/ha)
	1975–78				
Terbufos	1.0	13.2	1.4	2.6	3.4
	0.5	24.8	1.8	2.4	2.7
MIPC	1.0	18.9	2.1	1.5	3.2
	0.5	22.6	1.5	4.0	2.8
MPT[a]	--	7.8	0.0	1.8	3.7
Check	--	49.1	6.1	10.2	1.9

[a]Maximum Protection treatment involving seedling root dip, granular application at 1 kg a.i./ha at 20, 40, and 60 days after transplanting, and sprays at 0.5 kg a.i./ha as needed.

P. diplosiae, Platygaster sp., *Telenomus israeli, Proleptacis oryzae, Tetrasticus pachydiplosis, Neanastutus garcillius, Anisopteromalus camerunus, Obtusiclava oryzae, Dicopulus* sp., and *Caffitula* sp. The predators are *Nabis oapsiformis,*

Table 8. Incidence of gall midge and stem borers, and grain yield in root-zone application trials conducted in 1973 kharif, at 3 sites in India.

Insecticide	Gall midge (% silver shoots)	Stem borer (%)		Grain yield (t/ha)
		Deadhearts	Whiteheads	
BPMC	15.2	2.2	4.1	2.9
Carbofuran	3.8	1.2	3.0	3.1
Cartap	25.1	2.1	0.0	2.7
Chlordimeform	24.8	1.0	1.0	2.9
Mephosfolan	2.0	1.5	0.7	3.8
Diazinon	7.4	1.5	4.2	3.0
Untreated control	21.1	10.1	3.6	2.1

Ophionia indica, Gasonoides interstitalis, Isohnura senegalensis, Asilid sp., *Empidid* sp., *Tetragnatha* sp. (spider), and *Amblyseius* sp. (mite). the egg larval parasite *Platygaster oryzae* is reportedly the most important natural enemy of gall midge (Hidaka 1974, Prakasa Rao 1974). In India, the percentage of parasitism increased with the buildup of the pest population (Prakasa Rao 1971), continued beyond the peak midge incidence, and suppressed the population late in the season. The average parasitism during a crop season ranged from 27 to 77% at different sites in Thailand (Hidaka et al 1974). Rice damage was definitely reduced when parasitism reached 50% at an early date.

These studies show the possibility of controlling gall midge buildup through inundative releases of parasites early in the season. Field trials of this kind are yet to be done.

Integrated pest management

In 1975 AICRIP initiated studies on integrated pest management involving resistant and susceptible varieties. Integrated control aims at encouraging maximum control by natural enemies and cultural practices, and applying insecticides only when the former factors fail to suppress the gall midge population. Prescheduled maximum insecticide protection always controlled

Table 9. Role of pest management with resistant and susceptible varieties in gall midge control.[a]

	1977				1978						
	Sambalpur		Cuttack		Cuttack		Bhubaneswar		Mean		
	SS (%) (50 DT)	Yield (t/ha)	SS (%) (30 DT)	Yield (t/ha)	SS (%) (50 DT)	Yield (t/ha)	SS (%) (50 DT)	Yield (t/ha)	SS (%)	Yield (t/ha)	Increase (%)
					Resistant variety						
	CR94-MR1550		*Shakti*		*CR188-10*		*Shakti*				
PM	1.9	3.8	5.1	3.7	3.7	3.8	0.0	3.2	2.7	3.6	16.2
PSM	1.5	4.3	2.0	3.4	1.7	4.1	0.0	3.1	1.3	3.8	26.9
NM	1.8	3.1	4.0	3.6	5.7	2.8	1.4	3.0	3.2	3.1	--
					Susceptible variety[b]						
PM	49.6	1.8	15.0	1.2	24.3	2.0	10.4	3.2	24.8	2.1	22.5
PSM	14.1	2.9	15.1	1.7	19.2	2.8	4.5	2.9	13.2	2.6	53.3
NM	43.0	1.0	20.1	0.9	37.6	2.2	23.2	2.6	30.9	1.7	--

[a]SS = silver shoot, DT = days after transplanting, PM = pest management based on surveillance methodology, PSM = prescheduled maximum insecticide protection, NM = no insecticide.
[b]All trials with a susceptible variety used Jaya.

gall midge better than integrated control in susceptible varieties. But when resistant varieties were used, pre-scheduled maximum insecticide protection and integrated control were similar (Table 9). That suggests that gall midge control is better with resistant varieties even without insecticide application.

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VARIETAL RESISTANCE TO THE BROWN PLANTHOPPER AND YELLOW STEM BORER

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Significant advances have been made in the development of rice varieties with resistance to the brown planthopper (BPH) and the yellow stem borer (YSB), important rice pests throughout tropical Asia, including southern China. Varieties resistant to those pests are widely grown in Asia. Through evaluation of more than 33,000 varieties from the world rice collection, about 300 with high BPH resistance have been identified. Four BPH-resistance genes have been identified and used in IRRI's breeding program. Several BPH biotypes have been characterized through international collaboration to investigate the response of differential varieties. New techniques quantify BPH resistance levels more accurately.

Of about 9,000 world-collection varieties evaluated for YSB resistance, only about 20 showed moderate resistance. The multiple crossing technique is being used to raise the levels of YSB resistance above those of the donor parents.

Insecticides have been used extensively to control BPH and YSF. In the last decade advances in the development of varieties with BPH and YSB resistance have been significant. This paper discusses the advances in development of methodology to identify and characterize varietal resistance to these rice insects.

Records of brown planthopper (BPH) attacks on rice date to 18 AD in Korea and to 697 AD in Japan (Suenaga and Nakatsuka 1958). But the BPH has only recently been considered a major pest in tropical Asia. Since 1973 losses in Indonesia alone have been estimated at US$l50 million. The yellow stem borer (YSB) is a recurring pest. Of the approximately 20 stem borer species reported to attack rice, the YSB is the most destructive and widely distributed. It is found in regions of Asia and in West Africa.

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BROWN PLANTHOPPER

Indian scientists reported the existence of varietal resistance to the BPH in the field in 1954 (Khush 1972). All of the Ch varieties introduced from China were highly susceptible, but several local Indian varieties were resistant. IRRI began to screen for BPH resistance in 1967. Today several Asian countries have active programs to identify and incorporate BPH resistance into agronomically desirable plant types.

Screening for resistance

Greenhouse. Greenhouse screening has been emphasized, but verification tests must also be conducted in areas with high BPH field populations. Greenhouse screening techniques developed at IRRI are being used (with modifications in some cases) in Bangladesh, India, Indonesia, Japan, Korea, Malaysia, the Solomon Islands, Sri Lanka, Taiwan, and Thailand. The screening methods were described by Choi (1979).

At IRRI, virus-free insects are reared on 40- to 50-day-old plants of the susceptible Taichung Native 1 (TN1) or other highly susceptible varieties in a 0.5- x 0.5- x 1-m cage. Each cage supports 2,000-3,000 late-instar nymphs. (In Japan and Korea, insects are mass-reared on seedlings in a transparent plastic cage -- a useful method in areas with cold winters because the cages are small and can easily be accommodated in laboratory rearing rooms.)

The test entries are sown in two types of seedboxes. In the 60- x 45- x 10-cm seedbox, each line is planted in a 15-cm row along with the susceptible check TN1 and the resistant check (Mudgo and ASD7 for biotype 1 screening, ASD7 for biotype 2, and Mudgo for biotype 3). To conserve space, a new seedbox has been developed. It is 106 x 61 x 7 cm and has 252- x 5- x 5-cm compartments. Susceptible and resistant checks are planted in the outer compartments and in two rows of compartments near the center. The seedboxes are then placed on a galvanized iron tray containing water. At about 7 days after seeding, seedlings at the 1- or 2-leaf stage are infested wi-th about 5 second- and third-instar nymphs/plant. When about 90% of the susceptible check plants are killed (about 7-12 days after infestation), the damage is scored (Table 1). In the screening of the germplasm collection or in other nonreplicated tests, entries rated 0-3 are retested. Selected lines or varieties are often further evaluated to determine the mechanisms of resistance.

Field. Before release breeding lines identified as resistant in the greenhouse must be evaluated in the field. Because field resistance may not be expressed in the seedling stage, field screening also identifies varieties with field or general resistance to the various BPH biotypes.

Table 1. Ratings and symptoms used to score brown planthopper resistance in the greenhouse and in the field.

Grade[a]	Rating[b]	Damage symptoms	
		Greenhouse	Field[c]
0	HR	No visible damage (equal to resistant check)	No visible damage
1	R	Partial yellowing of 1st leaf	Partial yellowing with sooty mold at base of plant
3	MR	1st and 2d leaves partially yellow	Stunting and yellowing
5	MS	Pronounced yellowing, some stunting or wilting	Pronounced yellowing or browning, stunting, some dead plants
7	S	More than half of the plants wilting or dead, remaining plants severely stunted	Most plants browning or dead
9	HS	All plants dead (equal to susceptible check)	All plants dead

[a]Standard Evaluation System for Rice (SES). [b]HR = highly resistant, R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, HS = highly susceptible. [c]Mochida et al 1979.

Field screening at some locations is often difficult because of the unpredictability of BPH populations. But the discovery that entomologists could manipulate BPH populations by applying certain insecticides that cause BPH resurgence has made field screening in certain locations possible (Heinrichs et al 1978).

For field screening several border rows are first planted with a BPH-susceptible variety. Depending on seed availability, one to four 5-m long rows of the test entries are planted. One to three rows of the susceptible check are planted between each test entry. The amount of susceptible material depends on the level of expected infestation. BPH populations are induced by spraying the susceptible rows at the end of the test entry with methyl parathion, fenthion, fenitrothion,

diazinon at 100 g a.i./ha, with decamethrin at 10 g a.i./ha, or with any other insecticide that causes resurgence. The BPH on each of 5 hills in each plot are counted between 40 and 50 days after transplanting (DT). Two similar countings are done every 20 days. The varieties are rated for damage on the field scale in Table 1. Damage is rated when about 95% of the TN1 plants have been killed and 3 more times at 5-day intervals.

Sources of resistance

Of the more than 33,000 varieties from the world collection screened by IRRI entomologists for resistance to BPH since 1966, about 300 have been selected. All are indicas; most are from South India and Sri Lanka. More than 500 indica varieties and lines have been found resistant to BPH in screening in the Philippines, Japan, Korea, Taiwan, Thailand, Indonesia, India, Sri Lanka, and Solomon Islands (Choi 1979). Also identified as resistant to the 3 Philippine biotypes at IRRI are 27 accessions of wild rices including *Oryza australiensis, O. brachyantha, O. latifolia,* and *O. punctata* from Australia, India, Africa, Costa Rica, and Guatemala.

Genetic studies have identified four BPH resistance genes (Table 2) Besides the monogenic BPH-resistant varieties listed in the table, four others -- PTB21, PTB33, Sudu Hondarawala, and Sinna Sivappu -- have two unidentified genes for resistance. The recently identified genes *Bph 3* from Rathu Heenati and *bph 4* from Babawee, and the two unidentified genes in PTB33 have been used in the breeding program.

Table 2. Genes of some brown planthopper-resistant varieties (Khush 1977 and IRRI 1978).

Varieties with given gene for resistance			
Bph 1	*bph 2*	*Bph 3*	*bPh 4*
TKM6	ASD7	Rathu Heenati	Babawee
Mudgo	PTB18	PTB19	Gambada Samba
MTU15	H105	Gangala	Hotel Samba
CO22	ASD9	Horana Mawee	Kahata Samba
	Palasithari 601	Muthumanikam	Thirissa
	H5	Kuruhondarawala	Sulai
		Mudu Kiriyal	Vellai Illankali
			Heenhoranamawee
			Kulu Kuruwee
			Lekam Samba
			Senawee

Several resulting new lines have resistance to the three Philippine biotypes and have been sent to other countries through the BPH Collaborative Project to determine their resistance to other biotypes.

Nature of resistance

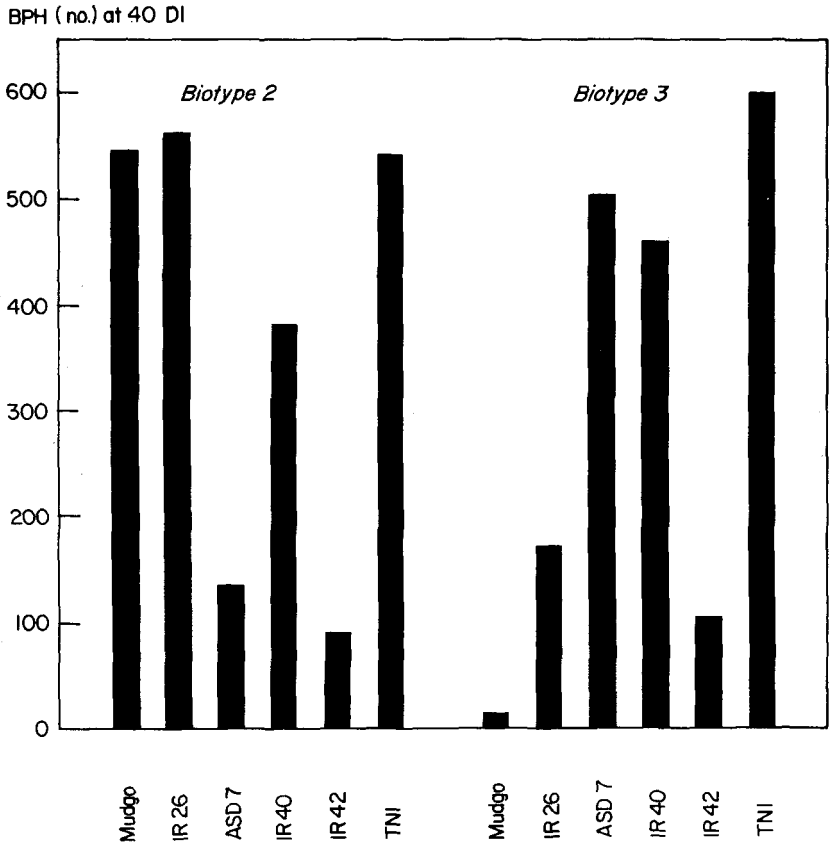
Preference. Pathak and Khush (1979) described a methodology for determining the preferences of BPH nymphs and adults. The seedling screening technique described earlier is used to determine nymphal preferences. The number of nymphs on each entry is recorded 24 hours after infestation and at 2–day intervals thereafter until the susceptible check is killed.

In determining adult preferences, individual plants of test entries are randomly grown 10 cm apart in seedboxes. At 30 days after sowing, the plants are pruned to 2 tillers/plant and 1– to 2–day-old adults are released on them. The insects are counted 3–12 hours after infestation, and then daily for 3 days. The number of eggs laid on each plant is then recorded.

Antibiosis. There are various techniques for measuring the BPH antibiosis levels of rice varieties. Although time–consuming, they are particularly useful in identifying varieties with moderate levels of resistance and with field resistance. The techniques that use survival and development of nymphs, population development, and feeding rates as measures of antibiosis are discussed.

1. *Survival and development of nymphs.* Ten 30–day-old plants of each test entry are transplanted into 10–cm clay pots, covered With 6– x 30–cm mylar film cages, and infested with 10 newly emerged nymphs. The number of surviving nymphs is recorded 24 hours after infestation and at 5–day intervals thereafter Until all nymphs on the susceptible check become adults.

2. *Survival and population development.* Ten–day-old seedlings are planted in 16–cm clay pots, in 5 replications. Each pot contains 3 seedlings (1 pot/replicate). Thirty days after transplanting (DT) the plants are placed inside 13– x 90–cm mylar cages with fine–mesh screen windows and infested with 10 freshly hatched nymphs. The surviving insects are counted at 20 days after infestation (DI) for insect survival and at 40 DI for populatipn buildup. In cases where heavy populations develop and kill the susceptible check before 40 DI, the insects on all test entries are counted just before the susceptible check dies, and the actual date of counting is recorded.

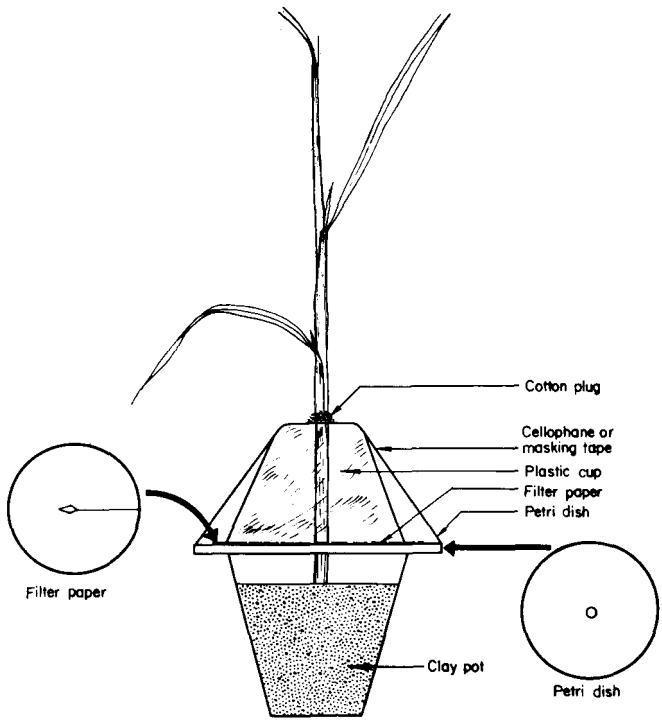


1. *Populations at 40 days after infestation (DI) resulting from 10 newly hatched nymphs of brown planthopper (BPH) females of biotypes 2 and 3 fed on selected varieties. IRRI greenhouse, 1978.*

Another method for determining the rate of population development is placing a pair of newly emerged adults on a 30-day-old plant growing in a 13- x 90-cm mylar film cage. The total number of insects at 20 and 40 DI indicates survival and population increase. Figure 1 illustrates the population development of biotypes 2 and 3 feeding on various varieties.

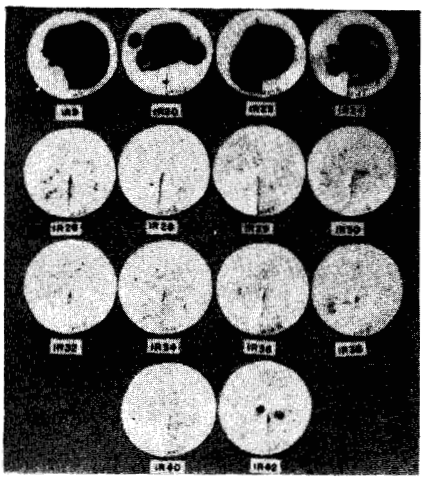
3. *Feeding rate.* Several techniques for determining the quantity of BPH feeding have been developed. The filter paper and volumetric techniques (Paguia et al 1980) are described.

The filter paper method uses a feeding chamber (Fig. 2) developed by Sogawa and Pathak (1970). The chamber consists of an inverted transparent plastic cup placed over filter paper resting on a plastic petri dish. Five 2-day-old adult



2. *An apparatus for collection of honeydew.*

females previously starved for about 5 hours are placed into the chamber through a hole at the top of the cup. The hole is plugged with a cotton wad to prevent insect escape. The insects are allowed to feed overnight. The next morning the filter paper is treated with 0.001% ninhydrin in acetone solution. After oven-drying for 5 minutes at 100°C, the honeydew stains appear as violet or purple because of the amino acid contents. The area covered by the purple stain indicates the amount of feeding (Fig. 3). The area of the spots can be estimated either visually or, more accurately, by using the tracing-paper technique. In the latter, the spots are traced on tracing paper. The tracing paper is placed over graphing paper and squares covered by the spots are counted. The method has been successfully used to determine the amount of feeding of the three biotypes of differential varieties (Table 3) and may be used to identify biotypes.



3. *Honeydew excreted on filter paper by 5 brown planthopper biotype 1 female adults on 30-day-old IR varieties. IRRI, 1978.*

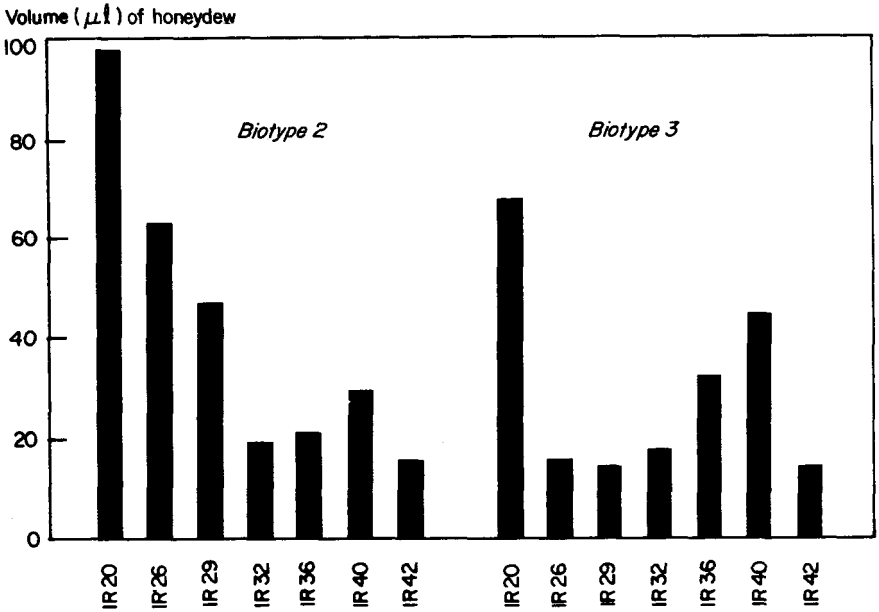
Another technique is cutting out the stained portions of the filter paper and weighing those portions on a milligram balance. Results are expressed in milligrams of filter paper containing honeydew droplets.

In the volumetric method, fresh honeydew is collected in a feeding chamber as described earlier but slightly modified by Alam (1978) and Iman (1978). Parafilm is stretched over the base of the inverted cup to seal the chamber. Five previously

Table 3. Area of ninhydrin-positive honeydew excreted by brown planthopper biotypes 1, 2, and 3 on rice varieties. IRRI, 1978.

Variety	Resistance gene	Area[a] (mm^2)		
		Biotype 1	Biotype 2	Biotype 3
TN1	None	668 a	838 a	929 a
Mudgo	*Bph 1*	83 b	504 a	74 b
ASD7	*bph 2*	68 b	229 b	625 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level.



4. *Volume of honeydew excreted by 5 brown planthopper females feeding on IR varieties. IRRI, 1978.*

starved 2-day-old BPH females are placed in the chamber through a small hole at the top of the cup. The hole is then tightly sealed with parafilm to minimize evaporation of the honeydew droplets and to make quantification possible. Overnight feeding provides sufficient honeydew droplets on the parafilm for measurement. Calibrated micropipettes of various sizes (1-100 μℓ) are used to measure the volume of excreted honeydew. Figure 4 indicates the volume of honeydew excreted by biotypes 2 and 3 feeding on IRRI varieties.

Tolerance. Some workers do not consider tolerance a desirable type of resistance. Few techniques have therefore been developed to determine tolerance levels. Tolerance is a component in recent IRRI studies to determine the mechanisms involved in the field resistance of certain varieties (Dang Thanh Ho, IRRI, personal communication). Varying BPH populations are placed on the test entries at 25 and 40 DT and the level of tolerance is based on the number of tillers produced, the leaf area index, and the yield.

Causes of resistance

Only recently have studies to determine the biochemical bases of BPH resistance received considerable research input at IRRI.

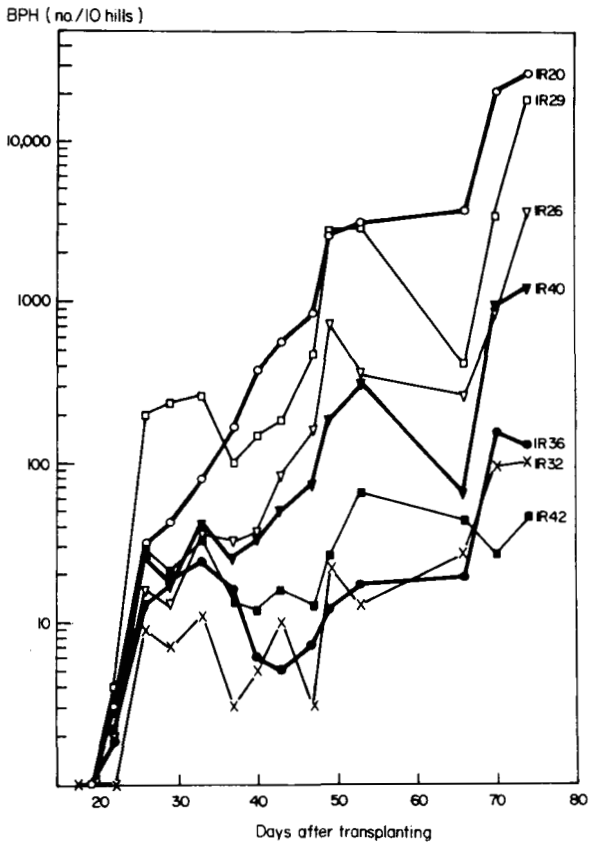
The various amino acid contents of cultivars vary. Studies in 1977 indicated that amino acids differ in activity as feeding stimulants in the three biotypes (IRRI 1978). Asparagine and valine are highly phagostimulatory to biotype 1, alanine to biotype 2, and valine and serine to biotype 3.

Cooperative studies with scientists from the Tropical Agriculture Research Center (TARC) and Hokkaido University in Japan showed that oxalic acid isolated from the resistant variety Mudgo acted as an antifeedant to BPH (IRRI 1978). More recent studies have shown oxalic acid to be present in all rice varieties tested, but levels are highest in BPH-resistant varieties (K. Sogawa, IRRI, personal communication).

Field resistance

Recognition of the occurrence of BPH biotypes has sparked interest in the development of varieties with field or general (horizontal) resistance to all biotypes. Plant pathologists are considering field resistance for disease control but it is a new concept in varietal resistance to rice insects. Certain varieties such as Kencana in Indonesia (Mochida et al 1979) have no major genes for resistance and are susceptible in greenhouse seedling screening as older plants but, are resistant in the field. At IRRI and at other locations, Triveni, which has no major resistance gene, has been observed as susceptible in the seedling stage but resistant in the field. IR26 and Mudgo, which carry the *Bph 1* gene for resistance, are susceptible to biotype 2 in the greenhouse. IR26 is readily killed in IRRI fields, where biotype 2 is abundant, but Mudgo is resistant. Techniques to identify field-resistant varieties and to determine the causes of field resistance are being developed through the Collaborative Project on BPH resistance.

Besides field screening, two other techniques are used to study the level of field resistance. One determines the rate of population development and the other the amount of feeding on varieties of various ages. In IRRI field tests, varieties with the same major resistance genes have responded differently to BPH attack. For example, Mudgo had low BPH populations while IR26, which has the same major resistance gene, had high BPH populations and was hopperburned. In field studies BPH populations were low on IR36, IR32, and IR42 but high in IR40 which has the same major resistance gene *bph 2* (Fig. 5). IR32, IR36, and IR42 may have minor genes that contribute to field resistance. Studies on the rate of papulation development and feeding on older plants have indicated that greenhouse techniques that can identify varieties with minor genes for field resistance can be developed. But additional techniques must be developed to efficiently identify field-resistant varieties, determine the mechanisms involved in field resistance, and breed for field resistance. The advantages of growing field-resistant varieties over growing vertically resistant varieties must also be assessed.



5. Brown plonthopper (BPH) populations on susceptible and resistant varieties sprayed 7 times with cypermethrin, a resurgence-inducing insecticide. IRRI, 1978.

Biotypes. The first indication of the existence of BPH biotypes was seen when IR26, the first BPH-resistant variety released by IRRI, was found susceptible when grown in India. After IR26 had been grown for 2 or 3 years in Indonesia and the Philippines, reports of hopper-burn damage indicated a shift in the BPH population where a virulent biotype was becoming abundant because of selection pressure.

Analysis of data from the International Rice Brown Planthopper Nursery (IRBPHN) provided additional information on the existence of BPH biotypes throughout Asia. The reactions of differential varieties indicate that biotypes in Southeast Asia are different from those in South Asia. ARC10550, which is susceptible throughout Southeast Asia, is resistant at all locations in South Asia (Table 4). Differential reactions occur even within even one country in South Asia (see reactions at Pattambi, Hyderabad, Cuttack, and Pantnagar, India,

Table 4. Differential reactions of rice varieties to brown planthopper (BPH) biotypes in greenhouse screening at various locations.[a]

Variety	Gene for resistance	Differential reaction to BPH								
		Southeast Asia			South Asia					
		Philippine biotype			Bangladesh	Pattambi, India	Hyderabad, India	Sri Lanka	Cuttack, India	Pantnagar, India
		1	2	3						
Sinna Sivappu	2, unidentified	R	R	R	R	R	R	R	R	R
Babawee	*bph 4*	R	R	R	R	R	R	R	S	S
PTB33	2, unidentified	R	R	R	R	R	R	–[b]	R	S
Rathu Heenati	*Bph 3*	R	R	R	R	R	S	R	S	S
ASD7	*bph 2*	R	R	S	S	S	S	S	S	S
Mudgo	*Bph 1*	R	S	R	S	S	S	S	S	S
ARC10550	?	S	S	S	R	R	R	R	R	R
TN1	None	S	S	S	S	S	S	S	S	S

[a] Based on International Rice Brown Planthopper Nursery (IRBPHN). 1976–78. R = resistant, S = susceptible. [b] Variable reactions.

Table 4). The Brown Planthopper Collaborative Project was developed to classify the various biotypes more accurately than can be done in the IRBPHN. Entomologists throughout Asia collaborate with IRRI to evaluate a set of differential varieties in greenhouses and fields.

So far, efforts to develop a practical method to characterize BPH biotypes other than by planting differential varieties and observing their reactions to BPH feeding, or the amount of feeding on each, have had little success (Paguia et al 1979). Sogawa (1978a) compared the electrophoretic variations in esterase among the Philippine biotypes and successfully separated out biotype 2 but could not separate biotypes 1 and 3. Sogawa (1978b) also attempted to identify morphologic characters that could be used to identify BPH biotypes. He found some variation in the average number of spines on the hind basitarsus among biotypes, but no sufficient differences to make the method useful for biotype identification.

YELLOW STEM BORER

Rice varieties are known to differ in their susceptibility to the yellow stem borer (YSB) for more than 60 years (Shiraki 1917). But the development of YSB-resistant varieties has been slower than of BPH-resistant varieties because of the lack of major genes that impart high levels of YSB resistance and the lack of efficient screening techniques.

When IRRI first began to screen for stem borer resistance, the field population was about 90% striped stem borers *Chilo suppressalis* and only 8% YSB. The striped borer initially received priority in the screening program (Pathak 1967). Later, screenhouse methods that facilitated screening for YSB resistance were developed.

Field screening for resistance

When conditions are suitable, field screening under natural infestation is preferred for evaluating varieties for stem borer resistance. Little labor is required, field space is not generally a problem, and entomologists can screen several thousand varieties per year. The major problems are that the stem borer populations are often a mixture of species and are too low for adequate evaluation. For proper screening, YSB populations must be sufficient to cause about 40% dead-hearts or 20% whiteheads. The following techniques should provide a population sufficient for field screening:

1. Location. Select a "hot spot" where stem borer populations are generally high.
2. Time of planting. Stem borer populations are seasonal; select the time of year when populations are highest. If light trap data from previous years are available, they can

be used as a guide in determining the planting date.

3. Lights. Adult stem borers are attracted to lights. Other insects are also attracted and, if abundant, may affect the stem borer study.

Planting of test entries. Each entry is planted in a 5-m row. One row of a susceptible (Rexoro or IR29) and another of a resistant check (IR1820-52-2-4-1) are planted after every 20 entries. In the initial screening of the germplasm collection, each entry is replicated only once, but in retests the selected varieties are replicated three times in a randomized complete block design.

Evaluation. Because the number of plants involved in the initial screening of the germplasm collection is large, damage is assessed visually and only the best entries are selected for retesting. In the evaluation of breeding lines and retesting of selected entries from the germplasm collection, deadhearts on all plants, except the two border plants at both ends of the rows, are counted at 30 and 50 DT. Because maturity varies widely in the germplasm collection, whiteheads are generally not counted.

The following rating system for deadheart incidence has been proposed for inclusion in the Standard Evaluation System (SES).

The test is considered valid if deadhearts in the susceptible check average at least 25%. Deadheart percentage are converted on the basis of the insect pressure, as indicated by the susceptible check.

$$\text{Deadheart index} = \frac{\text{Deadhearts (\%) in test entry}}{\text{Deadhearts (\%) in susceptible checks (av of 2 closest replicates)}}$$

The converted figure has a corresponding rating on the 0-9 SES scale as follows:

Scale	*Deadheart index*	*Level of resistance*
0	0	Highly resistant
1	0.10-0.20	Resistant
3	0.21-0.40	Moderately resistant
5	0.41-0.60	Moderately susceptible
7	0.61-0.80	Susceptible
9	>0.81	Highly susceptible

Screenhouse screening for resistance

Source of initial insect population. Egg masses are collected from rice seedlings grown in the field. The leaf portion on which they are

laid is detached, and placed on moist cotton inside a glass jar with a screen cover. Egg masses are often abundant on seedlings at 2 or 3 weeks after transplanting. Weekly planting can provide seedlings regularly if needed. Female moths can also be collected near lights in the evening. Newly laid eggs can be stored in an incubator at 15 to 20°C for about 2 weeks with no decrease in egg hatch.

Planting of test entries. IRRI uses a 25- x 22- x 2-m screen cage and 6 2.5-m wide concrete beds. Seeds of the susceptible check Rexoro or IR29, the resistant check IR1820-52-2, and the test entries are planted in wooden boxes in soil 5 cm deep. At 14 days after sowing, the seedlings are transplanted on the concrete beds, spaced 20 cm between rows and 10 cm within a row. Each variety is planted in 1 row. After every 10 rows of test entries, 1 row of the susceptible and another of the resistant check are planted.

Infesting plants with larvae. At 14 DT, plants are infested with newly hatched larvae. The larvae are removed from the jar with a fine camel's hair brush dipped in water. Five larvae are placed on one tiller in each hill. The larvae readily distribute themselves by moving to other tillers.

Evaluation. The deadhearts are counted 2 times, at 2 and at 4 weeks after infestation. Deadheart incidence is calculated and converted to the SES scale using the procedures described under field screening for resistance.

Sources of resistance

Extensive field screening at the Central Rice Research Institute (CRRI), India, in the 1950s identified TKM6, MTU15, and SL012 as moderately resistant to both deadheart and whitehead damage (Israel 1967). Since 1972 IRRI entomologists have evaluated more than 9,000 varieties from the world collection for YSB resistance in the field and in the house (Akinsola 1973, Manwan 1975, Heinrichs and Malabuyoc, unpubl.). Table 5 lists selected entries. Of the about 100 wild rices screened, none have shown good resistance. The screening of wild rices and *O. sativa* from the germplasm collection continues.

Through screening in the International Rice Stem Borer Nursery (IRSBN), IRRI has identified some breeding lines with resistance to YSB (Table 6). IR1820-52-2 has consistently shown good field and screenhouse resistance at IRRI and in the IRSBN in various countries.

Breeding for YSB resistance

Evaluation of thousands of rice varieties has revealed the generally low level and the continuous or polygenic nature of YSB resistance. To accumulate resistance from several donors for incorporation into

Table 5. Selected cultivars moderately resistant to the yellow stem borer. IRRI 1972-79.

Acc. no.	Cultivar	Origin
5816	CO15	India
6041	CO7	"
6365	MTU15	"
8763	DM27	Bangladesh
10191	Mainagiri	India
11055	Warangal Culture 1253 (EK 1253)	"
11057	Warangal Culture 1263 (EK 1263)	"
11261	Lepgu	Philippines
14423	IARI5829	India
20925	ARC10451	"
21959	ARC12171	"
22023	ARC12387	"
22948	Kong Sralas	Khmer Republic
23177	Phdao Pen DK-81	"
24739	Kuatik Serai Rendah	Indonesia
25832	Aus Balam	Bangladesh
26401	Moni Mukul	"
26952	Biplab	"
29953	Donangnouan	Laos
30848	Liberian Coll. Y-082	Liberia
	IRAM1642	Madagascar
12890	Ratna (CR44-11)	India
	Kwa-hwa-yuan	
	Kobumasari	

improved varieties, IRRI follows a systematic program involving multiple crosses of several rices with low or moderate resistance levels.

The first cycle of the hybridization program, begun in 1975, used these sources of resistance: IR1514A-E666, IR1539-823, IR1628-632, IR1704-3-2, IR1721-11, IR1820-52-2-4-1, IR1917-3-19, IR2061-628, Ratna, WC1263, and IR36. Single and double crosses involving IR36 survived severe field infestations of ragged stunt virus in 1976. In the 1977 dry season, plants were selected in the F_2 field and 459 F_3 lines from 10 crosses were screened under stem borer infestation. In the 1978 wet season those lines were tested in the observational yield trial for blast, bacterial blight, two BPH biotypes, and the green leafhopper (Table 7). The most promising lines were sent to various national programs for further stem borer resistance evaluation. Selected lines from the following crosses have also been included in the special IRTP stem borer screening nursery set: IR1365

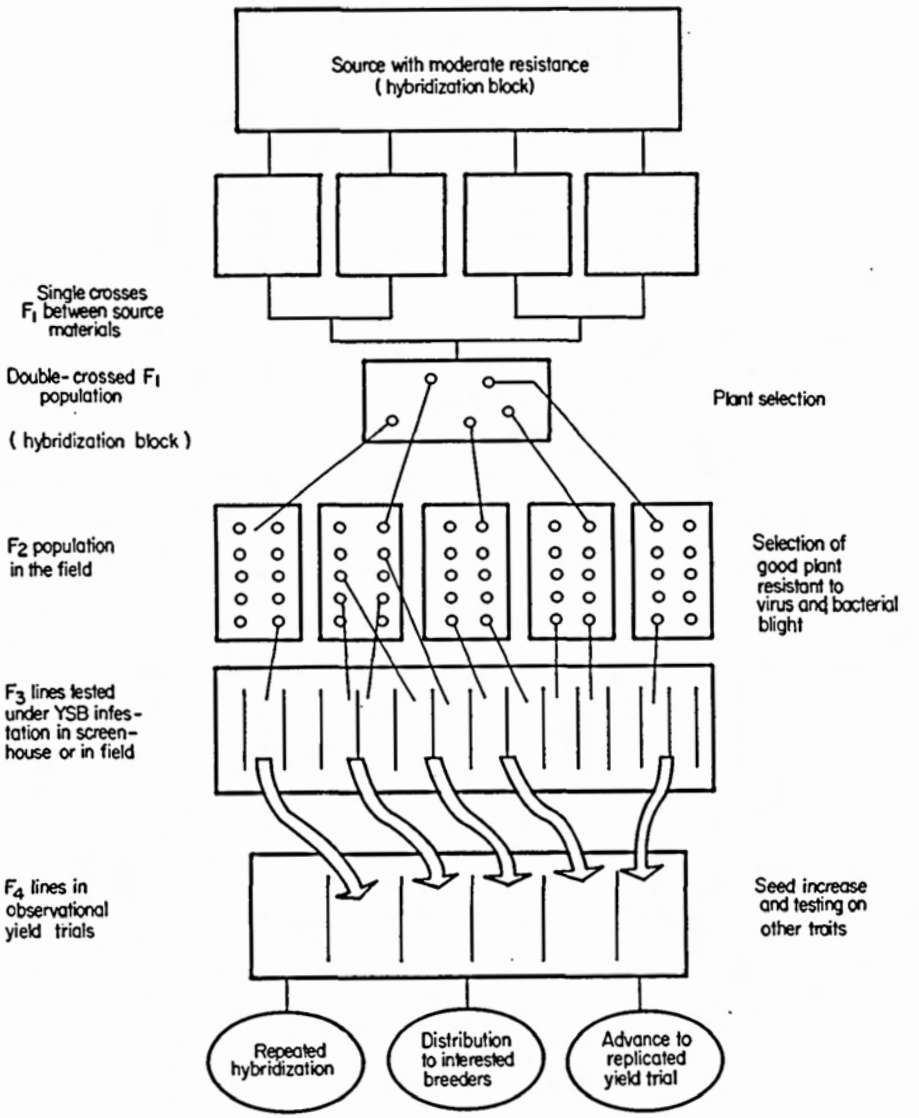
Table 6. Selected entries in the International Rice Stem Borer Nursery with resistance to the yellow stem borer in the Philippines. IRRI, 1976-78.

Designation	Cross	Origin
IET2845	TKM6/IR8	India
IET3093	TKM6/IR8	India
IET5262	IR22/NP130	India
IET5561	Panvel 17-18/IR8	India
IRl544-E666	IR20/TKM6	Philippines
IRl820-52-2	IR539-60/IR1416-128-5	Philippines
IR3941-97-1	CR26-42-5/IR2061-21-3	Philippines
IR5201-122-2	IRl820-52-2/IR2061-464-2	Philippines
IR5201-127-2	IRl820-52-2/IR2061-464-2	Philippines
IR36	IR1561//IR24*4/ *O. nivara* ///CR94-13	Philippines
RD9	LY*Z/TN1//W1256///RD2	Thailand

Table 7. Resistance of selected F_3 yellow stem borer-resistant lines to insects and diseases. IRRI, 1978.

Line	Damage rating[a]					
	Blast	Bacterial blight	Brown planthopper		Green leafhopper	Yellow stem borer
			Biotype 1	Biotype 2		
IR13639-37	1	1	1	1	3	3
IR13639-42	1	1	1	3	3	3
IRl3641-4	1	1	1	3	3	1
Check						
IRl820-52-2 (resistant)	2	7	1	9	3	5
Rexoro (susceptible)	-	-	-	-	-	9

[a]Standard Evaluation System (SES) for Rice: 1 = resistant, 9 = highly susceptible.



6. *Breeding program for resistance to the yellow stem borer (YSB).*

Table 8. Multiple crosses evaluated for yellow stem borer resistance (second cycle) at the Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, Philippines. MRRTC and IRRI, 1978–79.

Designation	Cross	Lines tested (no.)	Lines selected (no.)
IR19334	IR3941–92-2/IR1514A-E666//IR2071-625-1-252	250	43
IR19335	IR3941–9-2/IR1917-3-19-2//IR2071-625-1-252	255	42
IR19361	IR4227–28-3-2/IR1514A-E666//IR2071-625-1-252	250	47
IR19362	IR4227–28-3-2/IR1917-3-19-2//IR2071-625-1-252	200	53
IR19390	IR4427–51-6-3/1R1514A-E666//IR2071-625-1-252	250	86
IR19391	IR4427–51-6-3/IR1820-52-2//IR2071-625-1-252	244	100
IR19392	IR4427–51–6–3/IR1817–3–9–2//IR2071–625-1-252	301	67
	Total	1750	438

Table 9. Resistance to yellow stem borer of selected lines from multiple crosses. MRRTC[a] and IRRI, 1978.

Line	IRRI screenhouse		Field test at MRRTC	
	Deadheart (%)	Grade[b]	Deadhearts (%)	Grade[b]
IR19392-1	19	3	19	3
IR19392-6	19	3	13	1
IR19392-85	20	3	21	3
Rexoro (susceptible check)	65	9	85	9
IRl820-52-2 (resistant check)	23	3	23	3

[a] Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines. [b] 1 = resistant, 9 = susceptible.

(IR1628-632-1/IRl917-3-19-2//IR1539-823-1/IR2071-625-1-252), IR13639 (IR1704-3-2-3/IRl514A-E666//IR1628-632-1/IR2071-625-2-252), and IRl3641 (LRL721-11-68-3/IR2307-64-2//IR1628-632-1/IR1514A-E666). Figure 6 illustrates the flow of materials in the IRRI breeding program for YSB resistance.

In the second breeding cycle, new resistance sources from the International Rice Observational Nursery were used. IR2307-217-2-3, IR3941-97-1, and IR4427-51-6-3 (which are as resistant as IRl820-52-2) were crossed to resistance sources such as IR1514A-E666 and IRl820-52-2. In most crosses IR36 was topcrossed or included as a component of the parentage because of its resistance to the BPH and green leafhopper, and moderate stem borer resistance. During 1978-79, 1,750 F_3 lines were field evaluated in *hot spot* conditions at the Maligaya Rice Research and Training Center (Table 8). Many lines were outstanding (Table 9); those with lower deadheart readings than the resistant check IR1820-52-2 were included in the observational yield trial for selection of other important traits.

In the 1978 wet season, the third breeding cycle was initiated with smrces selected from the first IRSEN such as IET2815, IET2830, and IET2845 (selections of the RP6 cross, TKM6/IR8) and IET5540 (from the R34 cross, IR22/NP130). They were crossed with lines from the first cycle of IRRI's YSB breeding programs; the F_1s will be crossed with lines having the new BPH-resistance genes *Bph 3* and *bph 4.*

CONCLUSION

In the last decade significant advances in the development of rice varieties that are resistant to the BPH and YSB have been made. Those resistant varieties are grown on millions of hectares throughout Asia as components of an integrated control program. But serious obstacles still confront breeders and entomologists who work together developing resistant varieties. In many regions farmers still do not grow insect-resistant varieties because such varieties possess characters that affect their acceptability. The BPH is a constant threat because selection of new biotypes that can negate a resistant variety's value is possible. Although the level of YSB resistance has been increased through multiple crossing, higher resistance levels are still desirable. Such levels of resistance can most expediently be achieved through close cooperation among scientists of all disciplines involved in rice improvement.

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BREEDING RICE FOR MULTIPLE DISEASE AND INSECT RESISTANCE

G. S. Khush

Rice is the host of more than 60 disease organisms and more than 100 insects. Of international importance are five diseases (blast, sheath blight, bacterial blight, tungro, grassy stunt) and five insects (brown planthopper, green leafhopper, whitebacked planthopper, gall midge, and stem borer). Varietal resistance is the most economical and logical approach to protection of the rice crop. A large collection of rice germplasm maintained at IRRI has been screened for resistance to major pests. Sources of resistance to most of the major diseases and insects have been identified and transferred to cultivars of improved plant type. Improved germplasm with resistance to as many as 4 diseases and 5 insect species has been developed by using improved lines that are resistant to 1 or 2 pests. These multiple-resistant lines have been named as varieties and are widely grown in a number of countries. Breeding methods and procedures for developing multiple-resistance germplasm are discussed.

Disease and insect problems of rice have increased tremendously in recent years; the complexities of pest control have consequently multiplied. There is an acute awareness of the problems associated with chemical pest control. The need for alternate control methods are made obvious by rising costs of chemicals, the accumulation of undesirable residues, environmental pollution, pest resistance to insecticides, and the destruction of useful insects and fauna. Therefore, emphasis on the development and use of pest-resistant rice varieties has increased.

Resistant varieties control pests at no additional cost to the farmer, and are compatible with other control methods in

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integrated pest control programs. Cultivation of resistant varieties is not subject to vagaries of the weather, as are chemical and biological control methods. Resistant varieties are particularly valuable in developing countries where farms are small and economic constraints and lack of technical knowledge limit the use of chemicals.

MAJOR RICE DISEASES AND INSECTS

Rice is the host of more than 60 diseases and more than 100 insect pests. In most rice-growing areas, more than one disease or insect seriously reduce yields. In Latin America for example, blast, *hoja blanca* , and *Sogatodes oryzicola* are the major factors limiting rice production. In Africa, blast and stem borers take serious tolls of rice yields. In Asia, where 922 of the world's rice is grown and consumed, more than a dozen diseases and insects cause epidemic losses. In the Asian tropics, pest problems are more serious because of the year-round favorable climate and the long history of rice cultivation. One year, bacterial blight epidemic may occur; the next year, green leafhopper and tungro may cause serious damage; the following year, an outbreak of brown planthopper and associated grassy stunt may devastate crops. Therefore, varieties with multiple resistance to most major insects and diseases are needed to minimize yield losses. Five diseases -- blast, sheath blight, bacterial blight, tungro, and grassy stunt -- and five insects brown planthopper, green leafhopper, whitebacked planthopper, stem borer, and gall midge -- are common in most tropical and subtropical Asian countries (Khush 1977a).

GERMPLASM RESOURCES

The International Rice Research Institute (IRRI) maintains a large collection of rice germplasm; many national research centers maintain similar collections. Those collections have been evaluated for resistance to important pests; sources of resistance for each of them have been identified. Some of the cultivated germplasm were found highly resistant to blast (Ou et al 1975), bacterial blight (Ou et al 1971), tungro (Ling 1969), brown planthopper (Pathak 1972), green leafhopper (Cheng and Pathak 1972), and whitebacked planthopper (IRRI 1977). Although resistance to grassy stunt virus disease was not found among the cultivated varieties, one accession of the wild rice *Oryza nivara* was found highly resistant (Ling et al 1970). No high resistance levels to stem borer and sheath blight have been found. Varieties with moderate stem borer resistance have been identified (Pathak et al 1971). Several programs have identified sources of resistance to gall midge (Khush 1977b).

IMPROVING THE SOURCES OF RESISTANCE

Many donor parents have poor plant type -- typical of the tall traditional varieties of the tropics. As a first step the genes for resistance were transferred into cultivars of improved plant type (characterized by IR8) by crossing the donor parents with improved parents. In the earlier years TN1, IR8, IR24, and IR262-43-8 were extensively used as improved plant-type parents. Several improved pest-resistant lines with good grain quality were selected from those crosses. Highlights on each disease and insect resistance follow:

Blast

IRRI's blast resistance breeding program emphasizes the use of diverse resistance sources such as H105, Nahng Mon S4, Dawn, B589A4, Kam Bau Ngan, Gam Pai 15, Sigadis, and Tetep. Crosses involving TKM6 and *O. nivara* have also yielded several blast-resistant lines. IRRI's normal practice is to test the improved progeny in nurseries at least 2 or 3 times/year, for several years. Those lines are thus exposed to numerous prevalent blast races. Only those lines that show resistance for several years are selected and used in the crossing program. Many highly resistant breeding lines were selected from crosses including Tetep and Gam Pai 15. Three IRRI-named varieties -- IR28, IR29, and IR34 -- inherit their strong resistance from Gam Pai 15.

We have recently initiated a program of gene identification for known blast races. Major blast resistance genes will be identified and incorporated into progeny of improved plant type; many of those lines may be named as varieties in national programs.

Bacterial blight

IRRI's bacterial blight resistance breeding program has produced several successful varieties and breeding lines that are widely grown in Asia and that have served as parents in numerous crosses at IRRI and in national programs. The bacterial blight-resistant varieties IR20 and IR22 were released in 1969; IR26 in 1973; IR28, IR29, and IR30 in 1974; and IR32 and IR34 in 1975. The Philippine government has released several other resistant breeding lines such as IR36, IR38, IR40, IR42, IR44, and IR46. Those varieties all have a single dominant resistance gene *Xa 4.* We have incorporated *xa 5* into our improved materials; *Xa 6* and *Xa 7* are also being used in the breeding program.

Tungro

The breeding program for tungro virus resistance was initiated in 1966–67. Several resistant varieties –– Peta, Intan, Sigadis, TKM6, HR21, Malagkit Sungsong, Gam Pai 15, PTB18, Pankhari 203, and BJ1 –– were used as donor parents. Improved breeding lines with tungro resistance were identified from crosses of most of those parents: seven IRRI–named varieties are moderately to highly resistant to tungro; IR20, IR26, and IR30 inherit their moderate resistance from TKM6; Gam Pai 15 is the donor parent of the highly resistant IR28, IR29, and IR34; IR36, IR38, IR40, and IR42 inherit their resistance from PTB18. We now use several new resistance sources in our hybridization program. Strong resistance to tungro vectors also protects the crop from the disease's ravages. Many vector–resistant breeding lines, when screened by artificial inoculation techniques, show high tungro susceptibility, but escape disease infection in the field.

Grassy stunt

O. nivara is the only known source of resistance to grassy stunt virus. It is a wild plant with weak stems, spreading growth habit, shattering panicles, long awns, red pericarp, and low yield potential. In 1969 we crossed *O. nivara* with IR8, IR20, and IR24. The F_1 plants from those crosses were backcrossed four times using IR8, IR20, and IR24, respectively, as recurrent parents. For each successive backcross, we selected F_1 plants that morphologically resembled the recurrent parents. By late 1970, we had grassy stunt–resistant lines that resembled IR8, IR20, and IR24. But those lines lacked other desirable traits such as brown planthopper and tungro resistance. Therefore, we used them as parents in numerous crosses from 1971 to 1973. More than 80% of the crosses made in 1972 had at least one resistant parent. We evaluated segregating populations from those crosses in fields at IRRI where disease pressure was severe from 1971 to 1974. Rigorous IRRI field screening enabled us to select numerous grassy stunt–resistant lines that were also resistant to several other pests, and had the desired agronomic traits and grain quality. IRRI released the first grassy stunt–resistant varieties –– IR28, IR29, and IR30 –– in 1974, and IR32 and IR34 in 1975. The Philippine Government released the grassy stunt–resistant IR36 and IR38 in 1976, and IR40 and IR42 in 1977 (Khush et al 1977).

Brown planthopper

Breeding for brown planthopper (BPH) resistance was initiated when resistance sources were identified. Several promising breeding lines were developed from crosses of Mudgo with IR8, IR22, and IR24. Two improved breeding lines –– IR747B2–6–3

and IR1154-243 — were found resistant to BPH in the field, although none of their parents were resistant. We immediately crossed those lines with other promising lines. One such line -- IRl561-149-1 from the cross IR579-48-1-2/1R747B2-6-3 — was crossed with IR1737, a grassy stunt-resistant line from the 4th backcross of *O. nivara* to IR24. The F_1 was topcrossed in 1971 with IR833-6-2, a tungro-resistant line from the cross Peta[3]/ TNl//Gam Pai 15. Progeny from the cross were thoroughly evaluated for resistance to all major pests and for grain quality and agronomic traits. Three promising lines from this cross were named IR28, IR29, and IR34. These varieties, as well as IR26 and IR30, have the *Bph 1* gene for BPH resistance. The first of those lines, IR26, was released in 1973 and was widely grown in the Philippines, Indonesia, and Vietnam.

But within 3 years of their release and widespread cultivation, IR26 and other varieties with *Bph 1* resistance became susceptible to a new BPH biotype. By 1976 breeding lines with the *Bph 2* resistance genes were ready; several were released as varieties in the Philippines, Indonesia, and Vietnam. Some, such as IR36 and IR42, are widely grown. We have also developed breeding lines in which the *Bph 3* and *bph 4* genes govern resistance.

Green leafhopper

Several parents such as Peta, FB24, Tjeremas, and Sigadis were used in the IRRI crosses. Lines from those crosses were later found resistant to green leafhopper (GLH) (Cheng and Pathak 1972). Many progeny of those crosses -- including IR5, IR8, IR20, and IR24 -- inherited their GLH resistance from those parents; those varieties and many breeding lines with GLH resistance were used as resistance sources in crossing programs. Most of the IRRI crosses after 1969 had at least one parent with GLH resistance. Progeny from those crosses were thoroughly screened; only those with resistance were saved. All IRRI-named varieties, except IR22, and all the IRRI lines named by the Philippine Government are GLH-resistant. Of the five known genes for GLH resistance, three have been incorporated into improved varieties. We have also transferred some GLH-resistance genes from the progeny of *O. glaberrima* to those of *O. sativa* by backcrossing.

Whitebacked planthopper

IRRI's breeding program for resistance to the whitebacked plant-hopper (WBPH) was initiated in 1975, with the Indian variety N22 as resistance source. The dominant resistance gene *Whph 1* was transferred to progeny of improved plant type background by backcrossing; recurrent parents were IR32, IR36, and IR38. Many

improved breeding lines with multiple resistance to other important pests are now available. The newly identified *Wbph 2* gene is also being incorporated into improved progeny.

Gall midge

Although it does not occur in the Philippines, gall midge is a major pest in most of the other South and Southeast Asian rice-growing countries. India and Thailand have strong breeding programs for gall midge resistance. IRRI has developed some improved germplasm by using PTB18 and CR94-13 as resistance sources. The segregating populations of those crosses were screened in India. In India IR32, IR36, IR38, IR40, and IR42 are resistant to gall midge.

Stem borers

TKM6 from India has been widely used as a source of resistance to the striped stem borer. Many breeding lines and several named varieties such as IR20, IR26, IR30, IR32, IR36, IR38, and IR42 inherit their moderate resistance to striped stem borer from TKM6. Sources of yellow borer resistance include the breeding lines IR1820-52-2, IR1917-3-19, and IR1539-823-1-4 and the varieties W1263, MNP119, and PTB18. IR36 has good resistance to yellow borer.

DEVELOPING GERMPLASM WITH MULTIPLE RESISTANCE

Resistance to one or two rice diseases and insects is not enough; modern varieties must have multiple resistance to most of the important pests prevalent in the areas where they are to be grown. Therefore, we have tried to develop improved germplasm with multiple resistance to as many as four diseases and four insects. Improved lines with resistance to one or two pests were intercrossed and numerous topcrosses and double crosses were made to combine resistances. The segregating populations were thoroughly screened leading to the identification of multiple-resistant lines. In 1969, about 85% of the entries in the IRRI replicated yield trials were either susceptible to all the six diseases and insects (blast, bacterial blight, tungro, grassy stunt, BPH, GLH) or resistant to only one. Only 2% of the entries were resistant to three diseases and three insects. The proportions of entries with multiple resistance gradually increased and in the 1974 replicated yield trials 90% of the entries were resistant to 5 or 6 of the diseases and insects.

These breeding lines with multiple resistance have high yield potential, excellent grain quality, and early to intermediate growth duration. After evaluation for yield potential in international replicated yield trials, IRRI named six as varieties (IR26 in 1973; IR28, IR29, and IR30 in 1974; IR32 and

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

IRRI line	Level of resistance[a] to							
	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	MR	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[b]	R	R	R	R	R	R	MR	R
IR38[b]	R	R	R	R	R	R	MR	R
IR40[b]	R	R	R	R	R	R	MR	R
IR42[b]	R	R	R	R	R	R	MR	R

[a] S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant. Reactions were based on tests conducted in the Philippines for all diseases and insects except gall midge (conducted in India).

[b] Named as varieties by the Philippine Government.

IR34 in 1975). In 1975, IRRI changed its policy. We no longer name varieties but we continue to supply multiple-resistance germplasm to scientists in national programs to either use in their hybridization programs or to name as farmer varieties. Under the new policy, the Philippine Government released 4 multiple-resistance IRRI lines as varieties: IR36, IR38, IR40, and IR42. Table 1 shows the pest resistance ratings of IRRI-named varieties and IRRI lines named in the Philippines. The progressive increase in the varieties' resistance levels from IR5 to IR42 is evident.

FARMERS' ACCEPTANCE OF MULTIPLE-RESISTANCE VARIETIES

Many varieties with multiple disease and insect resistance are widely grown in the tropics and subtropics. In the Philippines,

for example, about 3 million ha are planted to IR26, IR32, IR36, IR42, IR44, and IR46. In Indonesia about 5 million ha are planted to IR26, IR32, IR36, IR38, IR42, and Asahan (IR2071-621-2). About 2.5 million ha in Vietnam are planted to TN73-2 (IR1561-228-3-3), IR26, IR30, IR36, IR42, NN4A (IR2070-734-3), and NN5A (IR2071-179-3). About 3 million ha are planted to IR28, IR30, IR34, and Prasad (IR1561-216-6) in India. Similarly a total of about 1 million ha are planted to multiple-resistance varieties in Nepal (IR2061-625-1-6-4-3 or Laxami and IR2071-124-6-4 or Sabitri), Bangladesh (BR6 or IR28 and BR7 or IR2053-87-3-l), Burma (Sinshwethwe or IR34), and Lao (IR38). IR26 is widely grown in the one-rice crop areas in Kiangsu and Hupei provinces of China. Thus these materials with multiple disease and insect resistance are planted in over 15 million ha of land in Asia. IR26 is also the restorer parent of F_1 hybrids which are grown in 5 million ha in China. The widely planted multiple-resistance varieties are listed in Table 2.

Table 2. Varieties with multiple disease and insect resistance grown in different countries.

Variety	Designation	Countries where grown
IR26	IR1541-102-7-491	Philippines, Indonesia, Vietnam, China
IR28	IR2061-214-3-8-2	India, Bangladesh
IR30	IR2153-159-1-4	India, Vietnam
IR32	IR2070-747-6-3-2	Indonesia, Philippines
IR34	IR2061-213-2-17	India, Burma
IR36	IR2071-625-1-252	Philippines, Indonesia, Vietnam, India, Cambodia
IR38	IR2070-423-2-5-6	Indonesia, Vietnam, Laos
IR42	IR2071-586-5-6-3	Philippines, Indonesia
IR44	IR2863-38-1-2	Philippines
IR46	IR2058-78-1-2-3	Philippines
TN73-2	IRl561-228-3-3	Vietnam
Prasad	IR1561-216-6	India
BR7	IR2053-87-3-1	Bangladesh
Asahan	IR2071-621-2	Indonesia
NN4A	IR2070-734-3	Vietnam
NN5A	IR2071-179-3	Vietnam
Laxmi	IR2061-628-1-6-4-3	Nepal
Sabitri	IR2071-124-6-4	Nepal

BREEDING METHODS EMPLOYED

We have used the pedigree method of breeding to develop germplasm with multiple resistance. Selection is based on comprehensive records of each line's pest reactions; selection of F_4 and later-generation lines is also based on the reaction of ancestral lines. We do not use the bulk method because it does not permit the concurrent screening for a number of pests. We also do not use extensively the backcross method because of an earlier lack of suitable recurrent parents. A few backcrosses with *O. nivara* were made for grassy stunt resistance; IR8, IR20, and IR24 were the recurrent parents. After three or four backcrosses we obtained breeding lines with grassy stunt resistance similar to that of the recurrent parents, but they lacked resistance to other important pests. Those lines, however, could be used as resistance sources for grassy stunt in our breeding program. Today numerous breeding lines and named varieties that can serve as recurrent parents are available. But we generally avoid the backcross method because we consider the development of germplasm with diverse genetic background desirable.

The pedigree method of breeding is eminently suited to disease and insect resistance programs if resistance is governed by major genes. Most resistance traits in rice are controlled by the major gene; the pedigree method has been successfully used in those cases. But pedigree breeding is not suitable for traits governed by polygenes. Resistance to rice stem borers and sheath blight appears to be under polygenic control. For those traits we use a diallel selective mating system proposed by Jensen (1970).

We are also exploring the possibility of using the single-seed descent method to improve traits governed by polygenic variation. Early-generation populations from multiple crosses involving 3 or 4 parents with minor resistance genes are propagated in bulk. We grow 3 or 4 generations/year. Selection is not practiced during that period. At the F_5 or F_6 stage, the bulk population is exposed to the targeted pest pressure and individuals with better resistance levels are identified and grown for further evaluation in progeny rows.

BREEDING PROCEDURES

Based on several years of experience in disease and insect resistance breeding, IRRI has developed procedures for handling donor parents, making crosses, growing and screening the segregating populations, and concurrently evaluating the progeny materials for agronomic traits and grain quality (Khush 1978). Brief outlines of those procedures follow:

Donor parents

Each season IRRI plants donor parents in a hybridization block (HB) consisting of 250 to 300 entries including both newly identified unimproved donors and breeding lines with specific pest resistance. The HB entries are planted 5 times/season every 2 weeks. This schedule ensures availability of donor materials for crossing at different times in the crossing season.

Hybridization

We make many crosses each season. To produce the single-cross F_1 hybrids, each donor parent or breeding line is crossed with a number of other breeding lines. Thus a set of single-cross F_1 progeny is available for double-crossing or topcrossing the next season. All the F_1's, including the donors, are grown together in the F_1 nursery. The best are used for top or double crosses. We select the topcross parents to complement deficiencies of the single-cross F_1 hybrids. Thus, if one parent of the single cross F_1 is resistant to GLH and BPH and the other is resistant to tungro, the topcross parent should be resistant to blast and bacterial blight. Use of topcross parents that are homozygous for resistance is desirable so that all of the F_1 plants inherit the trait. The use of improved breeding lines or varieties as topcross parents is also desirable. If the unimproved tall donor is used as a topcross parent, all F_1 progeny will be tall and only 25% of the F_2 progeny will be short.

From 300 to 400 F_1 seeds are obtained for each or double cross to allow us to sample gametic variability of the single-cross F_1 hybrids. Screening begins at the F_1. Let us consider a double cross between four parents; A is resistant to bacterial blight, B to grassy stunt, C to BPH, and D to GLH. All these traits are controlled by dominant genes that segregate independently of one another. About 400 seeds from the double cross A/B//C/D are harvested, germinated, and inoculated with grassy stunt virus in the greenhouse. About 50% of the seedlings are susceptible so they are eliminated. The remaining 200 seedlings are transplanted in the field and inoculated with bacterial blight at about 60 days of age; about 50% are susceptible and are destroyed. The remaining 100 plants are harvested individually. We take two small seed samples from each and progeny test them for BPH and GLH resistance. Those carrying the BPH-resistance gene (50%) and those carrying the GLH-resistance gene (50%) are identified. The F_2 populations are grown only from those carrying both genes (25-30 plants). Thus, by judicious and timely screening, the original F_1 sample of 400 plants is reduced to 25 or 30. All the F_2 populations grown from those plants segregate for the four resistance genes.

F_2 populations. Most of the F_2 populations are grown without insecticide protection to expose them to leafhopper and planthopper onslaughts. Generally, enough virus inoculum is present on the IRRI farm to initiate high disease incidence in the F_2 populations; tungro infection of all the F_2 plants of certain cross combinations is not uncommon. Such populations are discarded. Most of the F_2 populations are artificially inoculated with bacterial blight in the field; susceptible plants are destroyed. F_2 populations from the individual F_1 plants of top or double crosses are grown separately and selections are made only from agronomically suitable populations. We grow about 2,000 to 5,000 F_2 plants of each cross combination; 100 to 500 plants are selected from promising combinations to grow in the pedigree nurseries.

Pedigree nurseries. We generally obtain 25 to 30 g of F_2 seed of each plant selection. This sample is divided into 5 or 6 sets, 5 g each. One set is used to plant the pedigree nursery, where we grow one 5-m row consisting of 25 plants for each selection. The remaining seed sets are tested for resistance to blast, grassy stunt, GLH, BPH, grain quality, and sometimes, for other traits such as drought or salinity tolerance. The pedigree rows are inoculated with bacterial blight in the field. Most of the pedigree nursery is grown without insecticide protection to encourage the buildup of GLH populations. To insure tungro infection, we grow a tungro-susceptible variety around the borders of the pedigree nursery. Diseased plants from the previous nursery are maintained and occasionally transplanted around the nursery borders to provide tungro inoculum. Thus, we are able to screen for tungro and bacterial blight in the field. Data on blast are obtained from blast nursery screening; evaluation for resistance to grassy stunt, GLH, and BPH is conducted in the greenhouse. We record the data from various screening trials in the pedigree nursery book before making the selections in the field. The main selection criteria, besides agronomic characteristics and grain quality, are pest resistance ratings.

Three plants from each promising row are individually harvested. Seeds from the remaining plants of each selected row are bulk harvested. The total seed harvest of each selected plant is again divided into 5 or 6 sets, 5 g each. One set is replanted in the pedigree nursery, the others are used for disease ard insect screening. The three plant selections from each common source are planted together for comparison. Data from the ancestral row of the previous generation are transferred to the new book where the new data for each row's reaction are recorded. Thus in the F_4 and later generations, data from two seasons are available for each pedigree row to

facilitate selection. These procedures are repeated for several generations until the breeding lines become uniform in maturity, height, and other traits. More than 100,000 pedigree nursery rows/year are grown.

Yield trials. We evaluate 800 selected F_5, F_6, or later-generation lines each year for yield in replicated trials. Those entries are also screened for resistance to the major diseases and insects. All yield trial entries are also inoculated with sheath blight in the field and evaluated for stem borer resistance in the screenhouse. Promising materials with high yield, good grain quality, and multiple pest resistance are entered in the IRTP nurseries, through which seeds are disseminated to other programs. Bulk seed of the early generation lines is also supplied to national program scientists.

BREEDING STRATEGIES

IRRI's current strategy is to incorporate diverse major genes for resistance into progeny of improved plant type and to combine each of those progeny with major resistance genes for other pests. If cultivars with a particular gene become susceptible because new biotypes develop, varieties with a second gene should be available. This sequential-release strategy has been employed for BPH resistance. Thus, five BPH-resistant varieties with the *Bph 1* gene were released in 1973-74. In 1976 those varieties began to show susceptibility at some Philippine locations. But by that time, multiple pest resistance varieties with the *Bph 2* gene for resistance were available and were released as replacements for varieties with *Bph 1* for resistance. We now have breeding lines with the *Bph 3* and *bph 4* genes for resistance.

We are also trying to pyramid two major genes for BPH resistance. *Bph 1* and *bph 2* are closely linked and cannot be combined; so are *Bph 3* and *bph 4. Bph 1* and *Bph 3, Bph 1* and *bph 4, Bph 2, Bph 3,* and *bph 4* segregate independently of each other and can be combined together. We envisage that varieties with two resistance genes will have a longer useful life (Khush 1979).

Four known genes for BPH resistance are also being transferred to isogenic backgrounds by backcrossing. We are also searching for additional resistance genes. When 6 to 8 isogenic lines with different BPH-resistance genes become available, we plan to evaluate the feasibility of developing multiline varieties.

For traits that are under polygenic control, such as stem borer resistance, we use a diallel selective mating system proposed by Jensen (1970). The method involves: 1) crossing a number of moderately resistant parents in all possible combinations; 2) intercrossing the F_1 populations in all possible combinations; 3) screening the double-cross F_1 progeny for resistance; and 4) intercrossing the selected plants found to be more resistant than either parent. We will continue the crossing, screening, selection, and recrossing until minor genes from different sources are accumulated.

INHERITANCE OF RESISTANCE

Information on the genetics of resistance is useful in determining the breeding method to be used, the size of segregating populations to be grown, and the breeding strategy to be adopted. Little information on the genetics of pest resistance was available when IRRI's resistance breeding program was initiated. Since then a fairly large amount has accumulated.

Blast

Most of the work on the genetics of blast resistance has been conducted in Japan by Kiyosawa and coworkers (Kiyosawa 1972, 1974). Ten loci with major genes for resistance have been identified. Some are characterized by a multiple allelic series. Some of the loci have been assigned to the respective linkage groups by linkage analysis (Toriyama 1972). In independent studies, Atkins and Johnston (1965) identified two genes that they designated *Pi 1* and *Pi 6*. Similarly, Hsieh et al (1967) identified three dominant genes for resistance in japonica strains, which they designated *Pi 4, Pi 22,* and *Pi 25*. IRRI investigations are now under way to identify major resistance genes for tropical blast races.

Bacterial blight

The inheritance of resistance to Japanese isolates of the bacterial blight bacterium was investigated by Sakaguchi (1967) and Ezuka et al (1970, 1975); three resistance genes were identified: *Xa 1, Xa 2,* and *Xa 3*. Several IRRI studies on the inheritance of resistance to Philippine isolates of the bacterium led to the identification of several new genes for resistance (Librojo et al 1976, Petpesit et al 1977, Olufowote et al 1977, Sidhu and Khush 1978a, Sidhu et al 1978). Those new genes have been a designated *Xa 4, xa 5, Xa 6, Xa 7,* and *xa 8*. *Xa 1* and *Xa 2* are linked with a crossover value of 3%. *Xa 4* and *xa 5* segregate independently of each other. *Xa 4* and *Xa 6* are linked with a crossover value of 26%.

Grassy stunt

A single dominant gene *Gs* confers grassy stunt resistance in *O. nivara* (Khush and Ling 1974). *Gs* segregates independently of *Bph 1,* the dominant gene for resistance to BPH (the vector of grassy stunt).

Brown planthopper

Two genes for BPH resistance were identified by Athwal et al (1971) and designated *Bph 1* and *bph 2.* Those two genes are closely linked and no recombination has been observed between them. Lakshminarayana and Khush (1977) identified *Bph 3* and *bph 4,* which are also closely linked (Sidhu and Khush 1979b). The variety TKM6 from India is susceptible to BPH but yields some resistant progeny in the segregating populations when crossed with other susceptible varieties. Martinez and Khush (1974) showed that TKM6 is homozygous for *Bph 1* as well as for inhibitory gene *I-Bph 1,* which inhibits *Bph 1.*

Green leafhopper

Inheritance of GLH resistance was investigated by Athwal et al (1971). Three dominant genes that segregate independently of each other were identified and designated *Glh 1, Glh 2,* and *Glh 3.* Two more genes were identified by Siwi and Khush (1977). One is recessive and is designated *glh 4;* the other is dominant and is designated *Glh 5.* Two more dominant genes designated *Glh 6* and *Glh 7* were recently reported by Rezaul Karim (1979).

Whitebacked planthopper

A single dominant gene for WBPH resistance was identified by Sidhu et al (1979) and designated *Wbph 1.* This gene has been incorporated into progeny of improved plant type. Recently Angeles (1979) identified another dominant gene for WBPH resistance and designated it *Wbph 2.* Some varieties appear to have an additional recessive gene for resistance.

Gall midge

Gall midge resistance is also under major gene control. Satyanarayanaiah and Reddi (1972) showed that one dominant gene governs resistance to gall midge in the variety WC1263. Sastry and Prakasa Rao (1973) postulated the existence of three recessive genes for resistance.

VARIATION IN DISEASE AND INSECT ORGANISMS

Existence of races or strains of disease organisms and insect biotypes complicates resistance breeding. Race and biotype

differences have been detected for most of the important rice pests. Race variability of the blast fungus has been well recognized. As summarized by Ou (1972), many races of the fungus are often present in each country, and the races differ from country to country.

Strains of bacterial blight also differ from country to country and often within countries. Three distinct strains are known to occur in Japan (Sakaguchi et al 1968) and three in the Philippines (Mew and Vera Cruz 1979). Because of differences in strains, varieties that are resistant in one country are often susceptible in another. Thus varimeties with *Xa 4* are resistant to the predominant bacterial blight styain in the Philippines but are susceptible in Indonesia.

Extensive studies on the variation in tungro virus organism have not been conducted but some varieties such as Gam Pai 15, which are highly resistant in Indonesia and in the Philippines, are susceptible in India. That suggests strain differences from country to country. Within India, variations in tungro strain pathogenicity has been noted (Anjaneyulu and John 1972).

Occurrence of grassy stunt has been recorded in Indonesia, Philippines, Vietnam, Thailand, India, and Sri Lanka. Varieties and breeding lines with the GS gene for resistance from *O. nivara* are resistant in those countries. Thus grassy stunt strains from different countries appear identical.

Before BPH – resistant varieties were introduced and widely grown, two BPH biotypes were already present, one in East and Southeast Asia and the other in South Asia. A new biotype appeared in 1976 in the Philippines, Indonesia, and Vietnam -- probably influenced by host resistance. That biotype was designated *biotype 2* to distinguish it from the original East and Southeast Asian *biotype 1* (Khush 1977b). Another BPH biotype is known only in the laboratory.

Biotype variation in GLH has been suspected for some time (Khush 1977b). Rezaul Karin (1978) showed that varieties with the *Glh 1, Glh 2, Glh 3,* and *Glh 5* genes, which convey resistance to the Philippine GLH biotypes, are susceptible in Bangladesh. That clearly shows the presence of at least two GLH biotypes.

The occurrence of gall midge biotypes has also been known for some time: at least two are known in India. Biotypes in Thailand, India, and Sri Lanka differ, as shown by the differential reactions of resistant varieties in those countries.

CAUSES OF RESISTANCE

Knowledge of the exact mechanisms of resistance and the identification of plant characters that impart resistance to a pest are of great value in breeding programs for insect resistance. In rice some information on the causes of resistance to stem borers and planthoppers is available. Biochemical factors may determine the rice plant's susceptibility or resistance. A rice plant biochemical *oryzanone* (P–methyl acetophenone) was found to attract ovipositing–moths of the stem borer *Chilo suppressalis,* which laid more eggs on a treated than on an untreated surface (Munakata and Okamoto 1967). The odor of *oryzanone* also attracted the borer larvae.

Recent IRRI work showed that striped borer moths oviposited heavily on surfaces treated with the odorous extract of the susceptible variety Rexoro, but at a low level on untreated surfaces, and not at all on surfaces treated with the odorous extract of the resistant TKM6. But the moths oviposited heavily on the resistant TKM6 when it had been sprayed with the extract of the susceptible Rexoro. There was little oviposition, however, when Rexoro was sprayed with the odorous extract of TKM6 (IRRI 1977).

Planthoppers show distinct nonpreference for certain varieties. Their response in alighting on different varieties is gustatory, but their feeding is not sustained on resistant varieties. For example, BPH females fed little on resistant varieties, but ingested large quantities of sap from susceptible varieties as determined by measuring the amount of their excreta (Saxena and Pathak 1977). The insects gained little weight on resistant varieties compared with weight gains on susceptible varieties. The GLH also excreted more honeydew on the susceptible variety TN1 than on the resistant Pankhari 203 (Cheng and Pathak 1972).

The lack of feeding stimulants or presence of feeding deterrents or repellents may be responsible for reduced hopper feeding on resistant varieties. The resistance of Mudgo to BPH biotype 1 was attributed to its lower asparagine content, compared with that of the susceptible TN1 (Sogawa and Pathak 1970).

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INTEGRATED CONTROL OF RICE INSECT PESTS IN CHINA

Chiu Shin-Foon (Zhao Shan-huan)

Integrated control of rice insects in China is based on cultural, chemical, and biological practices. Cultural practices are the backbone, but the judicious use of insecticides when infestation is above the economic threshold is important.

The breeding of resistant varieties was the "missing link" in integrated pest control in China for a long time, but resistance breeding has been recently initiated. Certain varieties such as Nan You 6 and Vei You 6, selected in Hunan from IRRI material, are resistant to the brown planthopper in Chekiang, Kiangsu, Hunan, and Kwangsi Provinces. In biological control the conservation of indigenous natural enemies, particularly through rational insecticide use, such as root-zone application, is important and may be more effective than mass rearing and liberation of parasites and predators. Chemical and biological control must be integrated for an efficient program of integrated control.

The foundation of integrated insect control is a detailed knowledge of the crop's ecosystem; therefore, studies of the stability of the rice agro-ecosystem should be emphasized. The population dynamics of the key pests may be studied with empirical models of the predator (parasite)-insect pest interacting systems. The model should be developed from data obtained mainly under natural conditions. The paddy agroecosystem, a man-modified environment, is an integrated water-dependent system that includes man, rice, other crops, animals, weeds, and microorganisms. Because rice grows along water routes, the damage of pesticides to wildlife that drift downstream (especially fish) cannot be over-

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looked. Therefore, ecologic investigations on the rational use of pesticides, and field and environmental toxicology of pesticides in rice fields should be intensified. Finally we should point out that an integrated pest control program can be fully realized only when applied over an extended area. Thus, integrated program call for a new type of large-scale cooperative grower organization. The socialist system of the People's Republic of China, particularly the unique people's commune organization is well-suited for that purpose. We believe that the development of integrated control of rice insects in China will be greatly accelerated during the course of our socialist modernization.

Integrated plant protection for rice calls for the interdisciplinary approach in research as well as in implementation. Rice pest management, in the proper sense, should include insects, pathogens, and weeds. The scope of integrated control in this paper, however, is limited to some of the most important rice insects in China.

More than 200 insect species are injurious to rice in China. About 20 of them are common and of major significance. Insect pests are particularly abundant in central and southern China where double and triple cropping of rice is practiced. The most important species in South China are the yellow stem borer *Tryporyza incertulas,* the Asiatic rice borer *Chilo suppressalis,* the leaf roller *Cnaphalocrosis medinalis,* the brown planthopper *Nilaparvata lugens,* the green leafhopper *Nephotettix* spp., the rice gall midge *Orseolia (Pachydiplosis) oryzae,* the armyworm *Leucania separata,* and the rice thrip *Thrips oryzae.*

In recent years evidence has shown that the brown planthopper, the leaf folder, and the armyworm migrate over long distances. But larvae of the rice leaf folder may hibernate in weeds, according to research on weeds as infestation sources in Hunan Province.

The government of the People's Republic of China has for many years set the principle of plant protection as *prevention first, then integrated control.* A well-organized pest forecasting system, emphasizing prevention, is set up at four levels: the county, the commune, the production brigade, and the production team. Certain members of every production team are chosen as plant protectors. In this pest forecasting network, the county station is the center, the commune forecast group is the backbone, and plant protectors in the teams form the base. The

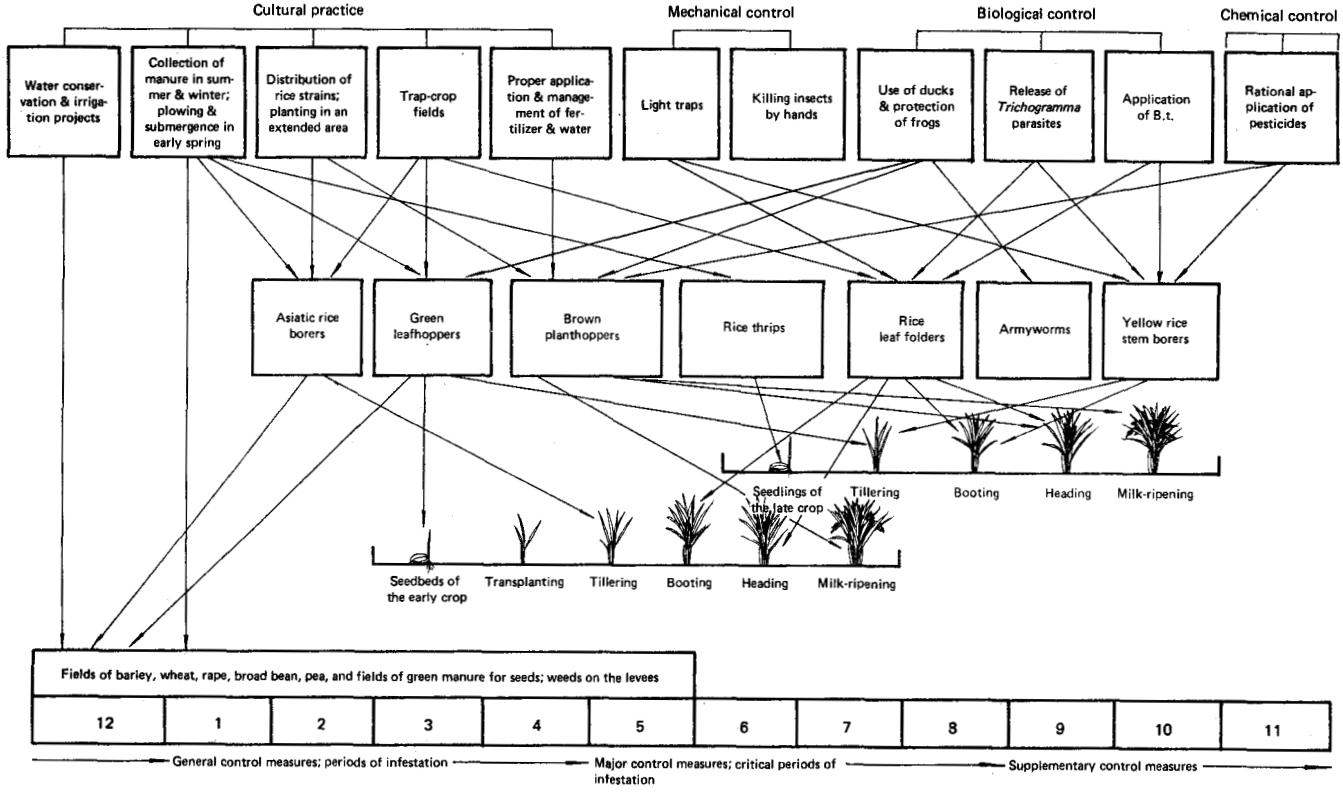
county forecasting station advises the commune and brigade on when and where to conduct control operations. Forecasts are based on data gathered through field monitoring of insect populations and through analysis of records of previous years. Decisions on insect control, however, are based mainly on the local status of insect pests, the rice plant, and the weather (particularly rainfall). Cultural practices, insecticides, biological control, light traps, and varietal resistance are the bases for rice pest management in China (Fig. 1).

CULTURAL PRACTICES

Good cultural practices are the foundation of integrated rice insect control. The cropping system determines the change of pest status, particularly the predominant species and the relative abundance of other species. The adoption of double- and triple-rice cropping systems in Kwangtung Province the past few years has favored outbreaks of the rice gall midge, the yellow stem borer, and the brown planthopper (BPH).

With the introduction of mixed cropping systems, the peak borer abundence shifted from the third to the fifth generation, and the population density increased greatly. Under such conditions, a short fallow interval between the two rice crops breaks the *bridge* for the insect's multiplication and allows successful control of the borers. Production teams also separate the double- and triple-cropped fields, particularly to prevent outbreaks of the rice gall midge, which migrates over only short distances.

Flooding the rice fields early in spring (in regions around Kwangchow, usually before 6 Mar) effectively controls the yellow stem borer. Investigations at the South China Agricultural College indicated a critical period in which the hibernating larvae can be killed by submergence. If the rice fields are flooded in winter or autumn shortly after harvest, it takes more than 1 month to kill the larvae: they have moved to the lower part of the stubble inside the stem to overwinter and are protected from the water. But in early spring, the overwintering larvae are susceptible to flooding as they begin to pupate: 95 to 100% can be killed in only 7 days. Laboratory experiments on the physiological activities of overwintering larvae show that their metabolism rate, as measured by respiration rate, is much higher in early spring than in winter. Thus the larvae's submergence susceptibility may be due to oxygen deficiency. In early spring too, the rice stubble has begun to decay and water can readily penetrate the plant tissue. The use of field flooding early in spring began over a large



1. *Illustration of the incidence of rice insects and the integrated control program in Hunan Province, China, 1977.*

area in the Pearl River Delta about 25 years ago when double-dropping was adopted. It is still practiced in some areas. For example, at Tahsia Commune, in Si-hui County, integrated control programs have been going on for years. Eighty percent of the rice fields there are submerged in 5-10 cm water before 6 March. Even in fields planted to green manure in winter, flooding for 3 days kills the insects during the peak of pupation but does not damage the crop.

Proper scheduling of sowing and transplanting of each crop is also important. For example, an early crop of early-maturing varieties may evade damage caused by the second generation of the yellow stem borer.

HOST PLANT RESISTANCE

Although some studies on BPH-resistant varieties have been conducted in Chekiang, Kiangsu, and Hunan Provinces, breeding for insect resistance is still in its infancy. But the importance of host resistance has been recognized and resistance breeding for gall midge and BPH has been initiated in Kwangtung and other provinces. Breeding for BPH resistance has also been initiated in Chekiang, Kiangsu, Hunan, and Kwangsi Provinces. Promising varieties include Nan You 6 and Vei You 6, selected in Hunan from IRRI materials.

The BPH biotype in South China (Kwangtung, Fukien, Kwangsi, and Chekiang Provinces) is biotype 1, according to preliminary test results involving 10 differential rice varieties (obtained in 1979 through the IRTP collaborative research project).

Other cultural practices used in certain districts are weeding, trapping, and draining of rice fields. Meticulous removal from the fields of weeds, particularly *Leersia hexandra,* the main host of the overwintering gall midge, is considered effective. Draining the rice fields helps suppress BPH populations, and also controls sheath blight and bacterial blight.

CHEMICAL CONTROL

Insecticides form an important part of the integrated control program. Large quantities of insecticides are used on rice in China. The treatments depend on insect population data and growth stage and development of the rice plant; they are usually confined to parts of the field, to individual fields, or even to infested spots (each area occupied by about 5-8 rice hills with 1 yellow borer egg mass) within a field. This method not only greatly reduces the amount of insecticide applied and saves labor, but also minimizes the adverse effects on the ecosystem,

thereby increasing the opportunity for natural control by rice insect enemies.

The correct timing of insecticide application is important. For control of the yellow stem borer and the leaf roller, foliar sprays should be applied during the peak of egg hatching and not during the peak of adult emergence. Because newly hatched larvae are very susceptible to insecticides, the infested spots should be treated in the early stage of deadhearts (when the shoots first begin to wither). For control of the second yellow stem borer generation, the insecticide should be applied during the peak of egg hatching, when the first panicle spikelets begin to appear. Spraying is usually more effective than dusting.

The selection of the proper insecticide formulations is important not only for effective control but also for impact on natural enemies. Broadcasting of granules or soil particles mixed with insecticides is better than conventional spraying or dusting. Mixed formulations have been recommended, particularly for control of resistant strains of rice insects. For example, mixtures of kitazine and dimethoate or of kitazine and malathion are effective against planthoppers and leafhoppers that have become resistant to BHC or DDT.

Finally the method of insecticide application must be considered. Seedling dips with trichlorfon, dimethoate, or chlordimeform are effective against the yellow stem borer and gall midge. Experiments showed that the use of ultralow-volume (ULV) ground spraying with a chemical formulation (25% dimethoate a.i., 25% octanol, 50% mixture of polyalkyl-benzene and polynaphthalene) was effective against leaf rollers and armyworms. A 25% trichlorfon ULV formulation has been used on a large scale in Szechuan Province. Studies in South China showed that the application of systemic insecticides in the root zone of rice plants is a breakthrough in integrated biological and chemical control methods. For example, 1 application of the new product *pyrhioxythion* (0, 0-diethyl-0 (2-methoxy-4-methyl-pyrimidyl-6)-phosphorothionate) at 1.5 kg a.i./ha into the root zone effectively controlled the rice gall midge in the entire crop and had practically no adverse effects on the rice pests' natural enemies.

Large volumes of BHC-parathion and BHC-methyl parathion mixtures have been used extensively in China. In recent years chlordimeform, padan, carbofuran, acephate, parathion, trichlorfon, malathion, phosphamidon, dimethoate, sumithion, cynox, carbaryl, and mipcin (MIPC) have been used. Dimilin has recently been found effective against armyworms.

Insecticides must be used for high rice yields. But it is essential to select the proper chemical, its formulation, and method and time of application. Results of our investigations during the last decade strongly suggest that a breakthrough in the chemical control of rice insect pests is feasible with an ecological approach.

BIOLOGICAL CONTROL

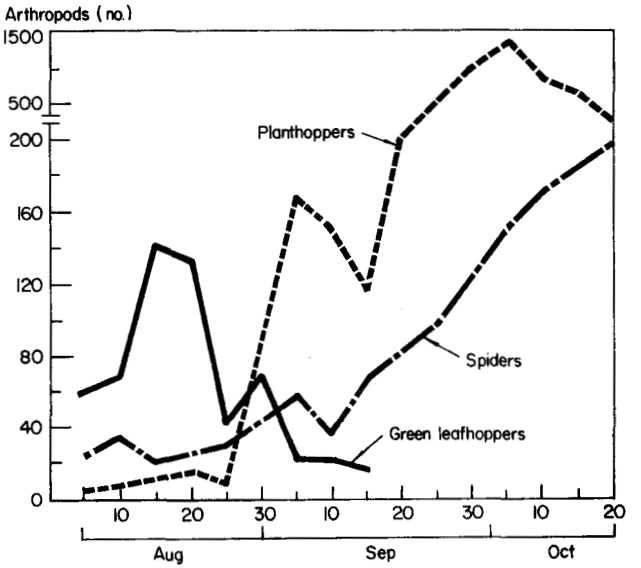
Heavy emphasis has been placed on the biological control of rice insects in China. Basic studies on natural enemies, particularly arthropod predators and parasites, have been conducted in several provinces. Altogether 276 species of natural enemies (parasites and predators, including spiders) have been described. This information provides guidelines for the introduction of natural enemies from foreign countries. Biological measures in the integrated control of rice pests are described as follows:

Protection of spiders

Spiders play an important role in suppressing the populations of leafhoppers and planthoppers. There are 39 species of spiders belonging to 12 families in the rice fields in South China. A large-scale experiment on protection of spiders in rice fields was conducted in 1977 on about 186 ha in Xiang-Yin county, Hunan Province. In protected fields where no insecticide was applied, the population density of spiders was 7 to 8 times higher than in fields with insecticide treatments. In the early crop, the predominant species was *Erigonidium graminicolum;* if the equilibrium density (spiders:hoppers) was 1:4, no outbreak of green leafhoppers and planthoppers occurred. In the late crop the predominant species were *Lycosa* spp. and *Pirata* spp.; if the equilibrium density was 1:8 or 9, no outbreak occurred and no insecticide treatments were necessary. But spiders are of little value in controlling borers and leaf folders; heavy infestations of those pests require insecticide application. A decrease in the number of insecticide treatments and the selective application of insecticides are important to protect spiders. Some carbamate compounds such as MIPC and BPMC (bassa), and organophosphorus compounds such as pyridafenthion, are toxic to hoppers and other insects but have almost no adverse effects on spiders (Fig. 2, 3).

Use of Trichogramma wasps

Among some 12 species of *Trichogramma* reported in China, 4 (*T. dendrolimi, T. confusum, T. ostrineae,* and *T. japonicum*) are found in rice fields. Usually, only *T. dendrolimi* and *T. confusum* are mass-produced by silkworm eggs in special laboratories. *T. japonicum* is an important species in rice

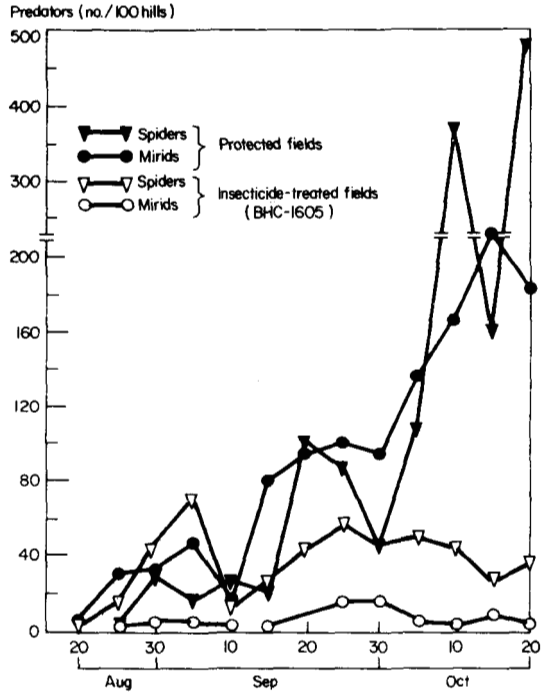


2. *Fluctuation of the population of spiders, green leafhoppers, and planthoppers in the late crop of rice, Hunan Province, 1976.*

fields but it can only be reared on the eggs of the rice grain moth *Coreyra cephalonica.* In south China *Trichogramma* is released chiefly for control of leaf folders. Depending on the density of leaf folder eggs, the wasp is released at 450,000 parasites/ha at definite points several times during the rice crop. Usually parasitization is about 80%, which is considered adequate for control. Although the use of *Trichogramma* for rice leaf folder control is a major success in some places, the method has not become very popular because of two problems: the supply of sufficient host insect eggs, and the necessity of applying insecticides when an outbreak of borers, thrips, or planthoppers occurs. *Trichogramma* wasps are susceptible to chemicals. Therefore, the integration of chemical control and the release of parasites presents great difficulties. The rice farmers often must spray to get more yields.

Use of pathogens

Basic studies and field experiments have been conducted on entomogenous bacteria for the control of rice leaf folders, skippers, and borers. The bacteria are particularly effective against rice skippers; 2 treatments give 90% control. The more than 50 strains studied at various institutes vary considerably



3. *Effect of protecting spiders and the predaceous mirid* Cyrtorhinus lividipennis *in rice fields in Hunan Province, 1976.*

in their virulence to various insects. Among them, *Bacilkus thuringiensis* var. *galleriae* is the most common. In some counties in Kwangtung Province special production facilities for *B. thuringiensis* were set up. *B. thuringiensis* is much more effective if used in combination with low-dosage (1/5-1/10 of the ordinary amount) application of conventional insecticides such as dimethoate or trichlorfon. It is important to have a highly virulent form of *B. thuringiensis.* It is rather expensive for general use because it requires the proper culture conditions of temperature, moisture, and time of fermentation. Thus *B. thuringiensis* has not been widely used in integrated insect control programs in Kwangtung Province in the last 2 years.

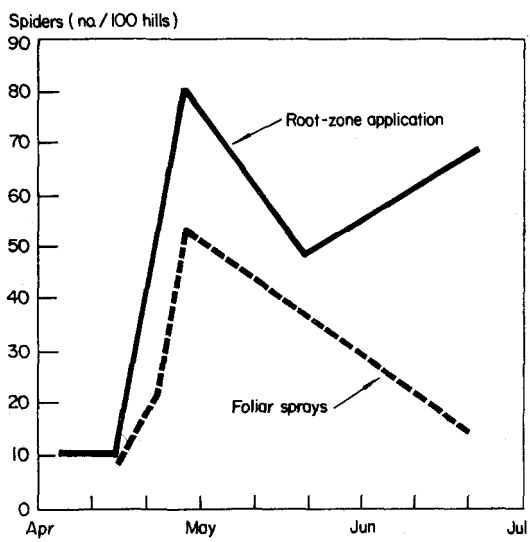
Ducks as biological control agents

Chinese farmers have used ducks for insect control for more than 100 years, but only recently has the bird become an important

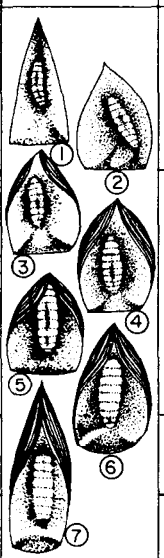
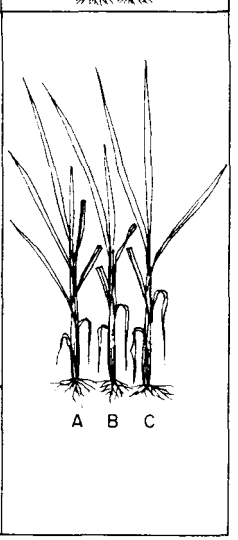
biological control agent. Results of extensive field trials indicated that, when properly "herded" through paddies, ducks are effective in controlling planthoppers, the rice weevil *Echinocnemus squameus*, and, to some extent, leaf folders and armyworms. Ducks are used at an average of 30–45/ha. The use of ducks and the need to protect spiders and frogs in the rice fields have greatly reduced insecticide application in areas where planthoppers are the main pests, and have thus improved environmental quality.

Ducks can destroy some beneficial insects, frogs, and spiders, and do not control borers, gall midge, or thrips. Also, duck herding is difficult in some regions such as Hua County, Kwangtung Province, where the rice fields are kept moist for most of the growing season to control diseases such as sheath blight.

The tropical and subtropical climate and weather in South China favor the use of natural enemies. The use of biological agents in integrated insect control shows promise but, like other control measures, it has limitations. Because yellow borers and thrips cannot yet be effectively controlled by parasites and predators, insecticide use is necessary. In subtropical rice fields, more than one species of insect pest usually occur simultaneously and their generations overlap, making biological control difficult. Our experiences in South China strongly suggest that with the rational use of pesticides (root-zone application, Fig. 4), other measures, and the protection



4. *Fluctuation of the population of spiders in the early rice crop, Kwongtung Province, 1978.*

Stage	Duration (days)	Status of gall formation	Diagram showing gall formation	Av length (mm) of the gall	Outer appearance of the rice plant	Type of gall
1st-instar larvae	Early period 1–3	Newly hatched larvae entering the growing point 1			Normal 1	
	Middle period 3–4	Oval-shaped chamber formed by the inner young leaf 2				
	Late period 5–6	Multiplication and thickening of the cells on the upper layer of the oval-shaped chamber 3			Practically normal. But the heart leaf turns green and the base of the plant swells. 2	
2d-instar larvae	Primary period 0.5	Multiplication and thickening of the sponge-shaped cells in the ova-shaped chamber 4		1.6		
	Middle & late period 1–1.5	A gall has completely formed 5			Features of type A galls: 1. The leaves turn deep green and become harder and stand straight. 2. No heart leaf, or the heart leaf shortened. 3. The distance of auricle from the top leaf gets longer, the angle of leaf blade tends to extend, resulting in abnormal growth of the blade. 4. The base of the plant markedly swells.	
3d-instar larvae	3–4	The length of the gall is equal to that of the insect body 6		2.4		
Pre-pupa	2	The gall begins to elongate 7		5.5		
Duration of pupae	1st stage pupae 1.4	The gall markedly elongates		9		
	2d stage pupae 1.4			28		
	3d stage pupae 1.4			53	Feature of type B galls: The galls elongate.	
	4th stage pupae 1.4	The gall elongates very rapidly		96		
	5th stage pupae 1.4			105		

A B C

5. *Diagram showing the process of formation of the gall and the characteristics of the injury due to the rice gall midge, Kwangtung Province. Observations were made on the injury on rice seedlings by the third generation of the rice gall midge in Du-yan Commune, Sin-hui County, Kwangtung Province, 1976.*

of natural enemies biological control as part of the integrated program will improve.

MECHANICAL CONTROL

Black-light traps have been widely used as a control technique in some regions. Although they effectively suppress the populations of some insects, they only serve as a supplementary measure for control of stem borers and some other insects. The use of light traps has greatly decreased because they catch large numbers of beneficial insects and are expensive. In some regions such as Kwangtung and Hunan Provinces, this technique is being phased out.

EXAMPLES OF SUCCESSFUL INTEGRATED CONTROL PROGRAMS

Integrated control of rice insects has been carried out extensively in most of China's rice-growing regions. So far, management of the yellow stem borer, the BPH, and the gall midge is as follows (Fig. 5):

1. Cultural practices: weeding to eradicate the overwintering larvae; proper timing of sowing and transplanting; separation of areas for two and three rice cropping systems; cultivation of strains with comparatively high tolerance for insect attack.

2. Chemical control: spraying or dusting at the peak of emergence of adults during rice tillering. The most effective insecticides are pyrimioxythion (N-23), carbofuran, and pyridafenthion; seedling dips with 0.1% trichlorfon; and root-zone applications of systemic insecticides either in the seedbeds or in the field. A mixture of carbofuran and chlordimeform gives good control of gall midge, leaf folders, and BPH.

A recent development is the use of light and pheromone traps for monitoring and for direct control. Field experiments have shown that gall midge are sensitive to lights with wavelengths of about 4,000 A (blue color) and that males are strongly attracted by females or by dichloromethane extracts of females. Pheromone traps are more effective than light traps in monitoring first and second generations when the population density is low.

Recent experience in Kwangtung Province indicates that integrated control of gall midge should emphasize weeding of the overwintering host *Leersia hexandra* and insecticide treatments in the third and fourth generations in seedbeds and late-crop rice fields. No control measures are needed in certain localities when gall midge parasitism reaches 60% or higher during the tillering stage of the late crop.

THE IMPORTANCE OF THE IRTP IN BRRI'S VARIETAL IMPROVEMENT WORK

S. M. H. Zaman

The introduction of breeding materials from other countries has strengthened Bangladesh's breeding programs for the major rice crops such as aus, transplanted aman, broadcast aman, and boro. Those crops are grown on 9.8 million ha on topography ranging from dry uplands to flooded lowlands. Desirable characters range from tolerance for drought and flood, to resistance to pests and soil problems. The Bangladesh Rice Research Institute (BRRI) has adopted the integrated multidisciplinary research approach to make research programs effective. BRRI has 11 research divisions and 5 research substations located in different agroecological zones of Bangladesh.

BRRI's early participation in the International Rice Testing Program (IRTP) facilitated the development of new varieties from the introduced germplasm. Among the introduced materials, IR26 (BR6) is an early-maturing variety with high yield potential. BRRI developed BR3, BR4, BR7, BR8, and BR9 from IRTP materials. At least one parent of each variety was developed at IRRI. About 350 entries are obtained annually through the International Rice Observational Nursery, the International Rice Yield Nursery, and other IRTP trials. BRRI uses important sources of resistance genes identified among these materials in its breeding programs. It has also established a sense of fraternity through exchange of information and personal acquaintance -- important factors in the improvement and acceleration of a country's breeding program.

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Introducing exotic germplasm into a country is one of the easier hethods of varietal improvement. Although Bangladesh has a vast source of rice germplasm, popular varieties such as Nizersail, Purbachi (Chen-Chu I), and Pajam (Mahsuri) were introduced from Nigeria, China, and Malaysia, respectively. IR5, IR8, and IR20 were introduced from the International Rice Research Institute (IRRI). Through the IRRI germplasm bank and the International Rice Testing Program (IRTP) breeders of any country now have access to desirable germplasm to use as sources of resistance to pests or to chemical toxicities or deficiencies.

Collection of exotic germplasm used to be difficult and dependent on individual efforts and good relationship between countries. Such barriers no longer exist and breeders can now routinely obtain breeding materials.

THE BANGLADESH BREEDING PROGRAM

Rice breeding has been conducted in Bangladesh since 1910, but it was intensified with the 1966 introduction of 303 varieties and lines for the development of modern varieties with high yield potential. In the succeeding years (until 1972) more advanced IRRI lines and varieties were introduced and tested in all seasons to identify suitable materials for varietal development. Independent efforts were also made to introduce germplasm from other sources, such as China, USA, Surinam, Egypt, Spain, and Australia. By 1972 the following varieties had been identified and recommended for farm production: IS, IR8, IR20, Chandina (IR532-1-176), and Mala (IR272-4-1-2) from IRRI, and Purbachi (Chen-Chu I) from China.

IR8, Chandina, Mala, and Purbachi were recommended for mass production during the aus and boro seasons, particularly for irrigated and high-input conditions. IR5 and IR20 were recommended for the transplanted aman season.

A breeding program has been initiated to improve the following Bangladesh rice crops.

Aus

The aus crop is mainly rainfed dryland with low inputs. It covers about 3.2 million ha in Bangladesh. The aus crop is usually broadcast from March to May, depending on rainfall. Traditional aus varieties are insensitive to photoperiod, have short growth duration (90-105 days) , and yield an average of about 1.5 to 2.0 t/ha. They are tall indicas with broad, thin, droopy leaves with early senescence. Aus rices respond poorly to nitrogen.

Transplanted aman

Transplanted aman rice covers about 3.6 million ha. It is usually seeded in beds from mid-June to mid-July, and then transplanted from mid-July to late September, depending on land availability and flood recession. The traditional varieties are photoperiod sensitive, with leaves and stems similar to those of the aus varieties. The transplanted aman varieties do not respond to more than 40 kg N/ha. Yields vary from 2.0 to 2.5 t/ha. Crops are usually harvested in the dry season (Nov-Dec).

Broadcast aman

Broadcast or deepwater aman covers about 1.8 million ha in low-lying areas where water depth may vary from 1 to 3 m. Seed is broadcast in March-April, usually long before the advent of flooding. Broadcast aman varieties are sensitive to photoperiod. The stems, leaf sheaths, and leaf blades have elongation capacity. Their yield potential is similar to that of transplanted aman varieties. The crop is harvested in November-December after the floodwater recedes.

A small group of deepwater rices called *Rayada* differs from the regular deepwater rices by their lack of seed dormancy and higher photoperiod sensitivity. Rayada seedlings have greater cold tolerance than typical transplanted aman seedlings. The Rayada crop is usually seeded in November-December (mixed with boro rice) and transplanted in January. Farmers harvest the crop in late October-November. Among rices in Bangladesh, the Rayadas have the longest life span.

Boro

Boro rice covers only about 1.2 million ha, but its yields are the highest among the traditional rices of Bangladesh. Farmers usually seed boro rice in seedbeds from November through January, then transplant 40- to 45-day-old seedlings. They harvest in April-May. Boro seedlings are fairly cold tolerant and are insensitive to photoperiod. The leaf and the stem characters are similar to those of aus varieties. The yield potential of boro rice is about 2.5 to 3.0 t/ha. Because the crop is grown in the dry months, irrigation is essential.

Most of aus and transplanted aman crops are grown in rainfed conditions, with no water control.

The primary breeding objectives in Bangladesh are:

- Faster seedling growth so that plant height reaches 40 to 45 cm within 30 days to enable the seedlings to

compete with weeds under rainfed dryland conditions, or to be transplanted in 25 to 30 cm standing water

- Intermediate plant height (115-120 cm) at maturity
- Leaf characters and other yield components similar to those of IR8
- Fair drought tolerance at the early vegetative stage for dryland aus rice
- Fair seed dormancy for aus rice
- Fair photoperiod sensitivity for transplanted aman rice
- Fair cold tolerance at the ripening stage for transplanted aman
- Fair cold tolerance at the early vegetative stage for boro rice.

Resistance to rice tungro virus, bacterial blight, and blast diseases is essential for new varieties.

The desirable characters for deepwater rice varieties are fair drought resistance at the seedling stage; basal and nodal tillering habit; the ability to produce nodal roots; elongation capacity for leaf sheaths, blades, and internodes; submergence tolerance; photoperiod sensitivity; and cold tolerance at the ripening stage.

Because most traditional rice varieties are tall with weak stems and long, thin, and droopy leaves that senesce early, they respond poorly to nitrogen and yield low. New gene sources had to be introduced to replace those undesirable characters. Therefore, germplasm collected or synthesized by IRRI was introduced and incorporated in our breeding program.

INTEGRATION OF EFFORTS

BRRI is pursuing an integrated, multidisciplinary research system to accelerate and increase the effectiveness of rice research. The BRRI research divisions are breeding, agronomy, soil chemistry, physiology, rice cropping systems, agricultural economics and statistics, agricultural engineering, rice technology, entomology, pathology, and applied research and training.

Priority programs are identified; a task force group of senior scientists then subdivides each program into pertinent projects and plans. Units are entrusted with the implementation of each program. The director and the associate director coordinate the programs.

Such an integrated system does not, however, eliminate independent research by any scientists in research divisions where integration of efforts is not essential. This approach provides research flexibility and accelerates progress.

IRTP AS A SOURCE OF IMPROVED GERMPLASM

BRRI became actively involved in the IRTP soon after the latter's launching in 1975. From 1975 to 1978 257 Southeast Asian entries of the International Rice Yield Nursery (IRYN) were tested at IRRI and its substations. In each season at least 4 or 5 outstanding lines with yields ranging from 4 to 5 t/ha were identified and retained in the regular varietal improvement program for further testing. The test results can be found in IRTP reports.

The International Rice Observational Nursery (IRON) is the most important source of exotic germplasm. As many as 351 entries are obtained annually, and the materials usually have wide variability. Apart from the IRYN and IRON, the pest and agroecologic nurseries also supply germplasm. The IRTP offers a speedy way for national breeding programs to test breeding materials and to develop varieties and elite lines.

Researchers can also observe the performance of their materials in diverse agroecologic zones and under a wide range of stresses.

The IRTP monitoring tours provide breeders an opportunity to exchange information and genetic materials and to make personal contacts.

ACHIEVEMENTS THROUGH IRTP

IR28 (IR2061-211-3-8-2) was recomnended as a new variety for Bangladesh in 1976, under the station number BR6. Outstanding hybrid lines developed at IRRI -- IR5-47-2, IR5-114-3-1, IR272-0-1-2, IR20, IR506, and IR2053-87-3-1 -- have been successfully used in both straight-selection programs and hybridization programs to develop varieties such as BR3 (IR506/Latisail), BR4 (BR51-91-6) [IR20/IR5-114-3-1], BR7 (IR2053-87-3-1), BR8 (BR167-2B-9)[IR272-4-1-2J_1/IR305-3-1-3] , BR9 (BR169-1-1) [IR272-4-1-2J1/IR8], BR10 (BR51-46-5) [IR5-114-3-1/

IR20], and BRll (BR52-87-1) [IR20/IR5]. Outstanding elite lines from Sri Lanka, India, Thailand, and Indonesia are continuously used as resistance sources for drought, submergence, and floods, and for diseases such as bacterial blight, bacterial leaf streak, tungro virus, and sheath blight (Table 1). They have outyielded or performed as well as the BRRI check varieties.

PEST RESISTANCE SOURCES

Table 2 lists only resistant materials that BRRI has obtained through the IRTP. Some persistently show pest resistance in both fields and laboratories.

Table 1. Outstanding varieties and elite lines selected from IRTP nurseries in Bangladesh.

Designation	Origin	IRTP nursery	Reference [a]
IET1444	India	3d IRYN-E	Table 12, 14
IR2061-465-1-5-5	IRRI	"	Table 12, 13, 14
IR2071-636-5-5	"	"	
IR1561-228-3-3	"	"	
BG34-8	Sri Lanka	"	Table 14, 15
IR2061-628-1-6-4-8	IRRI	"	
B57c-Md-10-2	Indonesia	"	Table 15
IET3125 (PAU125-1021)	India	4th IRYN-E	Table 15
IR2307-84-2-1-2	IRRI	"	Table 14
B541b-Pn-58-5-3-1	Indonesia	"	Table 14
RP319-34-8-1-3	India	"	Table 14, 15, 16, 17, 18, 19
RP633-9-5-8-1	India	"	
RP6-1899-25-4	India	"	Table 16
MTU63868	India	"	Table 16
IR2823-399-5-6	IRRI	"	Tables 16, 18
C168	Philippines	4th IRYN-M	Table 11
B542b-Pn-68-9-2-2	Indonesia	"	
BG374-1	Sri Lanka	"	Table 13, 15
BG375-1	Sri Lanka	"	Table 13
RP84-39-1	India	"	Table 13
IR2863-38-1-2	IRRI	"	Table 13
Taichung sen yu	Taiwan	"	Table 13
LD125	Sri-Lanka	"	Table 15
IR2053-375-1-1-5 [b]	IRRI	5th IRYN-M	Table 10
IR2071-199-3-6 [b]	IRRI		

[a] See references: Anonymous 1976a and b, 1977a and b, 1978a and b, 1979. [b] May be released as variety.

Table 2. IRTP materials found resistant to several diseases and insects at BRRI.

Pest	Resistant materials
Stem rot	IR32, B441b–126-2-3-1-9, IR2061–464-5-26
Bacterial blight	ARC7125, 7140, OYT6202, 6215 (Bulu Djambia), 6216 (Bulu Kewal), 6217 (Camor), 6220 (Djawa Srie)
Bakanae	B541b–Kn-58-5-3, IET4699 (Rp967), 100G5, IET1444, IR2053–160-3
Blast	SML242 (Alupi), SML1144 (Awini), B2, B4, Carreon, CIAT–ICA 14, Ciwini (67H + 20–7-1/Alupi), HR693–123-2-6, IR880–47-2-1-2, IR1416–2-3-3, IR1544–57-1-1, IR9559–PP870-1, IR9669–PP846-1, Milyang 30, RU369–7-2-1-4, Ta–poo-cho-z, Tetep, TOS 2259/7–3-2-9-B2, Tres Marias
Rice tungro virus	AC4236, ADT12, ARC5905, 10495, 11353, 11554, Ambemohar 159, Gam Pai 30–12-15, Kataribhog (India), Pankhari 203, PTB18
Brown planthopper (BPH)	29 lines are fairly resistant to loca1 BPH, including entries from India, Sri Lanka, Thailand, Indonesia, and IRRI.
Thrip	Of the 252 lines tested through 1977, 13 were found resistant.
Yellow stem borer	IET2845 (RP6–1899-25-4), TKM6/IR8, IET5540 (R34–73-200), IRl514A–E666, IR20/TKM6, IR1820–52-2, IR539–60/IR1416-128-5, IR4791–348-1, CNT7246–4-2-1, UR5311–295-3, IR2838–30–1–1, Wl263

The materials have shown comparatively low infestation in the field; however, BR4 and CR179-1-717 show 5 to 6 times more yellow stem borer infestation than the others.

Other materials identified as resistant to gall midge (Alam et al 1979) were obtained through the International Rice Gall Midge Nursery (IRGMN). We are testing these materials and may name one or more as varieties in the future.

BRRI ORGANIZATIONAL STRUCTURE

BRRI is the national institute established for conducting research on all aspects of rice production by parliamentary Act No. X, 1973, of the People's Republic of Bangladesh. The Institute's scientists also train agricultural extension agents and conduct adaptive research in farmers' fields to accelerate the transfer of new rice technology.

The Bangladesh Government provides financial grants to BRRI. The director, on behalf of the Board of Governors, is solely responsible for administration of the institute. The Board of Governors is composed of top officials and scientists from the Ministries of Agriculture and Forests, Finance, and Planning. The Minister of Agriculture and Forests is board chairman. Two members of Parliament represent farmers.

The Board is the sole authority for approving BRRI's research, development, and financial programs. The Board's wide composition assists research coordination at the national level. To promote research, the Board of Governors is empowered to negotiate bilateral technical assistance programs with foreign governments, organizations, and research institutes. BRRI presently has bilateral technical assistance programs with the governments of Canada, Australia, and UK and with organizations such as the Ford Foundation, IRRI, the Canadian International Development Agency, the International Development Research Council, and the West African Rice Development Association. This has helped the institute accelerate the pace of progress in only 7 years.

BRRI has 11 research divisions and 5 research substations located in specific zones in Bangladesh. BRRI scientists also act as guides to postgraduate students conducting thesis research for the MS and PhD degrees.

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RICE RESEARCH AND IRTP INVOLVEMENT IN SRI LANKA

I. Gunawardena

Sri Lanka's almost 0.6 million ha of rice land is distributed over a wide range of topographic, pedologic, and hydrologic conditions. More than 80% of this land is in inland valley systems that vary in form and size. There are 10 edaphic rice-growing regions in the country and 8 rice research centers cater to their research needs. Because of the diversity of rice-growing environments, rice varieties of different growth characteristics are required. The varieties should differ in growth duration, photoperiod sensitivity, plant type, and agronomic traits, as well as in tolerance for various biological and environmental stresses. Considerable progress has been made in rice varietal improvement and today the emphasis is on location specificity in varietal evaluation.

Sri Lanka's rice-growing soils have been well described and past research has yielded fertilizer-use recommendations that consider both environmental productivity and variety.

The eight rice research centers have been assigned specific responsibilities and rice research priorities. Research is coordinated through disciplinary committees established under the U.S. Agency for International Development (USAID)-International Rice Research Institute (IRRI) Rice Research Project.

Sri Lankan participation in the IRTP with respect to the nurseries tested and Sri Lankan entries, and involvement in IRTP monitoring tours is reviewed.

Sri Lanka, a tropical island situated in South Asia, is broadly divided into 3 climatic zones: a wet zone, 1.5 million ha, in the southwest quadrant; a dry zone, 4.2 million ha, comprising the bulk of the

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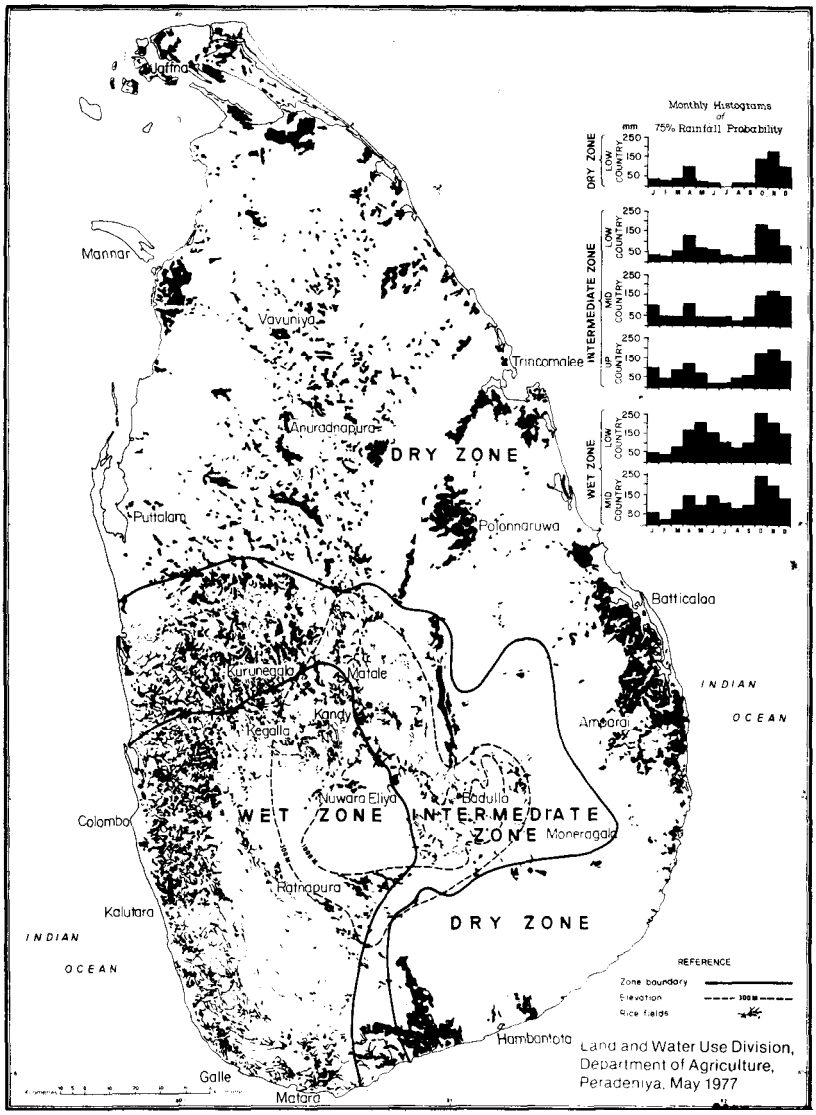


1. *Distribution of rice fields and rainfall characteristics of major rice-growing regions in Sri Lanka.*

rice land in the northeast, west, and southeast; and an intermediate zone, 0.9 million ha, sandwiched between the wet and dry zones. Rice is cultivated on about 0.6 million ha distributed over a wide range of topographic, pedologic, and hydrologic conditions throughout most of the country (Fig. 1).

The three climatic zones are subdivided into seven major agroclimatic zones by altitude and landform. Both the wet and intermediate zones range from low country (0-300 m above sea level) to mid-country (300-1,000 m above sea level) to up-country (1,000-2,500 m above sea level). The dry zone has only the low country. In the low country the landform generally varies from flat to undulating, but in the mid- and up-country it is undulating, rolling, and steeply dissected to mountainous. The 7 agroecological zones are further subdivided into 24 well-defined agroecological regions, each with a unique combination of rainfall pattern, elevation, landform, temperature range, and soil type (Fig. 2).

Annual rainfall ranges from 1,250 mm in the semihumid to dry regions to 5,000 mm in the wet regions. Rainfall distribution follows a bimodal pattern corresponding to the two monsoons, the northeast (Oct-Jan) and the southwest (May-Aug). Intermonsoonal rains and precipitation due to cyclonic depressions add to the total rainfall. In areas with sufficient moisture, the two rice crops grown in a year are rainfed but in the dry areas both crops must be irrigated. More than 80% of the rice is grown in inland valley systems varying in form and size, and is subject to a wide range of hydrologic conditions (Panabokke 1978).

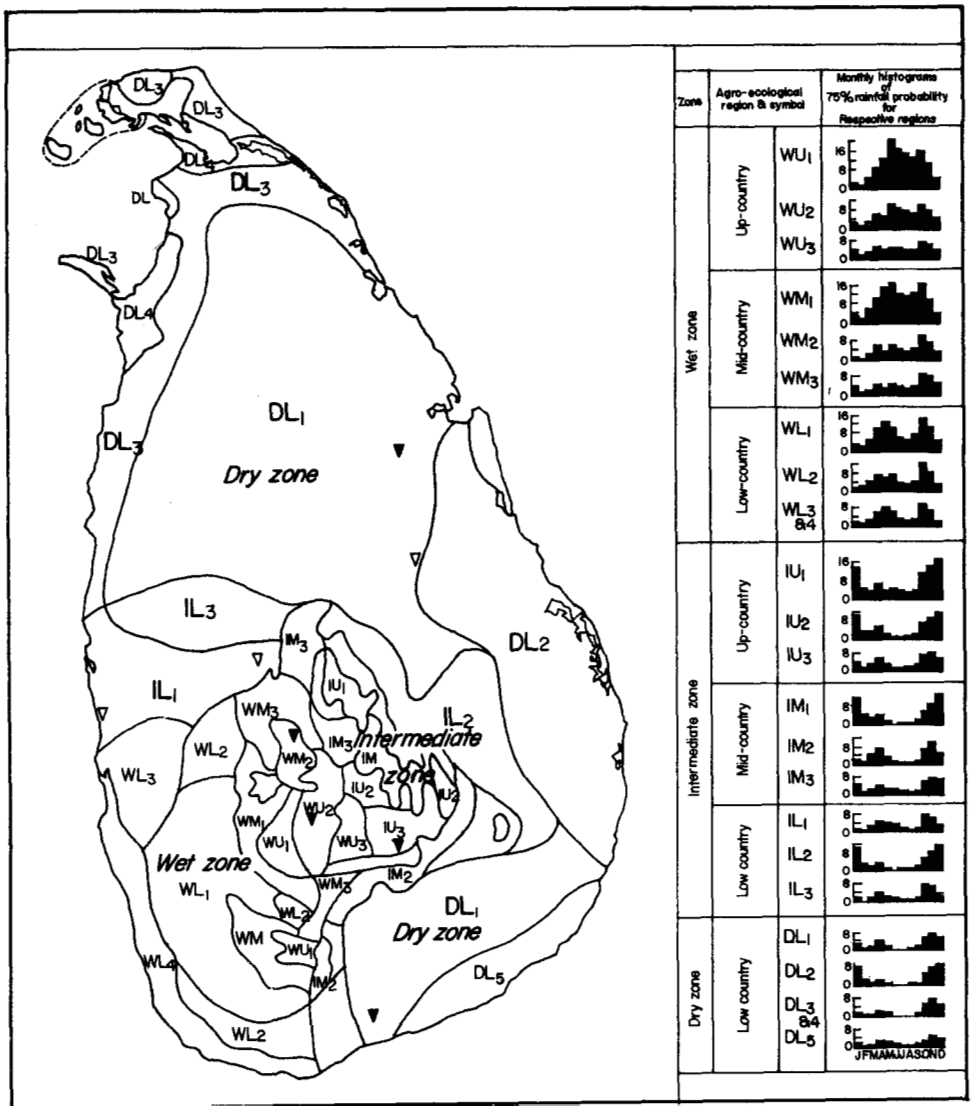
RICE RESEARCH

Organization

The Department of Agriculture (DA) of the Ministry of Agricultural Development and Research, under the supervision of the Deputy Director of Agriculture (Research) is responsible for rice research. The structure of the DA research organization has undergone periodic changes. The most recent change was made in the 1974-75 period to cater to the research needs of the various agroecological regions. Eight rice research centers are now in operation (Fig. 3). Table 1 describes the administrative districts and the agroecological regions within their comnand.

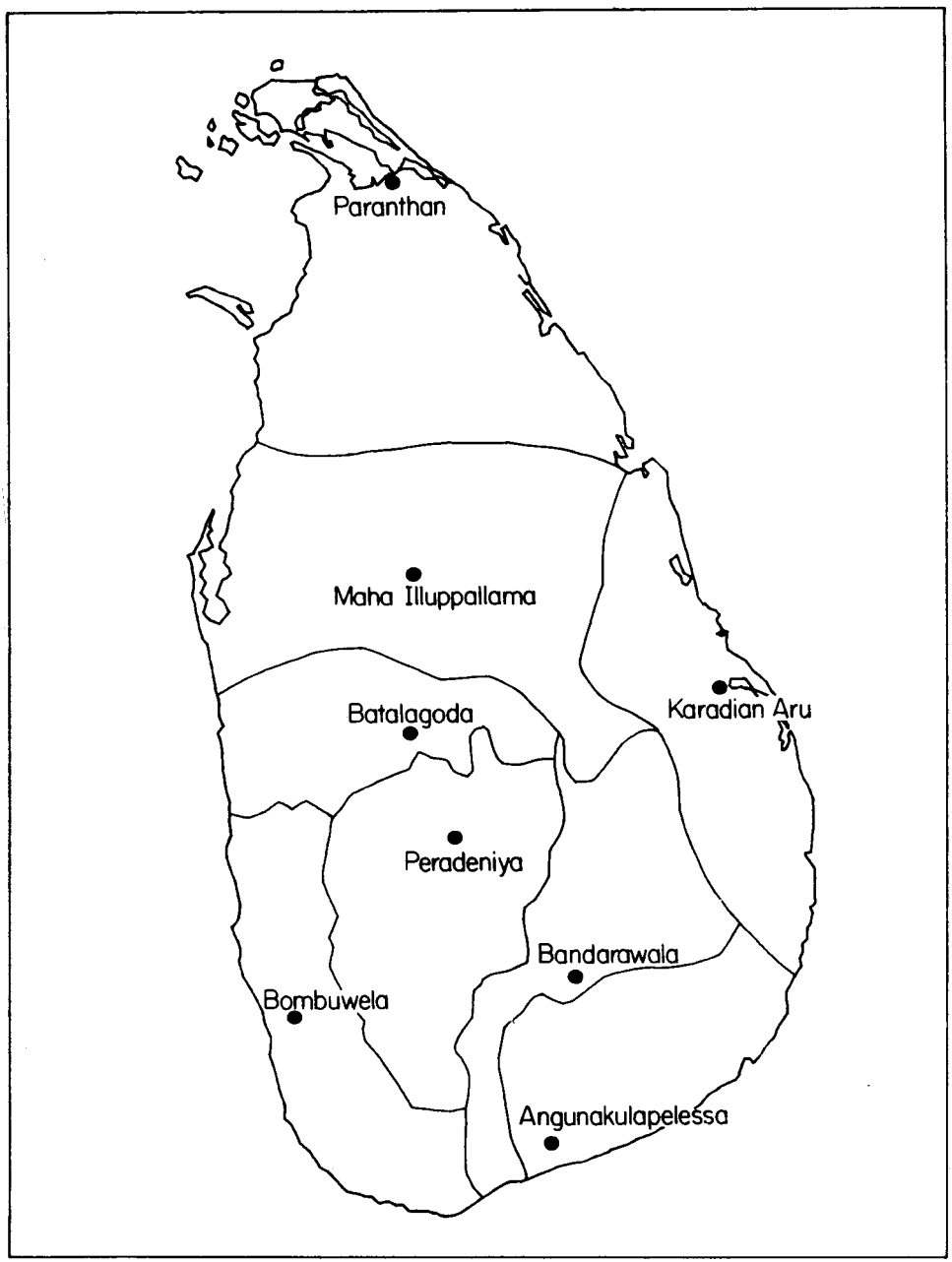
Status of rice research

The wide variation in edaphic and climatic factors in Sri Lanka accounts for the wide range of rice-growing environments. In developing its rice research program, the DA has fully recognized such environmental diversity.



2. *Agroecological regions of Sri Lanka.*

Rice varietal improvement. To meet the climatic and edaphic diversity of Sri Lanka, rice varieties should have growth durations ranging from 3 to 5.5 months, and should essentially be photoperiod-insensitive. In certain edaphic regimes, photoperiod-sensitive varieties with a growth duration of 5.5-6 months are required. Before 1958 the DA selected many traditional varieties from land races and released them as locally adapted pure lines. But those varieties



3. *Rice research centers in Sri Lanka.*

Table 1. Rice research centers, administrative districts, and the agroecologic regions they serve.

Research center	Administrative districts	Agroecological regions served[a]
Angunakolapelessa	Hambantota, Ratnapura (part), Matara (part), Moneragala (part)	Low-country dry zone in southern part - DL_1, DL_5
Bandarawela	Bandulla, Nuwara Eliya, Moneragala (part)	Mid-country and up-country intermediate zone - IM_1, IM_2, IM_3, IU_1, IU_2, IU_3
Batalagoda	Kurunegala, Matale (part)	Low-country and mid-country intermediate zone - IL_1, IL_2, IL_3, IM_1
Bombuwela	Colombo, Kalutara, Galle, Gampaha, Ratnapura (part), Matara (part)	Low-country wet zone - WL_1, WL_2, WL_3, WL_4
Karadian Aru	Batticaloa, Amparai, Trincomalee	Low-country dry zone - DL_2
Maha Illuppallama	Anuradhapura, Kalawewa, Polonnaruwa	Low-country dry zone (north) - DL_1
Paranthan	Jaffna, Vavuniya, Mannar, Mullaitivu	Low-country dry zone (far north) - DL_1, DL_3, DL_4
Peradeniya	Kandy, Kegalle, Matale (part)	Mid-country and up-country wet zone - WM_1, WM_2, WM_3, WU_2

[a]For explanation of symbols, see Figure 2.

invariably had many drawbacks, including poor response to fertilizer, susceptibility to blast, susceptibility to lodging, and poor plant type. A number of varieties of different growth durations were developed and released from 1958 to 1970 through the DA's hybridization and selection program. Particularly important were the varieties H4 and H8 (4-to 4.5-month duration), H7 (3.5 months), and 62-355 (3 months). These old improved varieties were a distinct improvement over the traditional varieties in responsiveness to fertilizer, resistance to blast, and stiffness of straw. But they lacked the semidwarf plant type that is now recognized as important for high yields. After 1970 a number of improved semidwarf varieties were released: BG34-8 (3-month duration); BG94-1 (3.5 months); BG11-11, LD66, and BG90-2 (4-4.5 months); and the photoperiod-sensitive BG3-5 (5.5 to 6 months). The DA soon realized that those varieties lacked tolerance for such pests as the brown planthopper and gall midge. The newest varieties BG400-1 (4 to 4.5 months) and BG276-5 (3 months) have high resistance to both the brown planthopper and gall midge. The major thrust is to develop new improved varieties with adequate levels of resistance to all major pests. (Blast and bacterial blight are the important rice diseases in Sri Lanka.)

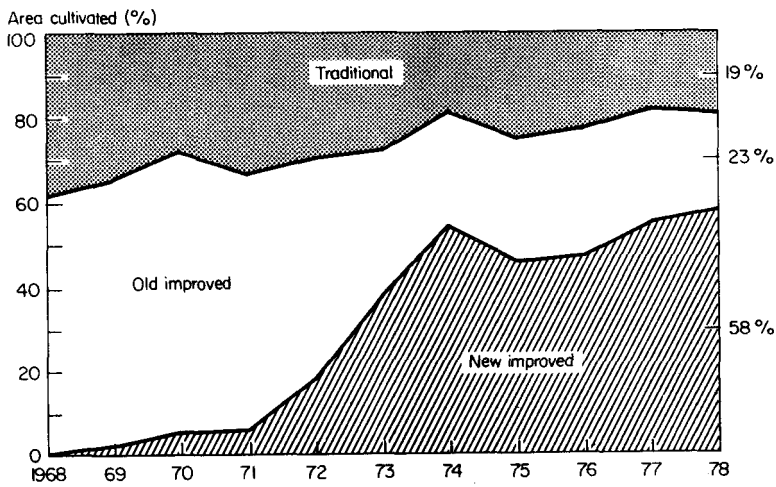
The area grown to new improved varieties increased sharply from 1971 to 1974, then levelled off at about 60%. The area under traditional varieties decreased from almost 40% in 1968 to about 20% in 1978; that under old improved varieties decreased from about 60% to 23% in the same period. The present 60% planted to new improved varieties may be the maximum limit to which the varieties are adapted (Fig. 4).

Most of the new improved varieties are grown in the so-called stable rice-growing environments with adequate water, fertile soils, and high solar radiation; the old improved varieties are grown in the so-called *moderately stable* environments where water supply is less assured and soils are less fertile; the traditional varieties remain in pockets of the so-called *unstable* or *poor* environments beset with many adverse factors. Some characteristic stresses in poor environments are mineral excesses or deficiencies -- too much iron and salts or too little phosphorus, and excessive soil reduction because of continuous inundation, flooding, or drought.

Because of the need for varieties adapted to specific environments, varieties with regional specificity have been bred and released (e.g. the 4- to 4.5-month BW78 and BW100 for the bog and half-bog soils of the low-country wet zone where inter alia iron toxicity is a major constraint). The variety A I6 (3.5 months) has been developed for the deep south, and PLI6 (4.5 months) for high-elevation cold areas. Even in national evaluations, phenotypic stability over a range of environments is measured to identify the varieties with wide adaptability and those with adaptability to specific environments.

Soils, fertilizers, and plant nutrition. Much useful information has been gathered from years of study of soils, fertilizers, and plant nutrition in Sri Lanka. Moormnann and Panabokke (1961) classified Sri Lanka's soils into great soil groups and subgroups. Their study included the more important hydromorphic soils on which rice is commonly grown. Ponnamperuma (1959) proposed a classification of the mineral soils, while Thenabadu and Fernando (1966) described the rice soils and their distribution in two inland valleys of the low-country wet zone. Tokutome (1970) proposed a scheme of rice soil classification based on rice soil surveys in four selected sample areas. Panabokke and Nagarajah (1964) reported on the fertility characteristics of rice soils based on a nationwide study. Panabokke (1977) defined the general problems of rice soils in the western and southwestern coastal plain and associated floodplains; the principal hydromorphic soils of this region, namely the bog, half-bog, and various alluvial soils, were described by Dimantha (1977). More recently Panabokke (1978) described Sri Lanka's rice soils in relation to geomorphology and hydrology of inland valley systems, where more than 80% of the rice lands are located; he dealt with problems farmers encounter in the use and management of such land.

Fertilizer studies have been done for years in Sri Lanka's rice-growing regions. Results of some such studies have been reviewed by Rodrigo (1966). Constable (1966) reported on fertilizer studies done under the Food and Agriculture Organization (FAO)-Freedom from



4. *Percentage of Sri lanka's rice area grown to traditional, old improved, and new improved varieties from 1968 to 1978.*

Hunger Campaigns Fertilizer Project. Chemical fertilizers were recommended for rice from as early as 1950, when three fertilizer mixtures were recommended for the wet-zone, dry-zone, and sandy rice tracts. Each mixture contained ammonium sulfate, saphosphosphate, concentrated superphosphate, and muriate of potash in different proportions; however, that for the dry zone had no potash. In 1956 DA changed the recommendations, eliminating concentrated superphosphate from both the wet-zone and sandy-tract mixtures, but retaining it as the only phosphorus source in the dry-zone mixture. The current recommendations were made in 1971 on a district-wide basis for traditional, old improved, and new improved varieties with consideration of the productive potential of those rice-growing environments (Ceylon Department of Agriculture 1971). Today, however, the fertilizer recommendations for rice are being reviewed and new proposals that consider the most recent research information have been made (Table 2).

A number of studies of the mineral nutrition of rice-growing in adverse soils have been conducted in Sri Lanka. Phosphorus deficiency is common (Takijima and Gunawardena 1969) and the remedial benefits of soluble phosphatic fertilizers have been demonstrated (Takijima et al 1969, Gunawardena and Wijeratne 1974). The nutritional disorders of rice, particularly in the low-country wet-zone soils, were reviewed (Gunawardena 1970). The fertility characteristics of soils and the nutritional and physiological problems of rice in the low-lying lands of the low-country wet zone were reported on (Thenabadu 1977). The physiological disease *bronzing* has been recognized as a rice-growth limiting factor in some wet-zone soils. Varieties are being screened to identify genotypes tolerant of those soil stresses (Gunawardena 1979), and both the soil and plant chemical characteristics during crop growth in iron-toxic and phosphorus-deficient soils are being monitored to gain understanding of the mechanisms of damage.

Agronomic practices. More than 75% of Sri Lanka's rice is broadcast sown. Transplanting is common only in small holdings of the mid- and up-country regions. Information is available on land preparation methods, optimum duration of seed soaking and incubation, seed rates, times and rates of fertilizer application, and chemical weed control (Jayasekara and Velmurugu 1966, Gunawardena and Siriwardena 1974) for broadcast sown traditional, old improved, and some new improved varieties. Information on nursery management, times and rates of fertilizer application, spacing, and weed control for transplanted rice is also available (Gunawardena and Siriwardena 1979). However, the optimum cultural practices for the new improved varieties should be determined. Future agronomic research will be regionalized and directed by the regional rice research centers.

Table 2. Proposed fertilizer recommendations for rice in Sri Lanka.

Zone[a]	Fertilizer	Recommended rate (kg/ha)					
		New improved varieties with growth duration of			Old improved and traditional varieties with growth duration of		
		3.0-3.5 mo	4.0-4.5 mo	5.5-6.0 mo	3.0-3.5 mo	4.0-4.5 mo	5.5-6.0 mo
LCDZ, IZ	N	88	102		47	57	57
	P_2O_5	59	59		40	40	40
	K_2O	51	51		36	42	42
LCDZ, IZ Rainfed upland and lowland	N	46			46	46	
	P_2O_5	30			30	40	
	K_2O	32			32	32	
MCWZ, UCWZ	N	88	102	102	47	57	57
	P_2O_5	59	59	59	40	40	40
	K_2O	51	51	51	36	42	42
LCWZ Bog soils	N	41	56	56	41	41	41
	P_2O_5	38	38	38	38	38	38
	K_2O	38	56	56	38	56	56
LCWZ, nonbog soils	N	73	88	88	56	56	56
	P_2O_5	48	48	48	38	38	38
	K_2O	67	67	67	56	56	56
LCDZ, IZ Light-textured soils	N	93	102	102			
	P_2O_5	59	59	59			
	K_2O	64	70	70			
UCDZ	N					53	
	P_2O_5					0	
	K_2O					25	

[a]LCDZ = low-country dry zone, IZ = intermediate zone, MCWZ = mid-country wet zone, LCWZ = low-country wet zone, UCWZ = up-country wet zone, UCDZ = up-country dry zone.

Research priorities

Sri Lanka's rice-growing lands are divided into 10 edaphic regimes for purposes of rice research. Characteristics considered important in rice varietal improvement for these edaphic regimes include age class, tolerance for various environmental stresses, and plant type (Table 3). The 8 rice research centers that cater to the research needs of the 10 edaphic regimes have the following specific breeding objectives:

Angunakolapelessa station. Breeding varieties of short and intermediate-growth duration with improved plant type and high pest and disease resistance and high fertilizer response, specifically for the "stable" rice lands of the southern dry zone, is the primary responsibility of the Angunakolapelessa station. Red rice is preferred.

Batalagoda station. Breeding early (3-3.5 month duration), medium (4-4.5 months), and photoperiod-sensitive late-maturing (5.5-6 months) varieties is a major function of the Batalagoda center. The early- to medium-maturing varieties are meant for the highly productive environments; the late-maturing, photoperiod-sensitive varieties are for parts of the wet and intermediate zones in the maha season. Emphasis is on incorporation of pest and disease resistance besides improved plant type and superior grain quality. The station also studies the genetics of pest resistance.

Bandarawela station. Varietal improvement for the high-elevation regions of the intermediate and wet zone is the Bandarawela station's responsibility.Short-duration, cold tolerance, and red pericarp are the required characters. The development of suitable agronomic and fertilizer practices for rice are additional responsibilities because in Bandarawela rice is grown in rotation with potatoes and vegetables. Because high levels of phosphate and potash are used for potatoes and vegetables, fertilizer use for rice in this region differs considerably from that in other rice-growing regions.

Bombuwela station. The Bombuwela station breeds varieties for the low-country wet zone. The major problems in the area are iron toxicity, phosphorus deficiency, flooding, salinity and, possibly, an excess of reduced organic products in the soil. The Bentota experimental location breeds varieties for the bog and half-bog soils of the southwest coastal plains. Late-maturing, photoperiod-insensitive varieties are required for yala (Apr-Aug), and photoperiod-sensitive and late-maturing ones in maha. The Bombuwela station breeds varieties with growth duration of 3, 3.5, and 4.5 months. Some selection work for the southern wet zone is also done at Labuduwa. Intermediate to tall plant types are required except for the mineral soils in the region. Resistance to gall midge, thrips, and blast is important. Red rice is preferred. The center also develops suitable agronomic and fertilizer practices.

Table 3. Rice breeding objectives for various edaphic regimes in Sri Lanka.[a]

Climatic zone and sail region	Edaphic regime	Area (ha)	Expected yield (t/ha)	Range of growth duration (mol Haha[b]	Range of growth duration (mol Yala[c]	Varietal requirements	Plant ideotype
I. Low-country dry zone and semidry intermediate zone	1. Major irrigation	162,000	6	3.5-4.5	3.0-3.5	High yield potential with high pest and disease resistance	Short erect type with response to high fertilizer level
	2. Minor irrigation	101,250	4.0-5.0	3.0-3.5	3.0	Adaptable to semi-irrigated conditions during early stages of growth	Intermediate type with response to moderate fertilizer level
Alfisols	3. Rainfed	50,625	2.0-2.5	3.0-4.0	–	Drought tolerance and high root vigor, blast resistance	Early shading habit and response to low fertilizer level
	4. Rainfed upland	50,625	2.0-2.3	3.0-4.0	–	Drought tolerance and high root vigor, blast resistance	Early shading habit and response to low fertilizer level
II. Low-country wet zone and semiwet intermediate zone, including ultrawet regions	5a. Irrigated, no flood hazard	30,375	4.0-5.0	4.0-5.0	3.5-4.5	High pest and diseese resistance. Tolerance for bronzing and low phosphorus	Intermediate type with response to moderate fertilizer level
	5b. Irrigated with some flood hazard	10,125	3.0-4.0	4.0-6.0	4.0-5.5	Flood tolerance at early stages of growth. Tolerance for bronzing and low phosphorus	Intermediate type with response to moderate fertilizer level
Ultisols	6. Rainfed stream fed, spring fed	81,000	2.5-3.5	4.0-6.0	3.5-5.0	High pest and disease resistance. Tolerance for bronzing. Photoperiod sensitivity (for some tracts in Kurunegala District). Tolerance for low phosphorus.	Early shading and intermediate plant type with response to moderate fertilizer level
III. Low-country wet zone ill-drained lowlands	7. Swampy, marshy, flood prone	28,350	2.0-3.0	4.0-6.0 and 3.0-3.5	4.5-6.0 and 3.0-4.0	High pest and disease resistance. Flood tolerance at all stages of growth. Tolerance for salinity at tidal elevations. Photoperiod sensitivity (maha). Tolerance for bronzing	Intermediate to tall plant types with response to low fertilizer level. Non-lodging and medium tall types for low elevations in bog soils
Histosols							

Table 3. (cont.)

Climatic zone and soil region		Edaphic regime	Area (ha)	Expected yield (t/ha)	Range of growtn duration (mo.) Maha[b]	Yala[c]	Varietal requirements	Plant ideotype
IV. Mid-country wet and intermediate zone Ultisols	8.	Terraces, slopes and narrow valleys, stream and spring fed	46,575	4.5-6.3	4.0-5.0	3.0-4.0	Adequate panicle development before flowering in order to ensure proper sink size. Tolerance for mada,[d] meda,[e] and goda kumbura land elements.	Intermediate type with response to moderate fertilizer level.
V. Up-country wet and intermediate zone Ultisols	9.	Narrow valley, spring fed	6,075	2.5-3.0	4.0-4.5	3.0-4.0	Cold tolerance. Tolerance for low phosphorus. Adaptable to mada,[d] meda,[e] and goda kumbura[f] land elements.	Intermediate type with response to moderate fertilizer level.
VI. Saline-alkaline	10.	Irrigated and semi-irrigated rainfed	18,225	4.0-5.0	3.5-4.0	3	Resistance to saline or alkali conditions or to both.	Intermediate type with response to moderate fertilizer level.

[a] Source: Research Division, Department of Agriculture. [b] September-January. [c] April-August. [d] Bog soils with reduced soil proflle.
[e] Well-drained soils. [f] Upper rice terraces generally subject to water stress.

Karadian aru station. The Karadian aru station is responsible for the eastern region of the country. *Manawari* (dry – seeded, rainfed crop that matures under continuous soil submergence of 15-20 cm), dryland, rainfed wetland, and irrigated wetland rice cultivation are practiced. Brown planthopper resistance is required. The major varietal age class is 3.5 months. Salt-tolerant varieties are required because salinity is becoming a problem. Blast resistance is important. Seeding rates for broadcasting are high and weed control is minimal. Suitable agronomic and fertilizer-use methods have to be developed particularly for *manawari* rice.

Maha Illuppallama station. At Maha Illuppallama, high seedling vigor, early maturity (3 months duration), blast resistance, and drought tolerance are bred into varieties for dryland and rainfed wetland (semi-irrigated) conditions. Grain quality and pest resistance are important. The rainfed wetland (semi-irrigated) areas are irrigated only once every 4 days in yala and once every 7 days during maha. Because weed competition is high, varieties need early seedling vigor. Salinity is encountered where the water table reaches the surface. Zinc deficiency is observed in low-lying lands that are often continuously submerged.

Suitable agronomic and fertilizer-use methods, particularly for semi-irrigated rice, must be developed.

Paranthan station. The Paranthan station caters to the northern dry zone region, where *manawari* rice culture is common. Blast and stem borer resistance are important varietal requirements. Other requirements are drought tolerance, heat tolerance during seed germination, rapid seedling emergence with the onset of rains, red pericarp, and short duration.

Peradeniya station. The Peradeniya center has both regional and national responsibilities. Its regional functions are rice breeding for the mid-country wet zone, and development of suitable agronomic and fertilizer-use methods for rice in the region. Early-, medium-, and late-matucing varieties are required for the different land classes. Phosphorus deficiency is common, and some iron toxicity occurs. Cold-tolerant varieties are required for high-elevation areas. Red rice is preferred. The center has national responsibility for such activities as soil, water, and pesticide residue analysis; basic research on the physiology and nutrition of rice varieties; studies including micro-nutrient elements; development of techniques, for assessing varietal resistance to pests; and monitoring of insect and disease incidence; development of integrated pest control methods; and conservation and evaluation of rice germplasm.

The center also coordinates activities related to the national rice varietal testing program, the IRTP, and collaborative research with other institutes.

TECHNICAL COOPERATION

Rice research in Sri Lanka has benefited from technical assistance programs of several countries and international organizations. It has received assistance under the C-plan, from Japan's Overseas Technical Cooperation Administration (OTCA), and from an IRRI-Ford Foundation project. It continues to receive support from OTCA and the International Atomic Energy Agency (IAEA), Vienna, Austria. The rice research program is also supported by the USAID-IRRI Project and the United Nations Development Programme (UNDP)-Food and Agriculture Organization (FAO) Plant Protection Services Project. The USAID-IRRI project aims to expand Sri Lanka's technological base to accelerate the development and use of improved rice varieties and cultural systems. The project will help develop and implement multidisciplinary programs in rice varietal improvement, rice resource capability surveys, rice-based cropping systems, and adaptive field research. The project also finances the training of research workers and provides commodities to strengthen rice research laboratory and field facilities. Committees for national coordination of rice research in entomology, pathology, soils and soil fertility, breeding, and problem soils have been established. The main objectives are to determine the research needs in Sri Lanka's different regions, to review ongoing research programs at various research centers, and to plan future research.

International Rice Testing Program

The multiplicity of rice-growing environments in Sri Lanka necessitates the use of rice varieties with variable growth characteristics in different edaphic regimes. Varieties must also have different photoperiod responses, growth habits, agronomic traits, and tolerance for various biological and environmental stresses. To meet such requirements, plant breeders must have access to elite germplasm. The IRTP is an effective source of such genetic materials, and the dissemination of germplasm is its most important objective. Sri Lanka's participation in the IRTP and in similar international testing programs dates back to 1973, with the first International Rice Yield Nursery (IRYN). An increasing number of nurseries have since been tested; promising materials from these tests have either been used in hybridization programs or advanced to station yield tests (Table 4).

Sri Lanka has submitted a number of its best entries for evaluation in the IRTP nurseries. It also has made available through the IRTP a number of other varieties, particularly those from the indigenous germplasm, with tolerance for various stresses (Table 5).

Sri Lankan scientists have joined five IRTP monitoring tours.

Table 4. IRTP nurseries grown in Sri Lanka.

Nursery[a]	Year						
	1973	1974	1975	1976	1977	1978	1979
IRYN-E			1	2		5	2
IRYN-M	1	1	1	1	2	4	2
IRYN-L							2
IURYN			2				
IRON			2	3	4	4	3
IURON			2	2	2	1	2
IRLRON						3	4
IRBN			1	2	2	2	2
IRSHBN			1	2	1	1	
IRBPHN			3	2	1	3	4
IRGMN			3	3	2	2	2
IRSATON				1	1	2	2
IRCTN			2	2		2	2
IRDWON				1	1	1	2
SB							3
Total	1	1	18	21	16	30	32

[a]IRYN-E = International Rice Yield Nursery-Early; IRYN-M = International Rice Yield Nursery-Medium; IRYN-L = International Rice Yield Nursery-Late; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRLRON = International Rainfed Lowland Rice Observational Nursery; IRBN = International Rice Blast Nursery; IRSHBN = International Rice Sheath Blight Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water Observational Nursery; SB = Stem Borer.

Table 5. Sri Lanka's entries in IRTP nurseries.

Nursery[a]	Entries (no.)
IRYN-E	1
IRYN-M	13
IRYN-L	6
IRGMN	18
IRBN	4
IURON	4
IURYN	4
IRCTN	12
IRBPHN	2
IRON	4
Total	68

[a]IRYN-E = International Rice Yield Nursery-Early; IRYN-M = International Rice Yield Nursery-Medium; IRYN-L = International Rice Yield Nursery-Late; IRGMN = International Rice Gall Midge Nursery; IRBN = International Rice Blast Nursery; IURON = International Upland Rice Observational Nursery; IURYN = International Upland Rice Yield Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRON = International Rice Observational Nursery.

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RICE RESEARCH AND IRTP INVOLVEMENT IN THAILAND

Sermsak Awakul

Rice research in Thailand began in 1916 or 63 years ago, but it was most active from 1950 to 1979. During the 1950s and 1960s breeding research was primarily aimed at pure line selection of indigenous varieties for yield, grain quality, and blast resistance. The first high yielding disease-resistant variety from a cross of IR8 and a tall, long-grained Thai variety was released to farmers in 1969. Twelve improved varieties have been released since then; 8 of them have genes for the semidwarf character.

Problem insects include gall midge, stem borers, brown planthoppers, and green leafhoppers. Major diseases are tungro, blast, bacterial blight, ragged stunt, and brown spot. Specific pest problems vary by rice production regions, but stem borers and blast are widespread.

Collaborative work with IRRI on deepwater rice, rainfed wetland rice, glutinous or waxy grain quality, and biotypes of the gall midge and brown planthopper is under way. Cooperative work with the Tropical Agriculture Research Center of Japan on varietal tolerance for acid sulfate soil is also under way.

Cooperative International Rice Testing Program (IRTP) experiments help determine the performance of Thai lines in other countries and provide new sources of resistance to pests and to adverse environmental conditions. Monitoring tours sponsored by the IRTP offer Thai breeders the opportunity to observe the performance of Thai breeding materials in other countries, and encourage international cooperation. Training in the 4-month Genetic Evaluation and

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Utilization (GEU) course at IRRI enables young breeders and other scientists to gain experience in combining numerous traits in improved varieties.

Rice research in Thailand began with the establishment in 1916 of the Rangsit Experiment Station about 43 km north of Bangkok. Phraya Phojakara was head of the station and plant breeder. His early program was devoted to selection of improved farm varieties. Yield and grain quality were emphasized. As a result of Phraya Phojakara's service at Rangsit, Thailand won the first prize and 10 other prizes for grain quality at the World Grain Exhibition Conference, Regina, Canada, in August 1933. The varieties selected were popular among farmers in the central plains.

The research program was accelerated by United States Agency for International Development (USAID) assistance in 1950, particularly through the service of Dr. H. H. Love, an experienced plant breeder from Cornell University who brought experience gained in China as well as in the USA. Dr. Love emphasized pure line selection within Thailand's diverse rice germplasm. During his 4-year stay in Thailand, superior varieties were identified and adopted by farmers, personnel training was upgraded, and new regional rice research stations were established.

After the establishment of IRRI, IR8 was used in crosses with the local Thai varieties. Consequently a continuing series of new semidwarf varieties, starting with RD1, began to flow to farmers in 1969. Many have disease and insect resistance and higher and more stable yields. We have found, however, that the natural growing conditions in vast parts of Thailand are not suitable for the semidwarfs because of lack of irrigation water or of water control. The modern varieties can be grown in few of the rainfed areas; thus our breeders and agronomists have sought other approaches to our problems. Thailand's 4 major rice-growing regions, their respective production problems, and rice breeding objectives follow.

RICE-GROWING REGIONS

The northern region

Glutinous varieties are grown on most of the 1 million ha of rice in the northern region. The major problems are gall midge and bacterial blight, although orange leaf virus and stem rot diseases also cause problems.

The northeast

The northeastern region farmers grow more than 3 million ha of rainfed wetland rice, most of which is on infertile soil and must survive erratic rainfall.

The most severe problems in the northeast are drought, flood, gall midge, brown planthopper, and low soil fertility. Farmers in this region are among Thailand's poorest. This area now receives much research attention.

The central plain

The central plain is characterized by large areas of flat land, which is waterlogged during much of the monsoon season. In pockets of land, water reaches a maximum depth of 4 m and farmers grow floating rice varieties. A large area is subject to flooding; farmers there grow tall traditional varieties because floods might destroy the semidwarfs. Tungro, ragged stunt, and grassy stunt virus diseases as well as bacterial blight, blast, and Helminthosporium are common. Stem borers and brown planthoppers often damage the dry season irrigated crops. Soils range from strongly acid sulfate to almost neutral in pH, but tend to be low in nitrogen and phosphorus.

The southern peninsula

The southern peninsula has the heaviest rainfall and also a large number of diseases attacking the rice crop. Blast, narrow brown leaf streak, Helminthosporium, bacterial blight, and collar rot are common. Flooding is often severe and soil fertility is low.

PRESENT RICE RESEARCH PROGRAM

The Department of Agriculture has organized research into Rice, Technical, Chemistry, Entomology, and Plant Pathology Divisions. The Rice Division focuses primarily on varietal improvement and administers the 22 rice stations throughout the country. A rice soil fertility group is also included.

The Rice Division is essentially organized by the Genetic Evaluation and Utilization (GEU) concept with breeders, pathologists, entomologists, grain quality technicians, and fertilizer specialists working together to evaluate breeding material for tolerance for the natural hazards rice must face. Rice breeders are assigned to various agroecological conditions such as wetland, deepwater, dryland, and rainfed cultures. Pathologists and entomologists screen for pest resistance; grain quality specialists advise on appearance and cooking

quality. Soil fertility researchers screen varieties for tolerance for acid sulfate and saline soils and test for fertilizer response in different soil types.

Associated divisions in the Department of Agriculture conduct basic research on rice problems not directly concerned with breeding: insecticide evaluation, disease races, insect biotypes, and other areas.

The Rice Division also maintains a germplasm preservation and evaluation unit containing more than 3,000 accessions from across Thailand as well as some foreign introductions.

NATURE OF EXPERIMENTS

Research is conducted at all 22 rice stations as well as in farmers' fields and at dryland crops stations. Trials measure yield, fertilizer response, and adaptation to different environmental conditions. Varieties are screened for various diseases, insects, and problem soils in special nurseries at sites where the problem actually exists (not necessarily at rice stations). Our soil fertility scientists have recently begun studying the prospects of growing azolla to produce nitrogen for the rice crop, and agronomists have initiated work on direct seeding in farmers' fields under rainfed conditions. Some of the results have been encouraging.

INTERNATIONAL RICE RESEARCH (COLLABORATIVE PROGRAMS)

Deepwater rice research

We cooperate with IRRI by providing facilities for an expanded program to develop improved varieties, particularly for rainfed wetland areas where the water is often too deep for the present high yielding varieties. Semidwarf varieties are crossed with floating or submergence-tolerant rices from various countries; segregating populations are screened in tanks and in farmers' fields at four of our rice stations. Seeds of promising lines are distributed to various countries, mostly through the IRTP. IRRI provides the services of a breeder and an agronomist to assist Thai personnel in the work, as well as a supplementary budget. The program is of mutual benefit because many of the breeding materials should be adapted to Thai conditions and Thai personnel have the opportunity to work with an experienced breeder. Through the IRTP monitoring tours Thai researchers have the opportunity to observe deepwater rice programs and problems in other countries.

Breeding for rainfed conditions

IRRI and Thai breeders are collaborating in the northeast region in selecting segregating lines under rainfed conditions and in subsequently testing their performance in other countries. An IRRI breeder spends at least 1 week (during the flowering stage) working with Thai breeders in selecting lines for the following year. It is hoped that through the procedure, lines suited to rainfed conditions and with wide adaptability will be identified.

Breeding waxy rice varieties

Thailand is the world's largest producer of waxy rice. We collaborate with IRRI cereal chemists to identify important waxy rice characters. Thai and IRRI chemists test waxy varieties and experimental lines.

Breeding for tolerance for acid sulfate soils

The Tropical Agriculture Research Center (TARC) organization of Japan has provided a Japanese breeder to assist Thai soil scientists in screening and identifying rice genotypes that are tolerant of acid sulfate soil. IRTP scientists visit and observe this research. We make seeds of promising lines and other information available to research workers in other countries.

IRTP nurseries

Thailand began cooperative testing with the inception of IRTP. We test most of the IRTP yield trials, observational nurseries, and agroecologic stress nurseries. Thai scientists from organizations other than the Rice Division also participate in tests where they have a special interest.

The Rice Division acts as a clearinghouse for seed requests, distribution of seeds, and follow up of reports.

IRTP benefits

Thailand has benefited from the IRTP in many ways. The performance of Thai lines has been tested in other countries; introduced lines from other countries have been used as parents in Thai crosses for certain stress conditions. IRTP lines that appear promising are further evaluated in our own tests -- even if IRTP has dropped them from international nurseries.

A second benefit is the participation of Thai scientists in IRTP monitoring tours to neighboring countries. The

monitoring tours permit Thai scientists to exchange ideas, to see how our genetic material performs under different conditions, and to compare our research with that conducted in other countries. Lasting and beneficial friendships created reduce provincial attitudes. Thai scientists attempt to return the hospitality of colleagues from other countries when we are hosts for IRTP tours.

Some Thai scientists also participate in the 4-month GEU training course at IRRI. Returnees from the GEU course endorse it readily and begin to apply GEU principles to our programs.

Finally, the rapid processing and publication of the IRTP reports as well as the monitoring tours permit Thai scientists to evaluate results rapidly. In our opinion, the IRTP has done much to tie Asian rice breeders together, to increase our understanding of new breeding materials, and to further internationalrelations.

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BROWN PLANTHOPPER SURVEY TECHNIQUE

Ida Nyoman Oka

IR26 and IR28, which were resistant to the brown planthopper (BPH) *Nilaparvata lugens,* were found susceptible to biotype 2 of the insect after four or five cropping seasons in many places in Indonesia. Natural selection for the new biotypes capable of attacking resistant varieties is rapid. The shift to biotype 2 was confirmed only after the pest had spread over wide areas and had caused appreciable yield losses. IR26 and IR28 are still widely planted and run great risks of attack by biotype 2. Replacing them with IR32 and IR36, which are resistant to biotype 2 in those sites, is effective, but the advantage might last for only a few years. Therefore, a field technique for early detection of new BPH biotypes has been developed. It is carried out twice a year -- in the wet and dry seasons -- at about 1,200 sites throughout the main rice areas. Biotype identification is important in determining the distribution of seeds of IR32, IR36, and other varieties resistant to BPH biotype 2. Replacing the varieties that become susceptible with resistant ones before the pest has had the chance to spread significantly reduces yield losses. So far there is no evidence of the field development of a BPH biotype capable of attacking IR32 and IR36.

There is a wide gap in the production in farmers' fields and that on demonstration and research farms. Farmers' rice yields average 2.7 t/ha; those on demonstration plots, 3 to 4 t/ha; and those on research farms, 6 t/ha (Anon. 1979). A main reason for the gap is inadequate pest control in farmers' fields, particularly for the brown planthopper (BPH) *Nilaparvata lugens.* The BPH was previously a minor rice pest, but since 1973 it has caused significant yield losses. The yield losses varied

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considerably in 1973, but the average loss in outbreak areas was estimated as 46%. Included in the estimate are losses caused by the BPH-vectored grassy stunt virus (GSV) and ragged stunt virus (RSV) diseases (Soenardi 1976).

The first reported breakdown of the BPH resistance of IR26 was in the Philippines and the Solomon Islands (Anon. 1975, Stapley 1975).

The use of resistant varieties as the only BPH control measure appeared successful for only 4 or 5 cropping seasons in Indonesia. By the end of 1976 IR26 had become susceptible to BPH in North Sumatra (Mochida et al 1977). In Banyuwangi (eastern Java) and in southern Bali, IR28 as well as IR26 became susceptible to BPH (Oka 1977b). Both varieties have the single dominant gene *Bph 1* for resistance. The BPH field population at those locations is rapidly selecting for a different biotype -- similar to that designated as biotype 2 at IRRI -- that attacks both IR26 and IR28 (Oka 1977a). The shift of the field population to biotype 2 was confirmed after the pest spread rapidly over wide areas and reduced yields appreciably. IR32 and IR36, which are resistant to biotype 2, were introduced in those areas. But this new genetic environment might again select the BPH population to a third biotype that could render IR32 and IR36 susceptible in a few seasons.

Both IR26 and IR28 are still widely planted throughout Indonesia, so the risk of their attack by biotype 2 -- either developing on the crop or migrating from other areas -- is great.

Therefore, early detection of the development of new BPH biotypes *is essential* so that varieties that have "broken down" can be replaced with resistant varieties *before the insect spreads over wide areas.*

In August 1977 BPH biotype detection was initiated at about 200 sites throughout Indonesia's main rice-growing areas. The biotype detection program, part of the general surveillance program of rice pests, is meant to be continuously carried out during each wet and dry season (Oka 1978a).

Responsibility for the planning and execution of the all-Indonesia surveillance program rests with the Directorate of Food Crop Protection, working in close cooperation with the Central Research Institute for Agriculture (CRIA), several universities, and the provincial and district extension services. Surveillance is particularly concentrated in the major rice regions. In 1978, field work was carried out by about 600

agricultural high school graduates assigned to the program. Each enumerator is responsible for 6,000 to 10,000 ha. The areas are divided into 4 or 5 subsections, 1,500 to 2,000 ha each. Rice pests in each subsection are surveyed once a week.

The number of survey sites has gradually increased; during the fourth survey (1979 wet season) 240 enumerators surveyed about 1,200 sites.

Each enumerator is responsible for maintaining four or five cages. BPH samples from each 1,500 to 2,000 ha area are used to infest each cage.

By late October 1977 the first distribution maps of BPH biotypes had been completed. Five subsequent detections have been conducted.

SURVEILLANCE METHODOLOGY

The differential rice varieties are TN1 (susceptible to all biotypes), Pelita I-1 (susceptible to all biotypes), IR26 and IR28 (susceptible to biotype 2 but resistant to biotypes 1 and 3), and IR32 and IR36 (susceptible to biotype 3 but resistant to biotypes 1 and 2) (Oka 1978b).

Each differential variety is seeded in double rows, spaced 4 cm. Four replicates of seeds of each differential are randomly glued between two sheets of absorbent tissue paper. Varietal names are copied opposite each row. CRIA prepares the sheets; the Directorate of Food Crop Protection distributes them throughout Indonesia. Seed preparation simplifies the work of field personnel and minimizes errors.

Field personnel place about 1 cm of field soil in plastic trays 30 x 25 x 5 cm in size. Urea is mixed with the soil at the rate of 90 kg N/ha before placing the planting sheet on the soil surface. Workers then place the plastic tray in an insect-proof cage, 30 x 30 x 25 cm. The cage, placed under direct sunlight to prevent seedling etiolation, is watered frequently. The seedlings are infested 3 to 4 days after emergence with adult BPH collected randomly from the 1,500 ha surveillance areas. About 100 to 150 adults/box are released. Assuming that half are females, they should reproduce about 2,000 nymphs/box. Each tray contains about 500 seedlings, so 4 to 5 nymphs infest each seedling.

During the first run, August 1977, only nymphs were present in many sites. Plants infested with nymphs in the second, third, or fourth instars were collected from those areas and

shaken to infest the seedlings. Later the whitebacked planthopper *Sogatella furcifera* was also found to be increasing and damaging rice at some locations. Because it is impossible for the field workers to distinguish between the nymphs of the two insects, we used only adult BPH for seedling infestation.

Workers remove the BPH predator *Cyrtorhinus lividipennis,* often found in the trays, with mouth aspirators.

Individual seedlings are scored as soon as the susceptible checks TN1 and Pelita I-1 die (1976 Standard Evaluation System for Rice score of 7-9: 7 = wilting and severe stunting, 9 = plant dead). Workers then airmail the results of the readings to the Directorate of Food Crop Protection, Jakarta, and to CRIA, Bogor, for analysis.

If TN1 and Pelita I-1 show a reading of 7 to 9 while IR26, IR28, IR32, and IR36 show low readings (2-3), then BPH biotype 1 prevails in the area. High readings on IR26, IR28, and both susceptible checks, but low readings on IR32 and IR36, suggest that biotype 2 may prevail. Biotypes may be mixed or biotype 2 may be increasing if both check varieties have high ratings (7-9), along with intermediate to high ratings (4-7) for IR26 and IR28, and low ratings for IR32 and IR36.

The first mapping showed biotype 2 to be present in northern Aceh Province, most of North Sumatra Province, two South Sumatra locations, and in West Java, eastern Java, and western Bali. No evidence of biotype 2 was found during the first and second runs for all of Central Java and most of West Java, South Sulawesi, West and South Kalimantan, or West Nusa Tenggara. But in the fourth and the fifth mapping, biotype 2 was found in almost all of East Java, Central Java, West and South Bali, and northeastern West Java. Biotype 2 was also increasingly detected in Aceh Province. There has been no indication to date of biotype 2 in South Sulawesi, South Kalimantan, and West Nusa Tenggara provinces.

Such information is passed to the mass guidance rice intensification program to guide them in distributing seed of IR32, IR36, and IR38 (which are resistant to biotype 2). Timely replacement of susceptible varieties with resistant ones will minimize yield losses.

This method may help us detect a third BPH biotype (if it develops) on IR32, IR36, and IR38, which are widely planted in rice centers infested with BPH biotype 2.

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WORKSHOP RECOMMENDATIONS

Participants in the International Rice Research Workshop grouped specific recommendations for future cooperation on rice research problems of mutual interest under five major areas:

INTERNATIONAL RICE TESTING PROGRAM

The Chinese participants requested the following nurseries for testing in 7 provinces during the 1980 rice-growing season:

			Location						
	Nursery	No.	Guangdong Prov.	Hunan Province	Zhejiang Province	Jiangsu Province	Guangxi Chuang Autonomous Region	Fujian Province	Shanghai Municipality
YIELD TRIALS									
- Irrigated (Very early)	IRYN-VE	3		1	1			1	
(Early)	IRYN-E	5	1	1		1	1	1	
(Medium)	IRYN-M	1				1			
- Upland	IURYN	1				1			
OBSERVATIONAL									
- Irrigated	IRON	4		1	1	1	1		
- Upland	IURON	1				1			
SCREENING									
- Salinity	IRSATON	1				1			
- Cold	IRCTN	1						1	
- Blast	IRBN	5	1	1	1		1	1	
- Sheath blight	IRSHBN*	5	1	1	1			1	1
- Brown planthopper	IRBPHN	7	2	1		1	1	1	1
- Gall midge	IRGMN	1	1						
- Stem borer	IRSBN	3	1	1				1	

*Special screening set.

INNOVATIVE BREEDING METHODOLOGIES

1. Hybrid rice

The participants agreed to initiate collaborative research on hybrid rice with the following objectives:

- Compare different cytoplasmic male sterility systems available now and search for better sources;
- Develop cytoplasmic male-sterile lines with disease and insect resistance and adaptability to tropical and subtropical conditions using the presently available cytosterile sources;
- Study the nature of hybrid vigor and identify lines with better general and specific combining abilities;
- Identify germplasm with large stigmas and longer flower-opening times, and transfer those traits to male-sterile lines;
- Study the ratooning potential of F_1 hybrids;
- Study the inheritance of fertility restoration;
- Investigate the ways and means of perpetuating the F_1 hybrids such as by converting them to apomictics.
- Study the techniques of hybrid seed production.

Scientists from the People's Republic of China (PROC), India, and IRRI will initially participate in the project. Representatives of Sri Lanka, Bangladesh, Thailand, and Indonesia will discuss the project with their colleagues and possibly join after they develop more manpower.

2. Tissue culture

It was agreed that collaborative work on tissue culture will be initiated with major emphasis on standardizing the culture media.

Seeds of about 30 crosses should be sent from IRRI to Mr. Zhang Zen-Hua by March 1980. He will select about 15 combinations, process them through anther culture techniques, and send seeds of 400-600 fixed lines back to IRRI for evaluation under specific environmental conditions and stresses.

Crosses of the following combinations may be considered:

Indica/japonica
Indica/indica
Japonica/japonica
Indica/glaberrima

Participants from PROC, Bangladesh, Sri Lanka, and IRRI expressed interest in joining the collaborative project. Representatives of Indonesia and India will discuss the project with their colleagues.

3. *Exchange of early-generation materials for early maturity*

Scientists agreed that the exchange of early-generation materials of crosses for early maturity would be of mutual benefit. IRRI will initially send 11 sets of about 300 early-generation breeding lines (10 g seed of each line) to China. The seed will be distributed to the agricultural academies of Guangdong, Guangxi, Zhejiang, Hunan, and Jiangsu provinces and to the Chinese Academy of Agricultural Sciences (CAAS), Beijing.

The materials will be evaluated in the two cropping seasons of those five provinces. A single plot consisting of about 4 rows, each 5 m long, will be grown. Observations on the growth duration and other traits will be recorded and selections for local trials will be made. The Chinese academies will similarly supply seed of their early-generation materials to IRRI.

Scientists in Sri Lanka, Bangladesh, India, and Indonesia will also exchange early-generation materials.

RICE DISEASES

1. *Virus diseases*

Because the major virus diseases in China differ from those in South and Southeast Asia, the cooperative work with China will be limited to an exchange of literature and information on virus diseases.

2. *Bacterial blight*

The objectives of the existing international collaborative project on pathogenic strains of *Xanthomonas oryzae* and host resistance in rice are:

- Establishment of a standard set of rice differentials in an isogenic background for a monogenic basis for strainal studies,
- Study of the virulence and variability of the bacteria in Asia, and
- Identification of diverse genes for resistance and incorporating them into improved germplasm.

Chinese scientists expressed their interest in participating in the project in four provincial academies: Guangdong, Zhejiang, Jiangsu, and Guangxi. Scientists in Bangladesh, India, Indonesia, and Thailand will continue to cooperate.

3. *Rice blast*

The group suggested the need for a collaborative project to study differentials for races of *Pyricularia oryzae* with the following objectives:

- Establishment of an improved international set of differentials to study the races of the fungus.
- Monitoring the distribution of races of *Pyricularia oryzae* and varietal resistance of commercial varieties.

It was suggested that the project be discussed further during the International Rice Research Conference at IRRI in April 1980.

RICE INSECTS

1. *BPH collaborative project*

The PROC scientists would like to carry on the collaborative project on the brown planthopper in the following locations:

Location	*Experiments*
Jiangsu Academy of Agricultural Sciences	A, B, C
Guangxi Academy of Agricultural Sciences	A
Guangdong Academy of Agricultural Sciences	A, B, C
South China College of Agriculture (Guangdong)	A, B, C

A = I.D. biotypes, B = new lines with major genes, C = horizontal resistance.

Scientists from Bangladesh, India, Indonesia, Sri Lanka and Thailand will continue to participate.

2. *Gall midge biotype collaborative project*

Chinese scientists at the Guangdong Academy of Agricultural Sciences (AAS) will conduct the trial.

3. *Spceial screening sets*

The Chinese scientists of Jiangsu AAS will conduct screening trials to identify:

- varieties resistant to all known BPH biotypes,
- thrip-resistant varieties, and
- leaf folder-resistant varieties.

4. *Biological control of rice insect pests*

To further the study of parasites and predators of stern borers, leaf folders, and planthoppers, there will be an exchange of preserved parasite and predator specimens to identify natural enemies that are native to certain countries and lacking in others. Natural field parasitism at IRRI and in China will be compared.

5. *Insecticides*

Literature on insecticide evaluation studies, application methods, etc. will be exchanged between IRRI and China.

CAAS-IRRI COLLABORATION ON GERMPLASM COLLECTION AND MAINTENANCE

The objectives of this project are:

- Expansion of the exchange of germplasm among institutions so that Chinese scientists in various provinces can supply fresh seed to IRRI every year as the seeds are rejuvenated.
- The inventory of Chinese accessions and comparison with those in the IRRI collections.
- CAAS and IRRI cooperation in field collection, characterization, seed storage, and data systems.
- Development of a procedure to inform both national and provincial agencies concerned on seed exchange activities.
- Seed increase at IRRI and as has been done in other instances, making seeds available to rice researchers of other countries upon request. Similarly, Chinese researchers can freely obtain from IRRI seeds of the deposited accessions to replace those that may have been lost.

Since the development of the exchanges of germplasm is very important for raising efficiency of rice breeding, the Crop Germplasm Institute at CAAS will take charge of coordinating the work in China and the cooperative work with IRRI.

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GLOSSARY

Varieties

Ai-Dong	矮董
Ai-Jiao-Bai-Mi-Zi	矮脚白米子
Ai-Jiao-Nan-Te (Ai-Chiao-Nan-Te)	矮脚南特
Ai-Lian-Bai	矮莲白
Ai-Nan-Zao	矮南早
Ai-Nan-Zao 1	矮南早 1
Ai-Nan-Zao 10	矮南早 10
Ai-Nan-Zhen 14	矮南珍 14
Ai-Zai-Zhan	矮仔占
Ai-Zai-Zhan 4	矮仔占 4
Ai-Zhen	矮珍
Ba-Si-Ai	八四矮
Bai-Kuo-Ai	白壳矮
Bao-Tai-Ai (Pao-Tai-Ai)	包胎矮
Bao-Tai-Bai	包胎白
Bao-Tai-Hong	包胎红
Bao-Xuan 2 (Bao-Shuan 2)	包选 2
Bo-Luo-Ai	博罗矮
Bei-Hua-Gu 67	北化古 67
Beijing 300	北京 300
Cai-Tang (Zhai-Tang)	寨糖
Chang-Bei-Hao	长白号
Chang-Li-Zao	长粒早
Chao-Yang 1 (Zhao-Yang)	朝阳 1
Chao-Yang-Zao 18	朝阳早 18
Cheng-Du-Ai 8	成都矮 8
Chong-Nong 4	中农 4
Chong-Shen-Zhan	中山占
Chung-Shen-Hong 156	中山红 156
Da-Jin-Feng	大金风
Da-Li-Xian-Lo-Nuo	大粒暹罗糯
Dai-Bai-Nuo	大白糯
Di-Jiao-Wu-Jian	低脚乌尖
Ding-Feng	汀丰
Dong-Nong 363 (Tong-Nong)	东农 363
Dong-Qiu-Zao	冬秋早
Dong-Ting-Wuan-Xian	洞庭晚稻

Er-Bai-Ai	二白矮
Er-Jiu-Ai	二九矮
Er-Jiu-Ai 3	二九矮 3
Er-Jiu-Ai 4	二九矮 4
Er-Jiu-Ai 7	二九矮 7
Er-Jiu-Gui	二九圭
Er-Jiu-Lu 1	二九陆 1
Er-Jiu-Nan 1	二九南 1
Er-Jiu-Nan 2	二九南 2
Er-Jiu-Qing	二九青
(Er-Jiu-Ging)	
Er-Jiu-Zao	二九早
Er-Jiu-Zao 283	二九早 283
E-Shan-Ta-Bei-Gu	峨山大白谷
Feng-Men-Bai	逢门白
Fu-Ai-Da-Sui	福矮大穗
Fu-Bao-Ai 22	福包矮 22
Fu-Lien-Ai	福莲矮
Fu-Lu-Zao	福陆早
Fu-She 58	福射 58
Fu-Yu 1	福育 1
Gan-Hua 2	赣化 2
Gan-Nan-Zao 15	赣南早 15
Gan-Nong 3425	赣农 3425
Gang-Hua-Da-Jian	钢化大占
Guang-Chang 13	广场 13
(Kwang-Chang 13)	
Guang-Chang-Ai	广场矮
Guang-Chang-Ai 5	广场矮 5
Guang-Chang-Ai 6	广场矮 6
Guang-Chang-Ai 13	广场矮 13
Guang-Chang-Ai 88	广场矮 88
Guang-Chang-Ai 98	广场矮 98
Guang-Chang-Ai 3784	广场矮3784
Guang-Chang-Ai 3785	广场矮3785
Guang-Chang-Ai 4182	广场矮4182
Guang-Chiu 4309-2	广秋4309-2
Guang-Qiu-Ai	广秋矮
(Guang-Chiu-Ai)	
Guang-Er-Ai	广二矮
Guang-Er-Ai 3	广二矮 3
Guang-Er-Xuan 2	广二选 2
Guang-Feng 9	广丰 9
Guang-Hua-Ai	广华矮
Guang-Jie 9	广解 9
Guang-Jie 607	广解 607
Guang-Liu-Lian	广六莲

Guang-Lu-Ai 4	广陆矮 4
Guang-Qiu-Ai 35	广秋矮 35
Guang-San-Xuan-Liu	广三选六
Guang-Xuan 3	广选 3
Gui 630	圭 630
Gui-Chao 2	桂朝 2
Gui-Feng-Ai 1	圭峰矮 1
Gui-Lu-Ai	圭陆矮
Gui-Lu-Ai 3	圭陆矮 3
Gui-Yang-Ai 49	桂阳矮 49
He-Jiang 18	合江 18
He-Jiang 742	合江 742
Hong 410	红 410
Hong-Jiao-Zhan	红脚占
Hong-Mei-Zao	红梅早
Hong-Qi 16	红旗 16
Hong-Wan	红晚
Hu-Xuan 19	沪选 19
Hua-Long-Shui-Tian-Gu	花龙水田谷
Hua-Nan 15	华南 15
Hui-Yang-Zhen-Zhu-Zao	惠阳珍珠早
Ja-Ding	咖叮
Ji-Bang-Dao	汲浜稻
Ji-Dui-Lum	鸡多伦
Ji-Keng 60	吉粳 60
Jiang-Ai-Zao	江矮早
Jiang-Nan 1224	江南1224
Jiang-Nan-Ze	江南择
Jie-Fang-Zhong	解放种
Jin-Wei-Ai	金围矮
Jin-Ya-Ai	金鸭矮
Jing-Gong 30	金刚 30
Jing-Gung-Shan 1	井岗山 1
Jing-Yin 66	京引 66
Jing-Yin 127	京引 127
Jing-Yue 1	京越 1
Ke-Ching 3	科情 3
Ke-Mei	科梅
Lao-Hu-Dao	老虎稻
Lao-Lai-Qing (Lao-Lai-Ching)	老来青
Li-Jiang-Xin-Tuan-Hei-Gu	丽江新团黑谷
Lian-Tang-Zao	莲塘早
Long-Fei 313	龙菲 313
Long-Ge 16	龙革 16
Long-Ge 113	龙革 113

Lu-Cai-Hao	陆财号
(Li-Zai-Hao)	
Lu-Nan-Zao 1	泸南早 1
Lu-Shuang 1011	泸双 1011
Lu-Yang-Zao	泸洋早
Luan-Jiao-Long	乱脚龙
Mei-Feng 7	梅峰 7
Mei-She 2	梅射 2
Mi-Chuan-Tu-Mang	米泉秃芒
Mu-Hua 1	牡花 1
Mu-Quan-Zhang	木泉种
Nan A	南A
Nan 56	南 56
Nan-Gao-Guang 1	南高广 1
Nan-Gao-Guang 3	南高广 3
Nan-Geng 11	南粳 11
Nan-Geng 15	南粳 15
(Nan-Keng)	
Nan-Jing 1	南京 1
Nan-Jing 2	南京 2
Nan-Jing 6	南京 6
Nan-Jing 11	南京 11
Nan-Lu-Ai	南陆矮
Nan-Pai	南稗
Nan-Ping 621	南平 621
Nan-Te 16	南特 16
Nan-Te-Hao	南特号
Nan-Te-Zhan	南特占
Nan-Xuan-Zao	南选早
Nan-You 2	南优 2
Nan-You 3	南优 3
Nan-You 6	南优 6
Nong-Ken 57	农垦 57
Nong-Ken 58	农垦 58
Nong-Hu 6	农虎 6
Qian-Nong 5782	黔农 5782
Qin-Er-Ai	青二矮
Qin-Dong 6	青董 6
Qing-Xiao-Jin-Zao	青小金早
Qiu-Ai	秋矮
Qiu-Ai 133	秋矮 133
Qiu-Bu-Liao	秋布了
Qiu-Chang 35	秋长 35
Qiu-Chang-Ai 39	秋长矮 39
Qiu-Chang-Ai 133	秋长矮 133
Rao-Wan 6	饶晚 6
San-Qi-Zao	三七早
Shan A	汕A
Shan-Ai-Xuan 4	汕矮选 4
Shan-You 2	汕优 2

Shan-You 3	汕优 3	Ui-Jin 33	跃进 33
Shan-You 6	汕优 6	Wan-Dan 7	晚单 7
Sheng-Ai 7	胜矮 7	Wan-Li-Xian	万利籼
Sheng-Li-Xian	胜利籼	Wei A	威A
(Sheng-Li-Hsien)		Wei-You 2	威优 2
Si A	四A	Wei-You 3	威优 3
Si-Feng 43	四丰 43	Wei-You 6	威优 6
Si-Tuo 2929	泗沱 2929	Wen-Xuan 10	温选 10
Si-You 2	四优 2	Wen-Zhen	温珍
Si-You 3	四优 3	Wu-Hu-Qi-Yi-Zao	芜湖七一早
Si-You 6	四优 6	Wu-Nong 1	芜农 1
Sin-Siu	新秀	Wu-Nong-Zao	武农早
Song-Liao-Hao	松辽号	Xen-Tie-Da	新铁大
Suang-Feng 4	双峰 4	Xi-Nan-Ai/Ding-Feng	溪南矮
Tai-Yin 1	太引 1		
Tang-Pu-Ai	塘埔矮	Xi-Xuan 4	溪选 4
(Tong-Pu-Ai)		Xian-Feng 1	先锋 1
Tang-Zhu	塘竹	Xian-Xue 9	暹黑 9
Tie-Gu-Ai	铁骨矮	Xiang-Ai-Zao 2	湘矮早 2
Tie-Gu-Zhong	铁骨种	Xiang-Ai-Zao 3	湘矮早 3
Tong-Ai-Zao 14	桐矮早 14	Xiang-Ai-Zao 4	湘矮早 4
Tong-Chang-Zao	桐场早	Xiang-Ai-Zao 7	湘矮早 7
Tuan-Jie 1	团结 1	Xiang-Ai-Zao 9	湘矮早 9
Tuan-Li-Ai	团粒矮	Xiong-Yue 613	熊岳 613
Uan-Fang	原丰	Ya-Zi-Ai	鸭子矮

Ya-Zi-Zhong	鸭子种
Yan-Ge-Zao	岩革早
Yang-Zao-Gu	洋早谷
Yin-Du-Zhan	印度占
Yin-Er-Ai	印二矮
You-Zhan-Zi	油粘子
Yuan-Feng-Zao	原丰早
Zao-Feng-Shou	早丰收
Zao-Jin-Feng 5	早金风 5
Zhai-Ye-Qing 8	竹叶青 8
Zhao-Tong-Ma-Xian-Gu	昭通麻线谷
Zhen-Ai	珍矮
Zhen-Fu 1	珍辐 1
Zhen-Cui 51	珍圭 51
Zhen-Gui 58	珍圭 58
Zhen-Jiang Ai 13	珍江矮 13
Zhen-Mu 85	珍木 85
Zhen-Long 13	珍龙 13
Zhen-Long 410	珍龙 410
Zhen-Shan 97	珍汕 97
Zhen-Zhu-Ai (Chen-Chu-Ai)	珍珠矮
Zhen-Zhu-Ai 9	珍珠矮 9
Zhen-Zhu-Ai 11	珍珠矮 11
Zhen-Zhu-Zao	珍珠早
Zhong-Shan 1	中山 1
Zhong-Shan-Hong	中山红
Zhong-Xi 7609	中系 7609
Zhu-Ai 33	竹矮 33
Zhu-Ko 2	竹科 2
Zhu-Lian-Ai	竹莲矮

Insects

Armyworm *(Leucania separata)*	粘虫
Asiatic rice borer *(Chilo suppressalis)*	二化螟
Brown planthopper *(Nilaparvata lugens)*	褐稻虱
Gall midge *(Pachydiplosis oryzae)*	稻瘿蚊
Gray planthopper *(Laodelphax striatella)*	灰稻虱
Green leafhopper *(Nephotettix cincticeps)*	黑尾叶蝉
Leaf roller *(Cnaphalocrosis medinalis)*	稻纵卷叶螟
Rice thrip *(Thrips oryzae)*	稻蓟马
Skippers *(Hesperiidae)*	弄蝶科害虫
Stem borer	水稻螟虫（包括二化螟、三化螟、大螟等）
Whitebacked planthopper *(Sogatella furcifera)*	白背飞虱
Yellow stem borer *(Tryporyza incertulas)*	三化螟

Diseases

Bacterial blight *(Xanthomonas oryzae)*	白叶枯病
Bacterial brown spot *(Pseudomonas oryzicola)*	细菌性褐斑病
Bacterial leaf streak *(Xanthomonas oryzicola)*	细菌性条斑病
Blast *(Pyricularia oryzae)*	稻瘟病
Brown spot *(Helminthosporium oryzae)*	胡麻斑病
Brown stripe *(Pseudomonas panici)*	细菌性褐条病
Common dwarf	普通矮缩病
Dwarf-like diseases	类普矮病
Grassy stunt	草丛矮缩病
Kresek disease	凋萎型白叶枯病
Leaf scald *(Rhynchosporium oryzae)*	云形斑病
Narrow brown leaf spot *(Cercospora oryzae)*	窄条斑病
Rice black-streaked dwarf	黑条矮缩病
Rice dwarf	矮缩病
Rice stripe	条纹叶枯病
Rice transitory yellowing	暂黄病
Rice tungro	东格罗病
Rice yellow dwarf	黄萎病
Rice yellow stunt	黄矮病
Sheath blight *(Corticium sasakii)*	纹枯病
Sheath rot *(Acrocylindrium oryzae)*	叶鞘腐败病
Stem rot *(Helminthosporium sigmoideum)*	小粒菌核病